

Abstract Volume

12th In Man Space Symposium

NASA/TM-97-

207601

**The Future of
Humans In Space**

*June 8-13, 1997
Washington, DC*



12th Man in Space Symposium

The Future of Humans in Space

June 8-13, 1997

Washington, D.C.

Abstract Volume



12TH MAN IN SPACE SYMPOSIUM
ABSTRACT VOLUME

International Academy of Astronautics
P. O. Box 1268-16
F-75766 Paris Cedex 16, France

National Aeronautics and Space Administration
Washington, D.C. 20546-0001
U.S.A.

Universities Space Research Association Division of Space Life Sciences
3600 Bay Area Boulevard
Houston, TX 77058 U.S.A.

Universities Space Research Association Division of Space Life Sciences operates under
Cooperative Agreement NCC9-41 with the National Aeronautics and Space Administration.

Abstracts in this volume may be cited as:

Author: Title of paper. 12th Man in Space Symposium: The Future of Humans in Space, June
8-13, 1997, Washington, D.C., pp. xxx.

FOREWORD

The National Aeronautics and Space Administration (NASA) is pleased to host the 12th IAA Man in Space Symposium. A truly international forum, this symposium brings together scientists, engineers, and managers interested in all aspects of human space flight to share the most recent research results and space agency planning related to the future of humans in space.

As we look out at the universe from our own uniquely human perspective, we see a world that we affect at the same time that it affects us. Our tomorrows are highlighted by the possibilities generated by our knowledge, our drive, and our dreams. This symposium will examine our future in space from the springboard of our achievements.

SCIENTIFIC AND ORGANIZING COMMITTEE

Honorary Chairmen

O. Gazenko (Russia) K. Klein (Germany)
A. Nicogossian (USA)

Honorary Vice Chairmen

A. Grigoriev (Russia) A. Guell (France)
K. Yajima (Japan)

Chairmen

J. Vernikos (USA) R. White (USA)

Vice Chairmen

G. Gargir (France) R. Gerzer (Germany)
A. Mortimer (Canada) S. Watanabe (Japan)
H. Oser (ESA) D. Short (USA)

Members

V. Baranov (Russia) A. Berthoz (France)
V. Blüm (Germany) V. Bogomolov (Russia)
J. Contant (France) R. Fassold (Canada)
M. A. Frey (USA) H. Hinghofer-Szalkay (Austria)
I. Kozlovskaya (Russia) L. Macho (Slovakia)
T. Mano (Japan) S. Nagaoka (Japan)
V. Petrov (Russia) J. Rummel (USA)
G. Ruyters (Germany) C. Sawin (USA)
V. Schneider (USA) J. Seylaz (France)
Y. Sinyak (Russia) I. Skoog (Sweden)
F. Sulzman (USA) H. Wegmann (Germany)
J. Wei (China)

TABLE OF CONTENTS

Mechanisms of Orthostatic Intolerance During Real and Simulated Microgravity.....	1 - 1
Orthostatic Tests After 42 Days of Simulated Weightlessness <i>A.P. Traon, D. Sigauo, P. Vasseur, A. Maillet, J.O. Fortrat, G. Gauquelin-Koch, C. Gharib</i>	2
Effects of 12 Days Exposure to Simulated Microgravity on Central Circulatory Hemodynamics in the Rhesus Monkey <i>S.C. Koenig, V.A. Convertino, V.P. Krotov, J.W. Fanton, V.I. Korolkov, E.V. Trambovetsky, A. Truzhennikov, R.D. Latham</i>	3
Increased Sensitivity and Resetting of Baroreflex Control of Exercise Heart Rate After Prolonged Bed-Rest <i>P. Sundblad, J. Spaak, B. Tedner, P.E. di Prampero, D. Linnarsson</i>	4
Complex Cardiovascular Dynamics and Deconditioning During Head-Down Bed Rest <i>J.O. Fortrat, D. Sigauo, G. Gauquelin-Koch, C. Gharib</i>	5
Evetts and Russomano (1995). The cardiovascular effects of 6 hours of head-down tilt upon athletes and non-athletes <i>S. Evetts, Russomano</i>	6
Individual Susceptibility To Post-Spaceflight Orthostatic Intolerance: Contributions of Gender-Related and Microgravity-Related Factors <i>J.M. Fritsch-Yelle, T.E. Brown, P.A. Whitson</i>	7
Cassiopee Mission 1996. Comparison of Cardiovascular Alteration After Short and Long-Term Spaceflights <i>D. Sigauo, J.O. Fortrat, A. Maillet, J. Frutoso, C. Andre'-Deshays, R. Kaspranski, I. Fountova, A. Guell, G. Gauquelin-Koch, C. Gharib</i>	8
Cerebral and Femoral Flow Response to LBNP during 6 Month MIR-Spaceflights (93-95) <i>Ph. Arbeille, G. Fomina, I. Alferova, M. Porcher, J. Coulon, A. Kotovskaya, V. Poliakov</i>	9
Cerebrovascular Changes Due To Space Flight and PostFlight Presyncope <i>A.P. Blaber, R.L. Bondar, P. Moradshahi, F. Stein, M.S. Kassam, T.E. Brown, J.M. Fritsch-Yelle</i>	11
Biological Life Support Systems.....	13 - 2
Crew Regenerative Life Support in Long-Duration Space Missions <i>N.M. Samsonov, A.I. Grigoriev, Ju. I. Grigoriev</i>	14

Bioconversion Systems for Food and Water on Long Term Space Missions <i>M.A. Benjaminson, S. Lehrer, D.A. Macklin</i>	15
Novel Laboratory Approaches to Multi-Purpose Aquatic Biogenerative Closed-Loop Food Production Systems <i>V. Blum, M. Andriske, K. Kreuzber, U. Paassen, M.P. Schreibman, D. Voeste</i>	17
Artificial Neural Network Derived Plant Growth Models <i>F. Zee</i>	19
Six-Month Space Greenhouse Experiments - A Step to Creation of Future Biological Life Support Systems <i>T.N. Ivanova, P.T. Kostov, S.M. Sapunova, I.W. Dandolov, V.N. Sytchov, M.A. Levinskikh, I.G. Podolski, G.E. Bingham, F.B. Salisbury, D.B. Bubenheim, G. Jahns</i>	20
Clinical and Educational Support for Space Flight via Telemedicine	21 - 3
Telemedicine: A User's Perspective <i>A.E. Nicogossian</i>	22
Health Care in Extreme Environments <i>J.D. Collier</i>	23
Integration of Emerging Technologies in Information and Telecommunications in Health Care Systems for Space <i>C.R. Doarn</i>	24
Telemedicine and Environmental Medicine in Russia: A First Step in Basic Medical Education <i>A.I. Grigoriev, V. A. Loginov, S.V. Boravkov, L.B. Buravkova, O.L. Vinogradova</i>	25
Clinical Utility of Internet Telemedicine <i>R.C. Merrell, P. Angood, C. Doarn</i>	26
A Web-Based Human Computer Interface for Internet Telemedicine <i>C.E. Lathan, Dava J. Newman, Marc Sebrechts, Charles Doarn</i>	27
Cognitive Sciences	28 - 4
Face recognition in microgravity: is gravity direction involved in the inversion effect? <i>S. de Schonen, G. Leone, M. Lipshitz</i>	29
Motor timing under microgravity <i>A. Semjen, G. Leone, M. Lipshitz</i>	30
Perceived Self-Motion Assessed By Computer-Generated Animations: Complexity and Reliability <i>D.E. Parker, D.L. Harm, G.R. Sandoz, N.C. Skinner</i>	31
Prolonged Weightlessness, Reference Frames and Visual Symmetry Detection <i>G. Leone, S. de Schonen, M. Lipshitz</i>	33
Mental Representation Of Gravity During A Locomotor Task <i>T. Pozzo, P. Stapley, A. Berthoz, R. Kaprinski</i>	34

Haptic Perception In Weightlessness: A Sense of Force Or A Sense Of Effort? <i>J. McIntyre, M. Lipshits</i>	36
Life Sciences Issues for a Mission to Mars	38 -5
Cardiovascular Concerns For A Mars Mission: Autonomic and Biomechanical Effects <i>D. D'Aunno, J. Yelle, G. Pantalos, T. Brown</i>	39
Reducing The Risk of Space Radiation Induced Bioeffects-Vehicle Design and Protectant Molecules <i>M. Stanford, J. Jones, H. Lane, P. Riggs, T. Yang</i>	40
Musculoskeletal Issues for Long Duration Mission: Muscle Mass Preservation, Renal Stone Risk Factors, Countermeasures, And Contingency Treatment Planning <i>P. Hilliard, J. Jones, R. Pietrzyk, P. Whitson</i>	42
Psychological Issues and Crew Selection For A Mars Mission: Maximizing the Mix For The Long Haul <i>S. Bishop, J. Wood, J. Jones</i>	44
Issues In Crew Health, Medical Selection and Medical Officer (CMO) Training For A Mission To Mars <i>C. Jernigan, B. Harris, R. Jennings</i>	45
Mechanisms of Cardiopulmonary Adaptation to Microgravity - 1	46 -6
Indices of Baroreceptor Reflex Sensitivity: The Use in Rehabilitation Medicine and Space Cardiology <i>J. Tank, R.M. Baevsky</i>	47
+Gz and +Gx Tolerance At Healthy Persons of Non-Flying Trades At Primary Selection on The Centrifuge <i>V. Yu. Lukianiouk, A.R. Kotovskaya, I.F. Vil-Viliams</i>	48
Effect of Dry Immersion on Calf Blood Supply During Sustained Contraction and Upright Exercise in Man <i>Y.M. Stioda, A.A. Kulakov, O.L. Vinogradova</i>	49
Cardiovascular and Valsalva Responses During Parabolic Flight <i>T.T. Schlegel, E. Benavides, D. Barker, T. Brown, D. Harm, P.A. Low</i>	50
An Analysis of The Cardiovascular Responses Under Hyper- and Hypo-Gravity Environments Using A Mathematical Model <i>Y. Hirata, K. Yoshimura, S. Usui, S. Nagaoka</i>	51
Effect of Very Gradual Onset Rate +Gz Exposures on the Cardiovascular System <i>T. Sasaki, K. Iwasaki, K. Hirayamagi, T. Kinone, A. Miyamoto, K. Yajima</i>	52

NASA Specialized Center of Research and Training (NSCORT) In Integrated Physiology: Mechanisms of Physiological Adaptations To Microgravity <i>C.G.Blomqvist</i>	55
Plant and Animal Gravitational Biology - 1	56 - 7
The Interaction of Microgravity and Ethylene on Soybean Growth and Metabolism <i>C.S. Brown, M.M. Sarwo, W.C. Piastuch, B.V. Peterson, E.C. Stryjewski, E. Hilaire, J.A. Guikema</i>	57
Structure and g-Sensitivity of Root Statocytes Under Different Mass Acceleration <i>R. Laurinavicius, D. Svegzdiene, V. Gaina</i>	58
Extracellular Production of Taxanes on Cell Surfaces In Simulated Microgravity and Hypergravity <i>D.J. Durzan, F. Ventimiglia, L. Havel</i>	59
Current Problems of Space Cell Phytobiology <i>E.L. Kordyum</i>	60
Biological Consequences of Microgravity-Induced Alterations in Water Metabolism of Plant Cells <i>D.O. Klymchuk</i>	61
Localization of Calcium Ions in Chlorella Cells Under Clinorotation <i>A.F. Popova</i>	62
Changes of Fatty Acids Content of Plant Cell Plasma Membranes Under Altered Gravity <i>Yu. Ya. Polulyakh</i>	63
Simulation of Gravity by Non-Symmetrical Vibrations and Ultrasound <i>O.A. Kuznetsov, A.A. Kuznetsov, K.H. Hasenstein</i>	64
Response to Simulated Weightlessness of In Vitro Cultures of Differentiated Epithelial Follicular Cells from Thyroid <i>A. Meli, G. Perrella, F. Curcio, F. S. Ambesi-Impiombato</i>	66
Visuo-Vestibular Interactions	67 - 8
Vestibulo-Oculomotor Interaction in Long-Term Microgravity <i>L.N. Kornilova, C. Mueller, N. Steinhoff, A. Clarke, V. Grigorova</i>	68
Effects of Weightlessness on the Spatial Orientation of Visually Induced Eye Movements <i>G. Clement, S.J. Wood, M.F. Reschke</i>	69
Adaptive Modification of the Three-Dimensional Vestibulo-Ocular Reflex During Prolonged Microgravity <i>A.H. Clarke, J. Grigull, W. Krzok, H. Scherer</i>	71
The Dynamic Change of Brain Potential Related to Selective Attention to Visual Signals from Left and Right Visual Fields <i>J. Wei, Lun Zhao, G. Yan, W. Chen, R. Duan, W. Ren</i>	72

Locomotor Errors Caused By Vestibular Suppression <i>D.G.D. Watt, N. Paquet</i>	73
A novel, image-based technique for three-dimensional eye movement measurement <i>A.H. Clarke, D. Schucker, W. Krzok, J. Grigull</i>	75
Effect of Microgravity on Bone Tissue and Calcium Metabolism	76 - 9
Human Bone Tissue Changes After Long-Term Space Flight: Phenomenology and Possible Mechanics <i>V. Organov, V. Schneider, A. Bakulin, V. Polyakov, L. Voronin, V. Morgun, L. Shackelford, A. LeBlanc, L. Murashko, V. Novikov</i>	77
Prediction of Femoral Neck Bone Mineral Density Change in Space <i>L. Shackelford, A. Feiveson, E. Spector, A. LeBlanc, V. Oganov</i>	78
Dietary Calcium in Space <i>D. Hatton, D. McCarron, Q. Yue, C. Rouillet, H. Xue, K. Otsuka, J. Chapman, T. Phanouvong, J. Rouillet, M. Watanabe, K. Nilan, V. Haight, J. Dierckx, J. Demerritt</i>	80
Calcium Metabolism During Extended-Duration Space Flight <i>S.M. Smith, V.S. Oganov, B.V. Morukov, I.M. Larina, L.E. Nyquist, C.-Y. Shih, M.E. Wastney, S.A. Abrams, H.W. Lane</i>	81
External Impact Loads on the Lower Extremity During Jumping In Simulated Microgravity and the Relationship to Internal Bone Strain <i>S.E. D'Andrea, B.L. Davis, A.C. Courtney, G.P. Perusek</i>	82
Bone Loss During Long Term Space Flight Is Prevented By The Application of An Short Term Impulsive Mechanical Stimulus <i>A.E. Goodship, J.L. Cunningham, P. Walker, V.Organov, J. Darling, A.W. Miles, G. Owen</i>	84
Cultural and Gender Issues in Long-Duration Flights	86 - 6
Psychosocial Issues During Long-Duration International Space Missions <i>N. Kanas</i>	87
Psychosocial Issues In Crew Selection: Finding the Right Mix of the Right Stuff <i>S.L. Bishop</i>	88
Culture, Gender and Mission Accomplishment: Operational Experience <i>A.W. Holland</i>	89
Interpersonal Tension in Multicultural Crews <i>H. Ursin, G.M. Sandal</i>	90
Personality and Coping in Extreme Environments <i>G.M. Sandal, H. Ursin</i>	91
Application of Expedition and Polar Work Group Findings For Enhancing Performance in Space <i>G.R. Leon, V.S. Koscheyev</i>	92

Mechanisms of Cardiopulmonary Adaptation to Microgravity - 2	93 -/1
Autonomic Regulation of Circulation and Mechanical Function of Heart at Different Stages of 14-th Month Space Flight <i>R.M. Baevsky, M. Moser, G.A. Nikulina, V.V. Polyakov, I.I. Funtova, A.G. Chernikova</i> ...	94
Cardiovascular oxygen transport in exercising humans in microgravity <i>G. Ferretti, F. Esposito, M. Girardis, D. Linnarsson, C. Moia, D. Pendergast</i>	95
Venous Hemodynamic Changes Assessed By Air Plethysmography During a 16-Day Spaceflight <i>F. Louisy, C. Andre'-Deshays, D. Cauquil, M. Lazerges, C. Lafaye, A.L. Camus, G. Fomina</i>	96
Respiratory Mechanics After 180 Days Space Mission (Euromir'95) <i>D. Venturoli, D. Negrini, G. Miserocchi</i>	97
Assessment of The Sympathetic and the Parasympathetic Nervous Activity During Parabolic Flight by Pupillary Light Reflex <i>K. Yamaji, Y. Hirata, S. Usui, S. Nagaoka</i>	98
Vascular Response to Different Gravity <i>F. Valkenberg</i>	99
Human Factors Research under Ground-Based and Space Conditions - 1....	102 -/2
Human Factors Engineering of the International Space Station Human Research Facility <i>B. Woolford</i>	103
Structured Methods For Identifying And Correcting Potential Human Errors in Space Operations <i>W.R. Nelson, L.N. Haney, L.T. Ostrom, R.E. Richards</i>	104
An Improved Procedure for Selecting Astronauts for Extended Space Missions <i>A.W. Holland, L. Galarza, R.D. Arvey, K.D. Curtis</i>	105
The NASA Performance Assessment Workstation: Cognitive Performance During Head-Down Bedrest <i>R.E. Schlegel, R. Shehab, S.G. Schiflett, D.R. Eddy</i>	106
Cognitive Performance Aboard the Life and Microgravity Spacelab <i>D.R. Eddy, S.G. Schiflett, R.E. Schlegel, R.L. Shehab</i>	107
Psychophysiological Reactivity Under MIR-Simulation And Real Micro-G <i>B. Johannes, V.P. Salnitski, V. Korsun, A.J. Kaleri, K. Kirsch, O.I. Schewtschenko, F. Fischer, A.V. Dudukin, C. Gunga</i>	108
Posture and Movement	109 -/3
Modification of Goal-Directed Arm Movements During Inflight Adaptation to Microgravity <i>M. Berger, S. Lechner-Steinleitner, I. Kozlovskaya, F. Gerstenbrand</i>	110
Quantitative Analysis of Motion Control In Long Term μ Gravity <i>G. Baroni, G. Ferrigno, A. Anolli, G. Andreoni, A. Pedotti</i>	111

Does The Centre Of Gravity Remain The Stabilised Reference During Complex Human Postural Equilibrium Tasks In Weightlessness? <i>P. Stapley, T. Pozzo, A. Grichine</i>	113
Arm End-Point Trajectories Under Normal And Micro-Gravity Environments <i>C. Papaxanthis, T. Pozzo, J. McIntyre</i>	115
The German/Russian MIR '97 Mission: An Overview	117-14
Life Science Experiments During the German-Russian MIR '97 Mission <i>G. Ruyters, H.-U. Hoffmann</i>	118
Orthostatic Intolerance following Microgravity: A Role for Autonomic Dysfunction <i>F.J. Baisch, L. Beck, J. Drescher, C.G. Blomqvist, D.L. Eckberg, D. Robertson</i>	119
Heart Rate Variability and Skin Blood Flow in Man During Orthostatic Stress in Weightlessness <i>J. Drescher, A. Diedrich</i>	121
Effects of Microgravity and Lower Body Negative Pressure on Circulatory Drives from Exercising Calf Muscles <i>D. Essfeld, K. Baum, U. Hoffmann, D. Leyk</i>	122
The MIR Station in Its Second Decade - Crew Science Operation During MIR '97 <i>R. Ewald</i>	123
Metabolic Ward (Water, Sodium, Calcium and Bone Metabolism) and Endocrinological Experiments During the MIR '97 Mission <i>C. Drummer, M. Heer, P. Norsk, P. Bie, P. Stehle, A. Zittermann, I. McCarthy, C. Vermeer, C. Alexandre, L. Shakelford, C. Gunga, M. Bidlingmaier, C. Strasburger, P. Rettberg, G. Horneck, V. Oganov, D. Vorobiev</i>	124
Long-Term Monitoring of the Spine-Geometry During the MIR '97 Mission. Introduction of a New Method <i>K. Baum, D. Essfeld</i>	125
Effects of 20 Days of Microgravity (German/Russian MIR '97 Mission) on the Mechanical and Electromyographic Characteristics of Explosive Efforts of the Lower Limbs and of Cycloergometric Exercises of Mild to Sprint-Like Intensity <i>G. Antonutto, P. Zamparo, F. Bodem, J. Kass, J. Heine, P.E. di Prampero</i>	126
Long-Duration Space Flight	128-15
Medical and Physiological Studies During 438-Days Space Flights <i>A.I. Grigoriev, V.V. Polyakov</i>	129
Human Performance During A 14 Months Space Mission <i>D. Manzey, B. Lorenz, V. Polyakov</i>	130
Homeostasis in Long-Term Microgravity Conditions <i>A.I. Grigoriev, A.D., Egorov, A.S. Kaplansky</i>	131

Strategy of Preservation of Health of Cosmonauts in Prolonged and Superprolonged Space Flights <i>A.I. Grigoriev, V.V. Polyakov, A.D. Egorov</i>	132
Rehabilitation of Cosmonauts' Health Following Long-Term Space Missions <i>V.V. Bogomolov, I.B. Kozlovskaya, V.I. Pochuev</i>	133
Perfect Cosmonaut: Some Features Of Bio-Portrait <i>N.G. Lacota, I.M. Larina, V.V. Polyakov</i>	134
Plant and Animal Gravitational Biology - 2	135 -16
The Asymmetrical Growth of Otoliths in Fish is Affected By Altered Gravity and Causes Kinetosis <i>R.H. Anken, T. Kappel, H. Rahmann</i>	136
Neurobiological Responses of Fish to Altered Gravity Conditions: A Review <i>H. Rahmann, R.H. Anken</i>	138
An Age-Dependent Sensitivity of the Roll-Induced Vestibuloocular Reflex To Hypergravity Exposure of Several Days In An Amphibian (<i>Xenopus Laevis</i>) <i>C. Sebastian, E. Horn</i>	140
Mechanically-Induced Membrane Wounding During Parabolic Flight <i>M. Clarke, D.L. Feedback</i>	141
Erythropoietin Stimulates Increased F Cell Numbers in Bone Marrow Cultures Established in Gravity and Microgravity Conditions <i>D. Houston-Hawkins, O.M. Hurst, S. Oduntan, S.O. Fadulu</i>	143
Technology - 1	145 -7
Physiolab A Cardio Vascular Laboratory <i>D. Cauquil, C. Laffaye, A.L. Camus, V. Gratchev, I. Alferova, A. Kotovskaya, G. Weerts</i>	146
MEDEX: A Flexible Modular Physiological Laboratory <i>J. Kass, G. Kampfer</i>	147
A Sensate Liner for Personnel Monitoring Applications <i>E.J. Lind, S. Jayaraman, R. Rajamanickam, S. Park, R. Eisler, G. Baird, D. Cadogan, T. McKee</i>	149
Secure Remote Access to Physiological Data <i>R. Gantenbein</i>	150
DARA Vestibular Equipment Onboard MIR <i>P. Hofmann, A. Kellig, H.-U. Hoffmann, G. Ruyters</i>	152
The Kinelite Project: A New Powerful Motion Analysis System for Spacelab Mission <i>M. Venet, H. Pinard, J. McIntyre, A. Berthoz, F. Lacquaniti</i>	153

The Technical Evolution of the French Neurosciences Multipurpose Instruments Onboard the MIR Station <i>J.M. Bois, Y. Matsakis, J. McIntyre, A. Shulenin</i>	155
Extended Ground-Based Research In Preparation For Life Sciences Experiments <i>M. Schuber, D. Seibt, J. Zange</i>	156
Medes Clinical Research Facility As A Tool To Prepare ISSA Space Flights <i>A. Maillet, A. P. Traon</i>	157
Human Behaviour in Long-Term Missions	159 -18
Psychological Support for International Space Station Missions <i>O.P. Kozerenko, O.O. Ryumin, A.D. Sled, A.W. Holland</i>	160
Psycho-Social Training for Man In Space <i>R. Kass, J. Kass</i>	161
Study of the Physiological Adaptation of the Crew During A 135-Day Space Simulation <i>E. Rosnet, G. Cazes, A. Vinokhodova</i>	162
Interpersonal Relationships in Space Simulation: The Long-Term Bed Rest in Head-Down Tilt Position <i>K. Weiss, G. Moser</i>	163
Psychological Adaptation in Groups of Varying Sizes and Environments <i>J. Wood, D. Lugg, D. Eksuzian, D.L. Harm, M. Shepanek</i>	164
Deviance Among Expeditioners: Defining The Off-Nominal Act in Space and Polar Field Analogs <i>M. Dudley-Rowley</i>	165
Getting Effective Sleep in the Space-Station Environment <i>W. Rhodes</i>	167
Human Sleep and Circadian Rhythms Are Altered During Spaceflight <i>A. Gundel, V.V. Polyakov</i>	168
Methodological Approach to Study of Cosmonauts Errors and Its Instrumental Support <i>A.P. Nechaev, V.I. Myasnikov, S.I. Stepanova, O.P. Kozerenko, G.F. Isaev, S.V. Bronnikov</i>	169
Human Factors Research under Ground-Based and Space Conditions - 2	170 -19
Training Astronauts Using Three-Dimensional Visualizations of the International Space Station <i>R. Bagaoutdinov, Barker, G. Bodrikov, Y. Borodin, M. Cheburkov, E. Dahlstrom, D. Ivanov, P. Karpunin, R. Katargin, A. Kiselyev, Y. Kotlayarevsky, N. Maris, D. Nelles, M.J. Rycroft, A. Schetinnikov, F. Tyerlov</i>	171
Measurement and Validation of Bidirectional Reflectance of Shuttle and Space Station Materials for Computerized Lighting Models <i>L. Fletcher, A. Aldridge, C. Wheelwright, J. Maida</i>	172

Effects Of Environmental Color On Mood And Performance Of Astronauts In ISS <i>N. Kwallek</i>	174
Psychophysical Measures of Motion and Orientation: Implications for Human Interface Design <i>A.M. Mead, B.D. Lawson</i>	175
The Sopite Syndrome Revisited: Drowsiness and Mood Changes in Student Aviators <i>B. Lawson, A.M. Mead, A. Apple, L. Barton</i>	176
Technology - 2	177 -20
Monitoring Physiological Variables With Membrane Probes <i>E.M. Janle, L. Yang, P.T. Kissinger</i>	178
Real Time Confocal Laser Scanning Microscopy: Potential Applications in Space Medicine and Cell Biology <i>Ana Rollan, A.P. McHale</i>	180
Optimum Versus Universal Planetary and Interplanetary Habitats <i>M.M. Cohen</i>	182
Application of Remote Sensing and Geographic Information System Technologies to the Prevention of Diarrheal Diseases in Nigeria <i>P.C. Njemanze, S. Dister, B. Lobitz, L. Beck, B. Wood</i>	184
A Small G Loading Human Centrifuge for Space Station ERA <i>K. Yajima, K. Iwasaki, R. Murai, T. Nakazato, M. Itoh, K. Hirayanaagi, A. Miyamoto, M. Igarashi</i>	185
Use of the Bicycle Ergometer on the International Space Station and Its Influence On The Microgravity Environment <i>N. Penley, G. Banta</i>	186
Munich Space Chair (MSC) - A Next Generation Body Restraint System for Astronauts <i>E. Igenbergs, W. Naumann, P. Eckart, E. Pfeiffer</i>	187
Thermoelectric Human-Body Cooling Units Used By NASA Space Shuttle Astronauts <i>P. Heenan, R. Theisen, B. MathiPrakasam, S. Walker, B. Sauser</i>	188
Radiation: Physical Characterization and Environmental Measurements....	189 -21
Production of Neutrons From Interactions of GCR-Like Particles <i>L. Heilbronn</i>	190
Solar Particle Event Dose Distributions: Parameterization of Dose-Time Profiles <i>E.N. Zapp, C.R. Ramsey, L.W. Townsend, G.D. Badhwar</i>	192
Assessment of Nuclear Events In The Body Produced By Neutrons and High-Energy Charged Particles <i>R.A. Noulty, H. Ing, E.T.H. Clifford, B. Selkirk, J. Gamero, A. Mortimer</i>	194

Ground-Based Simulations of Cosmic Ray Heavy Ion Interactions In Spacecraft and Planetary Habitat Shielding Materials <i>J. Miller, C. Zeitlin, L. Heilbronn, T. Borak, T. Carter, K.A. Frankel, S.E. Rademacher, C. Stronach</i>	196
Radiation Measurements in Space Missions <i>G. Reitz, I. Apathy, R. Beaujean, S. Deme, C. Heilmann, J. Kopp, M. Leicher, K. Strauch</i>	198
Radiation Measurements in Civil Aircraft <i>R. Beaujean, J. Kopp, F. Roos, G. Reitz</i>	199
Analysis of The Pre-Flight and Post-Flight Calibration Procedures Performed on the Liulin Space Radiation Dosimeter <i>T. Dachev, J. Semkova, V. Petrov, V. Redko, V. Bengin, T. Kostereva, J. Miller, L. Heilbronn, C. Zeitlin</i>	200
Radiation Environment Monitoring for Astronauts <i>G. Mackay, I. Thomson, N. Sultan, A. Ng, P. Sullivan</i>	201
The National Space Biomedical Research Institute	203 ^{omit}
Panel Discussion & Special Presentations	204
Studies Relating to EVA	205 ⁻²²
The Staged Decompression To The Hypobaric Atmosphere As A Prophylactic Measure Against Decompression Sickness During Repetitive EVA <i>V.I. Chadov, S.N. Filipenkov, L.R. Isseev, S.R. Kislyhin, A.J. Mednih, V.V. Polyakov, G.F. Vorobiev</i>	206
A New Preoxygenation Procedure For Extravehicular Activity (EVA) <i>J. Webb, A. Pilmanis</i>	207
Metabolic Assessments During Extra-Vehicular Activity <i>Yu. Yu. Osipov, A.N. Spichkov, S.N. Filipenkov</i>	208
Evaluation of Safety of Hypobaric Decompressions and EVA From Positions of Probabilistic Theory <i>V.P. Nikolaev</i>	209
Fatty Acid Composition of Plasma Lipids and Erythrocyte Membranes During Simulation of Extravehicular Activity <i>M.A. Skedina, L.B. Buravkova, V.P. Katuntsev, V.P. Naidina</i>	210
Biomedical Studies Relating To Decompression Stress With Simulated EVA: Overview <i>B.D. Butler, T. Little, M. Powell, R.R. Robinson</i>	211
The Joint Angle and Muscle Signature (JAMS) System - Current Uses and Future Applications <i>C.U. Ranniger, D.L. Akin</i>	213
Experimental Investigation of Cooperative Human-Robotic Roles in An EVA Work Site <i>D.L. Akin</i>	215

Body Fluid Regulation and Hemopoiesis in Space Flight	217-23
Bodymass And Fluid Distribution During Longterm Spaceflight With and Without Countermeasures <i>K. Kirsch, F. Baartz, H.C. Gunga, E. Koralewski, B. Johannes</i>	218
Plasma Volume, Extracellular Fluid Volume, and Regulatory Hormones During Long-Term Space Flight <i>H.W. Lane, B.V. Morukov, I.M. Larina, S.M. Smith, A.I. Grigoriev, C.S. Leach</i>	219
Effect of Microgravity and Its Ground-Based Models on Fluid Volumes and Hemocirculatory Volumes <i>V.I. Lobachik, V.V. Polyakov, S.A. Chupushtanov, S.F. Voronov</i>	220
Seventeen Weeks of Horizontal Bed Rest, Lower Body Negative Pressure Testing, and the Associated Plasma Volume Response <i>C. Lathers, J. Charles</i>	221
Evaporative Waterloss In Space Theoretical And Experimental Studies <i>Fa. Baartz, K.Kirsch, F. Castrucci, H.C. Gunga, E. Koralewski</i>	222
Erythropoietin Under Real And Simulated Micro-G Conditions In Humans <i>H.C. Gunga, K. Kirsch, A. Maillet, F. Baartz, C. Gharib, W. Nalishiti, I. Rich, L. Rocker</i>	223
Vertebral Bone Marrow Changes Following Space Flight <i>A. LeBlanc, C. Lin, H. Evans, L. Shackelford, S. West, T. Hedricks</i>	224
Effect of Real and Simulated Microgravity on Muscle Function	226-24
Changes in Calf Muscle Performance, Energy Metabolism, and Muscle Volume Caused By Long Term Stay on Space Station MIR <i>J. Zange, K. Muller, M. Schuber, H. Wackerhage, U. Hoffman, R.W. Gunther, G. Adam, J.M. Neuerburg, A.O. Bacharev, V.E. Sinitsyn, O.I. Belichenko</i>	227
Vibrographic Signs of Autonomous Muscle Tone Studied In Long Term Space Missions <i>E. Gallasch, T. Kenner, I.B. Kozlovskaya</i>	229
Reduction of Muscle Strength After Long Duration Space Flights Is Associated Primarily With Changes In Neuromuscular Function <i>S.F. Siconolfi, I.B. Kozlovskaya</i>	230
The Effects of a 115-Day Spaceflight on Neuromuscular Function in Crewman <i>Y. Koryak, I.B. Kozlovskaya</i>	231
Effects of 17-Day Spaceflight on Human Triceps Surae Electrically-Evoked Contractions <i>M. Narici, B. Kayser, P. Barattini, P. Cerretelli</i>	232
Effects of Muscle Unloading on EMG Spectral Parameters <i>S. Roy, E.J. Kupa, C.J. De Luca, S.C. Kandarian, P. Bonato</i>	234
Myofiber Wound-Mediated FGF Release and Muscle Atrophy During Bedrest <i>M. Clarke, M.M. Bamman, D.L. Feedback</i>	236

Education and Space: NASA Reaches for the Stars	238	<i>omit</i>
Panel Discussion & Special Presentations	239	
Neurolab: A Space Shuttle Mission Dedicated To Neuroscience Research...	241	<i>+25</i>
NASA/NIH Neurolab Collaborations		
<i>J.B. Snow</i>	242	
The Neurolab Mission: An Example of International Cooperation		
<i>A. Guell</i>	243	
NEUROLAB: An Overview of the Planned Scientific Investigations		
<i>J.L. Homick</i>	244	
EDEN: A payload for Neurolab dedicated to Neuro Vestibular Research		
<i>F. Bellossi</i>	246	
Neurolab Experiments on the Role of Visual Cues in Microgravity Spatial Orientation		
<i>C.M. Oman, I.P. Howard, T. Carpenter-Smith, A.C. Beall</i>	248	
The Role of Space in the Exploration of the Mammalian Vestibular System		
<i>M.D. Ross</i>	249	
Medical, Psychophysiological, and Human Performance Problems During		
Extended EVA.....	250	<i>-26</i>
New Developments In The Assessment of the Risk of Decompression Sickness in Null Gravity During Extravehicular Activity		
<i>M.R. Powell</i>	251	
The Dynamic of Physiological Reactions of Cosmonauts Under the Influence of Repeated EVA Workouts: The Russian Experience		
<i>A.S. Barer, N.K. Gnoevaia, V.P. Katunczev, U. U. Osipov</i>	252	
Medical Emergencies In Space		
<i>S.L. Pool</i>	253	
The Evolution from 'Physiological Adequacy' to 'Physiological Tuning'		
<i>P.A. Hancock, V.S. Koscheyev</i>	254	
Five Zones of Symmetrical and Asymmetrical Conflicting Temperatures on the Human Body: Physiological Consequences		
<i>V.S. Koscheyev</i>	255	
Human Performance and Subjective Perception in Nonuniform Thermal Conditions		
<i>G.R. Leon</i>	256	
The Hand as a Control System: Implications for Hand-Finger Dexterity During Extended EVA		
<i>T.J. Smith, M.G. Wade</i>	257	
Understanding the Skill of Extravehicular Mass Handling		
<i>P.V. McDonald, G.E. Riccio, B.T. Peters, C.S. Layne, J.J. Bloomberg</i>	258	

Metabolic and Regulatory Systems in Space Flight.....	259	27
The Dynamics of Blood Biochemical Parameters in Cosmonauts During Long-Term Space Flights		
<i>V. Polyakov, A. Markin, L. Strogonova, T. Tigner</i>	260	
Efficiency of Functional Loading Test for Investigations of Metabolic Responses to Weightlessness		
<i>I.A. Popova, I.V. Zabolotskaya, O.I. Balashov, L.B. Buravkova</i>	261	
Human Cellular immunity and space flight		
<i>A. Lesnyak, G. Mitirev, I. Vorotnikova, E. Antropova, G. Levicheva, I. Konstantinova</i> ...	262	
Cytokine Production And Head-Down Tilt Bed Rest		
<i>D.A. Schmitt, A. Cogoli, M. Abbal</i>	263	
Plasma and Urine Amino Acids During Human Space Flight		
<i>T.P. Stein, M.J. Leskiw, M.D. Schluter</i>	264	
DNA Fingerprinting: Applications to Space Microbiology		
<i>D.L. Pierson, S.K. Mehta, C. Brauning, G. M. Weinstock</i>	265	
Gravitational Biology: The Rat Model.....	266	28
Morphology of brain, pituitary and thyroid in the rats exposed to altered gravity		
<i>I.B. Krasnov, L.N. Dyachkova, E.I. Alexeev, V.I. Loginov, K. O'Mara, W. Hinds</i>	267	
Biochemical Properties of <i>B</i> Adrenoceptors After Spaceflight (LMS-ST578) or Hindlimb Suspension In Rats		
<i>S. Fagette, L. Somody, F. Bouzeghrane, N. Gallo-Bona, L. Eward, M. Viso, C. Gharib, G. Gauquelin</i>	269	
Influence of Hypergravity on the Development of Monoaminergic Systems in the Rat Spinal Cord		
<i>M. Gimenez y Ribotta, A. Privat</i>	270	
A Vestibular Evoked Potentials (VsEPs) Study of the Function of the Otolith Organs in Different Head Orientations with respect to Earth Gravity Vector in the Rat		
<i>M. Plotnik, M. Mager, J. Elidan, H. Sohmer</i>	271	
Quantitative Observations on the Structure of Selected Proprioceptive Components in Adult Rats That Underwent About Half of Their Fetal Development in Space		
<i>M. DeSantis, E. Eldrid, C. Helmick, J. Hines, A. Wong</i>	272	
Effects of a Nine-Day Shuttle Mission on the Development of the Neonatal Rat Nervous System: A Behavioral Study		
<i>D. Sulica, C. Heffernan, L. Benavides, D. Anshel, K. Walton</i>	274	
Muscle Atrophy Associated To Microgravity In Rat: Basic Data For Countermeasures		
<i>M. Falempin, Y. Mounier</i>	275	

Simulated Weightlessness By Unloading In The Rat. Results Of A Time Course Study Of Biochemical Events Occuring During Unloading And Lack of Effect Of A rhBMP-2 Treatment On Bone Formation And Bone Mineral Content In Unloading Rats <i>E. Zerath, X. Holy, A. Malouvier, B. Noel, M. Hott, C. André, S. Renault, P.J. Marie</i>	276
Cytological Mechanism Of The Osteogenesis Under Microgravity Conditions <i>N.V. Rodionova, V.S. Oganov</i>	277
Biological Bases of Space Radiation Risk	279 -29
Hematopoiesis Dynamics in Irradiated Mammals: Mathematical Modeling <i>O.A. Smirnova</i>	280
Estimating Health Risks in Space from Galactic Cosmic Rays <i>F.A. Cucinotta, J.W. Wilson, J.F. Dicello, J.R. Williams, Mack Mabry</i>	281
Failure of Heavy Ions to Affect Physiological Integrity of the Corneal Endothelial Monolayer <i>J.P. Koniarek, B. V. Worgul</i>	282
Application of an Unbiased Two-Gel cDNA Library Screening Method To Expression Monitoring of Genes in Irradiated <u>Versus</u> Control Cells <i>E.K. Balcer-Kubiczek, S.J. Meltzer, L.H. Han, X.F. Zhang, M.-S. Zhong, G.H. Harrison, J.M. Abraham</i>	284
Detection of Radiation-Induced DNA Strand Breaks In Mammalian Cells By Enzymatic Post-Labeling <i>S. Nagaoka, Y. Taniguchi, S. Endo, T. Onizuka, M. Hirano, K. Fujitaka, T. Ohnishi</i>	286
Evaluation of Bleomycin-Induced Chromosome Aberrations Under Microgravity Conditions in Human Lymphocytes, Using "Fish" Techniques <i>P. Mosesso, M. Schuber, D. Seibt, A. Schatz, A. Fosci, E. Fonti, F. Palitti</i>	287
Technical Description of the Space Exposure Biology Assembly Seba on ISS <i>P. Hofmann, P. Rank, J.U. Schott, H. Konig</i>	288
Cytogenetic Research in Biological Dosimetry <i>V. Shevchenko, G. Snigiryova, V. Petrov, B. Fedorenko, S. Druzhinin</i>	289
The Cooperative U.S./Ukrainian Experiment: An Overview	290-30
History of the Cooperative U.S./Ukrainian Experiment (CUE) <i>J.A. Guikema, E.L. Kordyum, E. Hilaire, J.E. Leach</i>	291
The Collaborative Ukrainian Experiment: Science Overview <i>C.S. Brown</i>	292
Double Fertilization of Inquiring Minds: Teachers and Students Investigating Plants in Space for the Collaborative Ukrainian Experiment <i>P.H. Williams</i>	293
Mission Operations for the Collaborative Ukrainian Experiment <i>C. Martin</i>	294

Countermeasures for Maintenance of Cardiovascular and Muscle Function in Space Flight	295 - 31
Effects of Repeated Long Duration +2Gz Load on Man's Cardiovascular Function <i>K. Iwasake, K. Hirayanagi, T. Sasaki, T. Kinoue, M. Ito, A. Miyamoto, M. Igarashi, K. Yajima.....</i>	296
Certain Approaches To the Development of On-Board Automated Training System <i>V.D. Sonkin, I.B. Kozlovskaya, V.V. Zaitseva, M.V. Bourchick, V.I. Stepantsov.....</i>	298
Cardiac, Arterial and Venous Adaptation to 0g during 6 Month MIR-Spaceflights With and Without "Thigh Cuffs" (93-95) <i>Ph. Arbeille, G. Fomina, I. Alferova, M. Porcher, J. Coulon, A. Kotovskaya, V. Poliakov.....</i>	300
Space Cycle™ Induced Physiologic Responses <i>A. Kreitenberg, V. Caiozzo.....</i>	302
Muscular Deconditioning During Long-term Spaceflight Exercise Recommendations To Optimize Crew Performance <i>N. Bachl, H. Tschan, R. Baron, I.B. Kozlovskaya, Yu. Koryak, M. Mossaheb, R. Albrecht.....</i>	303
Structure And Function of Knee Extensors After Long-Duration Spaceflight In Man: Effects of Countermeasure Exercise Training <i>B.S. Shenkman, I.B. Kozlovskaya, S. Siconolfi, G.H. Gilbert, T.L. Nemirovskaya, I. A. Cheglova, V.I. Stepantsov, V.V. Stepantsov, Yu.A. Koryak.....</i>	304
Force and power characteristics of an exercise ergometer designed for use in space <i>H.E. Berg, P. A. Tesch.....</i>	305
The simulating of overgravity conditions for astronauts' motor apparatus at the conditions of the training for orbital flights <i>A.N. Laputin.....</i>	306
Results From the Joint U.S.-Russian Sensory-Motor Investigations	307 - 32
The Effect of Long Duration Space Flight on the Acquisition of Predictable Targets in Three Dimensional Space <i>M.F. Reschke, I.B. Kozlovskaya, W.P. Huebner, W.H. Paloski, J.M. Krnavek, J.A. Krug, J.J. Bloomberg, D.L. Harm, E.R. Eichelman.....</i>	308
Effects of Microgravity on Spinal Reflex Mechanisms <i>I.B. Kozlovskaya, N.I. Burlachkova.....</i>	310
Three Dimensional Head Movement Control During Locomotion After Long-Duration Space Flight <i>J.J. Bloomberg, A.P. Mulavara, P.O. Riley, C.S. Layne, P.V. McDonald, S.L. Smith, I.B. Kozlovskaya.....</i>	312
Human Body Shock Wave Transmission Properties After Long Duration Space Flight <i>P.V. McDonald, C.S. Layne, J.J. Bloomberg, I.B. Kozlovskaya.....</i>	313

Adaptation of Neuromuscular Activation Patterns During Locomotion After Long-Duration Space Flight <i>C.S. Layne, G.W. Lange, C.J. Pruett, P.V. McDonald, L.A. Merkle, S.L. Smith, I.B. Kozlovskaya, J.J. Bloomberg</i>	314
Balance Control Deficits Following Long-Duration Space Flight <i>W.H. Paloski, I.B. Kozlovskaya, M.P. Shestakov, S.C. Nicholas, A.M. Ivanov, M.F. Reschke</i>	316
Influence of Weightlessness on Postural Muscular Activity Coordination <i>M.P. Shestakov, W.H. Paloski, I.B. Kozlovskaya, A.M. Ivanov</i>	318
The Use of Inflight Foot Pressure as a Countermeasure To Neuromuscular Degradation <i>C.S. Layne, A.P. Mulavara, C.J. Pruett, P.V. McDonald, I.B. Kozlovskaya, J.J. Bloomberg</i>	320
Operational Aspect of Space Radiation	321 - 33
Solar Particle Events and the International Space Station <i>J. Baker, R. Turner</i>	322
Radiation Environment on Mir and ISS Orbits During the Solar Cycle <i>M.V. Teltsov, M.I. Panasyuk, V.F. Bashkirov</i>	323
New approach to Radiation Risk Assessment <i>E.E. Kovalev, O.A. Smirnova</i>	324
A Industrial Method To Predict Major Solar Flares for a Better Protection of Human Beings in Space <i>M.C. Calvet, J. Bourrieau, P. Lantos</i>	325
Description of the Space Radiation Control System for the Russian Segment of ISS <i>M. Panasyuk, A. Biryukov, A. Myasnikov, A. Akulin, S. Filipuchev, S. Svertilov, M. Teltsov, V. Bashkirov, A. Lobakov, V. Lyugushin, Ts. Dachev, J. Semkova, B. Tomov, Yu. Matviichuk, P. Dimitrov, V. Petrov, R. Beaujean, G. Reitz</i>	326
Orbit Selection and Its Impact on Radiation Warning Architecture for a Human Mission to Mars <i>J. Levine, R. Turner</i>	327
Space Nuclear Power: Technology, Policy and Risk Considerations in Human Missions to Mars <i>V.P. Friedensen</i>	328
Poster Session	329 - 34
Development of correlative measures for the assessment of attention and memory <i>J. DeFrance, J. Degioanni, C. Hymel, F. Schweitzer, S. Estes, R. Calkins, F. Kutyna, I. Tarkka</i>	330
Biodynamical Responses of the Crewmember Head/Neck System During Emergence Ejection <i>T. He, R. L. Huston, Dajun Zhang</i>	331

Fecundation in the Sky: A Ten Years Old Experiment in Microgravity <i>Luc Henriet</i>	332
A Modified Botex Incubator As A Transport System For Developing Crickets Into Space <i>E. Horn, S. Pfalzer, P. Riewe, C. Sebastian, G. Kamper, U. Friedrich, P. Junk</i>	334
Chromosomal Aberrations In Peripheral Lymphocytes Of Cosmonauts And Astronauts After Space Flights <i>I. Johannes, N. Heckeley, K. Hallman, G. Obe</i>	335
Method for Establishing Long term Bone Marrow Cultures Under Microgravity Conditions <i>N.N. Khan, S.O. Fadulu</i>	336
Reproduction Under Simulated WeightlessnessMammalian in vivo Experiments Under Suspension <i>T. Kinoue, M. Ito, S. Kita, Y. Ohira, R. Hashizume, H. Katoh, N. Yamaguchi, R. Maru, K. Yajima</i>	337
Towards Human Movement Analysis Without The Use of Markers <i>F. Marzani, T. Pozzo, L. Legrand, M. Venet</i>	339
Habitability Requirements For A Cogent Mars Mission <i>Susmita Mohanty</i>	341
The Saucer Concept for Space Habitats <i>Susmita Mohanty</i>	342
New Way In Modeling The Growth Of The Organism <i>L. Novak</i>	343
The Fractionation of Hydrogen and Oxygen Stable Isotopes By Life Support Systems of Space Station "MIR" <i>R. L. Sauer, I. E. Siniak, V.B. Gaidadimov, B.G. Pokrovski</i>	345
Effect of Space Flight on Neutrophil Function <i>R. Stowe, S. Mehta, I. Kaur, M. Jones, D. Feedback, A. Barrett, D. Pierson</i>	346

Monday, June 9

Session MP1
Room 1
2:30 - 5:30 p.m.

51-52

072143

121

326954

**Mechanisms of Orthostatic
Intolerance During Real and
Simulated Microgravity**

ORTHOSTATIC TESTS AFTER 42 DAYS OF SIMULATED WEIGHTLESSNESS

A. Pavy-Le Traon^{1/2}, D. Sigaud¹, P. Vasseur², A. Maillat^{1/2}, J.O. Fortrat¹, G. Gauquelin-Koch¹, C. Gharib¹

1- Laboratoire de Physiologie de l'Environnement, 8 avenue de Rockefeller, 69373 LYON Cedex 08, FRANCE
Fax : (33) 4 78 01 74 67 - E-mail : gharib@univ-lyon1.fr

2- MEDES (Institut de Médecine et de Physiologie Spatiales), 18 avenue Edouard Belin, 31401 TOULOUSE Cedex 4, Fax : (33) 5 61 28 30 02 - E-mail : Anne.Pavy-Le.Traon@cst.cnes.fr

INTRODUCTION

Orthostatic intolerance remains an issue after space flights and change in autonomic cardiovascular regulation is one of the main mechanisms involved. Heart rate variability (HRV) using spectral analysis has been used as a tool for short term assessment of parasympathetic and sympathetic nervous system control of heart rate. The aim of this study was the analysis of cardiovascular responses to orthostatic tests performed before and after a prolonged 42 day (-6°) Head-Down Bed-Rest (HDBR) simulating effects of a long-duration flight.

METHODS

Seven men (28 +/-0.9 years) participated in this experiment. Blood pressure (sphygmomanometer, and continuous non-invasive finger cuff method: Finapres) and RR interval were measured at rest and during stand tests (10 min.) and Lower Body Negative Pressure (LBNP) tests (5 min. at -25, -35 and -45 mmHg) performed before (D-3) and at the end (R+1) of HDBR. We have used coarse graining spectral analysis of heart rate to extract the harmonic components for calculation of parasympathetic (PNS) and sympathetic (SNS) indicators. The integrated power in the low frequency (P_L) region (0-0.15 Hz) and in the high frequency (P_H) region (0.15-0.50 Hz) were calculated as well as total spectral power (P_T). Normalized PNS and SNS indicators were calculated as P_H/P_T and P_L/P_H respectively. Data of RR intervals and blood pressure (Finapres) were also analyzed to point up spontaneous baroreflex sequences, which reflect the heart rate responses to spontaneous variations of blood pressure and calculate spontaneous baroreflex slope (SBS).

RESULTS

4 and 1 subjects (among 7) did not complete respectively the stand and the LBNP tests at R+1. Greater heart rate increase during the stand and LBNP tests, and decrease in blood pressure during the stand tests reflecting a reduced vasomotor response, characterized the orthostatic responses at R+1 (Table I).

Table I: Heart Rate and Blood Pressure variations

STAND TEST	D-3	R+1
Heart Rate (b/min.)	+44 %	+57 %
Systolic Blood Pressure (mm Hg)	+5 %	-9 %
Mean Blood Pressure (mm Hg)	+21 %	-8 %
Diastolic Blood Pressure (mm Hg)	+18%	-10 %

Mean Heart Rate and Blood Pressure (Systolic, Mean and Diastolic) variations during STAND TESTS performed before (D-3) and after (R+1) the 42 day HDBR (n= 7). Values are expressed as percentage compared to baseline data (measured in supine position before standing up).

The main findings in HRV and SBS included after HDBR : significant reductions in RR interval and in total power suggesting a decrease in cardiovascular neurovegetative control induced by HDBR, a decrease in PNS indicator and an increase in SNS indicator, and a reduced SBS. RR interval, P_T and PNS indicator were further reduced by standing and LBNP exposure as well as SBS. The reduced PNS indicator and SBS suggest the vagal component of the cardiovascular control has been diminished.

CONCLUSION

These changes in autonomic cardiovascular control constituted important contributors to the reduced orthostatic tolerance observed in this experiment and found after space flights. The same kind of autonomic changes, but less pronounced, were already reported after HDBR of shorter duration. Several factors might play a role in cardiovascular adaptation in HDBR, in particular reduced physical activity and some autonomic changes could be opposed to those observed with training.

EFFECTS OF 12 DAYS EXPOSURE TO SIMULATED MICROGRAVITY ON CENTRAL CIRCULATORY HEMODYNAMICS IN THE RHESUS MONKEY

S.C. Koenig¹, V.A. Convertino¹, V.P. Krotov², J.W. Fanton³, V.I. Korolkov², E.V. Trambovetsky², A. Truzhennikov², and R.D. Latham⁴

¹Physiology Research Branch, Clinical Sciences Division, Brooks Air Force Base, Texas;

²Institute of Biomedical Problems, Moscow, Russia; ³Veterinary Resources Branch, Veterinary Science Division, Brooks Air Force Base, Texas; ⁴U.S. Army Aeromedical Research Laboratory, Fort Rucker, Alabama

INTRODUCTION

Our current understanding of cardiac and hemodynamic responses and adaptations to actual spaceflight or groundbased simulations of microgravity has been primarily limited to non-invasive measurements of heart rate, blood pressures, and echocardiography because of ethical and logistical constraints imposed on experiments in human subjects. Confirmation of microgravity effects on possible changes in cardiac function and structure as well as underlying mechanisms would be desirable. This study provided the opportunity to obtain preliminary data using a groundbased animal model to test the hypotheses that: 1) alterations in stroke volume and cardiac output during extended exposure to microgravity was associated with reduced cardiac function; and 2) that microgravity causes a change in cardiac compliance.

METHODS

Central circulatory hemodynamic responses were measured before and during 12 days of 10° head-down tilt (HDT) in 4 flight-sized juvenile rhesus monkeys who were surgically instrumented with a variety of intrathoracic catheters and blood flow sensors to assess the effects of simulated microgravity on central circulatory hemodynamics. Each subject underwent measurements of aortic and left ventricular pressures, and aortic flow before and during HDT as well as during a passive head-up postural test before and after HDT. Heart rate, stroke volume, cardiac output, and left ventricular end-diastolic pressure were measured, and dP/dt and left ventricular elastance was calculated from hemodynamic measurements. The postural test consisted of 5 min of supine baseline control followed by 5 minutes of 90° upright tilt (HUT).

RESULTS

Heart rate decreased during the initial 3 days of HDT followed by a gradual elevation and overshoot during the remainder of HDT. Stroke volume was unchanged during the initial 7 days of HDT followed by an increase during the final 5 days of HDT. As a result, cardiac output was increased during the latter phase of HDT. Left ventricular elastance was reduced throughout HDT, indicating that cardiac compliance was increased. HDT increased left ventricular $+dP/dt$, indicating an elevation in cardiac contractility. Heart rate during the post-HDT HUT postural test was elevated compared to pre-HDT while post-HDT cardiac output was decreased by 47% as a result of a 20% reduction in stroke volume throughout HUT.

CONCLUSION

Results from this study using an instrumented rhesus monkey suggest that exposure to a groundbased analog of microgravity may cause increased ventricular compliance and cardiac contractility. Our project revealed that an invasively-instrumented animal model should be viable for use in spaceflight cardiovascular experiments to assess potential changes in myocardial function and cardiac compliance.

INCREASED SENSITIVITY AND RESETTING OF BAROREFLEX CONTROL OF EXERCISE HEART RATE AFTER PROLONGED BED-REST

Sundblad, P*, J. Spaak*, B. Tedner*, P.E. di Prampero** and D. Linnarsson*

*Karolinska Institutet, Stockholm, Sweden

**University of Udine, Udine, Italy

Background

Studies during spaceflight and prolonged bed-rest simulations of spaceflight have been used to investigate basic mechanisms of orthostatic intolerance. Such studies in resting humans have shown an association between reduced sensitivity of the arterial baroreflex and orthostatic intolerance, but corresponding data from exercise have so far not been available.

Methods

We studied baroreflex control of heart rate (HR) during steady-state exercise (50 W) with superimposed sudden tilts between supine and upright posture. Seven men were studied repeatedly before and 0 (8h), 2, 4, 8, 12, and 33 days after a 42-day period of bed-rest in -6° head down tilt position. Arterial and cardiopulmonary baroreflex inputs were computed from continuous estimates of mean carotid distending pressure (CDP) and thoracic blood volume. CDP was computed from continuous, photoplethysmographic recordings of the arterial blood pressure and the pressure in a hydrostatic fluid column between the neck and the Finapres cuff. Thoracic blood volume was estimated from transthoracic electrical impedance. Cardiac output was measured with an acetylene rebreathing method in the supine and the upright positions.

The sensitivity of the carotid-cardiac and the cardiopulmonary-cardiac baroreflex was determined from HR responses to increases in CDP and central blood volume during down tilts.

Results

Our preliminary analysis indicates that both arterial and cardiopulmonary baroreflex sensitivities were increased after bed-rest and then were gradually returned to control. There was normalization of the cardiopulmonary baroreflex sensitivity 4 days but not 2 days after bed-rest and of the arterial baroreflex 33 but not 12 days after bed-rest. Eight hours after bed-rest the steady-state mean arterial pressure was approximately 20 mmHg higher than before bed-rest; this resetting was normalized 2 days later. Tilt-induced changes in central blood volume were not different after bed-rest. Steady state exercise heart rates were higher after bed-rest and had returned towards normal on day 33. Cardiac output and stroke volume were decreased, in both supine and upright position, after bed-rest and did not fully recover in 33 days. Except generally higher heart rates, no sign of orthostatic intolerance were observed during the exercise-tilt test.

Conclusion

We conclude that baroreflex control after prolonged bed-rest differs between rest and light exercise in that blood pressure resetting and increased reflex sensitivity compensate for the fall in stroke volume and thus contribute to maintaining orthostatic tolerance during exercise.

COMPLEX CARDIOVASCULAR DYNAMICS AND DECONDITIONING DURING HEAD-DOWN BED REST.

J.O. Fortrat¹, D. Sigaud¹, G. Gauquelin-Koch² and C. Gharib¹.

¹ Laboratoire de Physiologie de l'Environnement, Faculté de Médecine de Lyon, 8 Av Rockefeller, F-69373 Lyon Cedex 08; E-mail : fortrat@cismsun.univ-lyon1.fr - ² CNES, F-75039 Paris Cedex 01

INTRODUCTION

Chaos theory provides new tools to study cardiovascular physiology and new hypotheses about its regulation. Some authors observed an alteration in cardiovascular dynamics complexity in circumstances where orthostatic tolerance is decreased. We hypothesised that fractal and non-linear dynamics of heart rate and blood pressure variability could be changed, even at rest, during a long-term ground based simulation of weightlessness.

METHODS

Beat-by-beat series of RR-intervals and systolic blood pressure of seven resting subjects were observed before, during and after a 42 day head-down bed rest (HDBR). The fractal component of series was examined using coarse graining spectral analysis (Yamamoto & Hughson, *Physica D.* 68:250-264; 1993), while non-linear predictions (Sugihara & May, *Nature.* 344:734-741; 1990) and correlation dimensions (Grassberger & Procaccia, *Physica D.* 9:189-208; 1983) were used to evaluate non-linear dynamics of series.

RESULTS

Results showed for RR-interval a fractal change while non-linear dynamics were not changed and for blood pressure no fractal change while non-linear dynamics were slightly changed. Despite strong regulatory relationships between RR-interval and blood pressure, RR-interval fractal change had no consequence on blood pressure fractals and blood pressure non-linear dynamics changes had no consequence on RR-interval non-linear dynamics. RR-interval fractal change is also observed during parasympathetic blockade. Blood pressure non-linear dynamics changes are also observed in barodenervated dogs. The individual RR-interval non-linear predictions before HDBR indicated differences between subjects. Two subjects have high prediction coefficients, two others have low coefficients and the remaining three have intermediate coefficients. Orthostatic intolerance after HDBR was observed on four subjects who included the two subjects with low coefficients and excluded the two subjects with high coefficients.

CONCLUSION

The conclusions were 1) HDBR induced alterations in cardiovascular dynamics complexity 2) during head down bed rest, complexity alterations of RR-interval and blood pressure variability were not bounded up with one another. These alterations could be involved in orthostatic intolerance observed after HDBR. Individual results of non-linear predictions do suggest an interesting way to select non-fainter subjects. Nevertheless these preliminary results have to be confirmed.

Abstract from Simon Evetts for submission to the Universities Space Research Association, IAA Man in Space Symposium.

Evetts and Russomano (1995). The cardiovascular effects of 6 hours of head-down tilt upon athletes and non-athletes.

The cardiovascular responses of athletes and non-athletes to a simulation of microgravity comprising a 6 hour exposure to 6° head-down tilt (HDT) were investigated. Eight healthy male subjects, aged 19-33, were placed in athletic (n = 4) and non-athletic (n = 4) groups according to their directly measured maximum oxygen uptake values. The effects of the 6 hour exposure to 6° HDT were studied by recording ECG and arterial blood pressure at intervals during HDT and during 10 minutes of 70° head-up tilt before and after the HDT. Baroreceptor responsiveness was examined by recording the heart rate and blood pressure responses to Valsalva's manoeuvres (mouth pressure of 40 mmHg held for 15 seconds) performed before and after the 6 hour period of HDT, whilst the subject was horizontal and in the 70° head-up position. The increase of heart rate and the decreases of systolic and diastolic pressures produced by the head-up tilt were significantly greater ($p < 0.05$) after the 6 hour exposure to HDT than before. The athletic group were also found to have a significantly greater mean baroreflex slope when compared to that of the non-athletic group mean ($p < 0.05$). Of seven subjects who successfully completed the experimentation none fainted before HDT and two fainted after HDT. The subjects who fainted were both athletes.

The results of this investigation support the hypothesis that physical fitness and microgravity simulation both adversely affect blood pressure control mechanisms.

INDIVIDUAL SUSCEPTIBILITY TO POST-SPACEFLIGHT ORTHOSTATIC INTOLERANCE: CONTRIBUTIONS OF GENDER-RELATED AND MICROGRAVITY-RELATED FACTORS

J. M. Fritsch-Yelle¹, T. E. Brown², and P. A. Whitson¹

¹Life Sciences Research Laboratories and ²KRUG Life Sciences, National Aeronautics and Space Administration, Johnson Space Center, Houston, Texas 77058

INTRODUCTION

The major manifestation and the most well documented (by preflight and landing day stand tests) of the cardiovascular changes associated with spaceflight is reduced orthostatic tolerance. Virtually every space traveler suffers this, although to different degrees. We now think this problem has a large autonomic component.

METHODS

In the past several years, our laboratories (*J. Appl. Physiol.* 73:664-71, 1992; *J. Appl. Physiol.* 77:1776-83, 1994; *J. Appl. Physiol.* 79:428-33, 1995; *J. Appl. Physiol.* 80:910-14, 1996; and *J. Appl. Physiol.* 81:2134-41, 1996) and others (*J. Appl. Physiol.* 81:7-18, 1996) have focused on determining the etiology of post-spaceflight orthostatic intolerance. We have recently begun to focus on the similarities and differences between short- and long-duration spaceflight and their effects on orthostatic mechanisms. Important findings have come from these studies.

RESULTS

First, there are distinct measurable individual differences in susceptibility to post-spaceflight orthostatic intolerance. Susceptible astronauts (about 25%) cannot remain standing for 10 minutes on landing day. These individuals, as a group, have different cardiovascular responses to standing, not only on landing day but also before flight, when they display lower peripheral vascular resistance and arterial pressures and higher heart rates than non-susceptible individuals. Susceptible astronauts are primarily female and primarily non-pilots.

Second, there is now clear evidence of autonomic dysfunction associated with spaceflight. During and after spaceflight, arterial baroreflex control mechanisms are attenuated, baroreflex sensitivity during Valsalva maneuvers is attenuated, and orthostatic tolerance during lower body negative pressure is reduced. On landing day, sympathetic responsiveness, measured by low frequency systolic pressure spectral power, norepinephrine release, peripheral vascular resistance, and arterial pressure, is reduced in susceptible individuals. Recent evidence from long-duration spaceflight indicates that the degree of attenuation is not greater after prolonged stays in space.

Third, all evaluations of cardiovascular changes associated with spaceflight must account for the influence of the many confounding factors which occur during spaceflight, even on dedicated life science missions. These include individual susceptibility of crew members to space motion sickness and exhaustion, sleep/wake cycles, medications, influence of conflicting research protocols, and influence of conflicting operational requirements.

CONCLUSIONS

These studies have both research and clinical applicability. We have begun to elucidate the mechanisms of post-spaceflight orthostatic intolerance. The next logical step is to explore the mechanisms of individual susceptibility, both gender-related and autonomic-related. Appropriate, individualized countermeasures may then be developed for astronauts thought to be susceptible. In addition, the mechanisms learned may be helpful to delineate mechanisms of the pathophysiology of autonomic disease.

CASSIOPEE MISSION 1996. COMPARISON OF CARDIOVASCULAR ALTERATION AFTER SHORT AND LONG-TERM SPACEFLIGHTS.

D. Sigauco¹, J.O. Fortrat¹, A. Maillet¹, J. Frutoso¹, C. André-Deshays², R. Kaspranski³, I. Fountova⁴, A. Güell², G. Gauquelin-Koch^{1,2} and C. Gharib¹

¹Laboratoire de Physiologie de l'Environnement, Faculté de Médecine, 8 avenue Rockefeller, 69373 Lyon cedex 08, France. E-mail: sigauco@cismsun.univ-lyon1.fr - ²CNES, 75039 Paris cedex 01, France - ³CPK, Moscow, Russia - ⁴IBMP, Moscow, Russia.

INTRODUCTION

After a spaceflight, returning astronauts present a cardiovascular deconditioning consisting of orthostatic intolerance (OI) and a decrease in exercise capacity. Defective central integration of cardiovascular control mechanisms could be a contributory factor to OI. To assess this hypothesis we studied heart rate variability and the spontaneous baroreflex sensitivity in 14 cosmonauts before and after several MIR missions (14 days - 6 months).

METHODS

We studied two different spaceflight durations: from 14 to 30 days (4 cosmonauts) and from 4 to 6 months (10 cosmonauts). Stand tests were performed within 60 and 30 days before launch, the first day of landing (L1), the second day (L2) and the fifth or sixth day (L5/6).

Heart rate variability was studied at supine rest using coarse graining spectral analysis. This method provided indicators of the sympathetic and parasympathetic nervous influence to the heart (SNS and PNS respectively). Spontaneous baroreflex slope was obtained by continuous monitoring of arterial blood pressure and RR-interval. This method estimates the spontaneous baroreflex sensitivity.

RESULTS

In our study, on L1, 4 of 14 cosmonauts did not complete the stand test because of presyncopal symptoms. Pre and postflight supine overall variability and spontaneous baroreflex results were similar after short and long-term spaceflights. After flight, in all cosmonauts, we observed a decrease of overall variability with a significant decrease of PNS indicator associated with an increase of SNS indicator. Both PNS and SNS indicators returned to preflight values on L5/6, whereas overall variability was still altered. Moreover, a significant decrease of spontaneous baroreflex sensitivity was observed on L1. Systolic blood pressure increased on L1 and returned to preflight values, while resting RR-interval was decreased from L1 to L5/6.

However, for Cassiopée mission (1 woman during 17 days) we did not observe any modification during and after flight.

CONCLUSION

These findings suggest that cardiovascular alteration develops early (before 14 days) during spaceflight and do not progress until 6 months. In addition, the incidence of OI seems to have no relation with the spaceflight duration.

CEREBRAL and FEMORAL FLOW RESPONSE to LBNP during 6 MONTH MIR-SPACEFLIGHTS (93-95).

Ph.Arbeille¹, G.Fomina², I.Alferova², M.Porcher¹, J.Coulon¹, A.Kotovskaya², V.Poliakov². (1) Med Physiol Spatiale, CHU Trousseau, 37044 -Tours - France. (2) IMBP Moscow- Russia.

INTRODUCTION: The objective of this study was to assess the heart rate and the peripheral arterial response to LBNP, in order to evaluate the orthostatic tolerance of 6 cosmonauts during 6 month Mir spaceflights.

METHOD: During LBNP the cerebral and femoral flows were monitored by using Doppler probes fixed on the skin, blood pressure (arm cuff) and ECG were also measured. The calf volume changes were assessed by plethysmography. The following parameters were calculated beat by beat: cerebral flow volume (Qc) and vascular resistance (Rc) changes (3) (in % of the pre LBNP value), femoral flow volume (Qf) and vascular resistance (Rf)(1,2), cerebral to femoral flow volume ratio (Qc/Qf)(4), heart rate (HR), mean blood pressure (MAP) and calf circumference (Calf C). The LBNP test consisted in 2 steps of 10mn long at -25mmHg and -45mmHg. Seven cosmonauts were submitted to LBNP preflight (-30d), inflight (at 1month, 3 to 4m, and 5.5 m), and postflight at +7 days. Data are presented as mean values on the 6 cosmonauts.

RESULTS: The HR increased (+20% +/-7 at -25mmHg; +40% +/-8 at -45mmHg) and MAP decreased (-5% +/-3 at -25mmHg; -8% +/-3 at -45mmHg). Rc decreased by 4% +/-4 at -25mmHg; 8% +/-5 at -45mmHg pre in and postflight. Qc decreased (3% +/-3 at -25mmHg; 8% +/-3 at -45mmHg) pre in and postflight. No significant difference was found for HR, MAP, Rc and Qc pre in and postflight. Rf increased significantly less inflight at 1m, 3-4m, and 5.5m, and postflight (+16% +/-3 at -25mmHg; +18% +/-5 at -45mmHg) than preflight (+40% +/-5 at -25mmHg p<0.01; +60% +/-5 at -45mmHg p<0.01). Qf decreased less inflight and postflight (-19% +/-7 at -25mmHg; -24% +/-3 at -45mmHg) than preflight (+32% +/-7 at -25mmHg p<0.05; -43% +/-5 p<0.05). The Qc/Qf flow volume ratio increased less inflight and postflight (+21% +/-7 at -25mmHg; +23% +/-6 at -45mmHg) than preflight (+46% +/-7 at -25mmHg p<0.05; +75% +/-6 at -45mmHg p<0.01). The calf circumference increased less at -45mmHg inflight (1m and 5.5m) and postflight (6% +/-1.5) than preflight (9% +/-1 p<0.05). (Fig 1 to 6)

CONCLUSION: The cerebral flow response remained adequate at any time during the flight or postflight, and comparable to preflight, which is in favor of the conservation of an efficient cerebral vascular regulation even after 6 months in Og. A significant lack of lower limb arterial resistance increase was observed in all cosmonaut inflight and postflight. This abnormal response may be in relation with a reduced vasoreactivity of the lower limb arterial bed, a reduction of the venous tone and muscle pressure, but also with an alteration of the baroreflex. As a consequence the cerebral to femoral flow volume ratio increased less inflight and postflight. This parameter confirmed a less efficient flow redistribution toward the brain although there was no significant reduction of the cerebral flow volume. The reduced calf volume increase was not in agreement with the increased venous distensibility found after head down tilts. This apparent contradiction may be due to the fact that in head down tilt the leg veins are empty, whereas inflight they are not empty and thus cannot expand during LBNP as much as after head down tilt. The amplitude of the vascular response to LBNP remained similarly altered throughout the flight which leads to suspect that the orthostatic intolerance develops very early inflight but remains stable a least for 6 months. During inflight LBNP no abnormal response in BP or HR was found leading to suspect that orthostatic intolerance will not exist postflight. Nevertheless all cosmonauts presented sign of orthostatic intolerance postflight which demonstrates the high sensitivity of the lower limb vascular resistance and the cerebral to femoral flow ratio as measured by Doppler ultrasound for the diagnosis of reduced orthostatic tolerance. These results confirm that during long term flights the cerebral hemodynamic response to fluid shift toward the legs (as induced by LBNP) is well maintained, however the lower limb arterial and venous reactivity are severely affected. Reliable hemodynamic indicators of inflight orthostatic intolerance (lower limb vascular resistance, flow redistribution ratio) have been successfully tested, and could be used for monitoring the efficiency of the countermeasures designed to improve orthostatic tolerance inflight (ie intensive LBNP..). Nevertheless only some components of the cardiovascular disadaptation were identified. The volemia was only moderately reduced, the hormonal system and the baro-reflex were not investigated during these flights. (Work supported by CNES grants)

References: 1 - Arbeille. Ph et al. High vascular resistance quantification by Doppler method. *Ultrasound Med Biol.* vol 21; n°3; p 10-18. 1995

2 - Arbeille.Ph, Pavy.le.Traon.A, Fomina.G, et al Femoral artery flow response to LBNP, as an indicator of orthostatic tolerance. Application to long term head down tilt, & spaceflight. Aviat, space, env, med.vol 66; p 131-136. 1995.

3 - Pavy le Traon.A, Vasseur.P, Arbeille.Ph et al. Tolerance to lower body negative pressure,during a 28 head down tilt, with & without countermeasure. Aviat,space,env,med. vol 66, 10, 982-991; 1995.

4 - Ph. Arbeille, Achaibou.F, G.Fomina, et al. Regional Blood Flow in Microgravity: Adaptation and Deconditioning. Medicine & Science in Sport & Exercise; vol 28; n° 10: p 14-25. 1996.

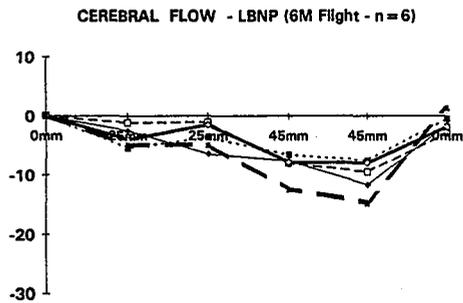


Fig 1: Middle cerebral mean flow velocity (Qc) changes in % of pre LBNP value. Changes in Qc pre, in, and post flight were not significantly different.

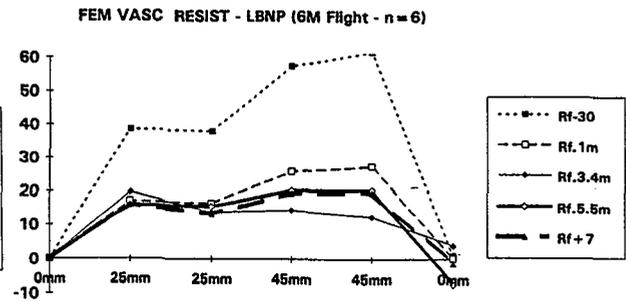


Fig 4: Lower limb vascular resistance (Rf) changes in % of the pre LBNP value. Rf increased less inflight and postflight than preflight (p < 0.01).

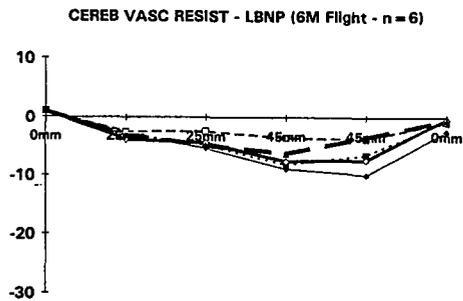


Fig 2: Middle cerebral vascular resistance (Rc) changes in % of pre LBNP value. Changes in Rc pre, in, and post flight were not significantly different.

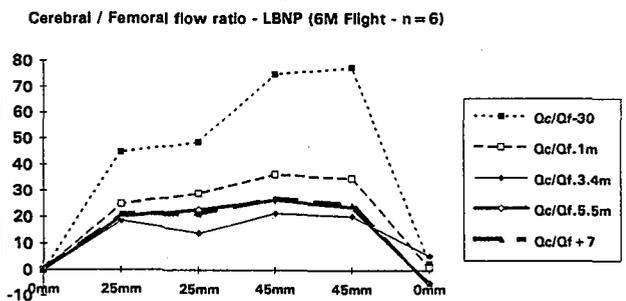


Fig 5: Cerebral to femoral flow ratio changes (Qc/Qf=Cerebral mean flow velocity/Femoral mean flow), in % of pre LBNP value. Qc/Qf increased less inflight and postflight than preflight (p < 0.01).

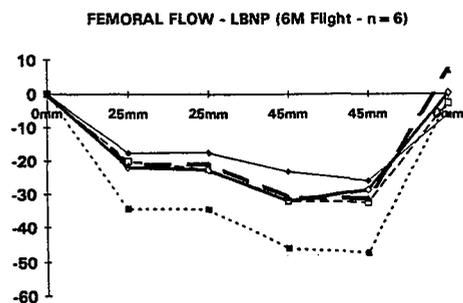


Fig 3: Femoral mean flow (Qf), changes in % of the pre LBNP value. Reduction of Qf was lower inflight and postflight (p < 0.05).

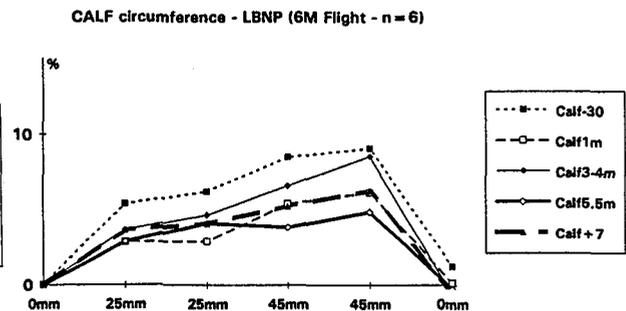


Fig 6: Calf cross section changes measured by ultrasound Plethysmography. (Calf), in % of the pre LBNP value. Calf section increased less inflight and postflight than preflight (p < 0.05).

CEREBROVASCULAR CHANGES DUE TO SPACEFLIGHT AND POSTFLIGHT PRESYNCOPE.

A. P. Blaber¹, R. L. Bondar¹, P. Moradshahi², F. Stein², M. S. Kassam², T. E. Brown³ and J.M. Fritsch-Yelle⁴

¹Faculty of Kinesiology, University of Western Ontario, London, ON N6A 3K7, ²CATE, Ryerson Polytechnic University, Toronto, ON M5B 2K3, ³KRUG Life Sciences and ⁴Medical Sciences Division, NASA, Johnson Space Center, Houston TX 77058.

INTRODUCTION

Virtually every astronaut returning from space exhibits symptoms of presyncope. Recently we reported that this may be due to centrally mediated hypoadrenergic responsiveness (Fritsch-Yelle *et al. J. Appl. Physiol.* 81(5):2134-2141, 1996). In this paper we investigate the cerebrovascular changes due to spaceflight and the interaction of the cardiovascular and cerebrovascular systems.

METHODS

Forty astronauts were studied 30 and 10 days before launch, on landing day (1-2 h after landing), and 3 days after landing, on shuttle missions lasting 8-16 days. Due to difficulty in collection and analysis of cerebral blood flow only 32 astronauts, whose mean age was 39.8 ± 5.2 yr, had sufficient data for analysis. Middle cerebral artery flow velocity (MFV), measured with a 2-MHZ pulsed transcranial Doppler ultrasound, and blood pressure, measured using the non-invasive Finapres, were recorded on digital tape and the final 256 beats in the supine and stand position were analysed off-line. Mean arterial blood pressure was adjusted to brain level (MAP_{brain}). After ~30 min. supine, subjects were assisted to the stand position and remained unassisted in the standing position for 10 min. Subjects who became presyncopal (PSL) were returned to a supine position. Subjects were grouped based on landing day presyncope. A repeated measures analysis of variance was used. Student's *t*-tests were performed to document differences when there were significant main effects.

Coarse-graining spectral analysis, CGSA, (Yamamoto & Hughson, *Physica D* 68:250-264, 1993) was used to characterize the harmonic and fractal power. Harmonic power was divided into low (P_{LO}) and high (P_{Hl}) frequency components. The fractal power was used to determine the complexity of blood pressure and cerebral blood flow regulation with the fractal spectral exponent, β . Complexity is thought to relate to the number of mechanisms interacting to produce the measured physiological signal. High and low degrees of regulatory complexity are indicated by values of β close to 1.0 and 2.0, respectively. Cross-spectral analysis was used to determine the transfer magnitude, TM, between MAP_{brain} and MFV (Blaber *et al. FASEB J.* 10(3):A587, 1996). We averaged the TM over the low frequency range (0.03 to 0.14 Hz) where the squared coherence (Coh²) function was greater than 0.5. The TM serves as an indicator of what magnitude of change in MFV is due to a change in MAP_{brain}. To determine the gain, TM (cm•s⁻¹•mmHg⁻¹) was normalized, by the average cerebrovascular resistance (CVR = MAP_{brain}/MFV) over the 256 beats, and converted to dB (Gain = 20•log[TM•CVR]). Gain therefore reflects the dynamic response of MFV to MAP_{brain} along with the CVR about which the variation occurs. If autoregulation serves to regulate the effect of changing MAP_{brain} on MFV, increased gain would indicate reduced effectiveness.

RESULTS

Eight of the astronauts were PSL on landing day. MAP_{brain} decreased significantly upon standing on all three measurement days in both the PSL and nonPSL group. The PSL group had consistently lower supine MAP_{brain}. On landing day nonPSL supine MAP_{brain} was greater than it was preflight (Table 1). CGSA and Cross-spectral gain data are shown in Table 1. CGSA of the input to autoregulation (MAP_{brain}) revealed interesting differences between nonPSL and PSL astronauts. In the nonPSL astronauts P_{LO} increased from supine to stand preflight ($p < 0.001$) and after landing ($p = 0.01$). The PSL group showed no changes with stand pre and postflight, with landing day P_{LO} less than the nonPSL group ($p = 0.046$). MAP_{brain}- β decreased from supine to stand in the nonPSL group preflight ($p = 0.011$) but not postflight and was lower during postflight stand than preflight ($p = 0.015$). The changes in MFV P_{LO} reflected those in MAP_{brain}. MFV- β did not change from supine to stand preflight in both groups, however, supine MFV- β was increased in the nonPSL immediately on landing and also decreased significantly upon standing ($p = 0.027$). The PSL group had no significant changes in MFV- β pre to postflight or from supine to stand.

Although the trends with P_{LO} were similar between *MAPbrain* and MFV the effect of autoregulation can be determined by the degree to which variations in *MAPbrain* are translated into variations in MFV. The standing gain increased ($p=0.047$), from pre to postflight in the PSL, but not the nonPSL group. The nonPSL group showed significant decreased gain from supine to standing on all three days of measurement, whereas the PSL group showed no decrease.

Table 1: CGSA of, and Cross-spectral analysis between, *MAPbrain* and MFV of nonPSL (n=24) and PSL (n=8) astronauts.

		Preflight		Landing		Postflight	
		supine	stand	supine	stand	supine	stand
CGSA of <i>MAPbrain</i>							
nonPSL	MAP	80.8±1.8	63.3±2.4†	89.3±2.7‡	66.7±3.2†	85.8±2.3	62.2±3.5†
	P_{LO}	0.94±0.23	2.87±0.41†	1.47±0.37	3.63±0.60†	1.13±0.28	1.89±0.29
	β	1.73±0.09	1.38±0.10†	1.67±0.09	1.70±0.07‡	1.64±0.08	1.63±0.09
PSL	MAP	74.5±3.4	59.2±4.4†	75.9±5.3#	61.7±5.5†	80.5±6.1	71.7±5.6†
	P_{LO}	1.42±0.75	2.00±0.58	2.07±1.38	1.65±0.34#	0.77±0.17	2.21±0.89
	β	1.54±0.16	1.44±0.11	1.70±0.21	1.76±0.21	1.62±0.26	1.51±0.16
CGSA-MFV							
nonPSL	MFV	53.4±5.5	43.1±2.1†	47.6±2.3	39.7±1.6	50.6±3.0	46.1±3.0
	P_{LO}	0.34±0.07	0.99±0.20†	0.81±0.20	1.16±0.26	0.86±0.27‡	0.83±0.14
	β	1.42±0.07	1.22±0.11	1.61±0.11	1.24±0.08†	1.39±0.67	1.26±0.08
PSL	MFV	58.9±5.7	51.2±2.5†	52.4±4.7	40.0±2.9	63.3±7.2	57.0±6.8
	P_{LO}	0.46±0.12	0.68±0.14	1.83±1.22	0.49±0.99	0.93±0.47	1.01±0.28
	β	1.27±0.16	1.16±0.13	1.39±0.25	1.38±0.09	1.49±0.11	1.19±0.14
Cross-spectral analysis							
nonPSL	Gain	2.90±0.68	0.26±0.62†	2.20±0.68	0.32±0.47†	2.78±0.55	-0.25±0.70†
PSL	Gain	1.84±1.39	-1.04±1.07	2.23±1.06	2.40±2.20	2.09±1.65	2.29±1.35‡

Values are means±SE; n, no of subjects; all $p<0.05$. †, significantly different from supine; ‡, significantly different from Preflight; #, significantly different from nonPSL.

Units: *MAPbrain*- P_{LO} ($\text{mmHg}^2 \cdot \text{Hz}^{-1}$); MFV- P_{LO} ($\text{cm}^2 \cdot \text{s}^2 \cdot \text{Hz}^{-1}$); Gain (dB).

CONCLUSIONS

The intergroup differences before flight suggest that there is a subset of the normal population who have orthostatic responses within normal ranges before flight but who are predisposed to postflight presyncope (Fritsch-Yelle *et al.* *J. Appl. Physiol.* 81(5)2134-2141, 1996). This group clearly had an impaired preflight sympathetic response to tilt as indicated by an unchanging *MAPbrain* and MFV P_{LO} upon standing. Upon landing this value was significantly lower than the nonPSL group. As well, the standing cerebrovascular gain was higher 3 days after landing. Although the PSL group had no changes in MFV complexity, the values were consistently high (β close to 1.0), this coupled with the lower *MAPbrain* and slightly higher MFV than the nonPSL group pre and postflight would suggest that the autoregulatory system in the PSL group was on the leftward side of the curve, closer to maximum capacity. Cerebrovascular gain was not affected by spaceflight in the nonPSL group. NonPSL *MAPbrain* and MFV complexity in the supine position were reduced on landing day. *MAPbrain* complexity failed to change with stand, however MFV complexity increased. These data suggest that in spaceflight the number of regulatory inputs used by the body to regulate blood pressure and cerebral blood flow is reduced. Cerebral autoregulation may be adversely affected on return from spaceflight in the PSL but not the nonPSL astronauts.

Monday, June 9

Session MP2
Room 2
2:30 - 5:30 p.m.

52-51
072168

326955

8p.

Biological Life Support Systems

CREW REGENERATIVE LIFE SUPPORT IN LONG-DURATION SPACE MISSIONS

N.M. Samsonov,¹ A.I. Grigoriev,² Ju.I. Grigoriev³

¹NIICHIMMASH, B. Novodmitrovskaya, 14 125015 Moscow, Russia, ²IBMP, Moscow, Russia, ³RSC Energia, Korolev, Russia

The paper deals with the status and prospects of spacecraft and base crew life support. A key problem governing human stay and activities in long-duration space missions and planet exploration is the development of regenerative life support systems (LSS). The use of systems for water recovery and air revitalization and in prospective food from the end products of life as well as an integrated bioengineering system enables the crew to be provided with water, oxygen, and food, thereby creating a habitat environment on spacecraft or base. In Russia (former USSR) extensive research has been done to prove the feasibility of integrated long-life regenerative chemical/physical and biological systems. The first chemical/physical systems were installed on Salut orbital space stations to recover potable from humidity condensate. The Russian Mir space station incorporates systems for water recovery from humidity condensate, from urine reclamation and hygiene waste water processing, a system for oxygen generation by electrolysis, a system for the removal of CO₂ and other trace contaminants. The systems allow a considerable reduction in specific mass water and oxygen supplied from the Earth. A modular construction of the regenerative systems provides for their updates. The Mir updated systems complemented with a system for CO₂ collection and concentration and a Sabatier CO₂ system followed by a vitamin greenhouse are planned to be installed on the Russian segment of the International Space Station (ISS). The ISS LSS will be a baseline of new regeneration spacecraft and planetary base LSS. Advanced LSS will be based on the water recover efficiency, low energy and mass demand, LSS reliability enhancement with a gradual transition from physical/chemical to integrated physico-chemical/biological systems.

For successful space exploration and missions to the Moon and Mars a R&D program for building new generation LSS should be developed. Experience gained on development of ISS shows that the most effective way to accomplish this is international cooperation and partnership.

BIOCONVERSION SYSTEMS FOR FOOD AND WATER ON LONG TERM SPACE MISSIONS.

M.A. Benjaminson, S. Lehrer and D.A. Macklin

NSR/EOD Joint Venture and NSR/Touro Applied BioScience Research Consortium. Dix Hills, NY 11746.

INTRODUCTION

Regenerative biosystems are logistical and economic requirements for long duration space missions on which expendables are often expensive and resupply is not tenable. Therefore wastewater recycling and crop plant generated waste biomass conversion to food would prove beneficial. We fabricated and laboratory tested both a biological wastewater reclamation system (BWWR) and a waste cellulose to edible mushroom conversion system (CMCS) with simulated waste products. The BWWR is designed to remove bacteria, microalgae and other microbiota from water without the use of ionizing radiation, disposable filters, intense heat or toxic chemicals and convert them to a harmless cellulosic product. The CMCS converts the waste cellulose anticipated from the BWWR and plant crop waste cellulosic biomass, such as the ligno-cellulose stalks and other non-food plant parts from controlled ecological life support systems (CELSS), into edible mushrooms. The CMCS test substrate was hay treated with a variety of mulching techniques and inoculated with straw mushroom spawn.

METHODS

The pilot scale BWWR consists of two modules which are designed to process the contaminated water sequentially. The first consists of two connected 19-L plastic tanks one of which serves as a holding tank and the other as a reactor vessel. The reaction chamber contains a mixing paddle composed of four vertical panels. Sampling ports are located at four different levels. The biologically active components of the first module are the non-pathogenic Dictyostelium amoebae which prey on other microbiota such as bacteria. These are added to microbially contaminated water in the holding tank. This water is then transferred to a mixing chamber where the relative numbers of amoebae and contaminating microbiota are monitored. Predation is allowed to continue until a marked reduction in microbial contaminants is detected in the mix. Bacterial numbers are determined by standard plating techniques on 1% lactose-peptone agar (LPA) and recorded as colony forming units (CFU). The liquid is pumped from the mixing chamber and fed into the second module, an environmentally controlled "dry" reaction chamber. In this chamber, the liquid is spread onto perforated stainless steel surfaces. Here, the amoebae (having converted engulfed microbiota into Dictyostelium cell substance) respond to their genetic programming for life on a solid substrate, in the presence of light, and differentiate into mature cellulosic stalks which can be harvested and added to the feed stock for the CMCS.

Parametric bench-top experiments studied the dynamics of stirred vs. static binary cultures of E. coli and D. dictyostelium in cell substance) respond to their genetic programming for life on a solid substrate, in the presence of light, and differentiate into mature cellulosic stalks which can be harvested and added to the feed stock for the CMCS.

Parametric bench-top experiments studied the dynamics of stirred vs. static binary cultures of E. coli and D. discoideum in nutrient poor vs. enriched media. The data, in terms of reduction of bacterial numbers over time were applied to BWWR liquid reactor experimental design. The superiority of perforated stainless steel over porous plastic test surfaces was also determined in bench-top studies carried out by inoculating candidate surface materials with liquid reactor effluents in water agar petri plates.

The CMCS consists of a chamber with programmable controlled temperature, relative humidity, air exchange, simulated sunlight lux levels and substrate moisture. The substrate and mushroom spawn are housed in a perforated rotation cylinder divided longitudinally into four compartments to enable comparative studies and to provide for even exposure to the chamber environment. When mushrooms appear they can be harvested. The design of the experiments which were carried out in the CMCS was based on a series of trials of various spawning media and substrate preparation/mulching techniques.

RESULTS

BWWR: As expected, bacteria continued to exist in water with extremely low levels of nutrients for protracted periods of time (in excess of 17 days). In the liquid reactor, contrary to the usual logarithmic growth curve anticipated in a closed system, the counts of CFU from samples in the mixing tank described a saw-toothed course, the graph of CFU vs. time looking much like a fever chart. The number of CFU plunged from a high of over 400 colonies down to 2 CFU in 3 days. It rose again to the same level in 5 days and then plunged down to 7 CFU at 6 days. It peaked again at 6 days, dropped down to 350 CFU at 7 days and rose again to over 400 CFU at 8 days when the experiment was terminated. In the holding tank,

starting from a low of 7 CFU at 1 day, the numbers rose to 10 CFU at day 3 and dropped to 1 CFU at day 4. They then rose precipitously to over 400 CFU on day 5 and were down to 2 CFU by day 7. The number of CFU fluctuated between 4 and 2 until day 11 when they rose to 400 CFU, dropping to 1 CFU on day 14. On day 16, a dose of over 1000 Dictyostelium amoebae were added to the holding tank. On day 17 the experiment was terminated and the count was 1 CFU.

When liquid reactor effluent was inoculated onto the surface of perforated stainless steel inserts, in the "dry" reactor, growth was not detected by visual observation until day 19. At that time, mature cellulose stalks and intermediate Dictyostelium stages were detected on the stainless steel surfaces.

CMCS: Examination of the four compartments of the rotating cylinder showed that, in order for mushroom primordia to appear, special care must be take to provide adequate moisture to the substrate. This was dramatically demonstrated by the lack of growth in the cylinder chambers where substrate moisture was allowed to dissipate during primordium formation. Primordia appeared only in the chamber where substrate moisture had been maintained by plastic covering and frequent misting.

CONCLUSION

With proper manipulation and augmentation, the BWWR appears to provide a potential for the safe biological removal of microbes from waste water. Similarly, the CMCS has demonstrated a possible means for effectively converting biomass to food. Both deserve further exploration.

(Supported by NASA contracts, NAS 8-40127 and NAS 13-662)

NOVEL LABORATORY APPROACHES TO MULTI-PURPOSE AQUATIC BIOREGENERATIVE CLOSED-LOOP FOOD PRODUCTION SYSTEMS

V. Blüm¹, M. Andriske¹, K. Kreuzber², U. Paassen¹, M. P. Schreibman³, and D. Voeste¹

¹Ruhr-University Bochum, Faculty of Biology, C.E.B.A.S. Center of Excellence, Bochum, Germany, ²German Aerospace Establishment, Executive Department, Cologne-Porz, Germany and ³City University of New York, Brooklyn College, Department of Biology, Brook-lyn, N. Y., U. S. A.

INTRODUCTION

The Closed Equilibrated Biological Aquatic System (C.E.B.A.S.) is an artificial (man-made) aquatic ecosystem which was primarily developed to study the long-term influence of space conditions on several subsequent generations of aquatic animals and plants the „evolution“ of which was consequently reported on all IAF-congresses and IAA Man in Space Symposia since 1989. Its development was directed by an international scientific program in which 5 German and 3 U. S. American universities, the Institute of Biophysics of the Russian Academy of Sciences in Krasnoyarsk and the Institute for Medical-Biological Problems in Moscow are involved. C.E.B.A.S. is operative in 2 different versions: the „Original C.E.B.A.S.“ with a volume of more than 150 liters and the „C.E.B.A.S. MINI MODULE“ with about 9 liters volume. Based on the latter a spaceflight version fitting into a spaceshuttle middeck locker is currently under construction and ground test which is dedicated to two different spaceshuttle missions in late 1997 and early 1998.

CONSTRUCTION PRINCIPLE AND RESULTS

Based on the construction principle of the Closed Equilibrated Biological Aquatic System (C.E.B.A.S.) two novel combined animal-plant production systems were developed in laboratory scale the first of which is dedicated to mid-term operation in closed state up to two years. In principle both consist of the „classic“ C.E.B.A.S. subcomponents: animal tank (Zoological Component), plant cultivators (Botanical Component), ammonia converting bacteria filter (Microbial Component) and data acquisition/control unit (Electronical Component). The innovative approach in the first system is the utilization of minimally three aquatic plant cultivators for different species. In this one the animal tank has a volume of about 160 liters and is constructed as an „endless-way system“ surrounding a central unit containing the heat exchanger and the bacteria filter with volumes of about 1.5 liters each. A suspension plant cultivator (1 liter) for the edible duckweed *Wolffia arrhiza* is externally connected. The second plant cultivator is a meandric microalgal bioreactor for filamentous green algae. It consists of 3 x 2 subunits and may be as well exposed directly to sunlight with an automated oxygen level-dependent shading as illuminated with fluorescent lamps. The third plant growth facility is a chamber with about 2.5 liters volume for cultivation of the „traditional“ C.E.B.A.S. plant species, the rootless buoyant *Ceratophyllum demersum*. Both latter units are illuminated with 9 W fluorescent lamps. In the current experiment the animal tank contains the live-bearing teleost fish *Xiphophorus helleri* and the small pulmonate water snail *Biomphalaria glabrata* because their physiological adaptation to the closed system conditions is well known from many previous C.E.B.A.S. experiments. A part of the animals derives from a 13 month test of the C.E.B.A.S. prototype #3. The water temperature is maintained at 25°C and the oxygen level is regulated between 5 and 8 mg/l by switching on and off the plant cultivator illuminations according to a suitable pattern thus utilizing solely the oxygen produced by photosynthesis. The animals and the microorganisms of filter and biofilm provide the plants with a sufficient amount of carbon dioxide. Oxygen concentration, pH value, temperature and redox potential are on-line recorded. Ion concentrations and numbers of living germs in the system water are determined twice monthly in the laboratory from samples taken from a special „sample removal module“; the sample volume is automatically replaced from an reservoir container. A rotatory pump produces a water flow of about 38 l/min. System malfunctions are transmitted by an alert device to the person in duty who is able to control the system status and to perform certain settings via a modem. Figure 1 shows the construction scheme of this system. For a similar smaller test system with approx. 10 l volume developed from the C.E.B.A.S.-MINI-MODULE a novel indirect solar energy supply is tested which has a buffer capacity to maintain the system for 7 days in darkness under central European climate conditions also in winter. This time span may be increased by the implementation of additional batteries to simulate, e. g. a lunar night. It contains only a single plant cultivator which is operated with *Wolffia arrhiza*. This lemnean plant is able to produce large amounts of plant biomass in a short time by vegetative reproduction via daughter fronds. This easy-to-handle apparatus is dedicated to be operative more than 4 month. The experimental animals and microorganisms are the same as in the large system. The lecture presented here provides detailed information on the system construction principles and the biological, physical and chemical data of the first 7 month of the test runs of both systems.

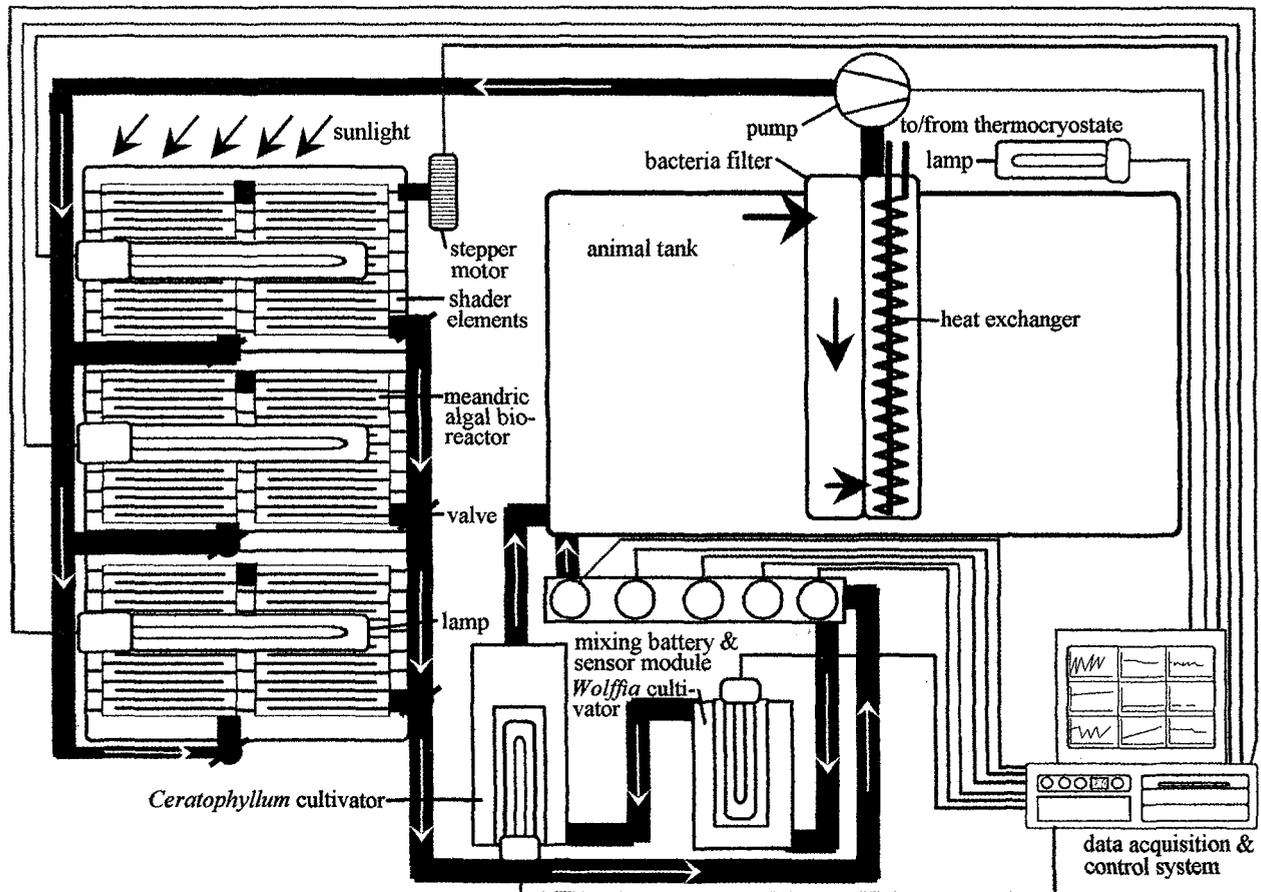


Figure 1: Construction scheme of the C.E.B.A.S.-based animal-plant production system

CONCLUSIONS

The test results from both systems will provide valuable information about first attempts to convert the laboratory devices into closed-loop production sites with herbivorous fishes which are fed with plants inedible for humans, mainly the *C. demersum*. Furthermore, the utilization of *Wolffia arrhiza* for human nutrition can be evaluated more precisely. Models for the combination of intensive aquaculture systems with higher plant hydroponics can be developed for terrestrial tests and actual biomass production. The data collected with the solar energy supply system allow serious calculations for the construction of those in larger scale for real production sites. Finally initial careful attempts can be made to develop dispositions for the implementation of aquatic food production modules into bioregenerative life support systems of a higher degree of complexity for a lunar or planetary base.

ACKNOWLEDGEMENTS

The C.E.B.A.S. Center of Excellence is generously funded by the Federal Ministry of Education and Research (BMBF) via the German Space Agency (DARA, grant #WS50WB9319-3) and the Ministry of Science and Research of the State of Nordrhein-Westfalen (grant #IVA1216-00588).

ARTIFICIAL NEURAL NETWORK DERIVED PLANT GROWTH MODELS *

Frank Zee
Center for Space Microelectronics Technology
Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109-8099

The goal of the Advanced Life Support Systems (ALSS) is to provide self-sufficiency in life support for productive research and exploration in space, for benefits on Earth and to provide a basis for planetary explorations. Part of this objective is to be able to grow crop plants in one or more controlled environments for the purpose of providing life essentials to a human crew, such as oxygen, potable water, and food. To do this reliably and efficiently, it is necessary to achieve control of the rates of various plant physiology processes, including: net exchange of exhaled carbon dioxide for oxygen (net photosynthesis), purification of water (transpiration), and food production (biomass production rate and harvest index).

To develop an efficient control system that will be able to manage, control, and optimize plant-based life support functions, system identification and modeling of plant growth behavior must first be done. We have developed a plant growth (physiology) model using artificial neural networks. Neural networks are very suitable for both steady-state and dynamic modeling and identification tasks, since they can be trained to approximate arbitrary nonlinear input-output mappings from a collection of input and output examples. In addition, they can be expanded to incorporate a large number of inputs and outputs as required, which makes it simple to model multivariable systems. Thus, unknown nonlinear functions in dynamical models and controllers can easily be parameterized by means of multilayer neural network architectures.

Artificial neural networks are composed of simple albeit numerous non-linear processing elements (modeled after biological neurons) interconnected through a complex network of variable strength connections (modeled after biological synapses). The topology of interconnections and the synaptic strengths essentially dictate the functionality of a given network. A typical network is capable of receiving a large number of analog/digital inputs (e.g., sensor signals) in parallel, and after a complex nonlinear transformation operation, provides the outputs (e.g., predicted growth, biomass). The unique strength of such neural network architectures emerges from their ability to build up their own rules through learning from examples the underlying input/output transformations in ill-defined problems.

In this paper, we will describe our approach to developing these models, the neural network architecture, and the results. With the use of neural networks, these complex, nonlinear, dynamic, multimodal, multivariable plant growth models will be able to better interpolate between all the various environmental conditions and parameters and be able to simulate both short-term (day-to-day) and long-term (plant life cycle) growth of various plants.

*Sponsored by NASA, Office of Life and Microgravity Sciences and Applications

SIX-MONTH SPACE GREENHOUSE EXPERIMENTS - A STEP TO CREATION OF FUTURE BIOLOGICAL LIFE SUPPORT SYSTEMS

T.N. Ivanova¹, P.T. Kostov¹, S.M. Sapunova¹, I.W. Dandolov¹, V.N. Sytchov², M.A. Levinskikh², I.G. Podolski², G.E. Bingham³, F.B. Salisbury³, D.B. Bubenheim⁴, G. Jahns⁴

¹Space Research Institute, Sofia, Bulgaria, ²Institute of Biomedical Problems, Moscow, Russia. ³Utah State University, Logan, Utah 84322. ⁴NASA Ames Research Center, Sunnyvale, CA

INTRODUCTION

SVET Space Greenhouse (SG) - the first automated facility for growing of higher plants in microgravity conditions was designed in the eighty years under the joint Bulgarian-Russian project "Study of the ways and means for use of higher plants in Biological Life Support Systems" for future long term manned missions in Space. The first successful 54-days experiment with vegetable plants was carried out on the MIR Orbital Complex (OC) in 1990.

The experiments in SVET SG were resumed in 1995. An American Gas Exchange Measurement System (GEMS) was added to the existing Bulgarian plant life support system. A three-month wheat plant experiment was carried out as part of MIR-NASA-3 fundamental biological program.

A set of SVET-2 SG equipment (a greenhouse of new generation) was developed by Bulgarian scientists and launched on board the MIR OC and successful six-month experiments for growing up of two crops of wheat were conducted in 1996-97 as part of MIR-NASA-5 program.

METHODS

Some optimizations in the SVET-2 SG hardware have been made to improve the environmental conditions in the 1996-97 experiments. A new, optimized Light Unit with considerably improved technical and biotechnical characteristics and a new Secondary Pump Power Supply have been designed. Software improvements in the Control Unit made the substrate moisture measurement more precise and provided a possibility for individual, consecutive and independent measurement of each sensor. Another software improvements enable the LP parameter (duration of the lighting period) to be changed.

The American GEMS system has the additional capability to measure a wide range of environmental parameters, except the gas exchange measurements that give a possibility to calculate photosynthesis, respiration and transpiration.

The upgraded basic plant life support system SVET-2 SG as well as the new GEMS system that increased the information possibilities of the equipment were an important precondition for achievement of the experiments goals to grow wheat through a complete life cycle, to document the environmental parameters that might impact plant growth (in addition to microgravity); to collect samples for analysis on the ground; to improve conditions for plant growth as much as possible.

RESULTS

The Space Greenhouse Complex was used to grow a fully developed wheat crop for 4 months during 1996. In the space experiment duration of the full cycle of ontogenesis for the "Super-Dwarf" wheat plants as well as their specific stages was similar to that in ground controls. Nearly 300 heads were developed but no seeds were produced. After the harvest of the first planting, a second crop of wheat was planted in the SVET-GEMS system (with CO₂ measurements in the plant leaf area). The result was again a vigorously developing canopy. The plants were harvested after 42 days, frozen in liquid nitrogen for biochemical investigations after landing of the Shuttle STS-81 in the early 1997.

CONCLUSION

The results of these six-month experiments proved that normal technical and technological conditions for plant growth in microgravity had been provided. Only now the reasons for the lack of seeds will be considered. One of the hypothetical causes is the presence of harmful ingredients in the air - for example the gas, ethylene, probably produced by fungus growing in MIR on the walls. And maybe the microgravity is the principle factor that hinder the seed formation - we will find out about it through long investigations in future space and earth experiments.

Monday, June 9

53-52

072205

Session MP3

Room 3

2:30 - 5:30 p.m.

326956

71.

**Clinical and Educational Support for
Space Flight via Telemedicine**

“Telemedicine: A User’s Perspective”

Arnauld E. Nicogossian

NASA Headquarters

Telecommunications has been used to support human space flight since its inception. The recent emergence of computer technology to support medical communications has evolved over the years to make telemedicine a more widely distributed service for the delivery of health care. Recently, these systems have been demonstrated as a useful means to support medical education to remotely located physicians and allied medical professionals. In addition to the application of telemedicine in space flight, NASA has supported several terrestrial testbeds to evaluate technology and develop appropriate protocols and procedures. This evaluation has included a review of the systems and approaches by the user community, which can be defined in several categories. These include the astronauts and flight surgeons that provide medical support to the astronauts during flight; and those recipients of telemedicine services in the terrestrial testbeds, which includes physicians (both primary and consulting), the patient, and the technical support personnel that make it happen. The principle evaluation criteria can be characterized by the complexity of the system (i.e. is it user friendly), is it reliable and secure, is it convenient, is the information (e.g. images, audio, video, etc.) of diagnostic quality and representative of the illness or injury. Moreover, has the use of telemedicine enhanced decision making by the clinician. This paper will discuss the application of telemedicine from the user’s perspective. It will discuss the outcomes of recent technology evaluations and testbed activities conducted domestically and internationally. It will highlight the utility of this service as it relates to the delivery of medical care in spaceflight.

Health Care in Extreme Environments
James D. Collier
NASA Headquarters

From its inception, the United States' Space Program has, by design, placed humans into extreme environments. The challenge has been to provide for the health of these particular humans while they are in these harsh environs, remote from the providers of health care. The pillars of this health care system have been: selection, prevention, the assessment of risk from which training and medical supplies can be provided for each mission class, and the use of telecommunications. Selection of healthy persons into the astronaut corps reduces the likelihood of mission-related health problems, prevention efforts are designed to prevent the onset of disease or the occurrence of injury, and the assessment of the risk of inflight disease or injury has led to the design of training programs and the provision of medical supplies consistent with the applicable mission type. Despite updates to these three pillars as mission types changed and new knowledge of preventive medicine became available, the general concepts remained the same. In fact, NASA's efforts in these areas have been relatively similar to trends in general Earth-based health care. Where NASA has stood apart, and where some of the greatest strides have been made in caring for people in remote environments, has been the integration of the three pillars with the rapidly advancing field of telecommunications. In general, this new area is called telemedicine. This article examines the advances made or contemplated by NASA in the application of the four pillars, including telemedicine, to medical care in extreme environments; from limited telemetry of the Mercury program to the possibilities of telepresence in the exploration class missions.

Integration of Emerging Technologies in Information and Telecommunications in Health
Care Systems for Space
Charles R. Doarn
NASA Headquarters

NASA has been involved in the development and application of telemedicine since the early days of the space program. The integration of telecommunications and information systems into health care systems is of critical importance in space flight. Today, astronauts and medical support personnel on the ground depend on reliable communications link between spacecraft and the ground. This link allows telemedicine to be practiced on a routine basis in the human space flight program. In addition, limited inflight medical care systems to meet mission risks and requirements are available to support Shuttle and the International Space Station. However, as mission profiles increase in duration, complexity, and distance from Earth, the ability to meet appropriate medical needs and training of the crew will require an evolution in capability. This evolution will encompass the advent of the application of emerging technologies in information systems, telecommunications, medical diagnosis and treatment, and human-machine interfaces. Such technologies will include smart sensors, decision support systems, artificial intelligence, non-invasive diagnostic tools, haptic interfaces, and virtual presence. Communications and computers have always been a part of the space program. These technologies are experiencing rapid growth and demonstrate applicability to enhancing the delivery of medical care to humans in extreme environments. Investment in enabling technologies for the 21st Century will help NASA meet the new challenges of space exploration in the new millennium. Advances in technology in information systems, telecommunications, medical diagnosis and treatment, and human-machine interfaces will enhance NASA's ability to provide appropriate medical care to astronauts in remote environments. A strategy for developing these technologies through appropriate partnerships with other government agencies, academia, and industrial partners, will be presented.

TELEMEDICINE AND ENVIRONMENTAL MEDICINE IN RUSSIA: A FIRST STEP IN BASIC MEDICAL EDUCATION

A.I.Grigoriev, V.A.Loginov, S.V.Buravkov, L.B.Buravkova, O.L.Vinogradova
Chair of Aerospace and Environmental Medicine, Space Biomedical Center for Training and Research, 119899,
Lomonosovsky prosp., 31, build. 5, Moscow, Russia

INTRODUCTION

Rapid growth of world communication systems creates a problem in contemporary medical educational methodology. The main idea of modern medical education can be formulated as follows: physicians must be able to select and synthesize necessary information and to apply that information successfully. But the question is: how to prepare highly knowledgeable professionals both in clinical research and medical information exchange service? Since 1995 the Chair of Aerospace and Environmental Medicine at Space Biomedical Center for Training and Research has been helping medical students in Lomonosov Moscow State University to meet the challenge of information revolution and clinical training.

RESULTS

Among several courses which were designed for senior students during basic 6-year medical education there are Telemedicine (TM) and Environmental Medicine (EM). EM course, which is preliminary in the complete telemedicine education, deals with the main pathophysiological reactions of human body in extremal existing conditions. Students get acquainted with the principles of providing medical help under the crucial conditions of variability in atmospheric pressure and temperature, high level of solar, UV, ionizing and nonionizing radiation. The problems of adaptation and ecology are also considered, including toxic effects of the pollution. After one semester of EM students begin TM training course. It is mainly based on the principles and technical support of aerospace telemetry and includes: a) the main approaches to informational exchange, b) the technical review of the telemetric systems used in space medicine, c) the use of aerospace communication systems and multimedia stations in clinical practice, d) presentation of medical data with maximum information effectiveness, e) typical mistakes during advising and consulting by video and audio contact, f) the quality, standardization and economic effectiveness of medical help during teleconferences. At the end of the course students can take part in organizing teleconferences on urology, traumatology and cardiology.

CONCLUSION

The authors of the first Telemedicine educational program devoted considerable time and effort to make sure that information required by Russian medical school curricula is completely included.

Clinical Utility of Internet Telemedicine

Ronald C. Merrell, Yale University; Peter Angood, Yale University; Charles Doarn, NASA Headquarters

Telemedicine was introduced as an asset for clinical medicine with broad band width full motion features which required great resource commitment of satellite, transponders and the equivalent of a professional television studio. The availability of telemedicine for general use has in some ways been retarded by the tremendous cost of the pilot technology. Recent advances in computer based technology and almost generalized access to the Internet has invited experimentation with lower band width options at a fraction of the cost. Over the last three years Yale School of Medicine has been linked to the Moscow State University Medical School to test a variety of communication linkages. Currently we utilize SGI work stations and SGI Workstation has a 10mb connection to the Yale University backbone, and the University has dual T1 access to the Internet access to the Internet to produce web site storage of complex cases which can be downloaded from the server at Lewis and reviewed by clinicians. The evaluations can be discussed by Internet connectivity and a formal consultation can be generated back to the Web site. This store and forward methodology is highly appropriate given the ten hour time difference between New Haven and Moscow, Real time consultation is of limited use. The images coming from the SGI included ultrasound, computed tomography, magnetic resonance imaging, standard radiographs, patient photographs, plus large amounts of digital and graphic data.

Thirty case evaluations were completed by American specialists and returned to the web site. This connectivity offered full confidence for all static images and less so for stored moving images. The use of a standard consultation format made the confidence in presentation very high and allowed the rendering of advice without reservation. Prior experience between the two centers indicated that the information offered could be completely implemented in Russia. In the evaluation of the cases we conclude that the SGI workstation, Internet connection with Web site store and forward using a standardized is an effective and low cost structure to facilitate telemedicine consultation.

A Web-Based Human Computer Interface For Internet Telemedicine

Corinna E. Lathan*, Dava J. Newman**, Marc Sebrechts***, Charles Doarn****

*Biomedical Engineering, Catholic University of America

**Department of Aeronautics and Astronautics, Massachusetts Institute of Technology

***Department of Psychology, Catholic University of America

****Aerospace Medicine Division, Office of Life and Microgravity Sciences, NASA
Headquarters

Despite the exponential growth in the number of telemedicine projects and systems, relatively little attention has been paid to the human factors issues associated with such systems. Particularly, no guidelines exist to assist in the development of human-computer interfaces, associated with telemedicine systems, that address the human factors issues of human-computer interaction (HCI) and interface design. HCI is a growing field with the recognition that the human-technology interface is the key to optimizing human performance. Therefore, NASA has supported this effort to apply HCI design principles to the field of telemedicine. There are several efforts underway at NASA to develop telemedicine systems for use in addressing medical care issues in unique environments where health care providers may have limited access to medical facilities. In particular, the web/videoconferencing integrated interface for the Spacebridge to Russia project will be used in this paper to illustrate the principles of good interface design in general and as related to telemedicine systems. Three principles will be addressed: 1) user-centered design 2) modeling the human processor and 3) task and constraint-oriented design, i.e. What is unique to interface design for telemedicine systems.

SINGLE SCAN

34-53

072213

326957

Monday, June 9

10P.

Session MP4
Room 4
2:30 - 5:30 p.m.

Cognitive Sciences

IAA Man in Space Symposium, 1997

Face recognition in microgravity: is gravity direction involved in the inversion effect?

S. de Schonen*, Gilles Leone** and Mark Lipshits+

* CRCN - CNRS; Marseille; ** LPPA - CNRS College de France, Paris France;+ Institute for Problems of Information Transmission, Russian Academy of Sciences, Moscow, Russia.

Most objects are more difficult to recognize upside down than right side up. Face recognition is greatly impaired by inversion. The face inversion effect (Yin 1969, Diamond & Carey, 1986, Farak, Wilson, Dray & Tanaka, 1995) is a very robust effect observed under many different conditions. Moreover this effect has been used as a marker to indicate the involvement of specialized face processing mechanisms in the right cerebral hemisphere given that the normal right hemisphere advantage in face recognition vanishes when faces are presented upside down while the left hemisphere performances are not decreased by the stimulus inversion. Two possible candidates might act as a spatial reference for coding faces right side up: either the direction of gravity or the retinal references. Given the great importance of visual object processing in daily life it was decided to investigate with Cognilab in the Cassiopée Mission whether visual performances in object processing might be handicapped in microgravity. Three cosmonauts were tested before and during flight in the MIR station. One set of faces (photographs of unknown people) were learned before the flight and recognition of these faces was tested both before the flight and in the spatial station. A second set of faces (photographs of other unknown faces) was learned under microgravity in the spatial station and recognition was also tested in the spatial station. During the recognition tests, the learned faces were mixed with totally new faces and the cosmonauts had to decide as fast as possible whether a presented face was a learned one or a new one. Faces were presented either upside down or right side down in the right visual field (left hemisphere) or the left visual field (right hemisphere). Error rates and reaction times were measured. The inversion effect was observed in the recognition tests of both sets of faces (those learned on the ground and those learned in the station). This effect was present on the 6th, the 10th and the 14th day of flight with no significant change with time. Therefore the inversion effect does not seem to be related to the spatial reference given by gravity direction but rather to a retinal reference. Some aspects of the information processing seems however to be sensitive to microgravity or to the flight conditions: (i) The learning and recognition performances in the station are much poorer for faces learnt in the station than for faces learnt on the ground and, (ii) for the recognition of the faces learnt in the station, the right hemisphere advantage vanishes and a left hemisphere advantage emerges. It is concluded that face recognition by the right hemisphere is handicapped either by microgravity or by another factor present during the flight.

Support provided by the French Space Agency CNES and Russian fund for fundamental research.

MOTOR TIMING UNDER MICROGRAVITY

A. Semjen,¹ G. Leone,² and M. Lipshitz³

¹Centre Nationale de la Recherche Scientifique, Centre de Recherche en Neurosciences Cognitives, Marseille,

²Centre Nationale de la Recherche Scientifique, Collège de France, Laboratoire de Physiologie de la Perception et de l'Action, Paris, ³Russian Academy of Sciences, Institute for Problems of Information Transmission, Moscow

Five subjects performed sequences of periodic movements by synchronizing button presses with a series of acoustic stimuli (induction phase), and by continuing to produce the movements with the same rhythm after the metronome had been switched off (continuation phase). The required inter-response intervals were 350, 410, 470, or 530 ms. Three subjects were members of the CASSIOPEE 96 spaceflight mission, two subjects were control. The stimulus-response asynchronies observed during the induction phase and the inter-response intervals of the continuation phase were analyzed in terms of mean duration, variability, and sequential dependency. These data enabled us to partition the total variability of timing into variability due to internal timekeeping processes, and variability due to motor implementation processes, in the framework of the two-level timing model originally proposed by Wing and Kristofferson. During spaceflight, the subjects tended to accelerate their tapping, that is, their reproduction of the reference interval was less precise than under the control conditions. In addition, the timing became more variable (less regular). Most of the increase in variability could be attributed to the internal timekeeping processes. The results are discussed with reference to hypothesized physiological mechanisms underlying the timing of fast serial movements.

PERCEIVED SELF-MOTION ASSESSED BY COMPUTER-GENERATED ANIMATIONS: COMPLEXITY AND RELIABILITY

D. E. Parker¹, D. L. Harm², G. R. Sandoz³, and N. C. Skinner³

¹Department of Otolaryngology - HNS, University of Washington, Seattle, WA 98195, ²Space Biomedical Research Institute, Johnson Space Center, Houston, TX 77058, ³KRUG Life Sciences, Houston, TX 77058.

INTRODUCTION

Our overall goal is development of procedures to enhance assessment of spatial orientation, specifically self-orientation and self-motion perception. Our specific objective is to develop and evaluate computer-generated animations as potential tools for measuring perception. We compared perceived self-motion reports obtained using animations with those obtained using verbal reports.

METHODS

36 subjects reported perceived self-motion following exposure to complex inertial-visual motion stimuli. 12 subjects were assigned to each of 3 perceptual reporting procedures: animation movie selection (AMS), verbal report selection (VRS), and verbal report generation (VRG). The question addressed was: do reports produced by these procedures differ with respect to complexity and reliability? Following repeated (within-day and across-day) exposures to 4 different "motion profiles"(see Appendix), subjects in the AMS group selected, from a set of movies presented on a laptop computer, the movie that corresponded most closely with their motion experience. Subjects in the VRS group selected from a set of verbal description presented in a booklet, and VRG subjects provided their own self-motion verbal descriptions. "Complexity" and reliability "scores" were calculated.

RESULTS

Mean (and standard error of the mean) within-day reliability, across-day reliability and complexity scores for the data are presented in Table 1.

TABLE 1.
MEAN (SEM) COMPLEXITY AND RELIABILITY SCORES FOR 3 REPORTING PROCEDURES

	COMPLEXITY	WITHIN-DAY	ACROSS-DAY
AMS	0.546 (0.055)	0.319 (0.075)	0.228 (0.071)
VRS	0.577 (0.051)	0.302 (0.071)	0.221 (0.063)
VRG	0.431 (0.055)	0.327 (0.069)	0.295 (0.078)

The means were essentially equivalent for movie selection and verbal report selection procedures: no statistically significant differences between reporting procedures were observed. The data suggest that reports by verbal report generation subjects were less complex than for the other conditions. The hypothesis that movie selection would be more reliable than the verbal report procedures was not supported.

Frequency of "hill" and "valley" descriptions for 2 motion profiles for each of the 3 reporting procedures are presented in Table 2.

TABLE 2.
NUMBER OF SELECTIONS BY PROFILE AND REPORT TYPE

	PROFILE H8				PROFILE S8			
	AMS	VRS	VRG	SUM	AMS	VRS	VRG	SUM
HILL DESCRIPTION	8	13	16	37	0	0	3	3
VALLEY DESCRIPTION	0	0	0	0	24	22	14	60

Clearly, the H8 and S8 profiles elicited different responses (collapsed across reporting procedures, $X^2 = 85.7$; $p < 0.0001$).

DISCUSSION AND CONCLUSIONS

There are several possible reasons for the failure of this experiment to demonstrate clearly expected advantages of animations. First, appropriate, careful training to use a standard self-motion description vocabulary may eliminate possible differences between reporting procedures. Subjects may be better able to describe motion verbally than is usually believed. Second, the motions may not have been sufficiently complex. Based on the stimulus motions, only fairly simple self-motions (2 degrees-of-freedom (DOF) translational and 1 DOF rotational) would be expected.

Third, movies/verbal descriptions depicting combined scene and self-motion perception, which almost certainly corresponded with the subjects' actual experience, were not used. Fourth, individuals probably differ with respect to how they represent motion cognitively - some may use pictorial representations, whereas others may use verbal descriptions. Finally, possible differences in self-motion experiences for VRG subjects were not easily assessed because descriptions were often relatively simple. For example, many subject-generated verbal reports were vague at best, and omitted important information (e.g., whether a "ramp back" had an upward or downward slope). For AMS and VRS subjects, selections were made from a set of precise movies / reports; consequently, it was more likely that even subtle differences in the self-motion experience elicited by repeated exposures to a particular profile would result in selection of different movies / reports.

The hypothesis that a "real-time" animation reporting procedure, which permits omission of motion vocabulary training, will produce more reliable data than verbal reports is being examined currently. Because subjects cannot readily use the animation movies selection procedure without training, Experiment 2 employs cross-coupled rotation stimuli and a new reporting procedure: animation generation. This is accomplished by having the subject manipulate a mannequin so that the mannequin's motion corresponds to the perceived self-motion. Polhemus Fastrak sensors embedded in the mannequin permit "real-time" representation of the motion on a monitor as well as recording of that motion for later analysis.

Although not the primary purpose of this research, the results indicate that different combinations of tilt with respect to gravity and translation of a visual surround with respect to the subject can yield consistently different patterns of self-motion trajectory. The hypothesis that neural signals representing visual surround velocity are additive with those representing pitch position was supported (see Harm et al., *Aviat. Space Environ. Med.* 1993, 64, 820-26).

Supported by NASA Research Grant No. NAGW-4393

APPENDIX

MOTION DESCRIPTIONS

Hill description. Simultaneous pitch and hill: pitch forward as translate forward over the hill; pitch rearward as translate rearward back over the hill.

Valley description. Simultaneous pitch and valley: pitch rearward as translate forward down into and up out of a valley; pitch forward as translate rearward back down into and up out of the valley.

MOTION STIMULI

Motion stimuli were produced by the Tilt Translation Device, a 1 DOF moving base that combines pitch motion of the subject with translation of a visual surround with respect to that subject. Relationships between subject and visual surround motions can be easily manipulated. When both are sinusoidal, the visual surround may move either toward or away from the subject as they pitch forward; i.e., the phase angle between visual surround and subject motions can be controlled (see Harm et al, 1993).

TABLE 1. MOTION PROFILES

NAME	MFP	MRP	PHASE	FREQ. - Hz
H8	10	13	20	0.08
S8	5	9	180	0.08

MFP: maximum forward pitch (deg).

MRP: maximum rearward pitch (deg).

PHASE: amount by which maximum forward surround position (farthest rearward subject position in the surround) leads maximum forward pitch of the surround and subject (deg).

For profile H8, peak velocity of visual-surround-induced forward self-translation occurs during the transition from maximum forward to maximum rearward pitch; and, peak visual-surround-induced rearward self-translation velocity occurs during the transition from maximum rearward to maximum forward pitch.

For profile S8, peak visual-surround-induced forward self-translation velocity occurs during the transition from maximum rearward to maximum forward pitch; and, peak visual-surround-induced rearward self-translation velocity occurs during the transition from maximum forward to maximum rearward pitch.

Concerning this presentation, correspondence should be addressed to:

G. LEONE,

CNRS-LPPA, 11 place Marcelin Berthelot,

75005 Paris, France

Tel 33 1 44 27 12 98, Fax 33 1 44 27 13 82, Email GLE@ccr.jussieu.fr

PROLONGED WEIGHTLESSNESS, REFERENCE FRAMES AND VISUAL SYMMETRY DETECTION.

G. Leone¹, S. de Schonon², M. Lipshits³.

1 Laboratoire de Physiologie de la Perception et de l'Action, CNRS Collège de France, Paris, France;

2 Laboratoire de Neurosciences Cognitives, CNRS, Marseille, France

3 Institute for Problems of Information Transmission, Russian Academy of Sciences, Moscow, Russia;

Bilateral symmetry of form is assumed to be extracted early during visual processing in order to set an internal reference frame for the form. This internal reference frame will generally allow a coding of form invariant by rotation, prior to the form recognition (1). One of the most striking properties of bilateral symmetry detection is the spatial anisotropy in the performance of the visual system. Thus, patterns of error rates or response times (RT) as a function of symmetry axis orientation show superior performance for a vertical orientation of symmetry axis than for a horizontal one and superior performance for both of these orientations than for oblique ones, when the symmetrical shape is presented centrally. Several authors have suggested that either the anatomy or cells selectivities of the visual system could explain this anisotropy. From previous studies (2), it has been shown that meridional orientations of symmetry axis were always more salient than the oblique ones during prolonged weightlessness. However, the saliency of the vertical axis over the horizontal one, strongly evident on earth, was shown to gradually diminish over exposure to weightlessness, finally disappearing after a couple of weeks (3). From these data, it is concluded that the symmetry is detected in a retinal reference frame in which graviceptive cues are incorporated to elicit a vertical saliency.

We investigated, with three cosmonauts, during the French-Russian mission CASSIOPEE 96, whether similar reference frames are required to detect symmetry when presentation of stimulus is restricted to one visual hemifield. Indeed, the anatomy of the visual system allows one to stimulate preferentially one cerebral hemisphere when the stimulus is displayed to one side of a fixation point. The cosmonauts were maintained in COGNILAB's body restraint system, facing a computer screen where shapes were displayed. We tested two types of stimuli : closed 2D polygon and arrays of randomly positioned dots. A fixation cross was displayed in the centre of the screen, then a stimulus was presented during 100 ms either in the left or right visual field (right or left cerebral hemisphere respectively) or in the centre of the screen (both hemispheres). From trial to trial, the nature of the stimulus (symmetrical versus asymmetrical), the position of presentation and the orientation of symmetry axis (Vertical, Horizontal and 45° Oblique) were randomly varied. The subjects were asked to press the near button if shape was symmetrical or the far one if asymmetrical. We compared RTs and error rates for in-flight versus ground tests.

The results indicate that the processing of symmetry is better when both cerebral hemispheres are stimulated. In this condition, the saliency of a vertical axis of symmetry vanished during the exposure to weightlessness for the closed shapes, **but** increased for the random dots. This suggests that symmetry could be differently processed by the visual system as a function of type of shapes. In the case of the visual hemifield presentation, on earth as well as in weightlessness, the most salient orientation is amazingly the horizontal axis of symmetry. The saliency of the horizontal axis of symmetry (compared to the vertical axis) seems to be reduced in weightlessness **but** this diminution varies accordingly to the type of forms and to the stimulated cerebral hemisphere.

In conclusion, these results suggest that the processing of low level visual information integrates also non-visual information and that different symmetry detection mechanisms could exist.

Bibliography

1. D. Marr, *Vision* (Freeman, W.H. San Francisco, 1982).

2. G. Leone, M. I. Lipshits, J. McIntyre, V. S. Gurfinkel, *Spatial Vision* 9, 127 (1995).

3. G. Leone, M. Lipshits, V. Gurfinkel, A. Berthoz, *Acta Astronautica* 36, 743 (1995).

Acknowledgement: We thank cosmonauts and engineers for their fruitful participation in this project. This work was supported by CNES, and a grant from Russian Fund of Fundamental Research.

MENTAL REPRESENTATION OF GRAVITY DURING A LOCOMOTOR TASK

T.Pozzo¹, P.Stapley¹, A.Berthoz², R.Kaprinski³

¹ Groupe d'Analyse du Mouvement, Université de Bourgogne, Campus Universitaire, BP 138, 21004 Dijon, France.

² LPPA, CNRS, Collège de France, Paris, France.

³ Star City, Moscou, Russia.

INTRODUCTION

Droulez and Berthoz (1986) have proposed a theory which supposes that execution of complex movements and mental simulation of these movements are based on the same nervous processes. In addition, in normal gravity, several authors have reported isochrony phenomena during locomotor tasks, i.e, the time to walk mentally was similar to the time taken to actually walk (Decety et al. 1989). These results emphasize the hypothesis which suggest that mental movement and actual movement share the same cerebral mechanisms. We also think that such a simulation would play a major role in recovery after lesions or in self-adaptation to environmental modifications.

In a previous experiment (Papaxanthis et al 1997) we have demonstrated during arm pointing movement that the gravity does not only exert a local effect on muscle proprioceptors (as load or inertia) compensated for on the basis of feedback regulation, but is centrally represented in the central nervous system using the feedforward computation of gravity in the command to the muscles.

The aim of this experiment was to test whether this « on earth phenomena » still exists and is adapted to a normal 1g environment after prolonged exposure to condition of microgravity. indeed, casual report from cosmonauts have indicated that the perception of time is altered in 0g.

METHODS

Cosmonauts performed essentially a locomotor task involving 3 main phases : two steps and stepping onto a platform (2 steps of 25 cm each) (T1) ; jumping with both feet from the 50 cm platform (T2) and after landing and ensuring good postural stabilization, walking normally for a distance of 4 m (T3). The experiment was executed using normal vision and then repeated subjects' blindfolded. In the vision condition, no instruction to fix any specific point was given. In the blindfolded condition, subjects were allowed to look for 5 s in front of them before the beginning of each trial. During the performance of these tasks, the movement was analyzed by mean of an optical automatic TV-image processor (for other kinematic studies). Immediately following the execution of the task, cosmonauts were asked to mentally repeat all the movement (T1+T2+T3). Subjects held an electronic stopwatch in their hand. They started the stopwatch when they started to walk (actually and mentally) and stop it when they completed walking. Walking time was recorded directly by the experimenter from the stopwatch. Subjects were given no information concerning their temporal errors. Ten trials were performed in each of the two conditions (with and without vision). The experiment was conducted during pre (on days L-60 and L630) and post spaceflight. The post flight tests took place on the first day (R+1), second (R+2) and sixth day of return (R+6). The experiments reported here have been performed before and after several spatial missions aboard the russian orbital station « MIR », from 1994 to 1996.

RESULTS

Pre flight data (L-60 and L-30, see figure 1) show that in normal vision, mental time and actual time are similar, confirming the isochrony principle for the whole task. In contrast, when visual information is lacking movement times tend to be longer than in normal vision, and the mental time expressed as a percentage of the actual time (relative mental time) is greater than 1, that is to say longer than actual time.

Post flight data indicate that just after returning to earth (R+1), for the two visual conditions, movement time increased. In addition, mental time decreases with respect to the actual time (figure1). Then, on day R+2 and R+4 the relative mental time increases. On day R+6, relative mental time values become similar to those obtained during pre flight measures.

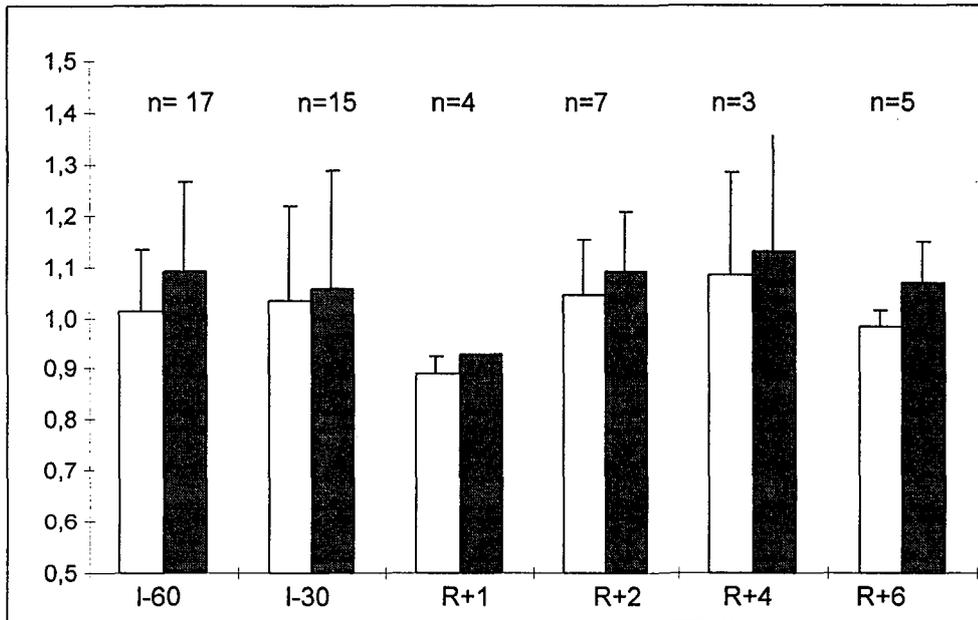


Figure 1 : Mean mental walking time and SD for all subjects tested in normal vision (white bars) and blind-folded (shaded bars) 60 and 30 days before launch (I-60 and -30) and 1, 2, 4, 6 days after landing (R+1, 2, 4 and 6). The mean mental walking time is expressed as a percentage of the actual walking time, represented value by 1. (n indicates the number of cosmonauts tested).

CONCLUSION

This experiment, based on a mental chronometry approach, confirms an isochrony between mental and actual time before spaceflight, suggesting that the mechanism involved during mental representation of movement is the same as the mechanism which is used to plan the actual movement. Just following return to earth (R+1) mental time was quicker than before flight. This result can be explained in the following way : after prolonged exposure to condition of microgravity, the subject continues to mentally imagine the movement using a non-Newtonian mechanic representation. After a few days of adaptation (R+2 and R+4) the mental time is adapted to real movement execution which is generated by centrally greater force production to overcome the resistance opposed by gravity. This increase in effort sensation may explain the greater values of mental time compared to actual time at R+2 and R+4.

These results suggest a central representation of gravity force. If it was not the case, similar times may have been recorded for mental and actual movements during the post flight tests.

Acknowledgements

This work was supported by a grant of the French Centre National d'Etudes Spatiales.

HAPTIC PERCEPTION IN WEIGHTLESSNESS: A SENSE OF FORCE OR A SENSE OF EFFORT?

J. McIntyre¹ and M. Lipshits²

¹Laboratoire de Physiologie de la Perception et de l'Action, CNRS/Collège de France, Paris, France

²Institute for Problems of Information Transmission, Russian Academy of Science, Moscow, Russia

INTRODUCTION

In generating a mechanical force by pushing or pulling with the arm, the human motor system can perceive the level of force produced by the limb through two different mechanisms. The CNS might measure the contact force directly, via nerve endings sensitive to pressure that are found in the skin of the hand. On the other hand, the CNS might instead use information about the muscular effort that is required to produce the necessary force level. Evidence has been accumulating for this latter "sense of effort". For instance, subjects tend to over-estimate the intensity of forces produced by fatigued muscles (Jones and Hunter, 1985).

In a normal gravity environment, the total muscular effort required to oppose a given external force includes, in addition, the muscle force necessary to support the limb against gravity. To accurately estimate the intensity of an externally applied force on the basis of muscular effort, the CNS must be able to distinguish between the component of muscle force due to the external load from muscle force generated in response to the effect of gravity on the limb itself. The CNS might accomplish this task based on a priori knowledge about the every-day gravitational environment. The CNS may use an *internal model* of the effects of gravity in order to correctly translate perceived muscular effort into an accurate perception of the applied force.

If the CNS indeed uses such an approach, one would expect that in the absence of gravity the perception of externally applied force loads would be perturbed. In particular, one would expect forces exerted downward (external force upward) to be over-estimated, since more muscular effort will be required to produce the same level of opposing force. This effect would be expected to persist until the CNS has the experience necessary to update its internal model to the absence of gravitational forces. On the other hand, if the CNS relies on pressure sensors in the skin, the perception of force intensity should remain unchanged in 0G. We tested these two hypotheses by asking subjects to perform a force matching task as part of the Cognilab experiment aboard the space station Mir.

METHODS

Subjects sat in a chair with restraining belts. A two-dimensional force-actuated joystick was attached to the right side of the chair, positioned so that the axis of the joystick projected horizontally toward the subject. With the right hand on the joystick grip and the joystick centered in its range of motion, both the joystick shaft and the forearm of the subject were oriented horizontally. The subject viewed a computer screen through an optical tunnel that thus prevented vision of the hand and joystick.

For a single experimental trial, the motors of the joystick were activated to produce a constant, downward force on the hand (the reference force). The subject was instructed to resist this force by pressing upward on the joystick so as to keep the handle in the center position. After a brief period in which the subject could sense the intensity of the applied force, he or she pressed a button to change the applied stimulus to an upward external force having a different intensity. Again, the subject resisted the external force with a downward pressure so as to hold the joystick in the center position. With a control knob, the subject was asked to adjust the intensity of the second upward force to match the intensity of the previously measured downward force. The subject could switch back and forth between the reference and the variable stimulus as often as desired, but had to finish a given trial within 1 minute. Each subject performed 7 such trials for each of 5 different reference intensities in a single session. Subjects performed 3 sessions prior to flight and 3 sessions in-flight over the course of the mission.

RESULTS

Figure 1 shows the measured force levels that were perceived as being equal for each of the 3 subjects. The measured intensities of the downward reference force and the upward response force are plotted along the X and Y axes respectively. Each point represents one trial. If the subjects were to perform perfectly this task, all points would fall along the line $x = y$. A point above the ideal line indicates that the subject required a greater intensity of upward stimulus force to match the perceived intensity of a downward force. In other words, a point above the line indicates an over-estimation of the downward external force, or equivalently, an under-estimation of an upward force. (NB: we refer here to the force produced by the joystick. In terms of the force produced by the arm, a point above the line represents an over-estimation of the upward generated force and/or an under-estimation of a downward exerted force.)

Results

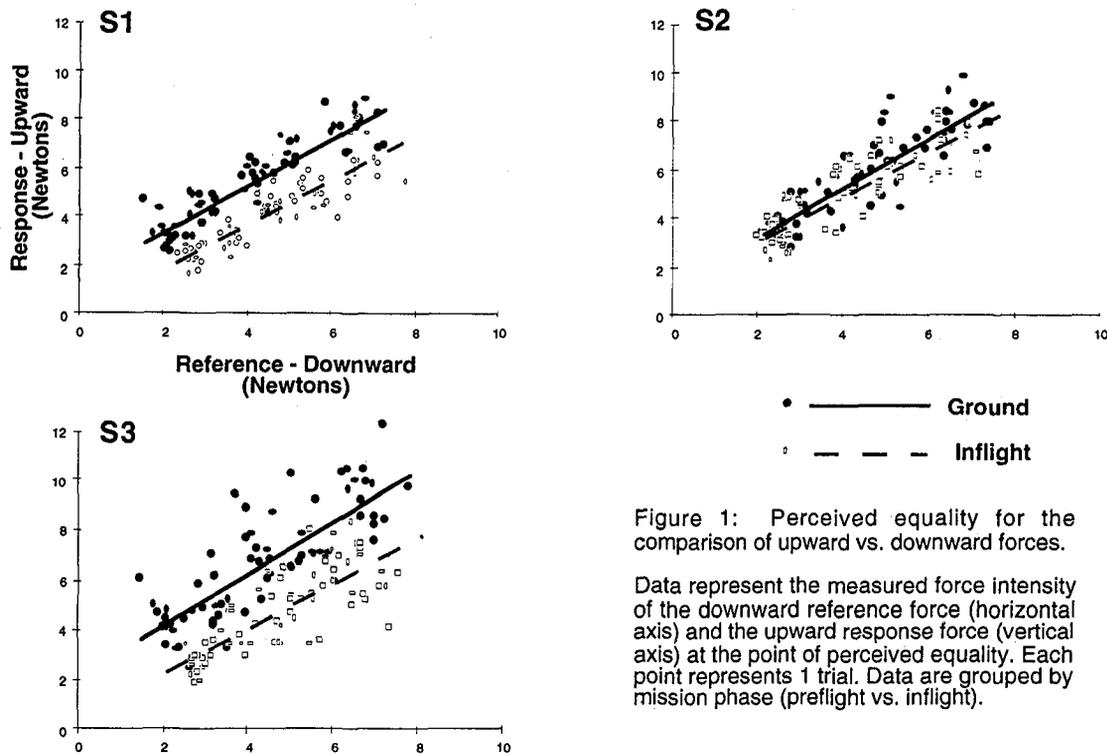


Figure 1: Perceived equality for the comparison of upward vs. downward forces.

Data represent the measured force intensity of the downward reference force (horizontal axis) and the upward response force (vertical axis) at the point of perceived equality. Each point represents 1 trial. Data are grouped by mission phase (preflight vs. inflight).

Data points are grouped by mission phase (pre-flight or inflight), and a linear regression is plotted for each group of data points. It can be seen that the best-fit regression lines shifted downward for all 3 subjects for tests carried out in weightlessness. Thus, to match the intensity of a given downward force, subjects set a level of upward stimulus that was lower inflight than on the ground. This is equivalent to saying that the perceived intensity of a downward (upward) external force is lower (greater) in orbit than on the ground.

DISCUSSION

The data plotted above clearly shows that subjects did not base their estimations of force intensity solely on direct measures of pressure on the skin. The same magnitude of applied downward force elicits different perceptual estimates depending upon the level of gravitational acceleration. These results are consistent with the "sense of effort" hypothesis. This is not the only possible explanation, however. When the data is plotted in terms of changes in force levels (relative to the baseline level between stimuli), the difference between inflight and ground data is reduced, though not eliminated (data not shown). This latter observation is consistent with a perceptual mechanism that is tuned to changes in force levels, as opposed to measures of absolute intensity (Jami, 1990). Such a scheme would allow the CNS to adapt more readily to changes in bias forces applied to the system. Further experiments are planned to test between the "sense of effort" and the "change in force" hypotheses.

ACKNOWLEDGEMENTS

We thank J.M. Bois, A. Shulenin, A. Polyakov and Y. Matsakis for technical support and A. Berthoz and V. Gurfinkel for helpful comments.

REFERENCES

Jami, L. Golgi tendon organs in mammalian skeletal muscle: Functional properties and central actions. *Physiological Reviews* 72:623-666, 1991.

Jones, L.A. and Hunter, I.W. Effect of fatigue on force sensation. *Exp. Neur.* 81:640-650, 1983.

Monday, June 9

Session MP5
Room 5
2:30 - 5:30 p.m.

55-51
072236

8P.

326958

**Life Sciences Issues for a Mission
to Mars**

CARDIOVASCULAR CONCERNS FOR A MARS MISSION: AUTONOMIC AND BIOMECHANICAL EFFECTS

¹D. D'ainno, ²J. Yelle, ³G. Pantalos, ⁴T. Brown

¹NASA-JSC/UTMB/USRA-CASS Houston, TX

²NASA-JSC Houston, TX

³Univ. of Utah Salt Lake City, UT

⁴KRUG Life Sciences Houston, TX

INTRODUCTION

From the perspective of the cardiovascular system there seems limited concern that the crew could survive the exposure to weightlessness necessary to achieve a Mars destination. The greatest obstacle extant is to deliver a crew to the surface, possessing a functional capacity permitting routine and emergency operations once planetfall is achieved.

Within moments of entering weightlessness, the cardiovascular system begins responding to the new environment. Altered baseline physiologic parameters have consistently been observed in flight. To date, these have not proved to impact adversely on mission objectives. However, the exact mechanism effecting these changes are not completely understood. A relatively stable steady-state is achieved in the short term. With longer duration missions, there has been some evidence of increased ventricular and supraventricular ectopy, the basis of which is unknown. Possible explanations include electrolyte abnormalities, autonomic dysfunction, hormonal influences and/or mechanical alterations. The cardiovascular response to stress and exertion is different in longer duration flights. These alterations have not become clinically significant nor have they hindered mission objectives. With missions of even greater duration planned however, these physiologic changes become a point of great concern. Not enough information is available to adequately predict long term cardiovascular changes and the health impact on the crew.

RESULTS

Crews returning to Earth from short and long duration space flights have demonstrated a reversible form of autonomic dysfunction. Recent studies have suggested that this is a major component of the sometimes severe orthostatic intolerance and syncope experienced by crew members once they return to gravity's domain. Too little is understood about the autonomic nervous system and its influence on cardiovascular fitness to predict what long term consequences would be, once this system is perturbed from long duration exposure to weightlessness.

An artificial cardiovascular system has been developed to observe the biomechanical effects of microgravity isolated from the autonomic/nervous influences. Results of parabolic flight-induced microgravity experiments, which segregate the vascular and ventricular contractile and compliance forces and pressures from inherent cardiovascular reflexes, will be discussed.

CONCLUSION

Incomplete knowledge of the mechanisms effecting cardiovascular change is a significant obstacle in devising effective countermeasures. Interventions should be developed to ensure a degree of cardiovascular fitness sufficient to permit crews landing on Mars the ability to rapidly carry out mission objectives and be able to negotiate any emergency situations that arise.

REDUCING THE RISK OF SPACE RADIATION INDUCED BIOEFFECTS- VEHICLE DESIGN AND PROTECTANT MOLECULES

M. Stanford¹, J. Jones², H.Lane³, P.Riggs³, T.Yang³

¹Center for Aerospace Medicine and Physiology, Galveston, TX

²NASA/JSC, USRA/CASS, UTMB- Houston, Galveston TX

³NASA/JSC Houston, TX

ENVIRONMENT

The space environment poses many significant challenges to mission planners of exploratory class missions to the moon and Mars. Radiation exposures received by the crew and spacecraft are a function of the location (LEO, free space, planetary surface), the time of flight with respect to the Solar Cycle, and whether or not solar particle events are being experienced in each of these different environments. Current knowledge of these different environments have uncertainties in the range of 2 to 4 times actual values. These uncertainties need to be reduced for proper mission planning and risk amelioration for exploratory class space flight.

SPACECRAFT DESIGN

Risk assessment must deal with biological impacts associated with human exposure to the space radiation environment as well as potentially harmful effects to spacecraft electronic systems due to damaging interactions with the space particulate radiation. Additionally, spacecraft design must use mass effectively to provide adequate shielding of crew and components during the long duration flight times envisioned in the exploratory class flight scenarios.

BIOEFFECT MODULATION

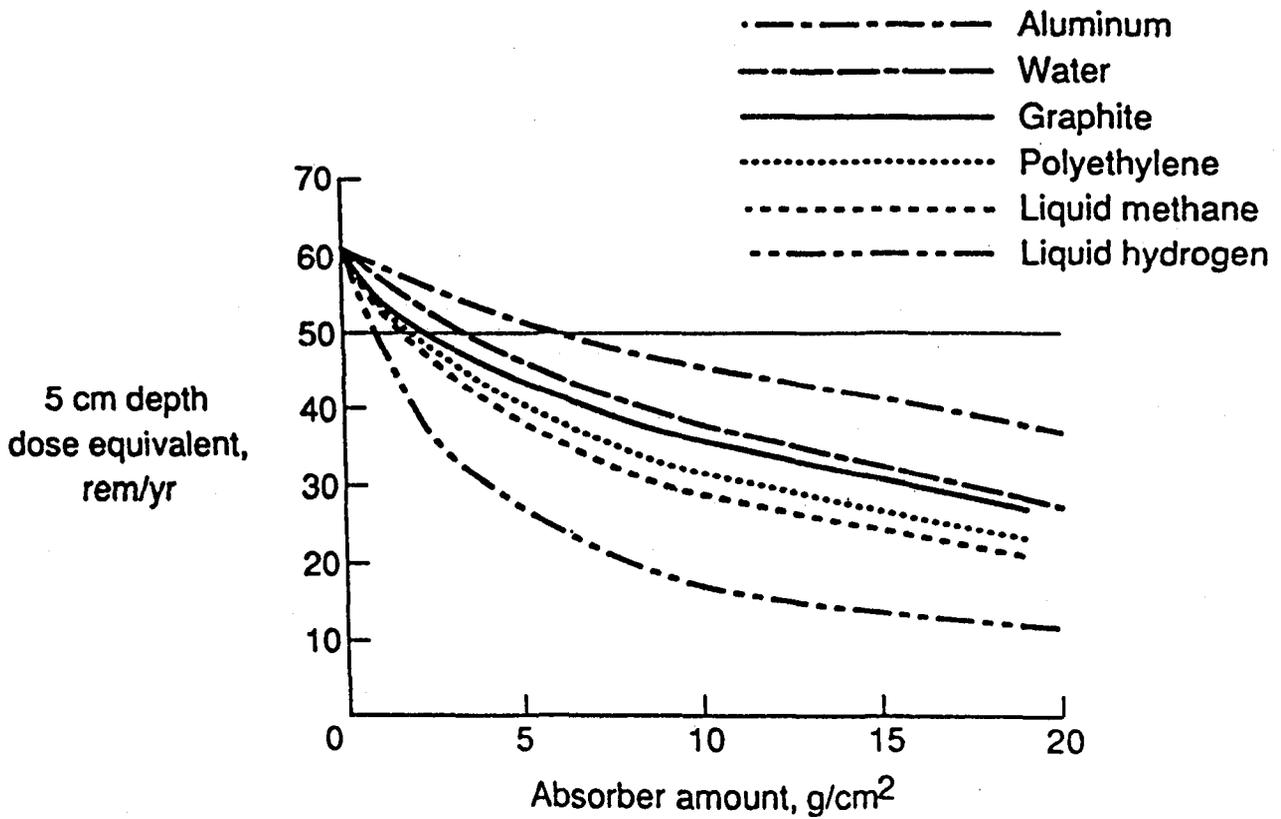
Space radiation bioeffects are often described both in terms of dose delivery to the organism: acute high dose vs. chronic low dose, as well as by the source of emanation: galactic cosmic rays(GCR) vs. Solar Particle Events(SPE's). Characterizing both the quality and quantity of radiation expected along the planned transfer route and on the Martian surface, is paramount in defining the radiation exposure risk. Developing improved measurement models(e.g. via onboard active dosimeters) for predicting SPE exposure and intervention strategies will also prove to be invaluable in a Mars mission. Shielding design may lower the crew's exposure and thus their chances of developing acute radiation sickness resulting from the delivery of a greater than 300 rem dose that might be expected from a high fluence SPE. However, the stochastic effects such as carcinogenesis, resulting from a long term exposure to daily GCR or from the secondary radiation events produced by HZE particle fragmentation by spacecraft shielding in deep space, may not have been adequately studied or mitigated to date. A number of radioprotectant molecules have been evaluated in the past, mainly by groups interested in lessening the effects on humans of nuclear explosions or therapeutic radiation for cancer treatment. Although some of these agents have been shown to reduce radiation toxicity, their side effects and delivery mode have limited their potential utility for flight crews. Newer, less toxic agents are showing promise in lessening the effects of ionizing radiation on eukaryotic DNA and cellular processes.

DISCUSSION

This session will discuss current thinking on the space radiation issue as well as pose some interesting ideas concerning the future work required in a radiation health/assessment program. Data shows that shielding effectiveness of certain materials, such as hydrogen and water, will impact the final design of an exploratory spacecraft to best utilize these materials in the overall shielding strategy(see Figure). Also strategies for potential reduction of bioeffects by molecules designed to limit the impact of ionizing radiation on mammalian cells will be discussed.

GALACTIC COSMIC RAYS - SOLAR MINIMUM

(Depth vs. Dose Functions for Selected Materials)



MUSCULOSKELETAL ISSUES FOR LONG DURATION MISSION: MUSCLE MASS PRESERVATION, RENAL STONE RISK FACTORS, COUNTERMEASURES, AND CONTINGENCY TREATMENT PLANNING

P.Hilliard¹, J.Jones¹
R. Pietrzyk², P.Whitson³

¹NASA/JSC, UTMB, USRA/CASS, Houston, Galveston, TX

²KRUG Life Sciences, Houston, TX

³NASA/JSC, Houston, TX

INTRODUCTION

One of the greatest physiologic challenges to long duration space flight is the maintenance of muscle mass and bone density. This would be especially true for a crew who would be required to rapidly establish a life support base on the Martian surface following an extended time in microgravity. Muscle atrophy and weakness occur even on short duration shuttle flights of 10-16 days duration. A greater effect is seen with extended stays in LEO. The potential consequences of bone and muscle weakness include inability to egress (in nominal and contingency situations), increased orthostatic intolerance, bone fractures, muscle injury, hypercalcemia, urinary lithiasis. With planned extended stay missions to orbiting space stations and potentially manned missions to Mars, there has been a concentrated effort to develop countermeasures to prevent bone and muscle loss.

Significant physiological changes occur in astronauts upon exposure to microgravity and the readaptation process that follows their return to Earth. Some well-documented changes that result from space flight, including increased urinary calcium and phosphorus excretion and decreased fluid intake/urine output, result in a urinary chemical environment in which there is a greater risk of renal stone formation.

RESULTS

Our studies have indicated that risk factors in addition to those previously anticipated contribute to an increased risk for renal stone formation during and after space flight. In particular, low urinary pH and hypocitraturia increase the renal stone-forming risk of uric acid and calcium-containing stones. Immediately after space flight the relative supersaturation for uric acid or calcium oxalate is greater than 2 times a normal non-stone forming population. During space flight, the risk is significantly elevated for calcium oxalate and brushite stones. These alterations in risk factors are reversible 7-14 days after return to Earth. Duration of space flight has not indicated greater risk as a function of mission duration; in general, the data are consistent for long and short duration space flights. Urine volumes greater than 2 liter/day were found to reduce the risk of stone formation in astronauts immediately after space flight as compared to those astronauts with urine volumes less than 2 liters/day. Although urine volume appears to be sufficient as a countermeasure to reduce stone-forming potential immediately after flight when the body is readapting to the Earth environment, hydration as a countermeasure may not be sufficient to reduce stone formation during flight where hypercalciuria and hypocitraturia are an ongoing problem. (See Table 1)

DISCUSSION

The panel will present an overview of the findings of countermeasure studies to date and discuss current and future countermeasure strategies for long duration space flight. Potential countermeasures for maintaining muscular and skeletal integrity include various resistance and endurance exercise regimens, and augmentation of these protocols with drugs, "penguin suits", or electrical stimulation. The potential of utilizing oral potassium citrate therapy will be discussed as a countermeasure to reduce renal stone formation during space flight. Finally potential contingency stone management strategies will be outlined.

Table 1. Renal Stone Risk in Astronauts Before, During and After Space Flight.

	PRE	Group 1 POST (n=279)	PRE	Group 2 IN-FLT (n = 6)	POST	
Calcium (mg/day)	191 (5.8)	241 (7.2)*	166 (32.7)	132 (22.0)	222 (34.4)	245 (70.2)*
Total Volume (l/day)	2.01 (0.06)	1.94 (0.06)	1.68 (0.09)	0.80 (0.08)	1.30 (0.17)	1.52 (0.35)
pH	6.01 (0.03)	5.68 (0.03)*	6.01 (0.18)	5.95 (0.19)	5.92 (0.13)	5.14 (0.05)*
Citrate (mg/day)	708 (17.5)	609 (19.1)*	718 (115)	469 (109)	522 (66)	456 (82)
Urinary Relative Supersaturation						
Calcium Oxalate	1.64 (0.06)	2.32 (0.06)*	1.52 (0.40)	2.95 (0.65)*	2.78 (0.47)*	2.07 (0.40)
Brushite	1.35 (0.07)	0.98 (0.06)	1.11 (0.32)	2.20 (0.32)*	2.10 (0.43)*	0.32 (0.07)
Sodium Urate	2.71 (0.14)	1.48 (0.08)	1.83 (0.47)	2.66 (0.50)	1.77 (0.42)	0.66 (0.42)
Struvite	2.04 (0.37)	0.56 (0.08)	1.29 (0.78)	3.46 (1.44)	0.99 (0.28)	0.05 (0.04)
Uric Acid Saturation	1.95 (0.10)	2.69 (0.11)*	1.96 (0.69)	2.31 (0.75)	1.68 (0.31)	2.84 (0.76)

For Group 1, the data represent the mean +/- sem obtained 10 days prior to launch (PRE) and on landing day (POST). For Group 2, the values for PRE are the means +/- sem from two separate preflight urine collections. In-Flt represents two separate urine collections during the early phase of the missions (flight days 3-4) and during the late phase of the mission (flight days 11-13). * denotes significant differences from before flight, p < 0.05.

PSYCHOLOGICAL ISSUES AND CREW SELECTION FOR A MARS MISSION: MAXIMIZING THE MIX FOR THE LONG HAUL

¹S. Bishop, ²J. Wood, ³J. Jones

¹Center for Aerospace Medicine and Physiology/UTMB Galveston, TX

²KRUG Life Sciences Houston, TX

³NASA/JSC, UTMB, USRA/CASS Houston, Galveston TX

INTRODUCTION

Historically, the process of mission specific crew selection for space flights has been severely limited. Mainly oriented towards ruling out pathology and maximizing specific field-relevant expertise, all other factors (e.g., gender, race, culture) have oftentimes been driven by political processes rather than attention to maximizing team processes.

RESULTS

Growing evidence from psychosocial research and a body of experience with long-term exposure to the space environment, indicate that the time has come to move towards identifying those individuals who are best suited to maintain maximal health and performance under conditions characterized by close confinement, reduced stimulation, weightlessness, isolation and extreme environmental danger. Evidence has clearly indicated problematic areas in which group functioning has been compromised to some extent by the presence of communication breakdowns, interpersonal conflict, individualized responses to environmental stresses and conflicts over authority and control. A renewed focus on psychosocial factors is beginning to yield information regarding crew size, gender mix, composition, structure and the necessary interpersonal skills required for effective group performance in extreme environments.

Lessons learned from military and remote outpost team member observational studies indicate that the pressures on individuals required to work and live together in extreme environments, could raise the need to address personality and behavior issues, not otherwise required in more limited missions. Group living training pre-flight may play a role in providing crew members with a variety of coping skills and strategies to effectively handle these personality/behavioral issues as they arise. Further research on the role of pre-flight mission simulation with proposed crews may provide insight into the factors predicting potential interpersonal conflicts during the mission. Mental health monitoring tools need to be developed that provide real-time assessment of behavioral conflicts and possible secondary somatization symptomatology. Defining resources that crews may have for intervention during periods of defined stress may prove invaluable for maximizing crew performance.

DISCUSSION

Pertinent issues for guiding psychological and behavioral factors in crew selection for long-duration missions will be discussed. Mental health monitoring and support strategies will be evaluated. Finally discussion will be made of interactive psychological appraisal tools used in monitoring assigned crews in the Antarctic and remote outposts.

ISSUES IN CREW HEALTH, MEDICAL SELECTION AND MEDICAL OFFICER(CMO) TRAINING FOR A MISSION TO MARS

¹C. Jernigan, ²B. Harris, ¹R. Jennings

¹Center for Aerospace Medicine and Physiology, UTMB, Galveston, TX

²Spacehab, Houston, TX

Crew medical selection criteria and plans for medical care should both derive from mission guidelines defining acceptable risk. Acceptable risk for events affecting mission completion, and for events affecting individual career completion should both be given proper weight. Low earth orbital missions and interplanetary missions expose crew members to categorically similar risks; but markedly increased return times and the absence of radiation shielding provided by Earth's magnetosphere greatly increase the magnitude of some categories of risk. These risks can be ameliorated by careful attention to habitat design, medical selection criteria, onboard medical capability and remote medical consultation capability. Habitat design must be carefully analyzed and incorporated into spacecraft design at the earliest stages in order to achieve the best cost/benefit ratio. Mission duration significantly influences the appropriate mix of medical personnel training, experience and skill and knowledge redundancy. Interplanetary communication lag times impose significant limitations on the use of earth based consultation. A discussion of needed Crew Medical Officer credentials, experience, and training in order to effectively liaison with ground-based flight surgeons will be conducted.

A Crew Health Maintenance Plan including transfer and surface requirements will be outlined. Special problems associated with medical diagnostics and treatment associated with potential lowered gravity environments will be discussed. Also included will be a summary of circadian physiology, crew rest and possible pharmacological and light-based countermeasures.

Tuesday, June 10

Session TA1
Room 1
8:30 - 11:30 a.m.

56-52
072248

10 P.

326960

**Mechanisms of Cardiopulmonary
Adaptation to Microgravity - 1**

INDICES OF BARORECEPTOR REFLEX SENSITIVITY: THE USE IN REHABILITATION MEDICINE AND SPACE CARDIOLOGY

J. Tank and R.M Baevsky
Clinic Bavaria, Kreischa, Germany,
Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

Several tests of baroreceptor reflex sensitivity (BRS) were developed and described in the literature . Normal values of BRS decrease with age, are higher for rising pressures and range between 5 to 50 ms/mmHg or even higher. The goal of our first studies was to evaluate different spectral and statistical indices of BRS in normal volunteers of different age and to improve our own method for routine use in rehabilitation medicine and space cardiology.

METHODS

47 normal volunteers (f=25,m=22) were studied while they were lying supine and after preres in a quiet room for 7min. and for 150 s during deep breathing with 6 breath per min. ECG signal and the finger arterial blood pressure (Finapress) were digitized at 200 Hz. The R-peaks of ECG and the systolic and diastolic pressure values were detected on a beat-to-beat basis. Power spectral analysis was performed by means of an FFT algorithm. BRS indices were calculated at supine rest as the quotient of the mean amplitudes in the HF band (0.5-0.15 Hz) of heart period duration and systolic blood pressure. During deep breathing the amplitudes in the MF bands (0.05-0.15 Hz) were used. In addition the scattergram between the heart period changes and systolic blood pressure changes was used. The BRS index was calculated as the slope of the linear regression line (BRSCC). The mean group values were than calculated for two different age groups (I:age 19-39 years,n=28 and II:age 40-64 years, n=19).

RESULTS

The spectral indices were higher than indices defined from crosscorrelation functions and showed more interindividual variability. We did not find significant differences between male and female subjects. Group differences were tested with an ANOVA Scheffe F-test ($P < 0.05$; #). The BRSCC defined during deep breathing showed the most stable and comparable to the literature results. The expected decrease with aging was shown for all indices.

Baroreceptor reflex sensitivity (BRS) in ms/mmHg ($M \pm SD$)

BRS (ms/mmHg)	I	II
deep breathing using fft	23 \pm 16	11 \pm 6 #
deep breathing using crosscorr.	15 \pm 9	7 \pm 4 #
supine using fft	28 \pm 17	13 \pm 6 #
supine using crosscorr.	14 \pm 10	4 \pm 2 #

CONCLUSION

BRS indices can be defined during deep breathing and at supine rest using the described methods and might be useful to followup patients during rehabilitation and cosmonauts-in space flights.

+Gz AND +Gx TOLERANCE AT HEALTHY PERSONS OF NON-FLYING TRADES AT PRIMARY SELECTION ON THE CENTRIFUGE

V.Yu.Lukianiouk, A.R.Kotovskaya, I.F.Vil-Viliams

State Research Center of Russian Federation - Institute for biomedical problems, Moscow, Russia

INTRODUCTION

Continued process of perfection of the existing and the development of new types of the space vehicles and orbital stations presents an opportunity for participation in the missions to persons of non-flying trades - competent experts of various areas of knowledge, who have senior age. The researches, carrying out on a human centrifuge in the system of selection of cosmonauts, permit not only to define their initial tolerance to acceleration, but also to reveal latent cardiovascular disorders, which did not expose by the other tests. The publications about the influence of age to G tolerance are non numerous and inconsistent. One authors marked the decreasing of the tolerance to +Gz stress at healthy persons after 40 years [Suvorov P.M., 1968], other - its increase [Hull D.H. et all, 1978] or an absence of sharp dependence [Shuljenko E.B. et all, 1981]. Also it is important to note, that almost all of these data were received at testing on a centrifuge of the pilots of high performance aircrafts.

METHODS

The object of research was experimental materials, accumulated during performing on the centrifuge of SRC of RF - IBMP of the expert tests of candidates to cosmonauts. All surveys, executed during 26 years, were conducted under the uniform circuit with presentation of identical modes of accelerations (+Gx stress - in a kind of "platforms" by levels of 4 and 6 g during 60 s and 8 g - 40 s with the speed of increase and reduction of acceleration 0.2 g/s and angle of seat's back to a vector of acceleration - 78°; +Gz stress - also in a kind of "platforms" by levels of 3, 4 and 5 g during 30 s each with the speed of increase and reduction of acceleration 0.2 g/s). During the whole period of investigation of G tolerance of candidates to cosmonauts an identical set of physiological parameters was measured, that permit to conduct the analysis and comparison of data.

The present work is partly supported by the Contract NAS15-10110.

RESULTS

Generously health persons of non-flying trades at primary testing on the centrifuge had good +Gz and +Gx tolerance in 80-100 % of cases.

An existence of age changes of +Gz tolerance up to 5 g was detected. The highest +Gz tolerance was at the persons in the age from 31 to 45 years, least - in groups of 21-25 and 46-50 years. Lowered +Gz-tolerance at the persons of young age was stipulated mainly by sharp fall of systolic pressure and amplitude of pulse oscillations in the vessels of ear lobe, occurrence of visual disturbances and loss of consciousness, i.e. by the symptoms, connected with insufficient blood circulation in the brain. At the persons of the senior age an extrasystolic arrhythmia became the main limiting factor. With an increase of age from 21-25 to 46-50 years less expressed sinus tachycardia at an effect of +Gz was observed. This difference was the most significant ($P < 0,05$) during +5Gz stress, when at the persons of young age (21-25 years) heart rate reached, on the average, 172 ± 4 beats/mines, and at the persons of the senior age group (45-50 years) - 148 ± 7 beats/mines.

No sharp dependence of changes of +Gz tolerance up to 8 g was found out.

CONCLUSION

1. The variability of age dynamics of +Gz tolerance up to 5 g during primary testing on the centrifuge at at practically healthy persons of non-flying trades was established. The highest +Gz tolerance was found at the persons in the age of 31-45 years, the least one - in groups of 21-25 and 46-50 years.

2. Age features of physiological reactions of organism on +Gz acceleration were determined. For the young persons (21-25 years) - asthenic type of reaction of systolic blood pressure in the vessels of ear lobe, development of functional visual disturbances and loss of consciousness were characteristic, for the persons senior than 45 years - disturbances of heart rhythm and limitation of maximal level of heart rate, which indicate about a decrease of functional reserves of their cardio-vascular system.

3. Generously healthy persons of non-flying trades at primary selection on the centrifuge did not show age-depending changes of +Gx tolerance up to 8g.

4. During +Gx accelerations to the persons of the senior age groups, in comparison with young subjects, it was characteristic an increase of frequency of occurrence extrasystolic arrhythmia and less expressed sinus tachycardia.

EFFECT OF DRY IMMERSION ON CALF BLOOD SUPPLY DURING SUSTAINED CONTRACTION AND UPRIGHT EXERCISE IN MAN

Y.M. Stoida, A.A. Kulakov, and O.L. Vinogradova

Space Biomedical Center for Training and Research, Lomonosovsky Prospekt 31 building 5, 119899, Moscow, Russia

INTRODUCTION

One of the important consequences of gravitational unloading concerns muscular activity and its blood supply, especially during upright exercise. The mechanisms of muscle blood supply during sustained contractions or exercise (natural locomotion) differ considerably. During local contractions muscle blood flow is regulated mainly by local changes inducing hyperemia. During locomotion blood supply of a certain muscle group is a result of a conflict between this muscle group demand and resources of central haemodynamics providing all the contracting muscles with blood without dramatic drop of blood pressure. The situation becomes even more complicated because of the orthostatic effect. Adaptation to simulated microgravity and its cessation is accompanied by pronounced changes of local muscular, central haemodynamic and regulating factors influencing blood supply of active muscles. The aim of the present investigation is to clarify the effect of simulated gravitational unloading (dry immersion) on blood flow during activity of various types - supine sustained contractions provoking "pure" functional hyperemia and natural locomotion in man.

METHODS

12 healthy males aged 21-36 gave their written consent to participate in the experiment. 6 subjects participated in a 5-day immersion study. They performed 3 min sustained contraction of ankle extensors at a tension of 10, 20, and 30% of preimmersion maximal voluntary contraction (MVC) in supine position. Calf blood flow was determined at rest and during the whole recovery period after contraction by venous occlusion plethysmography. Blood pressure was determined every min of postcontraction hyperemia with a sphygmomanometer. To evaluate maximal calf blood flow the subjects performed repeated ankle extensions during the last min of 10 min arterial occlusion. 6 other subjects participated in a 7-day immersion study. They performed graded treadmill exercise before and after 7-day dry immersion. The arterial inflow to calf was investigated during abrupt cessation of treadmill walking / running in the phase of transferring the investigated leg by plethysmographic technique based on the haemodynamic effect of a muscle pump.

RESULTS

Postimmersion calf blood flow after 3 min sustained contraction was higher than preimmersion index, the degree of the effect being more pronounced with the load increasing from 10 to 30% MVC. Peak post- and preimmersion blood flow after 30% MVC contraction was 38.1 ± 1.5 vs. 32.3 ± 2.8 ml \cdot min⁻¹ \cdot 100 ml⁻¹ and integrated hyperemia was 84.8 ± 18.0 vs. 53.2 ± 9.9 ml 100 ml⁻¹. An increase of postcontraction hyperemia seems to be unrelated to changes of central haemodynamic parameters: postimmersion blood pressure at the end of sustained contraction was not higher than preimmersion. During control upright graded exercise transition from walking to jogging induced substantial increase of calf blood flow and it stayed constant with further increase of running speed. During postimmersion upright graded exercise the calf blood flow was lower than in control exercise. When the maximal running speed and heart rate of more than 185 b \cdot min⁻¹ were reached, postimmersion blood flow was significantly lower than preimmersion index. Maximal calf blood flow after immersion did not differ from control values in both series.

CONCLUSIONS

The dry immersion induces reverse changes in calf blood supply during various types of muscle activity: an increase of postcontraction hyperemia and a decrease of blood flow during upright graded exercise. The latter might be caused by central vasoconstrictive influences directed at maintaining "circulation homeostasis".

CARDIOVASCULAR AND VALSALVA RESPONSES DURING PARABOLIC FLIGHT

T.T. Schlegel,¹ E. Benavides², D. Barker², T. Brown², D. Harm¹, and P. A. Low³
¹NASA Johnson Space Center, ²KRUG Life Sciences, ³Mayo Clinic

INTRODUCTION

We investigated passive and Valsalva-related mean arterial pressure (MAP), heart rate, and stroke volume responses to acute microgravity and hypergravity in sixteen seated human test subjects. Gravitational changes were induced by flight aboard NASA's KC-135 aircraft, which produces 25-30 sec periods of microgravity (0.01G) alternating with 50-55 sec periods of hypergravity (up to 1.8G).

METHODS

Seated MAP, heart rate and stroke volume responses were measured continuously via finger photoplethysmography (heart-referenced Portapres), electrocardiography, and impedance cardiography, respectively, while aircraft acceleration was recorded simultaneously via accelerometer. Controlled Valsalva maneuvers (30 mm Hg strain for 15 sec) were performed during alternating microgravity and hypergravity periods, every fourth parabola, punctuating periods of passive parabolic flight.

RESULTS

During passive flight, MAP and heart rate declined from high initial levels in acute microgravity and rose from low initial levels in acute hypergravity. Directional changes in heart rate, however, were tempered toward the middle of each gravitational condition, suggesting activation of compensatory baroreflexes. In microgravity, rises in stroke volume occurred that were variably delayed in comparison to falls in MAP and heart rate. In hypergravity, falls in stroke volume occurred simultaneous with rises in MAP and heart rate. Seated MAP rises occurring during late phase II of the Valsalva maneuver were significantly attenuated in microgravity compared to seated late-phase II MAP rises in either hypergravity ($p < 0.01$) or normogravity ($p < 0.01$). Seated MAP rises occurring during phase IV in microgravity were likewise attenuated [versus phase IV MAP rises in hypergravity ($p < 0.05$), but not versus phase IV MAP rises in normogravity]. Seated *early* phase II Valsalva MAP falls (or troughs) were not significantly changed across any of the gravitational conditions, in contrast to the lower early-phase II falls/troughs seen after transitions from the supine to the seated position in normogravity ($p < 0.05$). Valsalva results, however (particularly changes in MAP responses in late phase II, phase III, and phase IV), were dependent to a large extent on the method of Valsalva analysis employed, stressing the differences that can be obtained when using diverse interpretive methodologies.

CONCLUSION

Overall results suggest that gravity-sensitive receptors such as the otolith organs potentially supplement arterial and cardiopulmonary baroreceptors in providing important autonomic feedback information to brainstem cardiovascular regulatory areas.

AN ANALYSIS OF THE CARDIOVASCULAR RESPONSES UNDER HYPER- AND HYPO-GRAVITY ENVIRONMENTS USING A MATHEMATICAL MODEL

Y. Hirata¹, K. Yoshimura², S. Usui² and S. Nagaoka¹

¹National Space Development Agency of Japan, Tsukuba, Ibaraki, JAPAN

²Toyohashi University of Technology, Toyohashi, Aichi, JAPAN

INTRODUCTION

Gravity affects cardiac filling pressure and intravascular fluid distribution significantly. Internal control mechanism responsible for such cardiovascular changes under hypo- and hyper-gravity have not yet been fully understood, although many biological and physiological measurements as to cardiovascular system have been conducted since the man's first exploration to space. One reason for this arises from the difficulty in continuous and simultaneous measurements of hemodynamics of many parts of the body. To overcome the difficulty, a mathematical model was constructed based on the animal and human physiological evidences in our previous study^[1]. In this study, the model is used for explaining hemodynamics during hyper- and hypo-gravity environments obtained by parabolic flight.

METHOD

Parabolic flight was conducted by a small rear-jet MU300. One university male student volunteered as a subject. Nine to eleven parabolic flights per day were performed for 6 days. The subject sat on a chair either in an upright position or a 45 degree reclining position.

Electrocardiogram and finger blood pressure were measured continuously during the flights. Variable parameters of the model were adjusted so that heart rate and blood pressure of the model fit to those of the experiment.

RESULTS AND CONCLUSION

It was shown that the model can reproduce and predict quantitatively experimental heart rate and blood pressure as well as during a parabolic flight. Analysis of internal property of the model revealed hemodynamics of human cardiovascular system during a parabolic flight which explain the mechanism of cardiovascular responses under hyper- and hypo-gravitational environments.

REFERENCES

[1] Nakatomi, T., Hirata, Y., Usui, S. and Nagaoka, S. : " Electric Circuit Model of Cardiovascular System with Gravity Term and Analysis of Cardiovascular Responses during Hyper- and Hypo-gravity Environments(Japanese)", *IEICE*, in press.

EFFECT OF VERY GRADUAL ONSET RATE +Gz EXPOSURES ON THE CARDIOVASCULAR SYSTEM

T.Sasaki, K.Iwasaki, K.Hirayanagi, T.Kinoue, A.Miyamoto, K.Yajima

Department of Hygiene/Space Medicine, Nihon University School of Medicine, Itabashi, Tokyo 173, Japan

INTRODUCTION

The usage of short-arm centrifuge (SAC) could be one of the best means to prevent physiological deconditioning due to microgravity exposure in space or during the weightlessness simulations. However it is difficult to establish how high level, how long and how often we should apply artificial gravity. We reported several studies earlier using our 1.8 meter radius SAC that could fit inside the International Space Station. We designed this study because there are only few reports about the effect of very gradual onset rate of +Gz exposure on the cardiovascular system.

METHODS

Ten healthy male volunteers 20-26 years of age participated. We increased our SAC speed linearly from +1Gz up to +2.7Gz for each subject with four different onset times; 30 min, 15 min, 7.5 min, and 3.75 min. Their onset rates were varied but all were below 0.5g/min. During the +1Gz control condition in the cabin of SAC immediately prior to an exposure, and also during the +Gz exposure, ECG, heart rate (HR) and respiratory rate were monitored continuously, and systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured every one minute using an arm cuff. Also, RR interval was continuously measured with a real-time RR analyzer. Standard deviation (SD), low frequency band [0.04-0.15 Hz] power spectrum (LFP) and high frequency band [0.15-0.40 Hz] power spectrum (HFP) were calculated by fast Fourier transform (FFT) for control data. For the data with +Gz exposures, dynamic FFT was done, shifting beat series every half second.

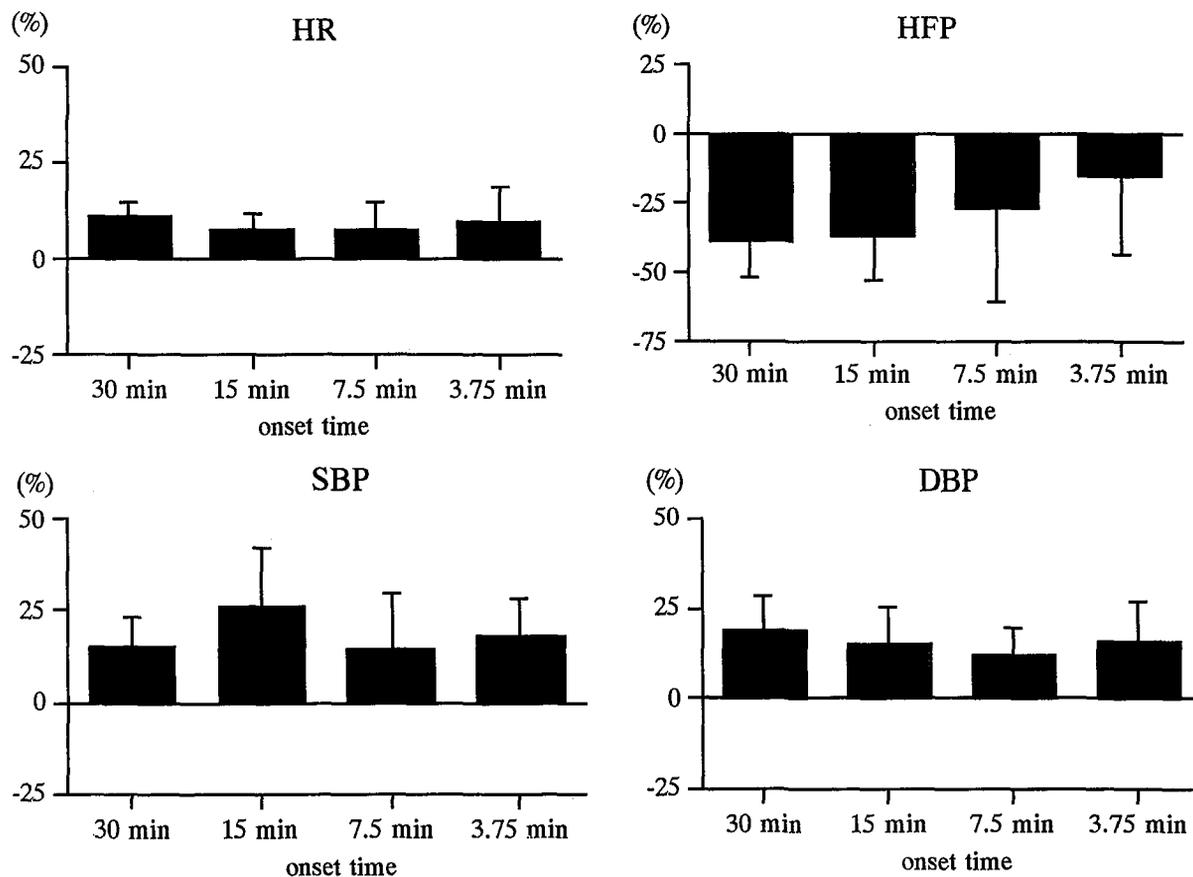


Fig.1. Mean % changes (\pm SD) at the +2.7Gz exposure.

RESULTS

All the subjects completed +Gz exposures without any complaints. No significant differences existed in the controls with various each onset times. Data at the +2.7Gz were normalized by the control. Mean % changes of HR, HFP, SBP, and DBP at the +2.7Gz exposure were significantly different from the controls (Fig.1). However, no significant differences were found with the +2.7Gz exposure between the different onset times (Fig.1). Dynamic FFT analysis of RR interval variability showed gradual changes of calculated parameters. SD and HFP of onset times of 15 min, 7.5 min, and 3.75 min. showed almost similar pattern of decline along the increase of +Gz (Fig.2). It seemed that the declines of vagal activities by +Gz stresses in this study were similar.

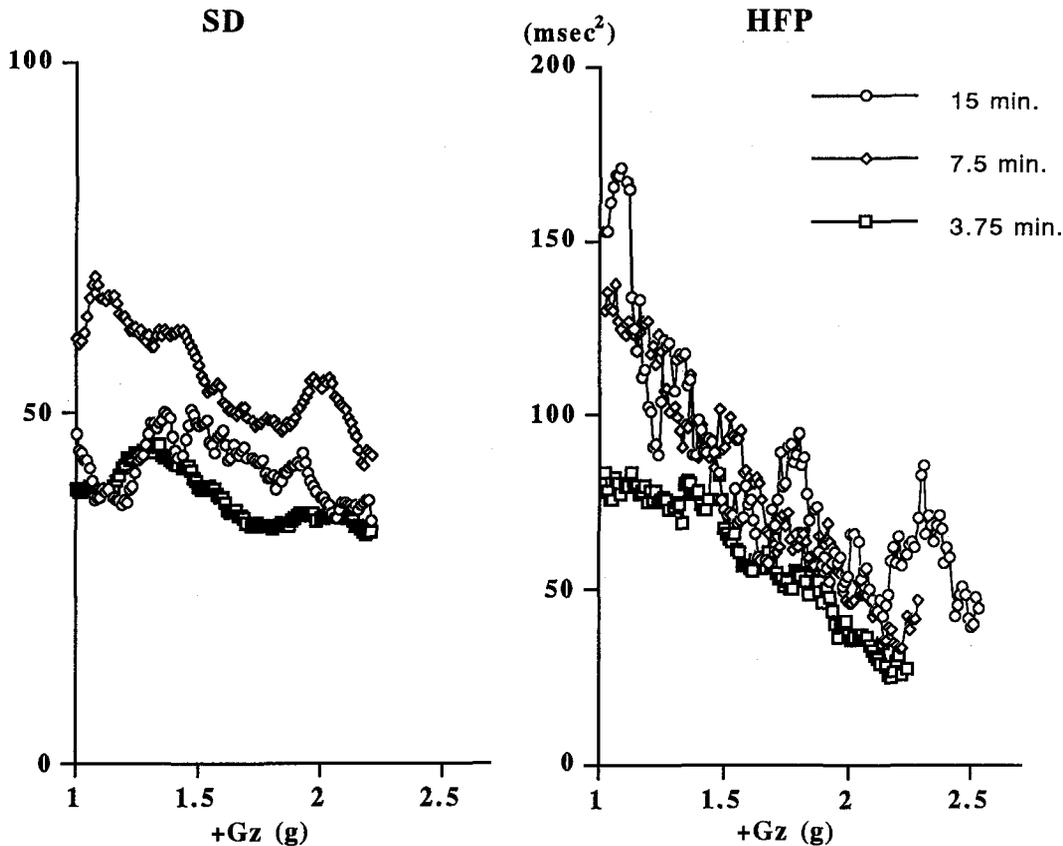


Fig.2. Changes of mean parameters along the +Gz changes. Datum at the point of every Gz was obtained by the spectral analysis of RR interval variability, from the time of the Gz level change for additional 64 seconds.

CONCLUSION

There were no significant differences among the effects of different onset rates, below 0.5g/min, on the cardiovascular system. Accordingly, we have chosen the onset rate of 0.4g/min to search optimal G-load profile avoiding the cardiovascular deconditioning during the weightlessness simulations.

Table I

Series		acceleration protocol	period	G level	Exposure time	Capsule	head mounted devices	n	comp- leted	%
A	I	1° /sec ²	133s	1.4	60m	fixed	head mounted CCD	9	5	56
	II		159s	1.7			ventilation-mask	6	2	33
	III		176s	2			head support	2	1	50
B	I	1° /sec ²	133s	1.4	60m	fixed	nothing	4	4	100
	II		159s	1.7				5	4	80
	III		176s	2				6	4	67
C	I	1° /sec ²	133s	1.4	30m	fixed	ventilation- mask	3	3	100
	II		159s	1.7				3	3	100
D	I	0.1° /sec ²	32m	2.2	20m	fixed	nothing	10	3	30
E	I	0.373G/min	3.75m	2.4	0m	freely movable	nothing	10	10	100
	II	0.187G/min	7.5m	2.4				10	10	100
	III	0.093G/min	15m	2.4				10	10	100
	IV	0.047G/min	30m	2.4				10	10	100
F	I	0.4G/min	2.5m	2 2	60m	freely movable	nothing	63	41	65

Table II

Series	n	incom- pleted	%	cardiovascular			vestibular	
				hypotension and tachycardia	hypotension and bradycardia	arrhythmia	nausea or vertigo	
A	I	9	4	44	1	0	0	3
	II	6	4	67	1	1	0	2
	III	2	1	50	0	0	0	1
	total	17	9	53	2	1	0	6
B	I	4	0	0	0	0	0	0
	II	5	1	20	0	1	0	0
	III	6	2	33	1	0	0	1
	total	15	3	20	1	1	0	1
D	I	10	7	70	2	1	2	2
F	I	63	22	35	3	4	1	14

NASA SPECIALIZED CENTER OF RESEARCH AND TRAINING (NSCORT) IN INTEGRATED PHYSIOLOGY: MECHANISMS OF PHYSIOLOGICAL ADAPTATIONS TO MICROGRAVITY.

C.G. Blomqvist, Departments of Internal Medicine and Physiology, University of Texas Southwestern Medical School, Dallas, Texas 75235-9034.

NASA's Life Sciences Division has developed a major program that supports a series of centers for research and training in areas relevant to the agency's mission. A center for integrated physiology, specifically for the study of the mechanisms of physiological adaptation to microgravity, was opened at University of Texas Southwestern Medical School in June, 1993.

The principal research areas of interest are (a) cellular and molecular mechanisms mediating responses to microgravity, (b) mineral metabolism, (c) skeletal muscle structure and function, and, (d) cardiovascular regulation. Members of the cardiovascular section are also active participants in a separately funded series of space flight experiments (Spacelab and Mir) on human adaptation to microgravity.

Dr. George N. DeMartino and his co-workers are studying the cellular mechanisms of intracellular protein degradation and have documented an important role of the proteasome and its specific regulatory proteins in skeletal muscle. Dr. Randall W. Moreadith and his group postulated that the proto-oncogenes *Ski* and *Sno* are involved in the control of muscle development but the results were inconsistent with this hypothesis. Present objectives includes a study of the regulation and function of VIaH, a muscle-specific subunit of cytochrome oxidase. Dr. Nina B. Radford is the current unit director. The unit on mineral metabolism is directed by Dr. Charles Y. Pak. The work of this group has been focussed on the mechanisms that mediate immobilization-induced hypercalcuria and bone loss, and on countermeasures, including the use of biphosphonates that have been shown to be effective during bed rest of relatively short duration. The NSCORT section on skeletal muscle and function includes three projects. Dr. Ronald G. Haller and his colleagues use inborn human oxidative defects as models to provide new insights into mechanisms of deconditioning and adaptation. Dr. Loren A. Bertocci and his co-investigators have applied magnetic resonance spectroscopy to provide new data on substrate regulation in skeletal muscle during exercise and the long-term effects of training and disuse. Dr. James L. Fleckenstein is using magnetic resonance imaging to examine fiber type distribution and water shifts in skeletal muscle. The cardiovascular unit, including Drs. Benjamin D. Levine, James A. Pawelczyk, Craig G. Crandall, and Peter B. Raven have conducted extensive studies on human regulatory mechanisms. The team has convincingly shown that prolonged bed rest causes decreased compliance of both the heart and the peripheral vasculature and also has multiple effects on regulation, including impaired cerebral autoregulation.

Training and educational activities have covered a wide range and included summer research programs for high school and undergraduate students. The NSCORT has provided strong support for the development of a new graduate school Ph.D. program in integrative biology within the Division of Cell and Molecular Biology in Southwestern Graduate School of Biomedical Sciences. Members of the NSCORT also had a major role in organizing and conducting in 1995 an International Workshop on Cardiovascular Research in Space, sponsored by NASA and the International Space Life Sciences Strategic Planning Working Group.

Tuesday, June 10

Session TA2
Room 2
8:30 - 11:30 a.m.

57-51
072 286

326 961
11 P.

Plant and Animal
Gravitational Biology - 1

THE INTERACTION OF MICROGRAVITY AND ETHYLENE ON SOYBEAN GROWTH AND METABOLISM

C.S. Brown¹, M.M. Sanwo², W.C. Piastuch², B.V. Peterson², E.C. Stryjewski², E. Hilaire³ and J.A. Guikema⁴
¹Dynamac Corporation, Durham, NC 27713 and NSCORT/NC State University, Raleigh, NC 27695, ²Dynamac Corporation, Kennedy Space Center, FL 32899, ³Department of Plant Pathology and ⁴Division of Biology, Kansas State University, Manhattan, KS 66506

INTRODUCTION

Spaceflight has profound effects on plant growth and metabolism, however the initial response of the plants to this unique environment is not known. There are several reports of enhanced ethylene production by plants which have been subjected to earth-based altered-gravity and/or spaceflight conditions. The experiments presented here were designed to determine 1) if spaceflight and/or ground-based microgravity simulations result in increased ethylene production in etiolated soybean seedlings, 2) the physiological impact of gravity-induced enhancement of ethylene production and 3) if removal of atmospheric ethylene ameliorates the observed physiological and metabolic effects of spaceflight.

METHODS

Soybean (*Glycine max* L. [Merr] cv. McCall) seeds were germinated and grown in Biological Research In Canister (BRIC) ground support and flight hardware. The BRIC hardware consists of two light-tight, independent compartments containing 4 passive pressure relief vents which were used for gas sampling ports. Individual surface sterilized seeds (13/compartment) were rolled in germination paper, inserted in a Teflon tube and placed within the BRIC hardware. The seeds were watered and the BRIC hardware was closed and loaded onto the Space Shuttle. For ground control experiments, the hardware was placed either on a clinostat or remained stationary in the vertical position. After the 8-day mission, gas samples were taken and analyzed for ethylene and CO₂ using gas chromatography. Plants were then harvested and analyzed for growth.

These experiments will be continued and expanded upon in the upcoming Collaborative Ukrainian Experiment (CUE), a joint project of the United States and Ukraine focusing on plant science which is scheduled to fly on-board the Space Shuttle (STS-87) in October 1997. In order to remove the atmospheric ethylene from the canisters in-flight without disturbing other canister atmospheric constituents (especially CO₂ and relative humidity), several passive scrubbing techniques were tested and the results are reported below.

RESULTS

Clinorotated soybean seedlings produced nearly twice as much ethylene as the upright stationary controls after 7 days. Space-grown seedlings also produced twice the ethylene as ground-controls. In both the clinostat and spaceflight experiments, there was no difference in the concentration of CO₂.

Root growth was enhanced and shoot growth diminished as a result of clinorotation. Root fresh weight was lower in space-grown plants relative to the ground controls but the root lengths were not different. The shoot/root fresh weight ratio was greater in the space-grown plants whereas it was diminished in the clinorotated plants.

One gram of Purafil[®] pellets in a mesh bag was found to effectively remove ethylene from a half BRIC canister for the duration of the proposed CUE experiment (up to 10 days). Using KMnO₄ (the active ingredient of Purafil[®]) alone did not scrub ethylene consistently and resulted in stunted seedling growth.

CONCLUSIONS

Spaceflight and clinorotation resulted in altered biomass partitioning and increased ethylene production in etiolated soybean seedlings. It is possible that the growth differences were due to the enhanced ethylene concentrations found in space-exposed or clinorotated canisters. We will test this hypothesis during the upcoming CUE experiment.

(Supported by NASA Grant NAG10-0142 to CSB and JAG and NASA Contract NAS10-12180 with Dynamac Corporation).

STRUCTURE AND G-SENSITIVITY OF ROOT STATOCYTES UNDER DIFFERENT MASS ACCELERATION

R. Laurinavicius, D. Svegzdienc, V. Gaina
Institute of Botany, Zaliuju ezeru 49, 2021 Vilnius, Lithuania

For the development of the conception that the structure and functions of a cell may be modified by the change of the direction of mass acceleration as well as its magnitude, experiments with *Hordeum*, *Lepidium*, and *Lactuca* primary roots on board of the orbital station Mir, biosatellite Bion-10 and Bion-11, on the slow (2 - 4 rpm) and fast (50 rpm) rotating clinostat, and on the centrifuge - clinostat of special construction were carried out. Two main questions were under investigation: (i) the role of gravity in the formulation and maintenance of the polar structure of root statocytes, and (ii) the threshold for detection of g-force by root gravisensors.

Statistical comparison of the spatial localization of main cell organelles (nucleus, amyloplasts, mitochondria) in the statocytes of different plant species grown under microgravity and on the clinostat revealed more similarities than differences. The analysis of the statolith statics and dynamics in experiments carried out with *Lactuca* and *Lepidium* roots exposed to accelerations of 0.005, 0.01, 0.1, and 1 g showed that gravity may be considered as an important though not a single factor that takes part in the functional organization of a statocyte structure. Some additional data on the role of a cytoskeleton in the structural self-organization of the statocyte are presented and considered.

The minimal acceleration acting in the longitudinal direction of a statocyte still capable of influencing the spatial localization of the statoliths was determined to be lower than 0.01 g. When a functional dependence between the lateral stimulation force (g) in the range of 0.005 - 0.1 g and the gravitropic response (R) was expressed as $R = a + b \ln(g)$, the threshold acceleration for gravitropic stimulation of *Lepidium* and *Lactuca* roots were calculated to be 2.6×10^{-3} and 3.7×10^{-3} g respectively. The obtained experimental data are considered from the point of view of the statolith theory.

EXTRACELLULAR PRODUCTION OF TAXANES ON CELL SURFACES IN SIMULATED MICROGRAVITY AND HYPERGRAVITY¹

D. J. Durzan² F. Ventimiglia^{2a} and L. Havel³

²Environmental Horticulture, University of California, Davis, CA 95616-8687 djdurzan@ucdavis.edu

³Botany and Plant Physiology, Mendel University of Agriculture and Forestry, 613-00, Brno, Czech Republic.

INTRODUCTION

Cell suspension cultures of *Taxus cuspidata* produce free and covalently bound taxanes at 1xg on the outer surfaces of cells. This study explores effects of gravitational forces on 'natural' paclitaxel (TaxolTM) production and release into the culture medium. Paclitaxel is an antimitotic drug for the treatment of human malignancies viz. ovarian and breast cancer. This research provides a model for the final assembly of extracellular paclitaxel and offers new bioproduct recovery strategies for plant cells in suspension cultures.

METHODS

Cells were grown in 100 ml rotary cell culture bioreactors (Synthecon, Houston TX) for 14 d to simulate microgravity and to produce taxanes on the outer cell surface (1). Taxanes and paclitaxel were localized with monoclonal antibodies (Hawaii Biotechnology Group) to the taxane ring of paclitaxel. Apoptotic cells were distinguished morphologically and histochemically from nonapoptotic cells (2,3). Free taxanes and those bound and released by xylanase were separated on taxil columns (MetaChem Technologies Inc.). Cells were also exposed to 1xg and to 3, and 24xg in a laboratory centrifuge.

RESULTS

Taxanes were localized by monoclonal antibodies on the surfaces of stressed cells. Taxane contents varied according to their physiological state and entry into apoptosis. Taxanes were located together with endonucleases on chromatin of apoptotic nuclei. After solvent extraction of cell suspensions, covalently bound taxanes were detected in cell debris and removed by xylanase treatment. Sites of taxane assembly were associated with cell surface fibrils and with membranes staining for peroxidase containing heavy/transition metals localized by colloidal silver. Cell growth was increased with microgravity to a doubling rate of 7-9 days, but with decreased taxane production. Exposure of cells to Earth's gravity and to hypergravity increased taxane production significantly. Cells continued to grow even at 24xg and survived these forces for over 4 months without subculture. Adaptation was postulated as related to *TCH* (touch) genes for responses to mechanical stress by endoxyloglucanase activity and to calcium-related sensing of gravitational forces (e.g. 4).

CONCLUSION

The final assembly of taxanes including paclitaxel on cell surfaces are responsive to gravitational forces. Sites of surface assembly reveal a confluence of membranes bearing heavy metals and particles that are released into the culture medium either a free or covalent bound taxanes. This work suggests new modifications to current bioproduct recovery strategies (5) using bioreactors suitable for the Space shuttle program.

1. Durzan DJ, Ventimiglia F 1996 US Patent No. 5,5547,866.
2. Havel L, Durzan DJ 1996 *Botanica Acta* 109: 268-277.
3. Havel L, Durzan DJ 1996 *Intl J Plant Sci* 157: 8-16.
4. Xu et al. 1995 *Plant Cell* 7: 1555-1567.
5. Gonda S 1996 MSAD OLMSA NASA HQ and Langley Res Cntr. Advanced Technology Development '96.

¹ Supported by NASA grant NAG 9-825.

CURRENT PROBLEMS OF SPACE CELL PHYTOBIOLOGY

E. L. Kordyum

Institute of Botany, National Academy of Sciences of Ukraine, Kiev, Ukraine

The discovery of cell gravisensitivity, including plant cells, focuses increasing attention to an elucidation of the mechanisms involved in microgravity effects at the cellular, subcellular and molecular levels. On the basis of the concept that microgravity has an essential effect on cell metabolism, proliferating and metabolizing cells are the most sensitive to the influence of altered gravity. Microgravity is assumed to induce rearrangements in the cytoplasmic membrane's physical-chemical organization; these changes underlie changes in its permeability (ion transport, receptor functions, bound enzyme activity) and the further chain of sequential changes in cell metabolism. Hence, the main focus in space cell phytobiology to date should be on the investigations of 1) primary events occurring at the membrane level, especially in the cytoplasmic membrane and the tonoplast under the influence of microgravity, 2) messenger systems providing the transduction of primary microgravity effects in the integrated intracellular responses (including Ca, inositol phospholipids, protein kinases, and cyclic mononucleotides), 3) levels of metabolism regulation (gene expression, phytohormones' content and composition, allosteric processes) in altered gravity, 4) photosynthesis and its intensity under the influence of altered gravity, and 5) peculiarities of secondary metabolism in cultured *in vitro* plant cells and organs in microgravity which are the products of biologically active substances. Possible approaches and objects for carrying out these investigations are discussed.

BIOLOGICAL CONSEQUENCES OF MICROGRAVITY-INDUCED ALTERATIONS IN WATER METABOLISM OF PLANT CELLS

D.O. Klymchuk

Institute of Botany, National Academy of Sciences
of Ukraine

There is considerable literature, directly or indirectly demonstrating that microgravity environments modify the water metabolism in plant cells. In particular, results obtained in the experiments with tissue cultures have showed: 1) a decrease in the biomass production of flight cultures; 2) a decrease in the relative content of water. So, the relative water content in the flight samples was 10% less for pea tissue culture and 26% less for haplopappus tissue culture than in control samples; 3) decrease the biomass production more than accumulate of dry matter. In contrary to the flight environments, the positive growth reaction in haplopappus tissue culture under clinostating (50 rev/min) was accompanied by an increase in biomass/dry ratio, cell vacuole size and cell volume. In spite of the differences in reaction of the cultured cells to the flight and model environments the obtained data allows to conclude that the change in the biomass/dry matter ratio reflects an alteration growth processes by cell expansion. Consequently, mechanisms by which the plant cells *in vitro* respond to altered gravity conditions involve mechanisms regulating the water exchange. An identification of the mechanisms maintained the water homeostasis of plant cells could clarify the mechanisms underlying adaptation to microgravity.

Expansive growth in plants is one of the most sensitive of plant processes to water deficit. Water plays a vital role in the functioning of diverse cell processes and decrease in its availability in microgravity may be a primary limitation to cell expansion, division and biomass production. Therefore, the above mentioned evidence and theoretical suggestions require evaluation of the gravity effects at this level. The most important aspects related to regulation of cell growth by expansion are discussed.

LOCALIZATION OF CALCIUM IONS IN CHLORELLA CELLS UNDER CLINOROTATION

A.F.Popova

Institute of Botany National Academy of Science of the Ukraine,
Tereschenkivska Str.,2, Kiev, 252004, Ukraine

Data obtained in the space flight and clinorotation experiments demonstrate numerous rearrangements in the ultrastructural organization of *Chlorella* cells, especially, energetic organelles - mitochondria and chloroplasts. Since the changes in intracellular calcium balance observed in altered gravity was supposed to play an essential role in cell metabolism, we have studied the localization of calcium ions in *Chlorella* cells (strain Larg-1) under clinorotation (3 rev/min) using a pyroantimonate method.

In *Chlorella* cells grown in the stationary conditions various granules of calcium pyroantimonate of different form, size and quantity were observed in different organelles. Thus, some organelles, in particular, a nucleolus, a chloroplast, the mitochondria and the

vacuoles of cell were marked intensively by precipitates, while a diffuse chromatin of nucleus, the cisterns of a dictyosome - more weaker.

The product of cytochemical reaction in mitochondrial matrix and in nucleolus has been observed in a form of small granules. While the sediment of pyroantimonate calcium revealed in a stroma of chloroplasts, around of the starch grain and among thylakoid bundles was observed in a form of more large granules.

Unlike control cells, there was a precipitate of the cytochemical reaction in the hyaloplasm; it was in the form of fine sediment in small quantity. Increased quantity of a precipitate was localized in the mitochondria and a chloroplast and also in the periplasmic space of vegetative cells and around autospores after cytokinesis. The peculiarities of calcium localization in cells and increased volume of a cytochemical reaction product in organelles under clinorotation are assumed to increase a general pool of ionized calcium in cell under the influence this factor. Obtained data correspond to the hypothesis of regulative role of calcium under impact of external stimulus on cell.

CHANGES OF FATTY ACIDS CONTENT OF PLANT CELL PLASMA
MEMBRANES UNDER ALTERED GRAVITY

Yu. Ya. Polulyakh

Institute of Botany, National Academy of Sciences of Ukraine

Studies were carried out with plasma membranes of pea roots seedling under normal conditions and under 24, 48, 72 and 96 h of clinostatting (2 rev/min). The plasma membranes fraction was isolated by differential centrifugation in stepped density gradient of saccharose. A fatty acid content of lipids was measured by gas-liquid chromatography. Microviscosity of plasma membranes and model phospholipid membranes – liposomes is studied by the method of fluorescent probes.

Lipids of plasma membranes of pea root cells include the following saturated fatty acids: myristic (C_{14:0}), palmitic (C_{16:0}), stearic (C_{18:0}) and unsaturated ones – myristoleic (C_{14:1}), oleic (C_{18:1}), linoleic (C_{18:2}), linolenic (C_{18:3}).

The total content of unsaturated fatty acids increased during clinostatting. There were increases of unsaturated fatty acids mainly at the expense of linoleic and linolenic acid and also a decrease of saturated fatty acids content at the expense of palmitic and stearic acids. Fatty acid composition of the plasma membrane was more variable in composition of plasma membranes was more variable in comparison with phospholipids. Data obtained suggest a high sensitivity of microviscosity indices of liposomes obtained from plasmalemma lipids after 24 h of clinostatting. These data agree with both the changes in a fatty acids content and an increase of the unsaturation index at the final stage (48, 96 h) of clinostatting and may be considered as one of the mechanisms maintaining fluidity of a lipid bilayer of the plasmalemma within certain limits that is homeoviscous membrane adaptation to these conditions.

SIMULATION OF GRAVITY BY NON-SYMMETRICAL VIBRATIONS AND ULTRASOUND

O. A. Kuznetsov¹, A. A. Kuznetsov², K. H. Hasenstein¹¹Biology Dept., University of SW Louisiana, Lafayette, LA 70504-2451, USA; ²Institute of Biochemical Physics, Russian Academy of Sciences, Kosygin St. 4, Moscow 117977, Russia

INTRODUCTION

The primary process of gravity perception involves the displacement of some mass under the gravitational force. In plants gravity perception depends on intracellular displacement of amyloplasts. Gravity perception of plants was commonly studied by clinorotation or centrifugation. However, the resultant forces affect the entire plant. An amyloplast-specific force was based on magnetic ponderomotive forces by high gradient magnetic fields (HGFMF), which resulted in the displacement of amyloplasts in statocytes [3] and caused curvature of roots away from and shoots toward the stronger field areas. In addition to HGFMF there are other physical principles can induce displacement and/or pressure changes of dense, intracellular particles, including inertial forces due to non-symmetrical vibrations and acoustic forces. The rheology and mechanical properties of plant cells have not been studied thoroughly yet, but available data indicate differences in mechanical properties between amyloplasts and the rest of the cell to be large enough to affect amyloplasts by these forces.

MODEL

If a body such as a columella cell is subjected to oscillations, relatively dense statoliths will move relative to other cellular structures. A non-inertial coordinate system $X'O'Y'$ (Fig. 1), that moves with the cell wall with the velocity $V(t)$ in a stationary system XOY , an inertial force $F_{in}(t) = m a(t)$ (with m = buoyant mass, $a(t)$ = momentary acceleration of the cell) acts on amyloplasts. The viscous friction F_{fr} acts on amyloplasts, that move with the velocity $v(t)$ in respect to the surrounding cytoplasm. Hence, movement of amyloplast can be described by the equation: $m(dv/dt) = \vec{F}_{in} - \vec{F}_{fr}$. If F_{fr} is linearly proportional to $v(t)$ and the mobility in both directions of the oscillation the same, then there would be no net displacement of amyloplasts. But the rheology of the intracellular medium is complex. Thus, non-symmetric oscillations (different accelerations during the positive and negative phase of the oscillation) and the non-linearity of the viscosity of the cytoplasm results in a residual force in the system (so-called vibrational force F_{vib} [1]) and causes displacement of amyloplasts. The displacement depends on the amplitude and the waveform of the oscillations [1,2]. Previous work [2] estimated the residual force with the following assumptions: (a) uniform cytoplasm (no structures); (b) the viscosity η being equal to that of water, if the velocity is less than v_{min} , or $\eta = 1.2$ if the velocity is higher than v_{min} , and (c) the net force causes linear amyloplast movement but no rotation. For amyloplast movement the Reynold number $Re = \rho R v / \eta \approx 10^{-6}$ to $10^{-7} \ll 1$ (R - radius of amyloplasts, ρ - density of cytoplasm), and Stoke's approximation can be used [2].

Therefore, the movement of the amyloplast is described by: $m \frac{dv}{dt} = \vec{F}_{in} - \vec{F}_{fr} = ma(t) - 6 \pi \eta R v(t)$, and

$a(t) = \frac{6 \pi \eta R}{m} v(t) + \frac{dv}{dt}$. Solving this equation yields the velocity profile $u(t)$ of the motion of amyloplast vs. cytoplasm.

The vibrational force is estimated as $F_{vib} = \frac{1}{\tau} \int_0^T F_{fr}[v(t)] dt$ and $S_T = \int_0^T v(t) dt$ describes the displacement of

amyloplasts per cycle.

MATERIALS AND METHODS.

2-day old flax (*Linum usitatissimum*) seedlings with straight roots were mounted vertically in a chamber (1×50×50 mm). The chamber was mounted to a vibrator so that the amyloplasts were affected horizontally by the force generated by a vibrator, and vertically by g . The vibrator was controlled by a 12-bit waveform generator (FG-102, Real Time Devices) and amplifier and the produced waveform was measured by an accelerometer. If vibration-induced amyloplast displacement causes curvature, the roots should curve (see Fig. 2). The profile of the tested acceleration is shown in Fig. 3. Estimation of the vibrational force for this profile yield $F_{vib} \approx 0.8$ mg, based on the above model and assumptions.

RESULTS AND DISCUSSION

Distribution of the observed root curvatures is shown in Fig.4. Root curvature depended upon the shape of the waveform, indicating that the roots response was in line with theoretical predictions. If the waveform was reversed, curvature in the opposite direction was obtained. Mean angles for the two directions were $22^\circ \pm 6.8$, and $25^\circ \pm 6.1$. Since

the tangent of this angle (ϕ) is equivalent to the ratio of horizontal force and the gravity force, the vibration induced force was equivalent to about $0.5g$, which is a rather good compliance of experimental results with the theoretical estimations of $0.8g$, given the crudeness of the model. Future experiments will test various types of oscillations and frequencies. Further development of the theoretical model and optimization of waveforms will be suitable to investigate whether forces exerted by (tethered) amyloplasts or their displacement initiates curvature. Studying the response of columella cells to frequency and waveform of applied oscillations will analyze the rheology of the cytoplasm and the elastic properties of the affected organelles.

ACOUSTIC FORCES

Increasing the vibration frequency leads to the ultrasonic part of the sound spectrum. If ultrasound passes through a mechanically heterogeneous medium, scattering and attenuation transfers a part of the sound momentum to the medium. Consequently, a system of ponderomotive forces affects amyloplasts immersed in the cytoplasm with a different acoustic impedance (density \times velocity of sound), and acoustic flow of the cell interior takes place. Therefore ultrasound will displace amyloplasts inside statocytes. Other organelles have acoustic impedances more similar to cytoplasm and are expected to be affected to a lesser extent. Theoretical estimations demonstrate the validity of the approach. Preliminary experiments with 2 day old flax seedlings with vertical straight roots (submerged in water), which were irradiated by ultrasound (frequency 0.8 MHz, intensity 0.1 W/cm²) have shown root curvature. Future investigations will determine optimal parameters of ultrasound and possible side effects on plants.

CONCLUSIONS

The described studies not only permit the study of rheological characteristics of statocytes and cytoplasm but similar to HGMF may result in novel methods that may substitute the gravity force in a microgravity environment.

REFERENCES

- 1) Blekhman II 1994 *Vibrational mechanics*. Moscow, "Nauka": 198-221
- 2) Kuznetsov OA 1993 *Non-uniform magnetic field and relaxational oscillations as instruments for plant cell exploration*. PhD thesis, Moscow, Russia
- 3) Kuznetsov OA, Hasenstein KH 1996 *Magnetophoretic induction of root curvature*. *Planta* 198: 87-94

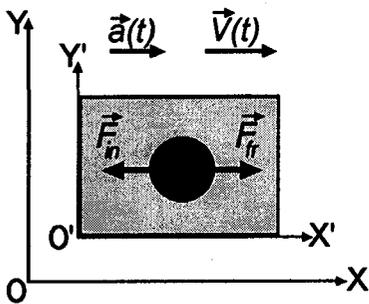


Fig.1 Model of the forces affecting amyloplasts (dark) due to non-symmetrical oscillations of statocytes (shaded).

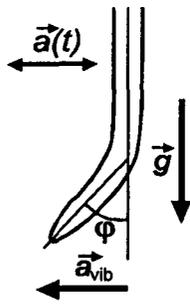


Fig.2 Force ratio of curving root.

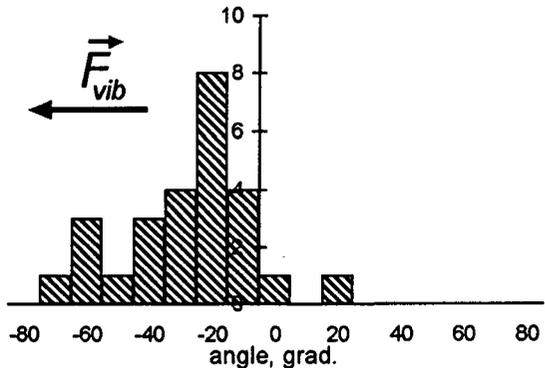
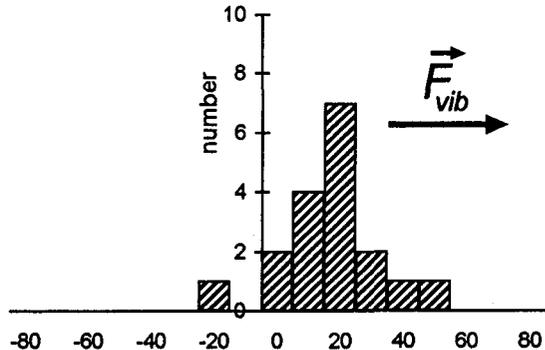


Fig.4 Distribution of curvature of flax roots subjected to the oscillations shown on fig.3.

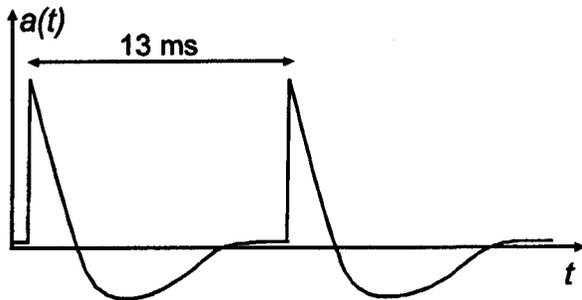


Fig.3 Acceleration profile

RESPONSE TO SIMULATED WEIGHTLESSNESS OF IN VITRO CULTURES OF DIFFERENTIATED EPITHELIAL FOLLICULAR CELLS FROM THYROID

Antonella Meli, Giuseppina Perrella, Francesco Curcio and F. Saverio Ambesi-Impiombato

*Dipartimento di Patologia e Medicina Sperimentale e Clinica, Università di Udine,
P.le S. M. della Misericordia, 33100 - Udine (Italy)*

Aim of this investigation is the study of the molecular modifications occurring in differentiated mammalian cells responding to gravitational changes. Our test system consist of a well characterized clone of differentiated, normal thyroid follicular cells (FRTL5) in long-term culture.

On the MASER-7 sounding rocket (flown by E.S.A. in May, 1996) for the first time we had the opportunity to expose FRTL5 cells to approximately 6 minutes of microgravity, in order to investigate how the gravitational field and the extraterrestrial environment may interfere with hormonal control mechanisms. In this context we evaluated FRTL5 cells responses to thyroid stimulating hormone (TSH) in terms of cAMP production and in terms of cytoskeleton organization and its functional modifications.

In this first experiment we found that in microgravity the TSH effect on cytoskeleton organization and particularly on actin polymerization was impaired to at least 50% as compared to its physiological effect occurring at 1 x g on-ground. cAMP data inexplicably turned out to be very low, dangerously close to background values, but they nevertheless were in the same direction of the above mentioned cytoskeleton experiment.

Due to the serious scarcity of long-term and sounding rocket missions with scientific payloads, particularly of those carrying biological samples and cell cultures, we are now running on-ground experiments which may be important to optimize experimental tools and strategies in preparation to, and in between real flight missions.

Following this approach, we evaluated the FRTL5 cells response to TSH in simulated microgravity obtained by means of a fast-rotating clinostat.

The TSH-dependent signal transduction was evaluated at the following different g-conditions:

- a) simulated weightlessness on a fast-rotating clinostat (60 rpm, approx. equal to 6.48×10^{-3} g);
- b) 1x g on-ground (control).

Cells pre-equilibrated (for 24 hours) in clinostat, and then acutely stimulated (for 6 min.) with TSH, increase their c-AMP production about 4x with respect to the unstimulated controls. Cells pre-equilibrated (24 hours) and then acutely stimulated (60 min.) with TSH, increase their production of c-AMP about 14x if compared to the unstimulated controls.

In acutely stimulated cells (no adaptation period in clinostat), more subtle differences were found, as compared to their unstimulated controls. Additional experiments are presently under way, to increase the significance of those differences.

In conclusion, our thyroid cultured cells preadapted to clinostat (simulated microgravity conditions) were less responsive to hormonal stimulation in terms of intracellular, more precisely post-receptorial signal transduction, whereas acutely stimulated cells, at the onset of their adaptation to microgravity, are still responding more physiologically to hormonal stimulation. These data may contribute in explaining, on an endocrine basis, a variety of pathophysiological changes repeatedly observed in astronauts, when exposed to long-term space environment. And this is now regarded as an increasingly frequent possibility.

Tuesday, June 10

Session TA3
Room 3
8:30 - 11:30 a.m.

58-53
072382
326963
9P.

Visuo-Vestibular Interactions

VESTIBULO-OCULOMOTOR INTERACTION IN LONG-TERM MICROGRAVITY.

Kornilova L.N.¹, Mueller Ch.², Steinhoff N.², Clarke A.³, Grigorova V.⁴

¹ Institute of Biomedical Problems, Khoroshevskoye Shosse 76a, 123007, Moscow, Russia

² University Clinic of Neurology, Vienna, Austria

³ Vestibular Research Laboratory, University Clinic of ORL Benjamin Franklin, Berlin, Germany

⁴ Institute of Physiology BAS, Sofia, Bulgaria

INTRODUCTION

The nature of interaction between vestibular and ocular systems is known to be directly related to tracking a visual object which is one of the key components of professional operator's activity. In this connection, of particular interest is a study of oculomotor reactions in long-term microgravity reflecting peculiarities and nature of vestibulo-ocular interactions.

METHODS

Vestibulo-oculomotor interaction was examined in 18 cosmonauts by the electrooculographic (EOG) method (one cosmonaut was examined by additional video-oculographic method) during long-term spaceflights (146-438 days). Spontaneous oculomotor activity, torsion ocular counterrolling during active, voluntary head-to-trunk roll tilt, pursuit function, gaze fixation ability and optokinetic function was investigated.

RESULTS

In the initial stage of adaptation to microgravity the changes in the operation of the vestibulo-oculomotor system are commonly observed in spaceflight (spontaneous nystagmus, disorders of tracking of vertical and diagonal movements of the stimulus, absence static torsional eye movement component during static head roll tilt). Changes in spontaneous and visually induced oculomotor reaction occur in a high proportion of persons exposed to such conditions, although there are individual differences with regard to severity, nature, time and duration of occurrence, and the dynamics of the process. After completion of initial stage of adaptation to microgravity the studied parameters improved, however anomalous spontaneous and evoked eye movement responses often observed after 50 days of exposure to microgravity. The adaptation process in during long-term spaceflight had an undulating course, in which a period of adaptation was followed by a period of de-adaptation.

CONCLUSION

Adaptation to microgravity, even if there is no subjective discomfort and no abnormal autonomic responsiveness, is associated with a resetting of the relation among sensory systems.

EFFECTS OF WEIGHTLESSNESS ON THE SPATIAL ORIENTATION OF VISUALLY INDUCED EYE MOVEMENTS

G. Clément¹, S.J. Wood², and M.F. Reschke²

¹ Cerveau et Cognition, CNRS UMR 5549, 133 route de Narbonne, F-31062 Toulouse Cedex, France

² Neuroscience Laboratories, NASA Johnson Space Center, Houston, Texas

INTRODUCTION

The purpose of this study was to examine changes in the spatial reference frame used for optokinetic nystagmus (OKN) and after-nystagmus (OKAN) as a function of spaceflight. Previous experiments have demonstrated components of eye movements out of the plane of the visual stimulus during tilted conditions on Earth in both monkeys and humans. Changes in the direction of OKN and OKAN have been interpreted as reflecting a function of central vestibular processing (known as velocity storage) in orienting gaze toward alignment with the gravitational frame of reference. For example, during roll-tilt with a horizontal optokinetic stimulus, vertical eye movements will cause a reorientation of the resultant eye velocity axis toward closer alignment with gravity. Previous spaceflight experiments have characterized OKN primarily on the basis of gain and beating field relative to the plane of stimulus. However, the effects of exposure to weightlessness on the spatial orientation of the eye movement in response to an optokinetic stimulation have never been investigated. The hypothesis of the present experiment was that the orientation of the OKN would move from an exocentric, gravitational frame of reference to an egocentric, body frame of reference. This hypothesis was tested during pre- and postflight testing by providing optokinetic nystagmus during roll-tilt, thereby disassociating the gravitational and body frames of reference.

METHODS

Horizontal and vertical optokinetic stimulation was provided by head-fixed stimulators during different static roll-tilt positions. This experiment was conducted in two parts during separate Shuttle missions. The first part was performed during the First International Microgravity Laboratory (IML-1) space mission as part of the Microgravity Vestibular Investigations. During this mission, three subjects were tested while seated upright and while lying on their left side (90 deg roll-tilt). The second part was conducted before, during, and after the Life and Microgravity Spacelab (LMS) mission. During this mission, four subjects were tested in both upright and ± 30 deg roll-tilt positions. Horizontal OKN with a 30 deg head tilt relative to the long body axis, and oblique OKN (45 deg stimulus orientation) with head upright were also evaluated as part of the LMS ground and flight testing. Eye position was recorded by an eye video system (during IML-1) and by electro-oculography (during LMS). Horizontal and vertical eye velocities were estimated using a two-point differentiation of the corresponding eye positions. The magnitude and orientation of the resultant eye velocity vector computed from horizontal and vertical components were then computed to evaluate the spatial orientation of the OKN responses.

RESULTS

During all phases of testing, the optokinetic nystagmus remained primarily aligned with the direction of the visual stimulus, with only small deviations toward alignment with gravity during the ground-based tests. For horizontal OKN during preflight testing, the resultant eye velocity was systematically reduced during roll-tilt. During early postflight testing; however, there was no difference in magnitude of horizontal OKN responses between upright and tilted body positions. For vertical OKN, only slight differences were observed between the upright and tilted body orientations during either pre or postflight testing. OKAN was sporadic, with no consistent changes observed as a function of flight phase.

CONCLUSION

This study and other recent ground-based studies in our laboratory have failed to duplicate the results of other investigators suggesting that OKN responses would reorient toward a gravitational frame of reference during roll-tilt on Earth. Since a reorientation of the OKN responses to align with gravity would not be compensatory for the visual stimulus, there may be individual differences in the degree to which subjects are able to maintain alignment of eye movement response with the visual stimulus axis. The lack of OKAN, which has been difficult to elicit in humans, may also suggest that the velocity storage elicited during our testing was weak and therefore was not sufficient to drive

TA3: Visuo-Vestibular Interactions

a reorientation in the response axis. However, the reduction in the magnitude of the horizontal OKN during roll-tilt may reflect the same spatial orientation function. We interpret this as follows. During natural horizontal head movements, the axis of head rotation and therefore optokinetic stimulation is normally aligned with gravity. During roll-tilt on Earth, the horizontal OKN is suppressed when the response axis is not aligned with gravity. Following adaptation to weightlessness, however, the horizontal OKN responses are no longer suppressed when the visual stimulus axis is not aligned with gravity. This change is therefore consistent with the hypothesis that the processing of low frequency graviceptor tilt information is altered as a function of spaceflight.

ADAPTIVE MODIFICATION OF THE THREE-DIMENSIONAL VESTIBULO-OCULAR REFLEX DURING PROLONGED MICROGRAVITY

Andrew H. Clarke, Jörg Grigull, Waldemar Krzok, Hans Scherer

Vestibular Research Laboratory, Klinikum Benjamin Franklin, Freie Universität Berlin, FRG.

INTRODUCTION

The flux of otolith-mediated, gravitoinertial information is radically altered in microgravity. Based on the results from a number of experiments onboard the MIR station, the influence of this adaptive modification on the three-dimensional vestibulo-ocular reflex (3D-VOR) is demonstrated.

METHODS

Eye and head movements were recorded by three-dimensional video-oculography (VOG) during active roll, pitch and yaw oscillations of the head, both in space and on earth. In the first experiment the oscillatory head movements were performed during visual fixation of space-fixed and imaginary targets. Analysis of the three-dimensional vestibulo-ocular response (3D-VOR) by way of 3x3 velocity gain matrices and estimation of minimal gain vectors yielded a compact representation of the orientation of the VOR coordinate system.

RESULTS

Distinct changes in the 3D-VOR were observed during the inflight and postflight phases of the mission. This was observable in the reduction in the vertical and horizontal components under microgravity conditions and their regeneration during the days after landing. These changes were reflected in the vector representation of the VOR coordinate system. This was particularly the case during the imaginary target condition, where the vestibular afferences play a greater role than during testing with visual control of gaze direction.

CONCLUSION

The results demonstrate that the co-ordinate system of the 3D-VOR is re-oriented during the inflight period, and again after return to the one-g environment. This is interpreted as evidence that - under one-g conditions - the otolith-mediated gravitational reference is used to stabilise the internal spatial co-ordinate system in the vestibular and oculomotor systems. . During prolonged microgravity, it appears that a body co-ordinate system, presumably mediated by distributed proprioception, is used as frame-of-reference. It is suggested that the loss of the unequivocal one-g, otolith-mediated reference, which corresponds closely to the visual frame, results in a "de-calibration" in the central vestibular system. The subsequent individual recalibration under microgravity conditions is dependent on proprioceptive and visual input and is less stable than on earth.

THE DYNAMIC CHANGE OF BRAIN POTENTIAL RELATED TO SELECTIVE ATTENTION TO VISUAL SIGNALS FROM LEFT AND RIGHT VISUAL FIELDS

Jinhe Wei , Lun Zhao , Gongdong Yan , Winjuan Chen , Ran Duan , Wei Ren
Institute of Space Medico-Engineering, Beijing 100094

INTRODUCTION

As it was found that the event-related potential(ERP), which was considered as the 2nd window to observe brain's activity, changed during simulated weightlessness, to study further the effect of HDT on ERP, the dynamic features of visual ERP changes during 2 hour HDT(-10⁰) were compared with that during HUT(+20⁰).

METHODS

20 normal subjects aged 19 to 27 participated the experiments. The stimuli were consisted of two color LED flashes appeared randomly in left or right visual field(LVF or RVF) with same probability. The subjects were asked to make switch response to target signals(T): switching left to T in LVF and right to T in RVF, and ignore non-target signals(NT). Five sets of tests were made at 10, 35, 55, 95 and 110 min after the subject was switched to HUT or HDT from supine position. Each subject completed two experiments on different days for HUT or HDT, respectively, of which the order was cross-balanced among subjects. ERPs were obtained from 9 locations on scalp, i.e., F5, F6, C5, C6, P5, P6, Fz, Cz, and Pz.

RESULTS

The main results were as follows. 1) Prominent slow positive potential(SPP) appeared at all locations recorded during signal selection both for T and NT; 2) The amplitudes of SPP were decreased both during HUT and HDT from the 1st to 5th set of tests; 3) While the amplitude of SPP during HDT were lower than that during HUT compared for each set of tests, the most prominent differences appeared at the 4th and 5th sets; 4) The effect of HDT on ERP revealed some dependency upon brain location and brain process.

CONCLUSION

As that the SPP probably reflects some active inhibition activity in brain's non-specific system during attention process, these data provide further evidence for the effect of simulated weightlessness on higher brain function which should be concerned during space flight.

LOCOMOTOR ERRORS CAUSED BY VESTIBULAR SUPPRESSION

D.G.D. Watt and N. Paquet

Aerospace Medical Research Unit, McGill University, Montreal, Canada H3G 1Y6

INTRODUCTION

Since the vestibular otolith organs function as linear accelerometers, sensing inertial acceleration and gravity, it has long been assumed that reflexes from these organs must be altered by the prolonged weightlessness of space flight. It is also known that postural and locomotor control are abnormal in returning astronauts. Unfortunately, it is still not clear if the former causes the latter. Indeed, the normal role of vestibulospinal reflexes in general is still a matter of some debate.

We have been studying the effects of "torso rotation" (TR), a natural way of temporarily and reversibly changing human vestibular function. (Watt et al, 1992) In summary, TR consists of continuously sweeping one's gaze back and forth, usually for 30 minutes. This abnormally high "duty cycle" of vestibular suppression causes changes in central processing that persist for some minutes after TR is ended. During that time, subjects experience gaze and postural instability, altered perception of self-movement and sometimes motion sickness.

While it has been relatively easy to document changes in oculomotor control after TR, it has been more difficult to measure objective changes in posture and locomotion. Furthermore, most experiments have concentrated on changes in reflexes originating in the semicircular canals rather than the otolith organs. The present experiment addresses both of these issues by forcing standing subjects to use an otolith organ reference to maintain the position of their head in space.

METHODS

Ten normal individuals were tested in this study. Each was asked to stand facing forward on a treadmill with the fore-aft position of the head and feet carefully standardized, and to close the eyes before motion began. A dental bite and system of linear bearings allowed only fore-aft and vertical linear motion of the head and a potentiometer measured fore-aft displacement. At an unexpected moment, the treadmill was started and allowed to run for 4 sec at 29 cm/sec. The subject's task was to keep the head in an imaginary, earth-fixed box by means of rapid, short steps. The latter were used to minimize the use of natural walking cadences as velocity references.

Each test series consisted of 60 treadmill starts over a period of 12.75 minutes, with the time between starts varied randomly. A complete experiment consisted of one series of 60 starts, a 30 minute break during which the subject continued normal activity, a second series of 60 starts, 30 minutes of torso rotation and a final series of 60 treadmill starts. During TR, the subjects were instructed to sweep their gaze back and forth between two visual targets located 135° to either side of straight ahead. The frequency of this rhythmical motion was set at 0.7 Hz by a sound cue.

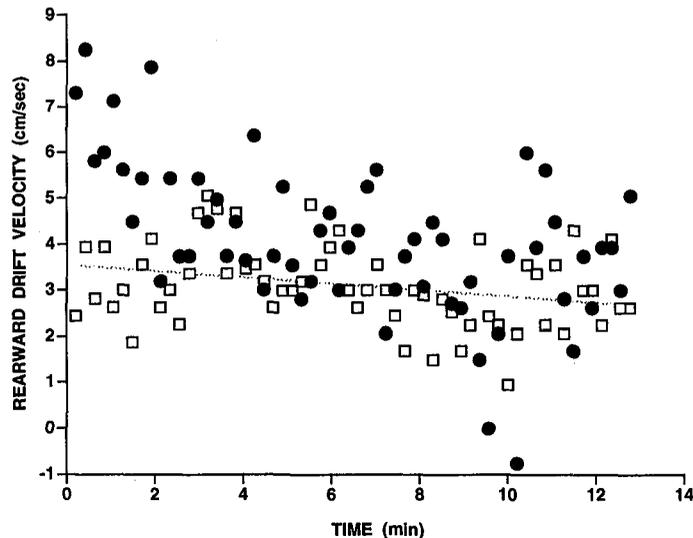
RESULTS

On average, subjects were able to maintain their position quite well during treadmill start-up, although most developed a slow, constant velocity, rearward drift. Every subject made occasional, significant errors at start-up, however, and in those cases no recovery was possible until contacting the limits of the linear bearing system. Presumably, this reflected the inability of the otolith organs to sense steady velocities and a lack of interpretable position cues that could be substituted.

More detailed data analysis began by averaging head position across the 10 subjects for each of the 180 treadmill starts. A linear regression line was then fitted to each of these average curves to determine drift velocity between 1 and 2 seconds after treadmill start. Data recorded before this period were complicated by treadmill acceleration and initial postural transients. Results recorded later than 2 sec were occasionally contaminated by the subject reaching the end stops, which provided an absolute position reference. However, if a drift was established in the time gate under study, it usually continued until the treadmill stopped.

Subjects demonstrated a small learning effect, as evidenced by a progressive reduction of rearward drift velocity during both series of control tests, and by a small decrease of average drift velocity between these two series. Statistical analysis showed these changes to be marginal, however.

While most subjects developed a slow, rearward drift even before TR, it was significantly increased afterward, especially during the first 5 minutes. This is illustrated in the following figure, in which all pre-TR control results have been combined and shown as boxes and the post-TR responses have been shown as filled circles. Time is measured relative to the start of each test series. A linear regression line has been fitted to the combined control data.



The magnitude of the increased drift seen for the first few minutes after TR was considerably greater than any previous tests, and the identical 30 minute delay between the two series of control tests had little if any effect on drift velocity. This rules out lack of practice as a cause of the degraded performance.

Finally, head displacement measured in the initial second of treadmill start-up was compared before and after TR. These results were surprisingly consistent from test to test and seemed unaltered by the manoeuvre. This demonstrates the importance of passive, biomechanical factors and suggests that measuring initial postural reactions to support perturbations may be a relatively insensitive way of testing for changes in vestibular function.

CONCLUSION

Under the conditions of this experiment, the presence of a slow, rearwards drift even in normal subjects suggests that the measurement of linear acceleration by the otolith organs, or conversion of that signal to position by double integration, is a less than perfect process. It can be compromised further by the simple application of excessive vestibular suppression, even that occurring during purely angular movement. The extra error disappears along a roughly exponential time course, with near-complete recovery in 10 minutes, similar to previous studies of the effect of TR on the angular vestibulo-ocular reflex (VOR). Interestingly, the method had little if any effect on short-term postural control. This suggests that relatively small changes in otolith sensitivity lead more to inertial navigational errors, i.e. problems in controlling locomotor trajectory, and less to problems in maintaining the upright position. This is consistent with the results of Glasauer et al (1994), who tested patients with bilateral vestibular deficits.

Astronauts have produced many anecdotal reports of bumping into walls, missing turns in hallways and other evidence of locomotor errors encountered soon after returning from prolonged space flight. If the central processing of otolith signals is modified by exposure to weightlessness, many of these phenomena could be explained by the incorrect perception of self-movement that would result. The errors would appear suddenly and apparently randomly when the individual happened to ignore visual cues because of distractions or other reasons and could occur in the absence of deficits in rapid postural control.

A NOVEL, IMAGE-BASED TECHNIQUE FOR THREE-DIMENSIONAL EYE MEASUREMENT

A.H. Clarke, D. Schücker, W. Krzok, J. Grigull

Vestibular Research Laboratory, Klinikum B. Franklin, Freie Universität Berlin, Germany

State-of-the-art image-processing technology facilitates the accurate measurement of all three components of eye rotation. The non-invasive character of such video-oculographic techniques render them particularly suitable for applications in difficult environments. However, the adherence of the system components employed (CCD cameras, framegrabbers) to standard video conventions has critically restricted spatio-temporal sampling performances. Essentially, sampling rates higher than 25/30 Hz can only be obtained at the cost of reducing spatial resolution.

A novel approach using non-standard imaging methods is introduced here, which yields sampling rates of 300 Hz and beyond. This is based on smart sensor devices which eliminate the bottleneck of the classical framegrabber concept.

The present technique draws from the principle of reducing image redundancy by means of coding, noise suppression, thresholding and selective pixel acquisition – all performed on the sensor/processor chip. This eliminates the extremely high data rate required for repetitious digitisation of full frames from a high resolution CCD sensor. Essential to this technique has been the recent development of CMOS imaging devices, which incorporate programmable sensor and data processing elements.

Currently, this smart sensor approach permits sampling rates of upwards of two hundred per second when measuring all three orthogonal components of eye rotation; for those applications requiring only horizontal and vertical components of eye movement, sampling rates of typically six hundred per second have been attained. These eye position data are processed and output in realtime. The image data stream, containing only the non-redundant pixel information from each image can also be stored on digital mass storage for subsequent re-evaluation.

A lightweight head-mounted assembly is currently being designed to facilitate realtime measurement of head and binocular eye movement, where it is foreseen that device slippage will be detected and compensated by additional processing of the corneal reflection. The smart-sensor approach provides the technical performance and non-invasiveness for accurate and comprehensive eye movement measurement of smooth pursuit, nystagmus, vergence and saccade behavior without the restrictions of many other current techniques.

SINGLE SCAD

072496

Tuesday, June 10

59-52

Session TA4

Room 4

8:30 - 11:30 a.m.

10P.

326967

**Effect of Microgravity on Bone
Tissue and Calcium Metabolism**

HUMAN BONE TISSUE CHANGES AFTER LONG-TERM SPACE FLIGHT: PHENOMENOLOGY AND POSSIBLE MECHANICS

V. Organov, V. Schneider, A. Bakulin, V. Polyakov, L. Voronin, V. Morgun, L. Shackelford, A. LeBlanc, L. Murashko, V. Novikov

Russian Science Center-IBMP, Moscow, Russia, NASA Johnson Space Center, Houston, TX, Gagarin's Cosmonaut Training Center, Moscow, Russia

INTRODUCTION:

Bone loss occurs when terrestrial vertebrates adapted to earth gravity are exposed to microgravity. We quantified the bone loss on Russian Cosmonauts after long term space flights. Bone loss could limit duration of space missions in the future. We report here the results obtained from pre and postflight cosmonaut bone mineral density determinations since 1990. Aims are: a) to define bone loss (anatomic location of loss, magnitude of loss) and b) to offer possible mechanisms of bone tissue changes that could be used in countermeasure development.

OBJECTS AND METHODS:

Twenty one cosmonauts were studied before and after long-term space flight (4.5-14.5 months) using dual energy X-ray absorptiometry (DEXA) on a Hologic QDR 1000 housed in Star City. Bone mineral content (BMC, g) and bone mineral density (BMD, g/cm²) were measured with regional analysis of the whole body scan (pencil beam mode) and with local analysis of the hip scan and the lumbar spine scan.

RESULTS:

The direction and magnitude of bone changes reveal a distinct dependence on the position of the skeletal segment along the gravity vector and confirms previously described tendencies. BMD in the lower half of the skeleton is decreased. The mean BMD decrease for all cosmonauts (% per month) was: lumbar spine -1%, proximal femur -1.3%, pelvis -2%. In the upper body (head, ribs, arms) a tendency toward an increase of BMC was sometimes indicated. A good correlation between the amount of bone loss in different parts of the skeleton and their loading by body weight in 1G was observed. The second important peculiarity was the extremely high interindividual differences. The high individual variations of changes after flight compared with preflight was established: in lumbar spine (BMD) from +3% to -12%; in pelvis (BMC) from -1% to -22%; in the femoral neck (BMD) from 0% to -17%. We were unable to correlate the magnitude of changes with flight duration alone. Bone changes have shown a slight negative correlation with age of cosmonauts and volume of on board physical exercises.

CONCLUSION:

The data is comparable to results of human head down bed rest studies and animal and bone culture in vitro experiments under actual and simulated microgravity. The bone loss in the lower part of the skeleton can be described as local osteopenia, resulting from the selective inhibition of the physiologic bone tissue remodeling in the weight bearing parts of the skeleton and is a result of the adaptive response to the decrease in mechanical load (deformation). There are reasons to presume the local osteopenia is the manifestation of the tissue adaptation resulting from changes in local factors regulating bone metabolism. The variability of the response of the human skeleton is associated in part with individual differences in peak bone mass peak, which has a genetic component. The regional increase in the mineral content may be a secondary response to other physiologic factors such as body fluid redistribution in the cranial direction in microgravity and/or hormonal and biochemical changes occurring in space flight.

PREDICTION OF FEMORAL NECK BONE MINERAL DENSITY CHANGE IN SPACE

L. Shackelford, A. Feiveson, E. Spector, A. Le Blanc, V. Oganov
Johnson Space Center, Krug Life Sciences, Baylor College of Medicine, IBMP-Russia

INTRODUCTION

Bone mineral density (BMD) losses in the femoral neck have been reported to average 1.16% of the preflight BMD with a standard deviation of $\pm 0.85\%$ for each month aboard the MIR space station. Actual changes in BMD have ranged from a loss of 0.189 gm/cm^2 (2.39% per month) to a gain of 0.034 gm/cm^2 (0.57% per month). All cosmonauts took part in an exercise program using a treadmill, bicycle ergometer and bungee cords. There has been no explanation for the large variation in the rate of BMD loss among individuals, but it has been speculated that the degree of individual compliance with the exercise program as well as individual exercise habits prior to flight are contributors. We now find that historical BMD changes in the femoral neck during spaceflight could have been fairly well predicted for men by a combination of factors related to biomechanical strength of the femoral neck, body composition and flight time.

METHODS

Using data from 15 male subjects that flew on MIR prior to 1995 with flight durations ranging from 117 to 438 days, pre-flight values of the femoral neck BMD ("B"), bone length ("L") in cm. and width ("W") in cm., along with average lean leg mass "M" (g), height ("H") in cm., were incorporated into a regression model predicting change in femoral neck BMD. Two terms involving functions of these measurements were used along with the flight time ("t") in days in the following prediction model, which produced the best fit:

$$\Delta BMD = C_0 + C_1 t^{1/2} + C_2 \frac{M}{H} t^{1/2} + C_3 BLW^2 t^{1/2}$$

where the ΔBMD is the change in BMD and the C_k are constants. Hip DEXA scans were used to obtain BMD, length and width measurements (see Figure 1). Average lean leg mass was obtained from whole body DEXA scans (Hologic QDR-1000).

RESULTS

The model explained 85.6% of the variation in BMD change over individuals, with residuals ranging from -0.052 to $+0.052 \text{ gm/cm}^2$ and an RMS error of 0.029 gm/cm^2 (see Figure 1). Taking into account the uncertainty in the estimated parameters, femoral neck BMD change for a new individual could be predicted by this model with a standard error of prediction ranging from 0.033 to 0.039 gm/cm^2 . By contrast the simple linear model based only on time, explains only 29.3% of the variation and has an RMS error of 0.056 gm/cm^2 with residuals ranging from -0.077 to $+0.110 \text{ gm/cm}^2$.

CONCLUSION

The prediction model for the femoral neck BMD may be used to anticipate serious bone loss for some space station users so that appropriate countermeasures can be implemented. Because the model is empirical, it requires validation by applying it to subjects whose BMD data was not used in the fitting process. This validation is being conducted using new pre and post flight DEXA measurements as the data become available. To date, the model predicted the change in BMD to within 0.002 gm/cm^2 for one new MIR subject and even predicted the change to within 0.024 and 0.066 gm/cm^2 for two bedrest subjects without exercise.

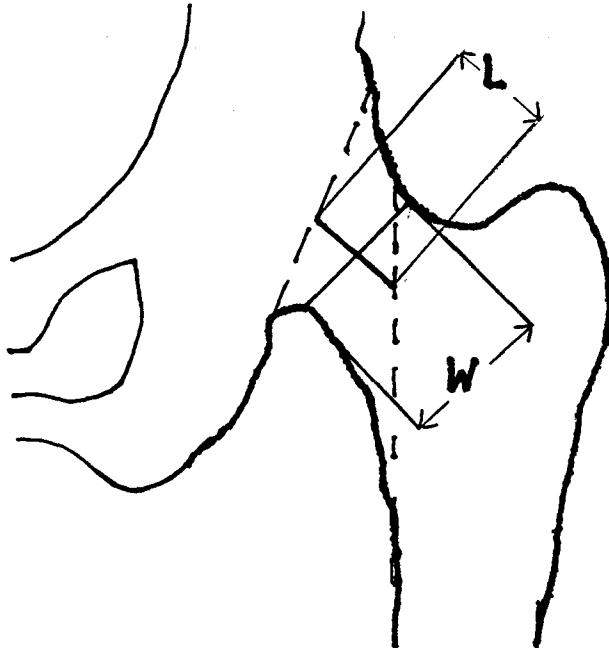


Figure 1. Hip neck measurements

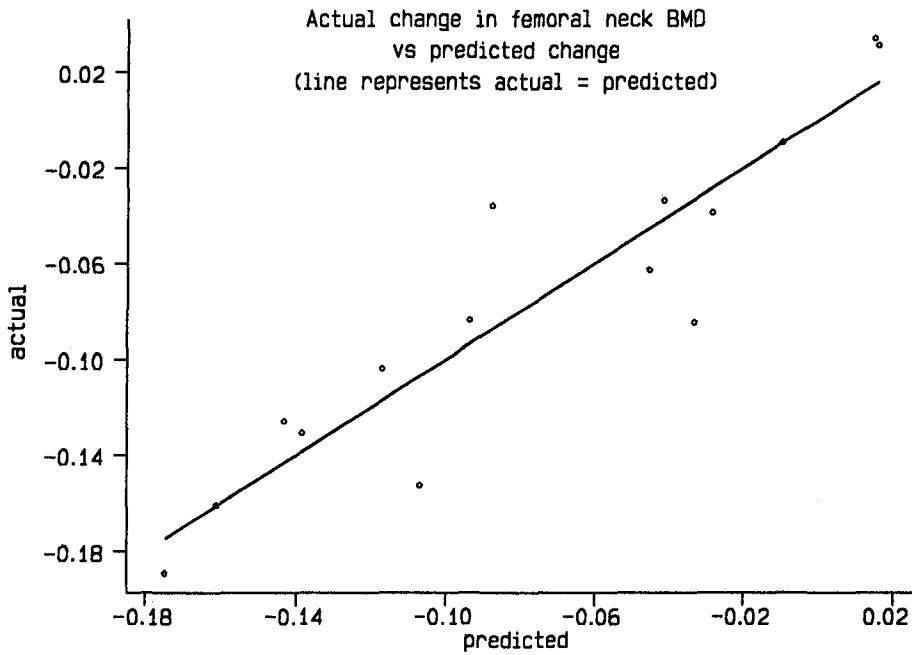


Figure 2. BMD change: actual vs. predicted

DIETARY CALCIUM IN SPACE

D. Hatton, D. McCarron, Q. Yue, C. Rouillet, H. Xue, K. Otsuka, J. Chapman, T. Phanouvong, J. Rouillet, M. Watanabe, K. Nilan, V. Haight, J. Dierckx, J. Demerritt
Division of Nephrology and Hypertension, Oregon Health Sciences University, Portland, OR 97201

INTRODUCTION

Deficits in calcium intake are associated with increased blood pressure, decreased bone mineralization and impaired calcium metabolism. Calcium losses due to exposure to microgravity may result in a similar constellation of outcomes.

METHODS

To test that hypothesis, fourteen 7-week-old, male spontaneously hypertensive rats (SHR) were flown on STS-80, an 18 day shuttle mission. Beginning at 3 weeks of age, half the rats were fed a low calcium diet (0.2%) and half were fed a high calcium (2.0%) diet. The animals were maintained on the diets throughout the experiment.

RESULTS

Preliminary results indicate that systolic blood pressure, measured in conscious SHR 3 hours after landing using an indirect tail cuff method, was somewhat lower in the flight animals relative to concurrent ground controls ($p=.053$). When anesthetized with halothane (2% in O_2) just prior to catheterization for blood sampling, direct arterial blood pressure was found to be significantly higher ($p<.0001$) in the flight animals than the control animals in both diet groups (+18 mmHg on average). The differences in blood pressure may have been related to variations in vascular smooth muscle function. Mesenteric resistance vessels from flight animals had smaller maximal contractions to norepinephrine than control animals ($p<.0001$) and showed poorer relaxation to acetylcholine, calcium and sodium nitroprusside ($p<.0001$). Ionized calcium values between diet groups were much closer together in the flight animals (1.34 vs 1.38 mmol/L, $p<.01$) than the controls (1.24 vs 1.36 mmol/L, $p<.0001$). Parathyroid hormone values for flight animals were 198 vs 127 pg/ml for the low and high calcium groups respectively ($p<.05$). Vivarium control values were 145 vs 46 pg/ml ($p<.001$). These values indicate that microgravity increased PTH levels while preserving the dietary difference. Basal free intracellular calcium values were decreased in platelets from flight animals ($p<.05$) while thrombin and ionomycin stimulated calcium levels did not differ from control animals. Finally, animals on low calcium diets were reported by the crew to be more active on orbit. Ground observations confirmed their report and found that the low calcium vivarium controls were more active as well.

CONCLUSIONS

Overall, the preliminary data indicate that exposure to microgravity had a profound effect on blood pressure regulation, vascular function, calcium metabolism and activity. As we continue our assays and analysis, additional observations and insights will be forthcoming.

CALCIUM METABOLISM DURING EXTENDED-DURATION SPACE FLIGHT

S.M. Smith, V.S. Oganov, B.V. Morukov, I.M. Larina, L.E. Nyquist, C.-Y. Shih, M.E. Wastney, S.A. Abrams, H.W. Lane. NASA Johnson Space Center, Houston, TX; Institute for Biomedical Problems, Moscow, Russia; Georgetown University Medical Center; and Baylor College of Medicine.

The effect of near-weightlessness on the human skeletal system is one of the most critical concerns in safely extending space missions. Minerals are lost from bones during flight as a result of skeletal unloading, thereby increasing calcium excretion in the urine. Bone loss contributes to the increased risk of renal-stone formation associated with high concentrations of solutes in the urine during and after flight. This study was designed to examine calcium and bone homeostasis during a 115-day mission on board the Mir space station.

Three male subjects participated, and data were collected before, during and after the mission. Blood and urine samples were collected, aliquoted, and frozen until postflight analysis, except for blood ionized calcium and pH, which were determined in "real-time" with a portable clinical blood analyzer. Biochemical and endocrine indices of bone metabolism were determined. Calcium absorption and kinetics were studied using a dual isotope technique. Oral (^{43}Ca , 125 μg) and intravenous (^{46}Ca , 8 μg) tracers were administered (oral tracer followed 1 hr later with I.V. tracer), with timed blood, urine, and saliva samples being collected over 3-5 days. Fecal samples were also collected during pre- and postflight sessions. Calcium isotopic enrichments in biological samples were determined using thermal ionization mass spectrometry. Absorption data were determined using the ratio of the two isotopes in samples obtained > 24 hours post dosing.

Serum concentrations of intact parathyroid hormone were reduced almost 30% during flight compared to preflight. Serum 25-OH Vitamin D (calcidiol) decreased during winter training in Russia (compared to autumn in Houston), and decreased further during flight. Serum 1,25(OH)₂ Vitamin D (calcitriol) concentrations were also reduced almost 30% during flight. Serum osteocalcin tended to decrease during winter, and was increased or unchanged during flight. Bone-specific alkaline phosphatase concentrations were an average of 39% lower on flight day 14 and 11% lower on flight day 110 than preflight values. Serum total calcium was unchanged, the ionized fraction increased slightly, and venous whole blood pH did not change. Urinary calcium excretion was higher during flight than before. Urinary collagen metabolite excretion (n-telopeptide and pyridinium crosslinks) was almost 40% greater than the preflight level. Calcium absorption decreased during (38 ± 18% below preflight values on flight day 110) and after flight (56 ± 9% below preflight on landing day, n = 2; and 29 ± 28% below preflight on return + 6 days). By 3 months postflight, calcium absorption had returned to 4 ± 20% below preflight values. These data showed that inflight bone loss is associated with increased resorption and decreased formation. Calcium balance is further altered by decreased PTH activation of calcidiol, with subsequent decreased calcium absorption. These data will be critical for assessing the efficacy of countermeasures to the weightlessness-induced bone loss. Further studies are needed to develop techniques to maintain bone and calcium homeostasis during extended-duration space flight.

EXTERNAL IMPACT LOADS ON THE LOWER EXTREMITY DURING JUMPING IN SIMULATED MICROGRAVITY AND THE RELATIONSHIP TO INTERNAL BONE STRAIN

S.E. D'Andrea, B.L. Davis, A.C. Courtney and G.P. Perusek
Department of Biomedical Engineering, The Cleveland Clinic Foundation, Cleveland, Ohio

INTRODUCTION

Exercise protocols have been developed to counteract the adverse reactions to space travel; however, to date no modality has been adequate in preventing space-flight induced osteoporosis. Exercises which afford functional weight bearing and more importantly deliver high dynamic loads to the lower extremities are thought to stimulate bone deposition by providing strain and strain rates to maintain bone integrity (Cavanagh et al., 1992). In support of this hypothesis, experimental results from animal studies have shown that strains above 0.1% are associated with substantial bone formation (Rubin and Lanyon, 1985). The relationship between the external impact forces and the internal bone strains, however, has yet to be elucidated. The purpose of this investigation, therefore, is to predict the strains found in simulated microgravity during jumping exercises which are known to impart high impact forces to the body in the earth's gravitational field.

METHODS

A zero gravity simulator (ZGS) was constructed using ten foot long latex cord and rope to suspend subjects from the ceiling in a supine position (Figure 1). The cords were attached to the center of gravity of the lower extremity segments. Body segment masses were calculated using regression equations and anthropometric measurements to assure that the tension in the cord matched the weight of each segment (Vaughan et al., 1992). Rope also supported the subject at chest and waist harnesses. A gravity replacement system consisting of two steel springs, attached at the waist in front and back, was used to tether the subject to the wall. The springs were tensioned in order to provide a force equal to 30-100% of the subject's body weight. Six subjects (four females and two males, ages 24-35) performed a countermovement jump in the zero gravity simulator with their feet landing on a wall mounted force plate.

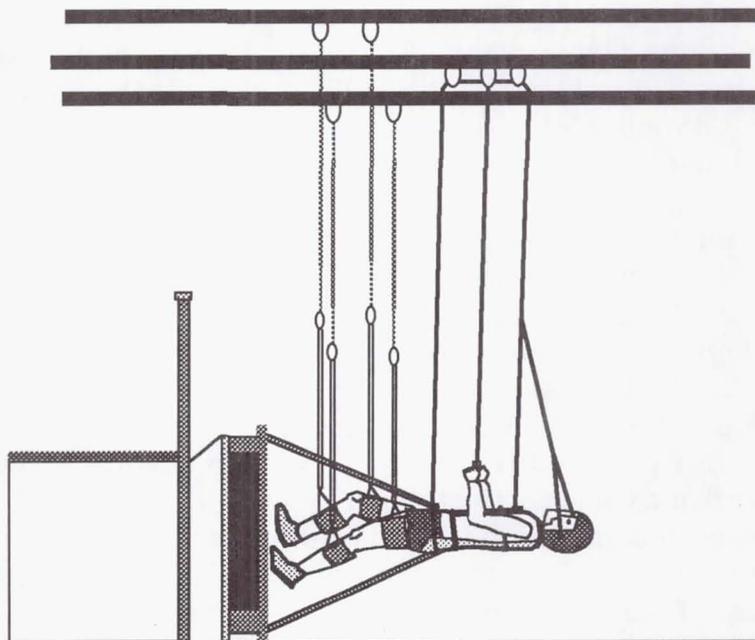


Figure 1: Schematic of Subject Suspended in Zero Gravity Simulator

In order to predict the internal bone strains achieved during jumping, data from drop tests of three cadaveric lower limbs were used. Tibial strains were measured by implanting two parallel K-wires into the distal, anteromedial tibia and clamping an extensometer on the exposed wires. The potted specimens were then secured in a custom drop test apparatus which enabled the peak load and impact velocity to be varied by altering the additional weight and drop height. Tibial strains and force profiles were recorded for each drop.

RESULTS

Peak forces during landing in the ZGS were determined and an average was calculated for trials at the same tension level in the springs for each subject. Peak forces ranged from 1400 N at the lower spring tensions to 3100 N at the higher tensions, corresponding to 1.7 - 4.0 times the subject's body weight. Results from the cadaveric limbs during the drop test showed peak loads ranging from 300-2300 N (0.5-2.5 time body weight) and tibial strains between 0.02 and 0.1%. Correlation between the peak load and the tibial strains resulted in a linear correlation coefficient, r , of 0.61 and the regression equation:

$$\text{Tibial Strain (\%)} = 0.0000245 * \text{Peak Load (N)} + 0.00566 \quad (p < 0.001) \quad (1)$$

Assuming that each foot was loaded symmetrically on the force plate during the jumping trials, the peak load during landing in the ZGS was halved and the predicted tibial strain for each foot was calculated according to Equation 1. This resulted in tibial strain in the ZGS that ranged from 0.0083 to 0.032%.

DISCUSSION

This investigation reveals the first attempts to relate external ground reaction force to the resulting internal bone strains in order to develop an effective countermeasure to space-flight induced osteoporosis. The peak loads in the zero gravity simulator during jumping are lower than values reported in the literature for 1G (McNitt-Gray, 1993). The results do, however, compare well to previous studies of jumping in simulated microgravity. Vrijotte (1991) reported average peak load values of 2043 N (± 1097) and 2055 N (± 922) with spring tension at 50% body weight. At similar conditions, the current investigation found peak loads between 1360 and 2268 N. The predicted peak tibial strains in the ZGS fell short of the known magnitude of 0.1% strain necessary for maintaining the integrity of bone (Rubin and Lanyon, 1985). Nonetheless, there were statistically significant relationships between peak load and strain in the cadaveric data suggesting that subjects may need to modify their exercises by altering their landing or by utilizing added mass. Furthermore, two thirds of the subjects could elicit loads under the calcaneus which is important given the fact that there is an absence of heel loading in exercises currently used during extended orbital missions.

REFERENCES

- Cavanagh, PR et al., (1992). *Aviation, Space and Environmental Medicine*, 63: 482-85.
 McNitt-Gray, JL (1993). *Journal of Biomechanics*, 26(9): 1037-1046.
 Rubin, CT and Lanyon, LE (1985). *Calcified Tissue International*, 37: 411-417.
 Vaughan, CL et al., (1992). *Dynamics of Human Gait*. Champagne, IL: Human Kinetics Publishers.
 Vrijotte, T (1991). Masters Thesis, Vrije Universiteit.

BONE LOSS DURING LONG TERM SPACE FLIGHT IS PREVENTED BY THE APPLICATION OF AN SHORT TERM IMPULSIVE MECHANICAL STIMULUS

A.E. Goodship, J.L. Cunningham, P. Walker, V. O:ganov[#], J. Darling*, A.W. Miles* and G. Owen*.
OSCOR, University of Bristol, [#]IPMB Star City, Moscow, Russia, *School of Mechanical Engineering, University of Bath.

INTRODUCTION

Bone mass is regulated by physical activity, and significant changes in bone mass have been observed when physical activity has been reduced or increased^(1,2). Lanyon *et al* ⁽³⁾ have hypothesised that the skeleton will regulate its mass in response to changes in activity, so that an increase in activity will trigger bone formation while a decrease in activity will have the opposite effect. In long term space flight, where the normal gravitational field is absent, the mechanical forces on the skeleton are reduced and are changed in character. This reduced skeletal loading results in a reduction in bone mass. Currently used exercise techniques can maintain muscle mass but the stimulus provided by this exercise does not prevent loss of bone mass particularly from bones of the lower limb. By applying an impulsive load (to mimic the heel strike transient) to the lower limb of an cosmonaut during a long term space flight (5 months), this study tests the hypothesis that the bone cells can be activated by an appropriate external mechanical stimulus to maintain bone mass throughout prolonged periods of weightlessness.

METHODS

An impulsive loading device was developed to mimic the stimulus provided by the heel strike transient which occurs during normal locomotion. The device comprised of two heel plates supported by two spring loaded actuators, each with identical spring characteristics. The springs were compressed by the cosmonaut loading the heel plates; at the end of travel of the 'test' actuator a 1 kg mass was released which impacted on the left heel plate. This produced an impact spike similar to that experienced at heel strike during a brisk walk. This impulsive loading stimulus was applied by the cosmonaut at a rate of approximately 0.5 Hz on a daily basis for 500 cycles. Pre- and post-flight measurements of bone mineral density (BMD) were made using a DXA (Dual Energy X-ray Absorptiometry) scan on both ossa-calces. To minimise variation in position between successive scans, the os-calcis and lower limb were supported in a specially constructed jig during scanning. Follow-up scans were made at 1, 3, 5 and 9 weeks post-flight. Additional scans were performed on both femoral necks at these same time points to determine the effect of the impulsive loading at a skeletal site remote from the point of application of the applied stimulus.

RESULTS

The results obtained from the os-calcis (Figure 1) demonstrate that BMD is maintained throughout the period of the space flight on the os-calcis which received the mechanical stimulus, while it is reduced by up to 7% on the os-calcis which received no stimulus. Post-flight, changes in BMD in both the stimulated and non-stimulated os-calcis are suggestive of a process of equalisation of BMD in the ossa-calces. For the femoral neck, no positive effect of the mechanical stimulus was noted (Figure 2).

CONCLUSION

This work suggests that high frequency transient loading with consequent high strain rates are important in maintaining peripheral bone mass.

REFERENCES

1. Woo, S. L.-Y. *et al.* J Bone and Joint Surg. 63-A, 780-787, 1981.
2. Lanyon, L.E. J. Biomech. 20, 1083-1093, 1987.
3. Lanyon, L.E *et al.* J. Biomech. 15, 141-154, 1982.

Region of Interest on Os-Calcis

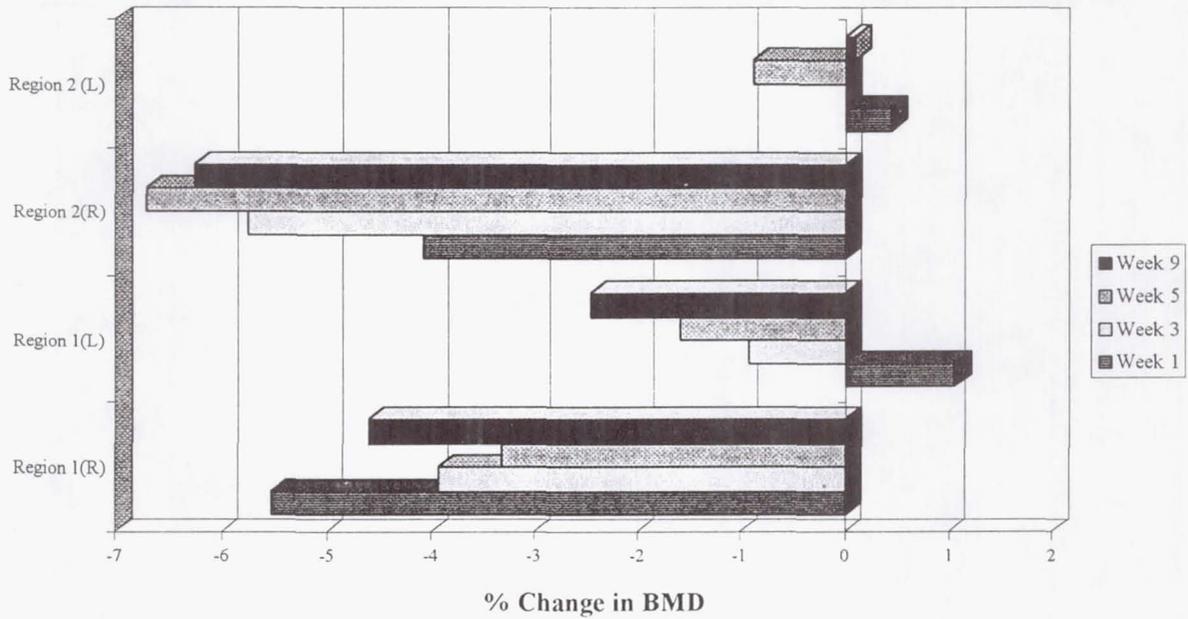


Figure 1. Percentage change in os-calcis BMD relative to pre-flight values at increasing times post-flight. The left os-calcis received the mechanical stimulus.

Region of Femoral Neck

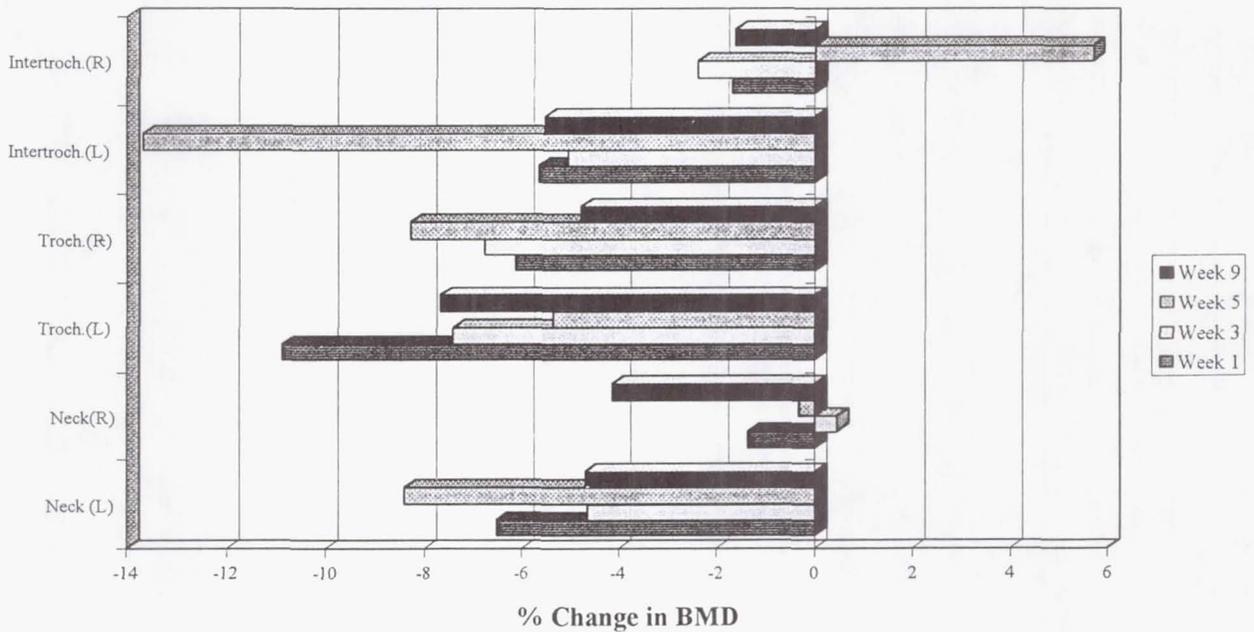


Figure 2. Percentage change in femoral neck BMD relative to pre-flight values at increasing times post flight. The mechanical stimulation was applied to the left side.

Tuesday, June 10

510-53

072700

71.

Session TA5

Room 5

8:30 - 11:30 a.m.

326967

**Cultural and Gender Issues
in Long-Duration Flights**

PSYCHOSOCIAL ISSUES DURING LONG-DURATION INTERNATIONAL SPACE MISSIONS

N. Kanas

Department of Psychiatry, University of California, and Psychiatry Service, VA Medical Center, San Francisco, California 94121

INTRODUCTION

Psychosocial issues will play an important role during future manned long-duration international space missions. In order to improve the chances for mission success, these issues must be identified, and their impact on space crews must be characterized.

METHODS

To explore these issues, a review was made of anecdotal reports from space and studies involving space simulation environments. This review included our survey of 54 astronauts and cosmonauts who had flown in space and our 135-day isolation study in the Mir space station simulator in Moscow. Based on this work, a number of important psychosocial issues were identified.

RESULTS

Crew heterogeneity, as manifested by differences in gender, cultural background, and work experience and motivation, is one such issue. Unless these differences are understood and accepted, they can lead to crew member withdrawal and territorial behavior, scapegoating of individuals who are perceived to be different, and subgrouping along demographic or functional lines. A second issue pertains to commonality in language and dialect. If crew members cannot understand each other, this can result in confusion, conflict, and inadequate response during times of danger. A final issue relates to leadership roles, especially those that are task-oriented (instrumental) or supportive (expressive). Both roles are important, but if one is ignored or used inappropriately, competition for leadership position and role confusion can result. All of these issues can negatively affect crew morale, compatibility, and cohesion. They also can lead to intra-crew tension, which may affect performance or be displaced to outside individuals on the ground, thus causing problems in crew-ground communication.

CONCLUSION

Based on anecdotal reports from space and simulation studies on Earth, a number of psychosocial issues have been identified which may play a role in the success of future long-duration international space missions. These issues need to be further characterized in the space environment, and we are hoping to do this during our ongoing study of crew member interactions during several of the current NASA/Mir missions.

PSYCHOSOCIAL ISSUES IN CREW SELECTION: FINDING THE RIGHT MIX OF THE RIGHT STUFF

S. L. Bishop

Department of Family Medicine, University of Texas Medical Branch at Galveston, Galveston Texas, 77555

INTRODUCTION

Historically, attention to psychosocial issues in the selection of space crews has been severely limited. There is now three decades of experience putting groups of individuals on top of rockets, shooting them into oftentimes an unknown and extreme environment, and expecting them to deal with close confinement, isolation, and physical and mental challenges found in no other environment on earth. Regarding crew selection, we can now conclude with some confidence that the time has come to move from simply ruling out psychopathology towards identifying those individuals who are best suited to maintain maximal health and performance under these conditions.

DISCUSSION

Current evidence clearly indicates problematic areas in which group functioning has been compromised to some extent. These include communication breakdowns, interpersonal dissension, conflicts over authority and control, and individual differences in response to environmental stressors. A renewed focus on psychosocial factors is beginning to yield significant information regarding optimal crew size, gender mix, composition, leadership structure, and the necessary interpersonal skills required for effective group performance in extreme environments. A broad overview of the issues surrounding the effects of isolation and confinement on group functioning in the space environment will be presented for discussion.

CULTURE, GENDER AND MISSION ACCOMPLISHMENT: OPERATIONAL EXPERIENCE

A. W. Holland

Medical Operations Branch, NASA Johnson Space Center, Houston, Texas 77058

INTRODUCTION

This presentation is an operational view of cultural and gender issues relevant to long duration spaceflight. Current and past space missions, including those of the NASA-Mir Program, are reviewed in terms of crew and organizational experience in these areas. Cultural adaptation is learned by both the individual astronauts as well as the organization as a whole. However, the principal cultural challenges occur at the organizational level, because the multinational crewmembers find considerable commonality through their shared aviation and spaceflight sub-culture. Within this environment, gender issues are clearly connected to cultural differences and reflect the evolution of gender roles within society at large.

RESULTS AND DISCUSSION

Current methods of pre-flight preparation and inflight support are detailed, including cross-cultural training and activities for deployed personnel. Short flight is compared with long flight; crew-level issues are compared with those of the wider organization; and *lessons learned* are reported. The presentation concludes with a look forward at issues relevant to the International Space Station.

INTERPERSONAL TENSION IN MULTICULTURAL CREWS

H. Ursin¹ and G.M. Sandal²

¹Department of Biological and Medical Psychology, University of Bergen, Bergen Norway N-5009; ²Department of Psychosocial Science, University of Bergen

INTRODUCTION

Future manned space missions are likely to result from collaboration of several space organizations and involve multinational crews. It is generally assumed that the likelihood of interpersonal tension increases as a function of crew heterogeneity, but specific questions related to cultural diversity have so far been a neglected area of research.

METHOD

Behavioral observations and questionnaires administered to crew members in actual and simulated missions in space, aircraft, diving environments and expeditions in remote areas were the assessment tools used.

RESULTS AND CONCLUSIONS

Studies from actual and simulated space missions (Santy et al., 1994; Sandal et al., 1995) and multinational airlines (Helmreich & Merrit), indicate that cultural factors that might negatively affect interpersonal compatibility include language problems, differences in need for privacy, contrasting norms and values, and prejudices. Also, conflicting views regarding appropriate gender behavior have been reported. Culturally based tension might be explained partially in the light of contrasting values, reflected in dimensions as power distance, collectivism, and masculinity. General group processes leading to clique formation and "scapegoating" of deviant members might also provide an explanatory framework.

PERSONALITY AND COPING IN EXTREME ENVIRONMENTS

G.M. Sandal¹ and H. Ursin²

¹Department of Psychosocial Science, University of Bergen, Bergen Norway N-5009, ²Department of Biological and Medical Psychology, University of Bergen

INTRODUCTION

A previous research program at NASA used the Personality Characteristic Inventory to evaluate personality predictors of performance in an aviation environment. This assessment battery includes scales measuring negative and positive aspects of expressivity and instrumentality. Three personality profiles were identified that differentially predicted performance. Interpersonal sensitivity combined with strong achievement motivation was consistently associated with superior performance. This profile was referred to as the "Right Stuff". Poor performance was linked to profiles typified by low interpersonal sensitivity and a hostile, competitive orientation ("Wrong Stuff"), or low interpersonal sensitivity combined with low achievement motivation ("No Stuff").

METHOD

The Personality Characteristic Inventory was used in our own studies to investigate relationships between particular personality profiles and coping in extreme environments. Groups of individuals were assessed in the following conditions: isolation in hyperbaric chambers, a polar expedition, military training, and submarine missions.

RESULTS

Study 1 (N=18) examined whether particular profiles predicted types of self-reported coping during isolation in hyperbaric chambers. The results indicated that the "Right Stuff" profile was associated with low anxiety and high well being. Study 2 (N=15) assessed possible differences in personality profiles among polar expedition members. The findings demonstrated that most participants were characterized by the "Right Stuff" profile. Study 3 (N=46) evaluated the relationship between personality profile and endocrine activation during military training, and found that the "Right Stuff" profile was associated with lower endocrine activation. Study 4 (N=56) examined relationships between personality and self-reported stress and endocrine activation during submarine missions. Those with the "Right Stuff" profile experienced relatively less stress due to interpersonal factors, and lower endocrine activation.

CONCLUSION

The results supported the predictive efficacy of the Personality Characteristic Inventory profiles for astronaut selection.

APPLICATION OF EXPEDITION AND POLAR WORK GROUP FINDINGS FOR ENHANCING PERFORMANCE IN SPACE

G. R. Leon¹ and V.S. Koscheyev²

¹Department of Psychology, University of Minnesota, Minneapolis, Minnesota 55455, ²School of Kinesiology and Leisure Studies, University of Minnesota

INTRODUCTION

Planning for the construction and operation of the International Space Station and future trips to Mars requires a consideration of psychosocial, cross-cultural, and gender factors as the crew lives and works together in carrying out their mission. Prolonged isolation and confinement exacerbated by monotony and boredom can lead to increased interpersonal and intrapersonal tension, with effects on group cohesiveness and work performance. Open antagonism directed toward fellow crew members or Mission Control, and social withdrawal and isolation have been documented. Social interactions and task performance of expedition teams and small work groups in polar and other extreme environments have been viewed as an analog to the performance of groups in space; examination of these findings can be informative for space mission planning.

METHOD

Data on personality characteristics, stress and coping patterns, group processes, and work performance were collected on two Soviet-American expedition teams, and a number of polar work groups. The composition of each group differed in terms of nationality, gender, and experience level of individual members. The intervals at which data were collected and the particular measures used varied for each group, depending on the specific questions of interest.

RESULTS

Evaluation of the Soviet-American expedition teams indicated differences across national groups in the specific motivation for participating in the trek. Cultural factors were also evident in the attitude of male team members about various aspects of the competence of their female team counterparts. Variations in the experience level of national co-leaders were associated with problems in group cohesion and task effectiveness at times of external stress and danger. Studies of polar work groups have demonstrated that individual differences in personality characteristics are highly important in how individuals cope with isolated environments. High achievement orientation, narrow interests and a low need for stimulation, a repressor or denial coping style, low stress reactivity, and low anxiety and bodily concerns were characteristic of those who performed better in isolated environments.

CONCLUSION

Recommendations for countermeasures to enhance work performance during space missions will be proposed, based on the review of findings from different types of polar expedition and work groups. The focus of these recommendations is on increasing the cohesiveness of the social network during long-duration space missions as a major means of improving daily living and task effectiveness.

Tuesday, June 10

Session TP1
Room 1
2:30 - 5:30 p.m.

511-52
072824
9A
326968

**Mechanisms of Cardiopulmonary
Adaptation to Microgravity - 2**

AUTONOMIC REGULATION OF CIRCULATION AND MECHANICAL FUNCTION OF HEART AT DIFFERENT STAGES OF 14-th MONTH SPACE FLIGHT

R.M. Baevsky, M. Moser*, G.A. Nikulina, V.V. Polyakov, I.I. Funtova and A.G. Chernikova

Institut of Biomedical Problems, Moscow, Russia;

*Institut of Physiology, University, Graz, Austria

INTRODUCTION

The flight of doctor-cosmonaut V.V. Polyakov is the most prolonged in history of manned space flights. In this flight the autonomic regulation of circulation and mechanical function of heart were studied.

METHODS

Heart rate variability analysis, ballistocardiography (BCG), seismocardiography (SCG) and 24-hour registration of ECG (Holter monitoring).

RESULTS

As have shown the results of researches, during the first half-year the changes of main cardiological parameters did not differ practically from the similar changes, observed at other cosmonauts. However, from the second half-year of stay under weightlessness conditions the following changes were detected for V.V. Polyakov: a) There is a tendency of heart rate decreasing during flight in comparison with the beginning of flight, especially it is expressed in a night period of day. b) For 7-8 months of flight the growth of low frequency (LF) spectral power of heart rate variability in a range 0.05-0.15 Hz and reduction of high frequency (HF) spectral power in a range 0.5-0.15 2Hz, which characterize the growth of sympathetic activity, are observed. c) At 8-10-th months of flight the relative spectral power in minute band to hour band for fluctuations of heart rate and other physiological parameters increases. The period of these fluctuations has been also increased. d) The amplitudes of BCG and especially of SCG tend to essential growth in the second half of flight. The SCG/BCG relation at the end of flight is increased. e) The growth of day-averaged values of middle frequency (MF) spectral power of heart rate variability (0.15 - 0.05 Hz), which reflects the activity of vasomotor center, is 2observed.

CONCLUSION

From the second half-year of stay under weightlessness conditions the decreasing of heart rate, the growth of vasomotoric center activity and the changes of periodicity and power of superlow fluctuations of physiological parameters, which reflect the activity of subcortical cardiovascular center and of higher levels of vegetatic regulation, are observed. The growth of total (SCG) and external (BCG) work of heart in the last months of flight has been also marked. All this gives us the basis to consider the observed changes as the result of developing of additional compensative mechanisms, directed on maintenance of blood pressure and of adequate circulation under new conditions.

Cardiovascular oxygen transport in exercising humans in microgravity

Guido Ferretti, Fabio Esposito, Massimo Girardis, Dag Linnarsson, Christian Moia and David R Pendergast.

Department of Physiology, Centre Médical Universitaire, 1211 Geneva 4, Switzerland, Department of Physiology, Karolinska Institute, S-171 77 Stockholm, Sweden, and Department of Physiology and Pharmacology, State University of New York, 14214 Buffalo NY, USA.

Oxygen consumption ($\dot{V}O_2$), by a closed circuit method, heart rate, by electrocardiography, cardiac output (Q), by the one-step CO_2 rebreathing method, blood hemoglobin concentration (Hb), by a photometric technique, and arterial oxygen saturation (Sa_{O_2}), by infrared oxymetry, were measured at rest and at the steady-state of three submaximal cycloergometric work loads (50, 75 and 100 W respectively) on two Cosmonauts before (1 g) and during (0 g) a 6-month-duration spaceflight on board the Russian Space Station MIR. Oxygen delivery was calculated as the product of Q times Sa_{O_2} times Hb times the physiological oxygen binding coefficient (1.34 ml l^{-1}). $\dot{V}O_2$ was linearly related to power both pre- and in-flight. At 0 g, $\dot{V}O_2$ did not change as a function of flight time. At any work load, $\dot{V}O_2$ was significantly lower at 0 g than at 1 g (-18.5 % and -13.8 % for subject 1 and 2, respectively). Similarly, lower Q values at exercise, independent of flight time, were found at 0 g than at 1 g (-8.1 % and -15.4 %, respectively). The Q vs $\dot{V}O_2$ relationship at exercise was the same in the two conditions. Resting Q was higher at in-flight than pre-flight, because a significant increase in stroke volume was only partially compensated for by a decrease in heart rate. The heart rate vs power relationships during exercise were slightly displaced upward at 0 g. No changes in stroke volume during exercise at 0 g were found. The concomitantly decreased (subject 1) or unchanged (subject 2) Hb at 0 g contributed to a significant decrease in oxygen delivery (-17.6 % and -11.2 %). The relationships between oxygen delivery and oxygen consumption were the same at 0 g as at 1 g in both subjects. This data reveal a tight coupling of cardiovascular response to exercise and peripheral metabolic demand. They suggest that the regulation of cardiovascular oxygen transport during exercise may predominate over fluid balance and blood pressure regulation.

Supported by the European Space Agency, the Federal Swiss Prodex Found and the National Swedish Space Board.

VENOUS HEMODYNAMIC CHANGES ASSESSED BY AIR PLETHYSMOGRAPHY DURING A 16- DAY SPACEFLIGHT.

F. Louisy¹, C. André-Deshays², D. Cauquil², M. Lazerges², C. Lafaye², A.L. Camus² and G. Fomina³.

¹Institut de Médecine Aérospatiale du Service de Santé des Armées, Brétigny sur Orge, France

²Centre National d'Etudes Spatiales, Toulouse, France

³Institute for Biomedical Problems, Moscow, Russia

INTRODUCTION.

The aim of the present study was 1/ to assess the feasibility of using Air Plethysmography as a valuable tool for studying venous hemodynamic changes during spaceflights and 2/ to have a more complete understanding of venous changes occurring in the legs during exposure to real microgravity. Air plethysmography was implemented during the past French - Russian mission CASSIOPEE on board the MIR station, within the framework of the PHYSIOLAB project.

METHODS.

Measurements were done on the French spationaut and on one Russian cosmonaut.

The Air plethysmograph consists of an instrument derived from the Air Plethysmograph APG 1000 (ACI corporation, Sun Valley, California), adapted for Space utilization. It consists of a long air cuff (suitable for legs and forearms) which measures limb volume changes. The cuff is connected to an air pump which assures its inflation. The plethysmograph is connected to a central processing unit whose aim is to manage the measurement session, to process and register data and to transfer experimental data to earth by telemetry. Different parameters were measured by venous occlusion plethysmography : leg compliance (pressure - volume curve of the leg) and venous capacity at different counterpressures, arterial flow index, venous filling index, venous filling time, ejection fraction, residual volume fraction and half-emptying time. Measurements were done before flight (twice), 3 times during flight and 3 times during post-flight recovery.

RESULTS.

Results obtained on the French and Russian cosmonauts showed : 1/ during flight, a tendency towards greater venous capacities at low counterpressures (10, 20 mmHg) without changes in venous compliance (compatible with a decrease in venous pressures), increases in venous filling time, capillary filtration rate and half-emptying time and decreases in arterial flow index, venous filling index and ejection fraction; 2/ after flight, the period just following return to earth (R_{+1}) was characterized, for the French cosmonaut, by a considerable increase in half-emptying time and decrease in ejection fraction. All parameters progressively returned to their control value at the end of the first week of recovery.

CONCLUSION.

These results show that during exposure to real microgravity, the pattern of venous hemodynamic changes is complex, and characterized by alterations of venous distensibility as well as by alterations of venous filling and emptying, leg muscle pump and capillary filtration rate. These alterations are compatible with the involving of venous network in the orthostatic intolerance syndrome occurring in astronauts during and after re-entry.

RESPIRATORY MECHANICS AFTER 180 DAYS SPACE MISSION (EUROMIR'95)

D. Venturoli, D. Negrini, and G. Miserocchi

Istituto di Fisiologia Umana, Università degli Studi di Milano, via Mangiagalli, n.32, I-20133 Milano, Italy.

INTRODUCTION

Several aspects of respiratory physiology, as lung and chest wall mechanics, regional blood perfusion and ventilation and consequently gas exchanges are greatly affected by gravity. Therefore, major changes ought to be expected when the respiratory system is exposed to microgravity. The present study reports data on static lung volumes and pressure-volume relationship of lung and chest wall following the 180 days long European - Russian EuroMir '95 space mission.

METHODS

The experiments were performed on 2 crew subjects. Lung volumes were calculated through integration of the respiratory flow signals obtained from a flowmeter (Isler-CIR-Innovision, Switzerland, Denmark). Esophageal pressures were measured via an esophageal balloon placed in the second third of the esophagus and connected to a pressure transducer (Innovision, Denmark). Pressure and volume data were simultaneously recorded during: quiet breathing, slow vital capacity (VC), inspiratory (IR) and expiratory (ER) relaxation performed against a resistance of 2.44×10^{-3} (cmH₂O·min)/liters starting from 0 and 100 % VC, respectively. The maneuvers were performed in the sitting and the supine posture. Esophageal pressure during slow VC reflected the pleural pressure exerted by the lung elastic recoil, whereas esophageal pressure obtained during the relaxation maneuvers reflected the chest wall recoil pressure.

RESULTS

Data presented refer to pre-flight (5 sessions of Baseline Data Collection, BDC) and post-flight (on Return + 1, 10, 12, 27 and 120 days) experiments. On day R+1, VC decreased by 21 and 30 % in sitting and supine posture, respectively, relative to the pre-flight BDCs. This decrease progressively waned and disappeared on day R+ 27. The decrease in VC occurred because of a reduction of the inspiratory and expiratory reserve volume. Lung compliance, estimated at a lung volume closed to functional residual capacity, was not significantly different after flight compared to pre-flight BDCs, averaging 0.28 liters/cmH₂O. Pre-flight chest wall compliance was 1.1 and 0.6 liters/cmH₂O in supine and sitting posture, respectively. After return chest wall compliance decreased to 0.3 liters/cmH₂O in both positions and remained unaltered up to 120 days.

CONCLUSION

The data shows that a space mission as long as 180 days primarily alters chest wall mechanics and weakens the action of respiratory muscles.

ASSESSMENT OF THE SYMPATHETIC AND THE PARASYMPATHETIC NERVOUS ACTIVITY DURING PARABOLIC FLIGHT BY PUPILLARY LIGHT REFLEX

K. Yamaji¹, Y. Hirata², S. Usui¹ and S. Nagaoka²

¹Toyohashi University of Technology, Toyohashi, Aichi, JAPAN

²National Space Development Agency of Japan, Tsukuba, Ibaraki, JAPAN

INTRODUCTION

The pupil of the eye can be a non-invasive monitor of the autonomic nervous activity. Because it is controlled by iris : sphincter and dilator which are innervated by the parasympathetic and sympathetic nerve, respectively. Previously, we proposed a method for assessing the autonomic nervous activity from pupillary behavior^[1,2]. In this study, we improved the method and attempted to evaluate the sympathetic and parasympathetic nervous activities under hyper- and hypo-gravity during a parabolic flight.

AUTONOMIC NERVOUS ACTIVITY ASSESSMENT METHOD

The method proposed previously, based on the analysis of internal property of human pupillary muscle system model^[3], enables a separate assessment of sympathetic and parasympathetic nervous activity from the changes in pupillary single flash response. However, relatively low gain of the dilator system compared with the sphincter makes it difficult to estimate the sympathetic nervous activity. The improved method utilizes comb-like flash stimulus which activates dilator system more efficiently than a single flash stimulus. The other part of the method is the same as in the previous method^[1,2]. The validity was proved by a study using autonomic nervous drugs.

PARABOLIC FLIGHT EXPERIMENT

Parabolic flight experiment was conducted by DAS MU300, a rear engine jet. Subject was a male university student. Stable pupillary responses to comb stimuli(Fig.1) could be measured by a face-attached TV pupillometer^[4].

RESULT

In hyper-gravity, significant change in activities both of sympathetic and parasympathetic nervous system was not seen comparing to ground 1G condition. On the other hand, in hypo-gravity, the sympathetic nervous activity was slightly activated, whereas the parasympathetic nervous activity was inhibited.

REFERENCES

- [1] Yamaji, K., Hirata, Y. and Usui, S. : "Evaluation of the Autonomic Nervous Activity using Pupillary Flash Response", *Technical Report of IEICE, MBE95-110*, pp.1-6 (1995)
- [2] Hirata, Y., Yamaji, K., Usui, S., and Nagaoka, S. : "Assessment of Autonomic Nervous Activity during Parabolic Flight using Pupillary Flash Response", *Proceeding of 20th International Symposium on Space Technology and Science* (1996)
- [3] Usui, S. and Hirata, Y. : "Estimation of Autonomic Nervous Activity using the Inverse Dynamic Model of the Pupil Muscle Plant", *Annals of Biomedical Engineering*, vol.23, pp.375-387 (1995)
- [4] Usui, S., Hirata, Y. and Nagaoka, S. : "Pupillary Light Response during a Parabolic Flight", *Proceeding of 40th International Congress of Aviation and Space Medicine*, p.141 (1992)

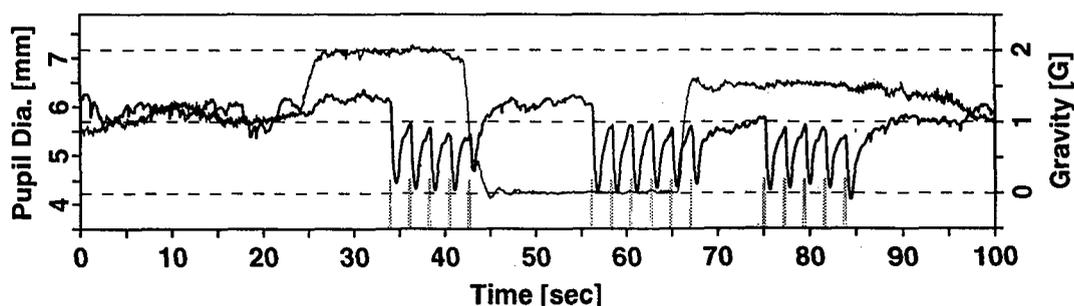


Fig.1 : Pupillary responses to comb stimuli during parabolic flight
Thick black : pupillary responses, thin black : gravitational changes, gray : comb-like flash stimuli

VASCULAR RESPONSE TO DIFFERENT GRAVITY

Florence Valkenberg
31, Rue Lambymaie
1342 Limelette, Belgium

Cardiovascular response to og exposure during 14 day space flight

- > Cardiovascular investigations were performed according to two programs ;
 1. At rest ; to study the cardiovascular adaptation to og at the level of - the heart
 - the deep vessels
 - the superficiaals vessels.
 2. During Low Body Negative Pressure (LBNP) ; to evaluate the orthostatic tolerance of the astronaut.

- > The results don't showed hypovolemia of the astronaut, but
 - a very stable cardiac volume
 - a very stable cardiac output = which is in agreement with the stability of volemia regulatin hormones.This is probably due : (1) to the inflatable cuffs "bracelet" that the astronaut maintained on the upper part of the thigh during the first inflight days
 - (2) and to the exercise
 - (3) and LBNP sessions performed inflight.This situation may explain the absence of significant renal flow resistance changes.

- > In the lower limits, the femoral flow was reduced although the vascular resistances were decreased and restable. This pattern is in favor of a vascular disadaptation which was confirmed by the LBNP test.

- > Finally the cardiovascular system adapts more progressively to the og exposure when using the thigh cuffs. But ; the vascular deconditioning still develops probably in relation with the deterioration of the peripheral venous/muscle system and the loss of sensitivity of the baro-reflex.

Artificial gravity as a tool to prevent cardiovascular deconditioning in space.

Cardiocirculatory responses to short radius rotation and exercise in human centrifuge.

- Cardiac Output (CO)
- Functional Residual Capacity (FRC)
- Arterial Blood Pressure (ABP)
- Heart Rahe (HR)

Were measured non invasively on six healthy males during submaximal cycloergometric exercise (50 W-150 W) under standard (1 g) or hypergravity conditions (1,41 g) obtained on a human centrifuge. The latter were chosen to simulate the "Twin Bikes System" (TBS). In conclusion the data show that the TBS can be appropriately utilized to maintain the cardiovascular conditions of the astronauts and that the pulse contour methode can be appropriately utilized under hypergravity conditions.

- > During prolonged Space Flight, exposure to microgravity (μg) has profound effects on the human body, particularly so on ;
 - the musculo-skeletal system
 - the cardio-circulatory system (μg deconditioning).
- > Indeed the cardiovascular system is challenged by two major interacting conditions :
 - (1) The loss of the hydrostatic gradients that normally prevail in the upright position at 1g.
 - (2) And, a reduction of the functional demands due to μg .
- > The effects of the adaptation to μg become evident upon the return of the astronauts on Earth, and consist mainly of ;
 - muscular hypotrophy and weakness
 - bone demineralization
 - arterail hypotension
 - orthostatic intolerance
- > To avoid μg -deconditioning, two major classes of countermeasures have been developed in the past. They consist in maintaining the physical fitness by muscular exercise, or in mimicking the gravitational effects on the musculo-skeletal and circulatory system.
- > We assist today to a renewal of interest in the possibility to simulate gravity in Space (artificial gravity) by means of centrifugal forces obtained by the rotation of the Space module on its axis.
- > We have suggested to combine the benefits of exercise with those of artificial gravity by the use of two mechanically coupled bicycles counter rotating at the very same speed along the inner wall of a Cylindral Space Module.
The characteristics of this proposal, the TBS, have been described.

- > In conclusion, these observations suggest that the TBS can be appropriately utilized to maintain the physical fitness of the astronauts, and that the cardiovascular load it includes is sufficient to prevent the microgravity deconditioning.

References

Fifth European Symposium on Life Sciences Research in Space
Arcachon, France, 26 september - 1 october 1993
ESA SP-366, august 1994

SINGLE SCAN

Tuesday, June 10

Session TP2

Room 2

2:30 - 5:30 p.m.

512-54

073 743

71.

306969

**Human Factors Research
Under Ground-Based and Space
Conditions - 1**

HUMAN FACTORS ENGINEERING OF THE INTERNATIONAL SPACE STATION HUMAN RESEARCH FACILITY

Barbara Woolford
Flight Crew Support Division, Johnson Space Center, Houston, TX 77058

INTRODUCTION

The Human Research Facility (HRF) is a collection of two to four racks of equipment to be flown on the International Space Station (ISS) containing the basic equipment necessary for virtually all research with human subjects. This equipment will be used by investigators and crews not yet selected, for the duration of the life of ISS. Since neither science users nor crew operators and subjects will be known during the development of the hardware, the HRF project included human factors engineers as an integral part of the design team from the earliest stages. The human factors engineers' role was to ensure the usability and maintainability of the equipment over the life of the HRF.

APPROACH

This paper describes the types of equipment evaluated and the human factors engineering techniques used for these various types. It addresses sources of data used for anticipating requirements when the ISS program has not completed its requirements development; types of evaluations performed, from analysis of drawings to evaluations in zero-gravity, and their relative cost effectiveness; and the process of integrating human factors engineers into design teams not accustomed to interacting with engineers from this field.

Critical human factors issues identified in working with the design teams are identified, and examples of evaluation methods and results are presented. Cases where broad guidelines or requirements must be provided are illustrated, and compared with situations where item-by-item analysis and inputs are necessary.

A description of the human factors issues unique to space research equipment is also given, with illustrations representing types of equipment ranging from computer workstations and interface hardware to body-worn sensors and data collection systems.

CONCLUSIONS

Lessons learned in the first eighteen months of this project show how space human factors engineers can provide cost-effective services to design teams which have never included human factors experts before.

STRUCTURED METHODS FOR IDENTIFYING AND CORRECTING POTENTIAL HUMAN ERRORS IN SPACE OPERATIONS

W.R. Nelson, L.N. Haney, L.T. Ostrom, and R.E. Richards
Idaho National Engineering Laboratory, Lockheed Martin Idaho Technologies,
P.O. Box 1625, Idaho Falls ID, 83415-3855

INTRODUCTION

Near and long term space operations will be highly dependent on human participation to ensure their success. Along with their significant capabilities to perform space operations and to diagnose and correct malfunctions when they occur, humans also come with a propensity to commit errors. Human errors have been identified as the source of approximately 60% of the incidents and accidents that occur in commercial aviation. It can be assumed that large numbers of human errors occur in space operations as well, even though in most cases the redundancies and diversities built into the design of space systems prevent the errors from leading to serious consequences. In addition, when it is acknowledged that many system failures (such as the Challenger accident) have their roots in human errors that occur in the design phase, it becomes apparent that the identification and elimination of potential human errors could significantly decrease the risks of space operations. This will become critical during the design of more complex and longer term missions such as the International Space Station and manned missions to Mars.

STRUCTURED METHODS TO IDENTIFY AND CORRECT HUMAN ERROR

The Idaho National Engineering Laboratory has worked for many years to develop and apply structured methods to identify and correct potential human errors. This work was initiated to support Probabilistic Risk Assessment (PRA) for the nuclear power industry. Methods of Human Reliability Analysis (HRA) have been adapted and extended so that potential human errors can be identified, their consequences in conjunction with other human errors and hardware failures can be assessed, and their relative contribution to overall system risk can be calculated. These methods have reached a state of maturity and acceptance in the commercial nuclear power industry.

During the last few years we have focused on adapting these tools to enhance their applicability as practical tools for system design, and to test their application to domains outside of nuclear power. Since 1994 we have performed research under the NASA Advanced Concepts Program in partnership with NASA Ames Research Center and the Boeing Commercial Airplane Group to develop methods and tools to apply human error analysis to the design of commercial transport aircraft. During the course of this program we have tested the applicability of human error analysis methods for application to maintenance tasks for commercial aviation. Based on this experience we are developing a software tool called THEA (Technique for Human Error Analysis) for use by airplane procedure developers and maintenance engineers. The tool is a structured approach for analyzing airplane maintenance tasks, identifying potential errors, identifying performance shaping factors that can influence errors, and identifying potential design or procedure changes that could reduce the likelihood for errors. The software has undergone testing at NASA and Boeing and will be available for release to the commercial aviation industry later this year.

We believe that our structured methods for human error analysis and our prototype software tool could be adapted for application to reduce the potential for human error in space operations. We are currently exploring the possibility to test our methods and tools for ground processing operations. If such an application proves successful, the methods could be adapted and applied to space operations in domains such as the Space Shuttle, Space Station, other potential manned space missions. We believe that such tools could contribute to minimize the potential for human errors in the design and operation of future space systems.

An Improved Procedure for Selecting Astronauts for Extended Space Missions

A. W. Holland¹, L. Galarza², R. D. Arvey³ and K. D. Curtis⁴

¹NASA Johnson Space Center, Houston; ²Rice University, Houston; ³University of Minnesota, Minneapolis; ⁴Krug Life Sciences, Houston

This paper describes the model, methods and outcomes of a recent upgrade to the psychological selection process for NASA astronauts. A prototypical model, behaviorally-based and goal-directed, is presented which links mission results, individual and team behaviors, individual proficiencies, and various selection tools. The construct validity methodology by which the proficiencies and tools were chosen is also presented, including the methods for gathering expert and incumbent judgments and ratings, evaluating competing instruments, and archiving supporting information. New technology used in the data collection and archiving stages is described and evaluated. Finally, the strengths and weaknesses of the present system are discussed from the technical, logistical and organizational perspectives, with particular attention being paid to the development of experiential predictors and predictive validity data.

**THE NASA PERFORMANCE ASSESSMENT WORKSTATION:
COGNITIVE PERFORMANCE DURING HEAD-DOWN BEDREST**

R.E. Schlegel*, R.L. Shehab*, S.G. Schiflett, D.R. Eddy*****

*** University of Oklahoma - Norman, OK, 73019 U.S.A.**

**** USAF Armstrong Laboratory - Brooks AFB, TX, 78235 U.S.A.**

***** NTI Incorporated - San Antonio, TX, 78239 U.S.A.**

The NASA Performance Assessment Workstation (PAWS) was used to assess cognitive performance changes in eight males subjected to seventeen days of 6-degree head-down bedrest. The PAWS uses six performance tasks to provide an assessment of directed and divided attention, spatial, mathematical, and memory skills, and tracking ability. Two subjective scales are also incorporated to assess overall fatigue and mood state. The PAWS tests were used to examine the impact of the space environment on flight crew performance on the Second International Microgravity Laboratory (IML-2) and on the Life and Microgravity Spacelab (LMS) space shuttle missions.

Following orientation and eight training trials, bedrest subjects completed sixteen additional practice trials on PAWS. The last eight practice trials and all bedrest trials were performed with subjects lying face-down on a gurney to minimize the potentially confounding effects of different subject positioning from practice to bedrest testing. During bedrest and recovery, subjects performed one session every other day, completing eight bedrest trials and four recovery trials.

In general, there was no apparent cumulative effect of bedrest. Following a short period of performance stabilization, a slight but steady trend of performance improvement was observed across all cognitive performance tasks. Performance improvement on the motor control tasks was more erratic, but much of this effect was attributed to differences in testing positions. For most tasks, this trend of performance improvement was enhanced during recovery. No statistically significant differences in performance were observed when comparing bedrest with the control (practice) period. Additionally, fatigue scores showed little change across all periods, with the exception of a dramatically lower fatigue level on the third recovery trial as the subjects readapted to a more "normal" living pattern.

**COGNITIVE PERFORMANCE ABOARD THE LIFE AND MICROGRAVITY
SPACELAB. D.R. Eddy, NTI, Inc., S.G. Schiflett, Armstrong Laboratory, R.E. Schlegel
and R.L. Shehab, University of Oklahoma**

INTRODUCTION. The impact of microgravity and other stressors related to space flight need to be quantified before long duration space flights are planned or attempted since countermeasures may be required. Quantitative measures of cognitive performance in-orbit can only be obtained on small numbers of subjects requiring special techniques to assess micro gravity effects. **METHODS.** Four astronauts completed 38 sessions of a 20-minute battery of six cognitive performance tests on a laptop computer. Twenty-four sessions were preflight, 9 sessions were in-orbit, and 5 sessions were postflight. Mathematical models were fit to each subject's preflight data for each of the 12 dependent variables. Expected values were generated from the models for in-orbit performance. The mathematical models of learning allowed the assessment of in-orbit effects while removing the expected, small effects of continued performance improvement. The models were linearized to allow the computation of a 95% confidence interval for in-orbit predicted values. **RESULTS.** Of the 48 data sets (4 subjects, 12 dependent measures), all were well fit by models, $p < .05$. Of those, 27 showed an in-orbit effect. The following tests showed degradation in at least one variable in three subjects: mathematical processing, spatial perception, and task switching. All subjects were degraded in two or more tasks. **CONCLUSIONS.** Although performance was found to be degraded, the factors causing the deterioration can not be determined from these preliminary results. Ongoing analysis of corresponding subjective fatigue scores and mood state data may explain performance degradations. Additional research involving appropriate ground control groups is required before concluding that microgravity is a determinant of degraded performance.

PSYCHOPHYSIOLOGICAL REACTIVITY UNDER MIR-SIMULATION AND REAL MICRO-G

B. Johannes¹, V.P.Salnitski², V.Korsun³, A.J.Kaleri⁴, K.Kirsch¹, O.I.Schewtschenko², F.Fischer¹,
A.V.Dudukin², C.Gunga¹,

¹ Free University Berlin, Dept. of Physiology, ² Institute of Biomedical Problems Moscow,

³Starcity,

⁴RKK Energia

INTRODUCTION

Psychophysiological reactivity to standardized mental stressors is known to be individually very different but relatively stable under comparably conditions. Knowing the influence of extreme stress conditions like long-term isolation and long-term micro-g on the healthy human organism is expected to explain abnormal mechanisms of psychological stress. The workability of special operators under extreme conditions often depends more on the psychological than the physical state. For the development of individual countermeasures it is necessary to assess the individual reactivity type and its changes. During two long-term MIR-simulation studies in IBMP Moscow (HUBES, EKOPSI-95) hard- and software were tested and finally designed to assess individual reactions. Within the russian medical scientific space program russian cosmonauts are running such an experiment on board MIR station on the system NEUROLAB-B.

METHODS

A set of noninvasive physiological measurements was used to describe the state of the autonomic nervous system, cardiovascular system and central nervous system (EEG/AEP, EOG, ECG, respiration, EMG, blood pressure, puls transition time, skin conductance, periphere skin temperature, voice frequencies). The experimental procedure induced a series of changes between mental loaded activity and tranquil relaxation by a word recognition controlled software using multimedia features. The statistical analysis focused on the changes of each physiological channel, induced by the changing challenges. By means of a discriminant function with selected physiological parameters based on data of former clinical studies in Berlin/Germany the subjects were grouped into four different types of psychophysiological reactivity. These different regulation types were correlated with voice reactive, autonomic reactive, cardiovascular reactive and hypertensive subjects.

RESULTS

Considering only voice reaction types during the HUBES study we found different changes for the three subjects during the timeline but a common final reaction type for all of them. During EKOPSI-95 the first time all physiological data were available in a fully by the subject self controlled experiment. One subject consisted all the time on one regulation type the other both switched between two types but without a significant tendency in time. These subjects also showed the same common final voice reaction type as the HUBES subjects but different „ways“ to it. The preflight data of the investigated eight russian cosmonauts for the 22. and 23. MIR-mission showed excellent quality. Two inflight experiments were run by both cosmonauts until now. The results from inflight and postflight experiments of MIR-mission 22 will be available at presentation.

CONCLUSIONS

The first experiments demonstrated that it is possible to run very complex psychophysiological experiments by trained subjects themselves. The stability of this first statistical approach to classify psychophysiological reactivity is good. Further development of these methods will lead to even better assessments of physiological regulation types. This diagnostical classification will improve the estimation of the psychophysiological state of operators under long-term isolated conditions and lead to new preventive therapeutical possibilities.

Tuesday, June 10

Session TP3
Room 3
2:30 - 5:30 p.m.

513-53
074007

8P.

326970

Posture and Movement

MODIFICATION OF GOAL-DIRECTED ARM MOVEMENTS DURING INFLIGHT ADAPTATION TO MICROGRAVITY

M.Berger^o, S.Lechner-Steinleitner^o, I.Kozlovskaya*, F.Gerstenbrand^o

^oInstitute of Space Neurology, Innsbruck/Austria

*Institute of Biomedical Problems, Moscow/Russia

INTRODUCTION

To investigate sensory motor functions in weightlessness the reproducibility of motor patterns which were learned either actively or passively, was examined pre-, in- and postflight. Results from these experiments are presented, concerning modification of spatial characteristics of pointing arm movements during inflight adaptation to microgravity and postflight readaptation to Earth's gravity.

METHODS

In this study one short-term and 9 long-term cosmonauts participated, age range 31-47 years. The inflight time was 1 week (one cosmonaut), 4 to 8 months (mean value 5.3 months) and 14 months (one cosmonaut) on the Russian MIR-station.

Measurements were performed inflight once a month, postflight tests were on the 2nd and 5th day after landing. In a first test the cosmonaut's outstretched arm was passively moved along a visually given pattern by the second cosmonaut. Still with eyes closed the test person tried to repeat actively the movement sequences (the shape of an isosceles triangle) from memory (passive learned movement). In a second test the cosmonaut traced the figure on the LEDs-matrix for three times with open eyes and repeated it with eyes closed. The position of the arm was measured by two IR scanning cameras. On Earth the subjects were sitting upright on a chair, the arm pointer placed on the right hand, the LEDs-matrix in front of them. In the space lab MIR the cosmonauts were fixed in supine position on the floor by belts.

RESULTS

The spatial position of the corners of each triangle, its area, circumference, lengths of the sides, slopes, angles and its central point were evaluated. In some cosmonauts the reproductions of actively learned movements differed significantly in length parameters of the memorized triangle from those passively learned. But the influence of the different gravity levels resulted in significant offsets and torsions of the reproduced figures in all cosmonauts.

CONCLUSION

In comparing the inflight with the preflight condition, intact proprioceptive afferentation seems to play an important role for reproducing movements from motor short-time memory.

QUANTITATIVE ANALYSIS OF MOTION CONTROL IN LONG TERM μ GRAVITY

G. Baroni^{1,2}, G. Ferrigno^{1,2}, A. Anolli², G. Andreoni^{1,2} and A. Pedotti^{1,2}

¹Dipartimento di Bioingegneria, Politecnico di Milano, Milano, Italy

²Centro di Bioingegneria, Fnd. Don Gnocchi, Politecnico di Milano, Milano, Italy

INTRODUCTION

During the 179-days EUROMIR '95 mission, two in-flight experiments (T4 and 38-D) required quantitative human movement analysis in μ -gravity. T4 was designed in order to assess effects of the long term adaptation to μ gravity. Among the experiments, three were voluntary postural perturbations: axial movements (AM), abduction of one leg (LR) and rhythmic oscillations of the body in the frontal plane (HT). Similar experiments were already performed during parabolic flights or in the course of a two weeks mission [1,2,3]. This work focuses on LR and HT. LR task is to elevate one leg up to 45° laterally keeping for few seconds the position and then to return back. During space sessions the supporting leg was fixed to the floor by a velcro shoe. Two conditions (open and closed eyes) were considered and for each condition the subject raised four times the right leg and four times the left one. On ground leg raising is split in two phases: *preparation* where the weight is displaced toward the supporting leg and *flight* where the leg is raised and the centre of gravity is "adjusted" inside the supporting area. We will show that this is no longer true in space, although the centre of gravity is still roughly maintained near the supporting foot [1]. Goal of HT was to verify experimental evidences concerning the dynamic vestibular contribution to head stabilisation[2]. Results will show the capability to stabilise the head in space without gravitatory inputs also without vision input.

METHOD

The ELITE system [4,5] has been used for data collection on the MIR station. It has been modified reducing the size to one half, increasing reliability and suiting space requirements, leading to the ELITE-s. Four cameras at 50 Hz were put in the core module. The field of view was 1810 x 2430 mm (h x v). LR has been performed by applying to the subject 14 markers (15 mm diameter) on the following body landmarks :

- | | | | |
|-------|------------------------------------------------|---------|---------------------------------------------|
| 1 - 2 | left and right infra-orbital margins; | 7 - 8 | left and right great trochanters; |
| 3 - 4 | left and right acromions; | 9 - 10 | left and right lateral femoral epicondyles; |
| 5 - 6 | left and right superior anterior iliac spines; | 11 - 12 | left and right external malleoli; |
| | | 13 - 14 | left and right fifth metatarsal heads. |

The subject presented alternatively his right and left side to the cameras one and two raising the leg facing these two cameras. Data were acquired on board and processed, including system calibration, on ground. Three-dimensional co-ordinates of the markers have been computed. Shoulders and pelvis displacements during the two phases of the LR (preparation and flight phases) were analysed, as well as the qualitative behaviour of the movement. Angle between the supporting leg and the horizontal (α) was computed.

For HT 12 markers (15 mm diameter) have been applied on the following body landmarks :

- | | | | |
|-------|------------------------------------------------|---------|-----------------------------------|
| 1 - 2 | left and right infra-orbital margins; | 7 - 8 | left and right great trochanters; |
| 3 - 4 | left and right acromions; | 9 - 10 | left and right tibial plates; |
| 5 - 6 | left and right superior anterior iliac spines; | 11 - 12 | left and right medial malleoli; |

Roll dispersion and anchoring indexes have been calculated, in order to evaluate subjects performances and strategy in head and other body segment stabilisation [3]. Roll dispersions and anchoring indexes have been analysed statistically (t-test, ANOVA for inter-condition significance). Cross-correlation function calculations for head and shoulder rotations have allowed to quantify the delays between their movements.

RESULTS

The results obtained on LR show a significant influence of the gravity on the whole motor strategy. In normogravity, body weight transfer on the supporting leg consists of two phases, as previously indicated. The preparation phase in which the body weight is displaced toward the supporting limb, no longer exists in μ g. This statement is supported by the results obtained with cinematic analysis of both the displacement of the pelvis toward the supporting leg and α angle. On Earth, centre of mass displacement toward the supporting side results from a rotation of the supporting leg around the antero-posterior ankle joint axis towards the supporting side, i.e. an α angle modification. In all the flight sessions, α is approximately nil, attesting that the supporting leg is fixed. Displacements results confirm this thesis. A consequence of this new motor strategy is that the second phase of the movement begins on the whole earlier in μ g than in normogravity.

The second phase is different from normogravity to μ g (Fig. 1) for several reasons. α variation during this

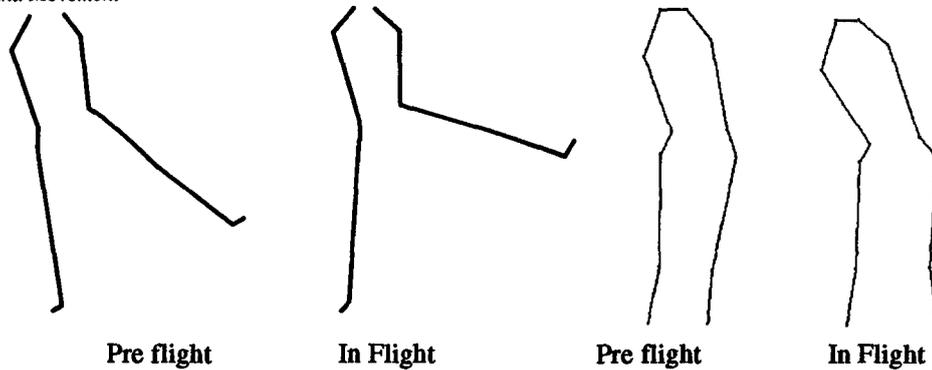


Figure 1 - Stick diagram for LR (left) and HT (right): differences between motor strategies at 0g and 1g.

phase indicates that the supporting leg is displaced toward the rising leg rather than in the opposite direction (movement which stabilises the body in standard g). Pelvis displacements confirm this result. The motor strategy observed in μ g might be linked to the conservation of the angular momentum or to the co-contraction of hip abductors. Other differences coupled with the μ gravity condition are the amplitude of the target movement (hip ϕ angle), which increases with time ($\phi_{\text{mean}} = 45^\circ$ for pre-flight and FD16 session, $\phi_{\text{mean}} = 62^\circ$ for FD19, $\phi_{\text{mean}} = 73^\circ$ for FD69) and the duration of the second phase, which diminishes with time. Despite this behaviour which seems to forget the gravity rules, the trunk is however rotated toward the supporting side and seemed to be not influenced by the gravity conditions. In particular, the more is the moving limb elevated, the more is the trunk toward the supporting side inclined. This behaviour could be dictated from the maintenance of the centre of mass within a limited area (even not sufficient for keeping the equilibrium under standard g) or to a better performance (increased hip angle). Head is better stabilised in space than on the ground during the LR movement.

About HT, subjects are still able to stabilise actively the head, even after a prolonged exposure to μ -gravity (Fig. 1). Roll dispersion shows no significant differences among sessions in-flight and on-ground before and after the flight. Head anchoring index significantly suggests that the absolute vertical direction is exploited as reference for head alignment, both in 1g and 0g. Due to low significant changes with eyes open and closed, vision does not seem to play a fundamental role. Concerning latencies between head and shoulder movements, variable segment activation strategies could be observed in both subjects.

CONCLUSIONS

Obtained results seem to confirm previous findings during short term μ -gravity exposures[3]. Rather than depending on static vestibular contribution and proprioceptive information (absent or greatly reduced in 0g), voluntary head stabilisation appears to be regulated by dynamic inputs, which are not modified by weightlessness [6]. No evidence of adaptation processes could be pointed out by means of the performed analysis. In terms of roll dispersion and head anchoring index, subject A does not change significantly his behaviour from the first to the last in-flight session (Flight Day 19-Flight Day 113).

ACKNOWLEDGEMENT

The Authors wish to thank the Italian Space Agency (ASI) for giving them the opportunity of flying ELITE.

REFERENCES

1. Mouchnino L, Cincera M, Fabre JC, Assaiante C, Amblard B, Pedotti A., Massion J (1996) Is the regulation of the centre of mass maintained during leg movement under microgravity conditions? *J. Neurophysiol.*, 1212-1223
2. Assaiante, C., Amblard, B., Fabre, J. C., Mouchnino, L. and Massion, J. (1993) Head stabilization in space during rhythmic oscillations of the trunk in the frontal plane during parabolic flights. In *Proceedings Vth European Symposium on Life Sciences Research in Space*. Arcachon, France, pp.395-397.
3. Massion J, Gurfinkel VS, Lipshits M, Obadia A, Popov K (1993) Axial synergies under microgravity conditions. *J Vestibular Res*, 3: 275-287.
4. Ferrigno G, Pedotti A. (1985) Elite: a Digital Dedicated Hardware System for Movement Analysis Via Real Time TV Signal Processing. *IEEE Transactions on Biomedical Engineering*, 32: 943-949.
5. Ferrigno, G., Borghese N.A. and Pedotti, A. (1990) Pattern recognition in 3-D automatic human motion analysis. *ISPRS Journal of Photogrammetry. Remote Sensing* 45, pp: 227-246.
6. Broinsein, A. M. (1988) Evidence for a vestibular input contributing to dynamic head stabilisation in man. *Acta Otolaryngology*, 105, pp. 1-6

DOES THE CENTRE OF GRAVITY REMAIN THE STABILISED REFERENCE DURING COMPLEX HUMAN POSTURAL EQUILIBRIUM TASKS IN WEIGHTLESSNESS?

P.Stapley¹, T.Pozzo¹, & A.Grichine².

¹ Groupe d'Analyse du Mouvement, U.F.R. S.T.A.P.S., Campus Universitaire, B.P.138, Université de Bourgogne, 21004, Dijon, FRANCE. Email : tpozso@satie.u-bourgogne.fr

² Institute for Problems of Information Transmission, 19 Ermolova Street, Moscow, RUSSIA.

INTRODUCTION

A number of studies have suggested that preceding voluntary movements in normal gravity conditions (1g), anticipatory postural adjustments (APA's) minimise forthcoming disequilibrium of the centre of gravity (CG) (Massion,1992). Clément et al.(1984) have confirmed such a goal of APA's to remain in conditions of weightlessness (0g). Locomotion studies in 1g have however, shown these APA's to be responsible for initiation in movements where the goal is to displace the CG (Brenière et al.,1987). Stapley et al.,(1997). have also recently suggested that APA's are responsible for movement initiation during dynamic equilibrium tasks conducted with a fixed base of support, creating necessary conditions for CG displacement Hence, there seems to be some confusion in terms of the role of APA's between static and dynamic equilibrium tasks in terms of the control of the CG.

Mouchnino et al.,(1996) have recently shown that during leg raising in 0g, the CG remains the stabilised reference. Their findings agreed with the suggestion that CG regulation is independent of gravity conditions (Lestienne & Gurfinkel, 1988). Nevertheless, during movements of whole body reaching in 0g, Pozzo et al.,(1994) have recorded anticipatory backward leaning postures that aimed to stretch ankle flexor muscles in order to obtain adequate joint torques for movement production. It was suggested that the purpose of APA's was not to minimise disequilibrium, but to prepare movement execution. In addition, CG amplitudes contradicted the idea of an invariance of the CG within the base of support.

The present study aimed to clarify these suggestions and answer two main issues : Firstly, are APA's modified in order to achieve task requirements in the absence of gravity? and secondly, in 0g conditions, does the CG remain the stabilised reference during multijoint forward oriented movements, involving dynamic postural equilibrium, but using a fixed base of support?

METHODS

The experimental task used during a series of parabolic flights was the same as that used aboard the Russian orbital station "Mir" as part of the experiment "synergy", during the spatial mission ALTAIR of 1994. 4 subjects (20-25yrs), previously unexposed to conditions of 0g participated in the study. Subjects were asked to begin in a standing upright position with both hands crossed at the level of the navel. The task consisted of 4 phases : reaching towards an object placed at 5 (D1) and 45cm (D2) distances in front of subjects' feet, (P1), lifting it to shoulder height (P2), pausing for two seconds and replacing it at its' starting position (P3), subjects finishing with a return to their original upright starting position (P4). Apart from constraints of distance, subjects executed movements at normal (N) and fast (F)speeds. In order to study the initiation of this whole body reaching (WBR) movement, here only P1 was considered. Movements have been measured using the optoelectronic device ELITE. Markers were placed at 11 anatomical sites, including the head (vestibular apparatus -the Frankfort plane), the trunk, arm, leg, and foot. Feet were strapped to the supporting surface, in order that subjects could generate forces necessary to reach the object. A total of 30 trials in 0g, and 30 in a 2min recovery period of 1g were conducted for each subject.

From kinematic measures of different segments, CG displacements were calculated using a rigid 7-link model and the technique of inverse dynamics. Joint torques at the ankle, knee, and hip were obtained from the same model by applying equations of motion to observed motions of a one-joint limb and thus treating the model as an open loop kinematic chain. All joint forces and torques were derived step-by-step considering one segment at a time. Each segments' mass, moment of gyration and position of its' CG were obtained using anthropometric data given by Winter,(1979). The total body CG was thus determined by considering each segments' mass and CG along AP and vertical axes and the subjects' overall mass.

RESULTS

- *Anticipatory postural adjustments* : In 1g, total torque produced at the ankle was taken as representing the sum of inertial activity (produced by postural muscles) and gravity force acting on the body. Anticipatory ankle torque (between -500ms and t_0 -1st segment displacement), causing ankle flexion was the precursor to forward and downward displacements of the CG. In 0g, significantly larger anticipatory total ankle torques were recorded in all subjects compared to 1g trials, in particular with constraints of speed.

- *CG Control* : In 1g conditions CG amplitudes in the AP axis ranged between values of 53.7mm (D1/N), and 89.5mm (D2/F). In the vertical axis, the CG displacements ranged between 392.8 (D1/N) and 537.3mm (D2/F). In 0g, along the AP axis, values ranged between 194.3 (D1/F) and 304mm (D2/F) but vertically between 384.3 (D1/N) and 428.6mm (D2/F). Therefore in 0g, reduced amplitude in the vertical axis was compensated for by increased AP displacement of the CG.

CONCLUSION

Under 1g conditions, during WBR target attainment is achieved through a rupture of static equilibrium caused by an initial backward displacement of the CP and a forward displacement of the CG (Stapley et al., 1997). This effect is stimulated by postural muscular activity, in particular of the soleus and tibialis anterior (TA) muscles. Thus, total muscular ankle torque possesses inertial and gravitational elements, which induce AP and vertical displacements, and a combined rotational effect of body segments towards the target. In 0g conditions, gravitational torques are lacking. Therefore, the sole source of ankle torque becomes muscular, with subjects being obliged to more greatly sollicit TA activity. The increase in total torque recorded in all subjects in conditions of 0g may be interpreted therefore as a compensation for the lack of a gravity component producing rotational displacement of body segments. Results concerning CG amplitudes have shown that far from being stabilised in 0g, the CG displaces to a greater extent in the AP axis than in 1g. Results from the present study would suggest that in the absence of gravity increased ankle torque is produced in order to move the CG over a larger distance in the AP axis, to compensate for the subjects' inability to use gravity. Further analysis of muscular activity preceding WBR in 0g may clarify such an hypothesis. In addition, analysis of head stabilisation or the conservation of segment verticality in prolonged 0g conditions may help in the identification of the stabilised reference in this particular postural task.

REFERENCES

- Brenière, Y., Do, M.C. & Bouisset, S. (1987). *J.Mot.Behav.* 19, (1), 62-76.
Clément, G., Gurfinkel, V.S., Lestienne, F., Lipshits, M.I. & Popov, K.E. (1984). *Exp.Brain Res.* 57, 61-72.
Lestienne, F. & Gurfinkel, V. (1988). *Trends Neurosci.* Vol.11, 359-363.
Massion, J. (1992). *Prog. in Neurobiol.* Vol.38, 35-56.
Mouchnino, L., Cincera, M., Fabre, J.C., Assaiante, C., Amblard, B., Pedotti, A. & Massion, J. (1996) *J.Neurophysiol.* Vol.76, (2), 1212-1223.
Pozzo, T., Berthoz, A. & Popov, C. (1994). *Vestibular & Neural Front.* K.Taguchi, M.Igarashi & S.Mori (Eds). 589.
Stapley, P., Pozzo, T. & Grichine, A. (1997). Submitted.

This study was supported by the CNES (Centre National d'Etudes Spatiales).

ARM END-POINT TRAJECTORIES UNDER NORMAL AND MICRO-GRAVITY ENVIRONMENTS

C. Papaxanthis¹, T. Pozzo¹, J. McIntyre²

¹Groupe d'Analyse du Mouvement (G.A.M), U.F.R. S.T.A.P.S., Campus Universitaire, Université de Bourgogne, B.P. 138, 21004 Dijon, France, ²Laboratoire de Physiologie de la Perception et de l'Action CNRS - Collège de France, Paris, France

INTRODUCTION

Neurophysiological (Georgopoulos et al., 1986) and behavioral studies (Soechting and Flanders, 1991) have argued that the brain encodes arm movements in terms of its' kinematics. Other alternative hypotheses that the brain may encode muscle activations and force (dynamics) instead of the direction of hand movements (Mussa Ivaldi, 1988), have been also proposed. Whether kinematic or dynamic representations of movement exist at the neuronal level still remains problematic.

In addition, how the brain encodes gravitational force as well as its' representation during arm movement planning and execution has not attracted a great deal of scientific attention. Gravity can either initiate or brake arm movements and consequently must be represented in the motor command.

In the present study an attempt has been made to study the role of gravity in the control of vertical arm pointing movements. Our working hypothesis was that the CNS takes into account the mechanical effects of gravitational force in order to correctly perform arm movements. Furthermore, we also hypothesized that gravitational force is represented during the planning of the movement and consequently used by the brain in the execution of arm movements in the sagittal plane.

METHODS

Data presented in this study were taken from experiments made in a normal gravitational environment (1G) and in microgravity (0G) collected during the mission EUROMIR (1994) aboard the Russian Space Station MIR.

1G experiment

Cosmonauts stood erect. Two targets were fixed in front of them, aligned with the midline of the body, one 60 cm above the other, and centered at the level of the shoulders. Subjects performed discrete visually guided, point-to-point reaching movements in upward (UD) and downward (DD) directions, with (0.5 kg) and without an additional load (hand empty). Movements were recorded and analyzed using an optoelectronic system (ELITE). Six markers (plastic spheres of 0.4 cm in diameter) covered with reflective material, were placed on the joints of the arm (shoulder, elbow, wrist and hand). Their positions during the movement were recorded and their centroides underwent 3D reconstruction.

0G experiment

The equipment and experimental protocole used for the reaching task in microgravity was the same as that described for the 1G experiment, except that the feet of the subject were fixed to the floor of the space station by straps. The tests were carried out 45 days before flight (PF 45), 4 times during the flight (FD 6, FD 12, FD 15, FD 18) and 2 times immediately after the subjects return to earth (R 1 and R 7). Both cosmonauts executed 10 movements in each direction per experimental session. The same type of markers as in the 1G experiment were used to calculate the position of the shoulder, elbow, wrist and hand. Movements were recorded using a videocamera (25 Hz). Data were analyzed after digitalization of the video recording, using a computer.

RESULTS

Figure 1 presents mean curvature values of the finger from the two cosmonauts for both movements, directions and loads, before, during and after space flight.

Hand paths without load

Both cosmonauts showed curved paths in pre-flight (PF 45) measurements. Movements in the upward direction presented greater curvature values than movements in downward direction. During exposure to the microgravity, for both cosmonauts, the downward movement curvatures decreased progressively with the length of the flight and showed almost straight paths on the 18th day. In contrast, upward movements, showed irregular patterns with mean curvature values varying during the flight, remaining of the same order as pre-flight values. Post flight measurements (R 1) for DD movements, showed almost straight paths for both

cosmonauts. For UD movements, curvatures decreased compared to inflight values. At R 7 measurements, both directions recovered approximately the curvature values obtained during pre-flight testing.

Hand paths with a 0.5 kg load

Curved paths for both directions and cosmonauts were also recorded for the load condition, during the pre-flight measurements. UD hand paths presented greater curvature values than hand paths in DD. The FD 6 hand curvature increased for both directions, representing greater values for the UD compared to DD. As in the unloaded condition, while the curvature of DD movements decreased progressively within flight, the curvature of UD movements remained almost of the same order as pre-flight values. With R 1 measurements, hand paths for the DD movements were straighter compared to 18th flight day. In contrast, UD curvature increased on R 1. At R 7 both directions tend to the same as values obtained during pre-flight testing.

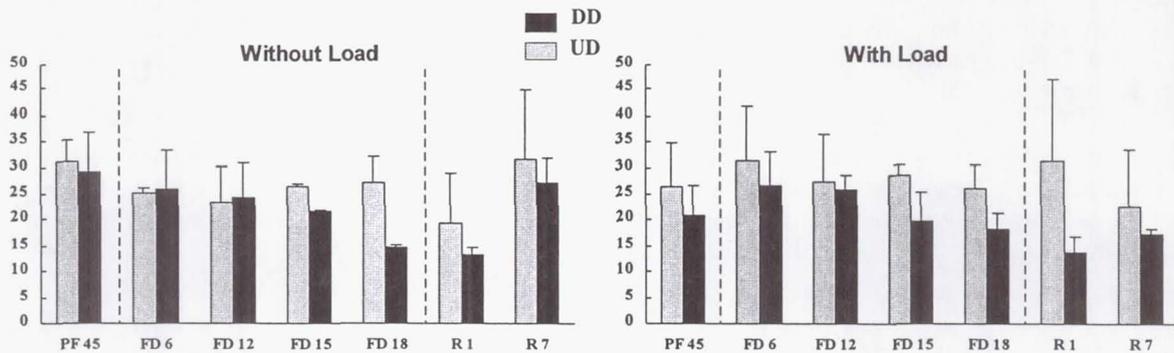


Figure 1. Means and standard errors from both cosmonauts, of the greater perpendicular distance from the path to the straight line. PF 45: pre-flight, FD 6 : 6th flight day, FD 12: 12th flight day, FD 15: 15th flight day, FD 18: 18th flight day, R+1: first-post flight day, R+7: 7th post-flight day. Pre-flight, flight and post-flight periods are separated by dotted lines.

CONCLUSION

The major finding of this study was the kinematic differences between the two directions tested in both normal and microgravity conditions. Hand paths were seen to straighten gradually, at least for downward movements, over the course of an 18 day space flight for both load conditions. The fact that hand paths remain curved early in flight, and that the hand paths remain straight shortly after return to earth supports the idea of an adaptation of the internal movement template, rather than a transient perturbation brought on by the sudden lack or addition of a constant bias force. This argument is further strengthened by the fact that hand path curvature returned to preflight levels after several days adaptation to a normal 1G environment. Attributing changes in movement kinematics according to the gravitational context to a representation of gravity in the planning stages of movement begs the question as to why the motor plan should be modified. Furthermore, what is the impetus behind different kinematic patterns for upward vs. downward movement? We propose that the CNS takes advantage of the gravity force to produce movements, rather than treating gravitational torques as a disturbance that needs to be cancelled. In this case, joint torques produced by gravity will be used by subjects to initiate (DD), and stop (UD) arm movements. Thus, gravity may be treated as a driving force whereas another, less predictable external load might not. A central representation of gravity force, which implies the encoding of vertical direction, is consistent with findings that neuronal populations in the motor cortex (Georgopoulos, 1986; Caminiti et al., 1991) encode the direction of the movement.

This study was supported by the European Space Agency and the Centre National d'Etudes Spatiales.

Tuesday, June 10

Session TP4
Room 4
2:30 - 5:30 p.m.

54-52

074051

326971

11P.

The German/Russian MIR '97
Mission: An Overview

LIFE SCIENCE EXPERIMENTS DURING THE GERMAN-RUSSIAN MIR '97 MISSION

G. Ruyters, H.-U. Hoffmann

Deutsche Agentur für Raumfahrtangelegenheiten (DARA, German Space Agency) GmbH, 53227 Bonn, Germany

INTRODUCTION

Manned spaceflight has been an important element of the German space program over the last decades. In February this year, the German cosmonaut Reinhold Ewald stayed for three weeks onboard of the Russian Space Station MIR together with his Russian colleagues Wasilij Zibliev and Alexander Lasudkin. This mission - the so-called German/Russian MIR '97 - was, of course, another cornerstone with regard to the cooperation between Russian and German space organizations. The cooperation in the area of manned missions began 1978 with the flight of the German cosmonaut Sigmund Jähn onboard of Salyut 6, which was followed by the flight of Klaus Dietrich Flade in March 1992 with his stay onboard of MIR. After two further successful ESA missions, EUROMIR '94 and '95 with the two German cosmonauts Ulf Merbold and Thomas Reiter, the decision was taken to perform another German/Russian MIR mission. In Germany, MIR'97 was managed and performed in a joint effort between several partners. DARA, the German Space Agency, was responsible for the overall program and project management, while DLR, the German Aerospace Research Establishment, was responsible for the cosmonaut training, for the mission control at GSOC in Oberpfaffenhofen as well as for the user support.

OBJECTIVES OF THE MISSION

From the very beginning main objectives of the mission were: continuity, cooperation and multidisciplinary. Continuity with regard to the scientific program meant to provide for access to space before the Intl. Space Station era. Partnership with international partners was to be achieved for strengthening cooperation from an operational as well as from the scientific point of view. And finally, multidisciplinary research comparable to that on the Intl. Space Station was desired as preparation of the upcoming era. In line with these considerations, the Life Sciences Research Announcement was made available not only to German scientists, but also to international participation via ESA, CNES and NASA. In fact, the final program in the area of space Life Sciences contained principal and co-investigators from several ESA member states including France, from the US, and from Russia and Ukraine. Also, the facilities for experimentation were provided not only from Germany, but also from NASA, ESA, and Russia. With regard to multidisciplinary, experiments from Materials Science, Technology and Operational Tests were performed in addition to those in Life Sciences. Being a manned mission, especially human physiology experiments were in the center of interest. Altogether 27 flight experiments were performed by the cosmonauts in addition to 11 pre-/postflight studies, 11 and 9 of them, respectively, in Life Sciences.

THE LIFE SCIENCES PROGRAM

With regard to the Life Sciences experiments, two main areas were the focal points of the mission, research on the cardiovascular system with the newly developed MEDEX system and research on the area of hormone-regulated processes such as fluid and bone metabolism. In addition, experiments were performed on cognitive processes, on the effects of spine geometry in microgravity, on the effects of microgravity on bone and muscle physiology and performance as well as on the effects of space radiation.

MEDEX is the new system for measuring various parameters of the cardiovascular system, such as ECG, EEG, blood pressure, body temperature, body impedance. The approach taken by DARA and the companies PANKOSMOS and ISM in developing this system was, firstly, to be modular by combining a central data unit with a suite of measuring modules as required for the experiments, and secondly, to use off-the-shelf H/W and adapt it for space application. ORTHOSON, another new small system, is a device for measuring spine geometry by ultrasound technique.

In the contributions following this overview, some of the principal investigators of the experiments will present preliminary results. Also in this regard, the MEDEX experiments and the so-called Metabolic Ward experiments are in the center of interest. In addition, preliminary results of changes in spine geometry and in biomechanical and bioenergetic properties of skeletal muscles and of magnetic resonance imaging will be presented in some detail. In addition, a short summary of the results of other life sciences experiments will be given in this overview.

ORTHOSTATIC INTOLERANCE FOLLOWING MICROGRAVITY: A ROLE FOR AUTONOMIC DYSFUNCTION

F. J. Baisch, L. Beck, J. Drescher,¹ C. G. Blomqvist,² D. L. Eckberg,³ and D. Robertson⁴

¹Institute of Aerospace Medicine, DLR, Cologne-Porz, Germany, ²University of Texas Southwestern Medical Center, Dallas, Texas 75235-9034, ³McGuire Research Institute, Inc., Department of Cardiovascular Physiology, 1201 Broad Rock Blvd., Richmond, VA 23249, ⁴Center for Space Physiology and Medicine, Department of Medicine, Pharmacology and Neurology, Vanderbilt University, Nashville, TN 37232-2195

The most common mechanism underlying orthostatic intolerance may be defined as the inability to maintain adequate tissue perfusion (particularly of the central nervous system) in the upright body position. Orthostatic intolerance is present in up to 500,000 Americans, mostly in individuals under 50 years of age and also a common finding after space flight.

The exact pathophysiological mechanisms are known only in a minority of patients by primary myocardial dysfunction is rarely a factor. Clinical orthostatic intolerance of cardiovascular origin has multiple potential components, including decreased cardiac filling and stroke volume, inadequate postural heart rate and/or systemic vasoconstrictor responses, and impaired cerebrovascular autoregulation. Hypovolemia with decreased cardiac filling is a prominent finding after space flight and a likely major factor contributing to the orthostatic intolerance that is present in a majority of crew members even after space flight and a likely major factor contributing to the orthostatic intolerance that is present in a majority of crew members even after space flight of relatively short duration. However, the hypovolemia is universal whereas the presence or absence of individual post-flight orthostatic intolerance appears to be linked to inadequate compensatory regulatory responses, including systemic vasoconstriction and baroreflex-mediated tachycardia.

We propose to test the general hypothesis that adaptation to microgravity produces cardiovascular regulatory dysfunction and to identify specific mechanisms by (i) evaluating the afferent signal flow to the brain in different receptive areas, (ii) by modeling central data processing, and (iii) by investigating efferent information flow via the sympathetic nervous system to the muscle vasculature, the main contributor to peripheral resistance.

Afferent signal flow to the brain will be tested by using multiple and relatively simple procedures (controlled breathing, Valsalva, static exercise, cold pressor, and LBNP, etc.) to produce quantifiable, reproducible, and reasonably specific cardiovascular responses, all mediated by the autonomic nervous system but activating different afferent pathways and (presumably) different sites for central integration.

Controlled breathing maneuvers will assess the CO₂ dependence of brain perfusion, heart rate variability, and blood pressure. With different Valsalva strain levels, baroreflex responses will be recorded. The cold pressor test will be used as a model nociceptive stimulus. With lower body negative pressure (LBNP) the cardiovascular system will be challenged by an orthostatic stress which can be applied on ground and in weightlessness.

To model central data processing, weight changes in an artificial neural network are tested. These weight changes representing plasticity will be analyzed whether or not neural plasticity is a contributor to altered cardiovascular neurohumoral regulation. In a preliminary approach, the baroreflex is simulated and hemodynamic post-flight data of blood pressure and heart rate will be compared with preflight responses. The artificial neural network will be trained to mimic pre-flight responses on one hand and on the other hand, the same network will be trained to reproduce post-flight presyncopal tracings. The weight changes in the artificial neural network will be analyzed if changes in afferent traffic have caused these alterations.

To evaluate sympathetic outflow, microneurography (for assessing electrical activity in sympathetic nerves) and norepinephrine spillover (for estimating neurotransmitter turnover and clearance) will be introduced step by step during the next Russian Mir missions. Pre- and post-flight investigations will be added initially and finally, in-flight tests will be performed in combination with LBNP on the NASA Neurolab Mission.

TP4: The German/Russian MIR '97 Mission: An Overview

The Autonomic function tests on DARA Mir 97 are the beginning of a chain of cardiovascular experiments on the Russian Mir Space Station and the NASA Space Shuttle.

With this integrated approach we should be able to detect whether or not post-flight orthostatic intolerance results from alterations in the afferent signal flow, and/or in central dynamic circulatory control, and/or in the efferent branches of the autonomic nervous system.

HEART RATE VARIABILITY AND SKIN BLOOD FLOW IN MAN DURING ORTHOSTATIC STRESS IN WEIGHTLESSNESS

J. Drescher; A. Diedrich

DLR-Institute of Aerospace Medicine Cologne; Working Group for Non-Invasive Diagnostics AGNID
RWTH Aachen / Chair of Flight Medicine ; Linder Höhe 51170 Cologne, Germany

INTRODUCTION

The question of cardiovascular deconditioning of cosmonauts during long term missions and development of adequate countermeasures are central tasks in space medicine. The cardiovascular adjustment to the weightlessness conditions, to real and artificial orthostatic stress simulated by Lower Body Negative Pressure application with the Russian Tschibis-LBNP device inflight are the primary topics of this research. We conducted a pilot study of stepwise Tschibis-LBNP application for the simulation of active standing, in -6° HDT body position. The ground based research data have to be compared with the inflight cardio-vascular reaction pattern during LBNP testing on the MIR 97 and MIR 97 Extension space missions.

METHODS

The DARA MEDEX diagnostic system with the BASIS-module for ECG, blood pressure and breathing pattern monitoring and the two channel MCD module for microcirculation diagnostics with Near Infrared in the forehead skin and the big toe are used. The Portapres and Transcranial Doppler measurements provide cardiovascular reference parameters. The investigations of the heart rate variability (HRV) as central mediated parameter and the skin microcirculation (MCD) in the upper and lower body regions are provided during Tilt table and LBNP functional testing. The tests were provided on young healthy men, cosmonauts and astronauts during the MIR 97 space mission.. The sympatho-vagal balance SVB and sympathetic vasoconstriction activity (SQN) are calculated during the experimental phases.

RESULTS

In preflight studies we already estimated the sympatho-vagal influences and regulatory pattern during real and simulated orthostatic stressor influences. The continuously ECG R-R interval analysis showed an increase of the spectral power of the HRV in the mid frequency range and a decrease of the HF power during orthostatic stressor load. Typical spectral power distributions SVB characterizing the amount of orthostatic stressor load during active standing were found during $-35 / -45$ mmHg. The noninvasive measurements of the local skin microcirculation dynamics (maximal volume velocity) discovered the blood volume shifts, blood velocity and flowmotion reaction pattern during ortho- and antiorthostatic stressor load.. The simulation of orthostatic stress comparable to the active standing body position needs a $-35 / -45$ mmHg LBNP pressure application in supine or -6° HDT body position. This has to be proofed for real spaceflight conditions.

CONCLUSION

The HRV dynamics and the skin microcirculatory reaction pattern in the upper and lower body regions contribute the clarification of space related disturbances of autonomous nervous functions, e.g. orthostatic syndrome. The temporal coordination and functional relationships between the macro- and microcirculatory systems enable the physician to estimate the risk of syncope. In case of dysregulation (maladaptation, autonomous disorders) the central modulation of the complex interactions of heart and blood vessels functions disappears and yields to orthostatic intolerance.

EFFECTS OF MICROGRAVITY AND LOWER BODY NEGATIVE PRESSURE ON CIRCULATORY DRIVES FROM EXERCISING CALF MUSCLES

D. Essfeld¹, K. Baum², U. Hoffmann¹, D. Leyk¹

¹Physiologisches Institut, ²Institut für Rehabilitation und Behindertensport, Deutsche Sporthochschule Köln, Carl-Diem-Weg 6, 50933 Cologne, Germany

INTRODUCTION

Skeletal muscles are reflexogenic areas of the cardiovascular system. It could be shown both on ground and during the MIR'92 mission that local fluid losses enhance cardiovascular drives from exercising lower limb muscles. These changes are probably mediated by slow-conducting afferents terminating as so-called free nerve endings in the interstitium of the muscle. According to our hypothesis the activity of these afferents during exercise in microgravity should be reduced by any measure that increases the interstitial fluid volume of the muscles. During the missions MIR'97 and MIR'97E we will study the immediate after-effects of lower body negative pressure.

METHODS

Heart rate and blood pressure responses to light, isometric foot plantarflexion will be measured in two cosmonauts during the missions MIR'97 and MIR'97E. The exercise protocol will be performed during a period of local circulatory arrest so that the role of muscle chemoreceptors can be distinguished from the influence of central command and muscle mechanoreceptors. Measurements before and immediately after lower body negative pressure (LBNP) will allow to study the short-term after-effects of LBNP. Ground controls are performed both during sitting and in a -90° tilted sitting posture assumed 30 min before the onset of local circulatory arrest.

RESULTS

The preflight measurements showed the expected increase in heart rate and blood pressure responses when lower limb volumes are decreased. The inflight exercise responses before and after LBNP during MIR'97 will be presented at the meeting.

THE MIR STATION IN ITS SECOND DECADE - CREW SCIENCE OPERATION DURING MIR '97

Reinhold Ewald, Y.A. Gagarin Cosmonaut Training Center, Star City, Russian Federation
and DLR Astronaut Office, D - 51170 Cologne

ABSTRACT

A first-hand report of the German-Russian MIR'97 spaceflight is given. The subjects covered are the cosmonauts' training and the actual working conditions on board the Russian MIR space station.

In analogy to the profile of the MIR '92 flight the German science research cosmonaut has performed a 20 day research program under μ g-conditions during the crew exchange in February 1997. In preparing this mission German Aerospace Research Establishment DLR assigned on request of DARA two members of the German Astronaut Team to take up training in the Y.A. Gagarin Cosmonaut Training Center (TsPK).

The training comprised the phases

- 0 Language course
- I Basic Cosmonautics
- II Soyuz and MIR systems
- III Crew Training

Additionally, in parallel to phases II and III the research cosmonauts trained for the experiment program. The duration of the training in TsPK is defined in accordance with duration and aim of the space flight and takes into account the experience of the foreign cosmonauts. In the full-task Soyuz simulator the flight profile is performed several times following the board documentation, as well in the nominal case as with selected off-nominals. The full-scale MIR station simulators (Base module, Kwant, Kwant II and Kristal) allow to run complete typical days with e.g. repair and maintenance tasks assigned to the MIR crew and a science program to the research cosmonaut.

In distinction from the situation in 1992 on board of MIR several cooperative programs are now run in parallel. On one hand an US-American astronaut is continuously present on board. On the other hand the Russian cosmonauts perform extension programs of other cooperative bilateral missions. So, the MIR-23 crew performs NASA and CNES experiments together with the DARA program. Subsequently this puts stress on the preparation period especially with regard to travel and BDC times. The German cosmonaut has worked together with the Soyuz TM 25 crew ("up"), but also with the "down" crew Soyuz TM 24 and the NASA-4 astronaut. Download items are returning in three vehicles, two Soyuz crafts and the Space Shuttle.

MIR '97 and other missions of this type already reflect crew training and working conditions of astronauts preparing for and performing a mission to the International Space Station. In this respect the exploitation of the experience gained on MIR in its second decade of function gives valuable information. Preparation and operation of future space station mission have to be adapted in order not to overload crew performance.

METABOLIC WARD (WATER, SODIUM, CALCIUM AND BONE METABOLISM) AND ENDOCRINOLOGICAL EXPERIMENTS DURING THE MIR '97 MISSION

C.Drummer[#], M.Heer, P.Norsk, P.Bie, P.Stehle, A.Zittermann, I.McCarthy, C.Vermeer, C.Alexandre, L.Shakelford, C.Gunga, M.Bidlingmaier, C.Strasburger, P.Rettberg, G.Horneck, V.Oganov, D.Vorobiev

[#]Spokesperson from DLR-Institute of Aerospace Medicine, Cologne, Germany

During the German-Russian MIR'97 Space-Mission, various medical disciplines, such as endocrinology, nutritional sciences, nephrology, physiology, clinical pharmacology, rheumatology, orthopedics, and radiology have been combined to perform joint metabolic experiments. The respective results will be evaluated not only on the basis of the individual's experiences, but shall lead to a potentiated understanding of microgravity induced alterations. During the complete 21-day space mission alimentary variables, such as energy-, sodium-, calcium-, and vitamin D intake, have not only been passively monitored but have been maintained at a constantly controlled level. Baseline values of blood and urine hormones which mediate water- and sodium-metabolism have been measured several times during the mission, as well as those hormones and biomarkers which participate in calcium- and bone metabolism. Metabolic balances have been determined on a daily base. Additionally, stimuli such as oral sodium load, water load, or calcium load have been applied, so that a more sensitive evaluation of microgravity induced alterations in body fluid regulation and calcium- and bone metabolism is obtained. An oral strontium load test has also been applied for evaluating intestinal calcium absorption. Biofilms have been fixed to the astronaut's body and to various places on board the MIR space station for the dosimetric measurement of UV-radiation, which is an essential component of endogenous vitamin D synthesis and thus of the vitamin D dependent calcium-metabolism. Before and after the spaceflight, various radiological measurements (Bone Densitometer, Bone Stiffness Measurement Device, Dual Energy X-ray Absorptiometry) have been applied to characterize bone architecture, substance, and quality. These measurements, in combination with respective biochemical analyses of samples that have been obtained during the flight, give a more comprehensive picture of the changes to the bone structure of the astronaut during the 21-day period in microgravity. In addition to body fluid and bone related questions, another endocrinological experiment also focuses on the microgravity-induced reduction in red cell mass and hemoglobin concentration. It was assumed that a reduced erythropoietin production by the kidneys might have been responsible for the reduced red cell mass, since this hormone is firmly established to be the predominant regulator of erythropoiesis. Therefore, erythropoietin production as well as bone marrow activity (by means of serum transferrin receptor concentrations) has been measured before, during and after flight. Finally, the influence of microgravity on the responsiveness of the cortisol-associated stress-hormone system to specific stress-stimuli has been examined. Throughout the mission, salivary cortisol concentrations in response to a psychomotor performance task as well as to a bicycle ergometric physical test (submaximal workload) have been measured. Respective blood hormone measurements during baseline data collections on ground will help to understand the altered stress hormone response in microgravity. First preliminary mission results will be presented.

LONG-TERM MONITORING OF THE SPINE-GEOMETRY DURING THE MIR'97 MISSION. INTRODUCTION OF A NEW METHOD.

K. Baum¹, D. Essfeld²

¹Institut für Rehabilitation und Behindertensport, ²Physiologisches Institut, Deutsche Sporthochschule Köln, Carl-Diem-Weg 6, D-50933 Köln

INTRODUCTION

During space flights the occurrence of back pains has often been reported by astronauts. This phenomenon comes as a surprise since on Earth unloading of the spine is frequently applied in rehabilitative programs of patients with back pain. The pain sensations under ug-conditions may be evoked by overall changes in the vertebral geometry leading to stretching of spinal and/or paraspinal tissues. Unfortunately, only poor information exists concerning the curvatures of the spinal column during microgravity. This also holds for daily activities on Earth. The lack of knowledge is probably due to the fact, that - so far - there was no adequate equipment available for long-term monitoring of the spine in freely moving subjects.

We expect that microgravity reduces range and frequency of spinal movements both during sleep and daily activities. After return to 1g-conditions, atrophy of trunk muscles may cause an altered geometry of the vertebral column in the upright position.

METHODS

Measurements will be made by means of 6 pairs of ultrasound transmitters and receivers fixed on the back in parallel to the spine. The approach is based on the fact that each change in the spinal curvature will also change the distance between the ultrasound transmitters and receivers. During the experiments, a small device generates the ultrasound signals and stores the data. The spatial resolution is less than 1 mm.

As a first approach to quantify the overall changes in the spinal curvature we will monitor continuously (sampling rate: 1 Hz) 48h profiles pre-, post, and inflight. In addition to the normal daily activities, the maximal flexion and extension of the trunc will be measured in standard positions.

RESULTS

All subjects reported that the equipment neither disturbs the daily activities nor sleeping. Preliminary results from preflight sessions show high variations in the vertebral geometry during daily activities. During sleep the variability is markedly reduced. A detailed analysis of pre-, post, and inflight data will be available by the time of the meeting.

EFFECTS OF 20 DAYS OF MICROGRAVITY (GERMAN/RUSSIAN MIR 97 MISSION) ON THE MECHANICAL AND ELECTROMYOGRAPHIC CHARACTERISTICS OF EXPLOSIVE EFFORTS OF THE LOWER LIMBS AND OF CYCLOERGOMETRIC EXERCISES OF MILD TO SPRINT-LIKE INTENSITY

G. Antonutto¹, P. Zamparo¹, F. Bodem², J. Kass², J. Heine², P.E. di Prampero¹

¹ Dept. of Biomedical Sciences, University of Udine, Italy, ² Dept. of Orthopaedic Surgery, Johannes Gutenberg University, Mainz, Germany.

INTRODUCTION

The power developed during very short (< 10 s) all out efforts of the lower limbs was determined on four subjects before and after the two missions Euromir 94 and 95. The duration of the exposure to microgravity (μg) lasted from 31 to 180 days.

The experiments were performed on a specially designed ergometer, the multipurpose ergometer dynamometer (MED), a detailed description of which is to be found elsewhere (1, 2). Briefly, the MED is constituted by a metal frame (3.0 x 0.9 m) hinged at one end to an equal frame. An isokinetic cycloergometer, powered by a 4 kW electric motor, and two force platforms are fixed to the upper frame. The subject sits on a seat free to move on rails fixed to the upper frame. The MED can be used as any isokinetic cycloergometer, in which case the seat is blocked in a predetermined position and the force platforms are lifted upwards, not to interfere with the motion of the pedals. Alternatively, the force platforms are lowered and the subject, pushing maximally on them, accelerates himself and the seat backwards. In this case, the seat is free to move on the rails which are inclined upwards (usually 20°). In this mode, the maximal mechanical power developed by the subject is obtained from the product of the force on the platforms times the velocity of the seat, determined by means of a wire tachometer. Thus, the MED allowed us to measure the maximal power developed during very short maximal explosive efforts, the duration of which (0.25 - 0.30 s) is essentially equal to that of a maximal standing high jump off both feet. The power developed during this type of efforts is defined Maximal Explosive Power (MEP). The subjects were also asked to perform a maximal cycling effort of 5 seconds on the isokinetic cycloergometer at a pedal frequency, imposed by the motor, of 1 Hz. This type of maximal power is defined Maximal Cycling Power (MCP).

The MEP was reduced to about 70 % of pre-flight values after one month (one subject) and to about 50% after six month (three subjects). MEP was also determined on one additional subject after, but not before, 438 days of space flight. Even if a direct comparison could not be made in this subject, MEP was reduced to about 50 % of the values expected, before flight, for normal subjects of his age and body mass. Thus, after about six months in space, MEP seems to attain a steady value which does not decline further. The reduction of MEP after one month in μg was larger than that observed after a similar period (42 days) of bed rest (Ferretti et al., 1996, personal communication). Furthermore, in all cases it was much larger than the concomitant decrease of muscle mass, which was on the order of 6-20 % (Zange et al., 1996, personal communication).

The decline of MCP after μg was significantly less than that of MEP: MCP was reduced to about 84 % of pre-flight values after one month (one subject) and to about 67 % after six month (three subjects). However, also in the case of MCP, the decline of power was larger than that of muscle mass.

It is concluded that a substantial fraction of the observed decreases of MEP and of MCP must be due to a deterioration of the motor co-ordination brought about by the absence of the constant pull of gravity. Furthermore, since in both type of all-out efforts: i) the energy source were the same, essentially phospho-creatine splitting, ii) no recovery of elastic energy could occur (2) and iii) the muscle groups involved were essentially the same, the two exercise modes can be directly compared. Hence, the observed larger decline of MEP, as compared to MCP, suggests that the deterioration of motor co-ordination is greater for those types of efforts in which the recruitment and derecruitment of the motor units of agonist and antagonist muscles must be fast and well balanced.

The aim of this study was to evaluate separately the effects of muscle atrophy and of motor co-ordination deterioration on the decrease of maximal all out power of the lower limbs due to μg . We therefore determined simultaneously the mechanical power and the electromyographic activity of agonist and antagonist muscle groups during MEP and MPC performances as well as during moderate cycloergometric exercises.

METHODS

The same equipment and experimental procedures described above will be used to measure the same variables (MEP and MCP) on two astronauts before and after 20 days of μg , in the course of the German/Russian MIR 97 mission. In addition, during the same type of explosive exercise in which MEP and MPC will be assessed, we plan to record also the electromyographic (EMG) activity by means of surface electrodes. The EMG activity will also be recorded during aerobic cycloergometric exercise, up to about 150 W. In addition, MPC will be determined during 5 s all out cycling efforts, not only at a pedal frequency of 1 Hz, as was the case in the experiments described

above, but also at lower and higher frequencies (from 0.6 to 2.5 Hz). Finally, we will also determine gas exchange, heart rate, arterial blood pressure and cardiac output, by means of a non invasive method (3), during several steps of three minutes duration of aerobic cycloergometric exercise of increasing intensity. This will allow us to obtain a close estimate of the astronauts' maximal oxygen consumption. The experiments will be performed three times before flight and 1, 6, 15 and 30 days after re-entry.

EXPECTED RESULTS AND CONCLUSION

Initially, the analysis of the data will be directed towards the assessment of the maximal power and of the electromyographic activity of the (agonist and antagonist) muscle groups of the lower limbs that are involved in MEP and MPC performance. In addition, the relationship between MPC and pedal frequency will also be determined. This combined assessment of maximal explosive power and of electromyographic activity of the same muscle groups ought allow us: 1) to evaluate the effects of μg on the activation pattern of the muscle groups involved in external power production and hence 2) to estimate separately the fractions of the decrease of MEP and of MPC after μg which are due to motor co-ordination deterioration or to muscle atrophy.

REFERENCES

1. Antonutto G., Capelli C., Girardis M., Zamparo P., di Prampero P.E.: Effects of microgravity on muscular explosive power of the lower limbs in humans. *Acta Astronautica* 36: 473-478, 1995.
2. Zamparo P., Antonutto G., Capelli C., Girardis M., Sepulcri L., di Prampero P.E.: Effects of elastic recoil on maximal explosive power of the lower limbs. *Eur. J. Appl. Physiol.*, 1996 (in press).
3. Antonutto G., Girardis M., Tuniz D., di Prampero P.E.: Noninvasive assessment of cardiac output from arterial pressure profiles during exercise. *Eur. J. Appl. Physiol.* 72: 18-24, 1995

SINGLE SEAT

WA1: Long-Duration Space Flight

Wednesday, June 11

*515-52
074088
7P.*

**Session WA1
Room 1
8:30 - 11:30 a.m.**

326972

Long-Duration Space Flight

MEDICAL AND PHYSIOLOGICAL STUDIES DURING 438-DAYS SPACE FLIGHTS

A.I.Grigoriev¹, V.V.Polyakov¹

¹State scientific centre - Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

As distinct from the previous long-term space flights, the program of activity cosmonaut-physician provided significant expansion of volume of medical and physiological researches directly during flight.

METHODS

The Mir station is supplied with modern medical and physiological equipment, that allowed to used adequate methods for studies of the main physiological systems of the human body.

RESULTS

Physiological and clinicophysiological researches, carried out cosmonaut-physician, as on most to self, and on other members of crews of three expeditions, making flights under this program by duration up to a half-year, have for the first time found out in flight: decrease of force parameters, developing mainly in leg muscular extensors; more expressed mineral losses in proximal parts of femur and lumbar vertebra at cosmonaut-physician and essential increase at him of risk of occurrence urolithiasis; progressing reduction of concentration in natriuretic peptide in blood; decrease of a level of hydration and volume of blood at the constant contents of erythrocytes. The ultrasonic researches have revealed presence of attributes hypovolemia in flight. In cervicocephalic region and pulmonary circulation signs of hypervolemia and increase of resistance in vessels and significant decrease of vessel tonus and blood flow in the low half of the body are found out. Under influence of stay in weightlessness reduction of ability in femoral vessels to interfere at influence of lower body negative pressure is revealed. It is also discovered decrease of ability cerebral vessels to control cerebral blood flow by reduction of vascular resistance, that testifies to change of hemodynamic regulation in these conditions. Decreased a level of hydration for the account of extracellular fluid, progressing in accordance with increase of flight time, is revealed in cosmonauts, including cosmonaut-physician, during long-term space flights. This is rather essential result, directly confirming the stated earlier assumptions. The found out shifts metabolism in a number of cases went outside the limits the clinical norms, but were convertible and rather quickly restored after end of flights. Conducted in postflight period clinicophysiological examination of a condition of health cosmonaut-physician allow to qualify his condition as appropriate usually observable after long space flights.

CONCLUSION

It is shown, that the person rather effectively works in conditions weightlessness duration till 438-days.

HUMAN PERFORMANCE DURING A 14 MONTHS SPACE MISSION

D. Manzey¹, B. Lorenz¹, & V. Polyakov²

¹DLR-Institute of Aviation and Space Medicine, Dept. of Aviation and Space Psychology, Hamburg, Germany

²Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

Results from first performance monitoring experiments during spaceflights conducted during the last 5 years suggest that basic cognitive processes remain fairly stable during spaceflights, whereas visuo-motor processes as well as higher attentional functions are prone to disturbance effects related to the impact of environmental stressors in space. However, all of the research so far has been conducted during short-term spaceflights lasting 6 to 20 days. The 438 days space mission of the Russian cosmonaut Valeri Polyakov provided a unique opportunity to conduct a first performance monitoring study during an extraordinary long-term space mission. The following questions were addressed in this study: How long does it take to recover fully from initial performance disturbances during long-term spaceflights? Is it possible to maintain stability of mental efficiency after complete adaptation to space during a long-term spaceflight? Do similar performance decrements as during adaptation to space emerge also during re-adaptation to Earth after a long-term spaceflight? Do prolonged stays in space induce any long-term performance deficits after return to Earth?

METHOD

One Russian cosmonaut participated in the study on his second long-term space mission. Performance monitoring was conducted by a self-administrable computerized performance monitoring device which included six tasks in order to assess the following performance functions: (1) logical reasoning and decision making functions (Grammatical Reasoning Task), (2) Memory retrieval functions (two levels of a Memory Search Task differing in memory load), (3) perceptual-motor functions (Unstable Tracking Task), (4) human time-sharing functions (two dual-tasks each consisting of Unstable Tracking with concurrent Memory Search). All tasks were taken from the battery of Standardized Tests for Research with Environmental Stressors (STRES) which has been published by AGARD. In addition to performance assessment, several subjective ratings concerning mood and workload were collected. The experiment included a total of 41 experimental sessions (4 pre-flight assessments, 29 in-flight assessments distributed over the entire 14 months in space, 6 post-flight assessments during the first two weeks after landing, 2 follow-up assessments six months after landing).

RESULTS

A comparison of *pre-flight* and *inflight* assessments showed: (1) Impairments of cognitive performance were found only during the week immediately *before* launch. After entering the space environment performance in the cognitive tasks recovered rapidly to pre-flight baseline level. (2) During the first week in space, significant disturbances of tracking performance were found; a complete recovery of tracking performance to pre-flight baseline level was achieved only after approximately three weeks. After this time period tracking performance remained fairly stable throughout the following 13 months. (3) Only few significant impairments of time-sharing performance were observed most of which occurred during the first two weeks in space. (4) Corresponding to the impairments of visuo-motor performance and dual-task performance, the subjective data indicated feelings of increased workload, increased fatigue and reduced emotional balance during the first three weeks in space. Results from *post-flight* assessments revealed significant disturbances of visuo-motor performance during the first week, and disturbances of cognitive and time-sharing functions during the first two weeks after landing. Again, these performance disturbances were accompanied by feelings of raised workload, increased fatigue, and reduced emotional balance. *Follow-up* assessments six months after the mission did not reveal long-lasting performance deficits after the stay in space.

CONCLUSIONS

The results of the present study provide first insights into the efficiency of human performance during extraordinary prolonged space flights. Two conclusions may be drawn: First, the first three weeks in space and the first two weeks after a long-term space mission appear to represent critical adaptational phases which are associated with both, considerable decrements of visuo-motor (tracking) performance and occasional dual-task performance decrements, as well as elevated workload ratings and clear drops in subjective mood. Secondly, the impressive stability of mood and performance during the second to fourteenth month in space indicates that after adaptation to the extreme environmental conditions during space flights, mental efficiency and emotional state can be maintained on a level as high or even higher as on Earth for a long period of exposure.

HOMEOSTASIS IN LONG-TERM MICROGRAVITY CONDITIONS

A.D.Egorov¹, A.I.Grigoriev¹, A.S.Kaplansky¹

¹State scientific centre - Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

Carried out in conditions of long-term microgravity researches were directed not only on study of phenomenology of this factor influence, but also on receiving of data, allowing to analyze a state of homeostasis in these conditions from the point of view of normal and pathologic physiology.

METHODS

The systematization and generalization of the data concerning responses of the main body systems of man and animals obtained in long-term space flight by using some physiological, biochemical, and morphological and others methods are made. On this basis mechanisms of changes and establishment of new level of homeostasis in microgravity conditions have been analyzed.

RESULTS

It is shown, that in conditions of long-term microgravity a level of functioning in the basic body systems and number of parameters of metabolism and internal medium are changed. As a consequence of these changes with the passage of time the new level of energy exchange and plastic (protein) metabolism is established. Catabolic processes are intensified and neuroendocrine regulatory mechanisms are altered. At the same time structural changes in some tissues and organs, especially in skeletal and muscle systems, are developed. The main changes in internal medium during long-term stay in microgravity conditions are manifested by hypohydration of organism (a reduction of volume of extracellular fluid), negative balance of some ions, functional erythrocytopenia, and others. The most significant changes of endocrine system are characterized by decrease of plasma and urine levels of ADG and activation of renin-angiotensin-aldosterone system on a background of absence of significant changes of stress-dependent hormones. Morphological changes of atrophic nature was found out primarily in bone and muscle systems of cosmonauts and animals. First of all it concerns to postural muscles and weight-bearing bones. There is also the redistribution of mineral components in bones as reduction of mineral density of the lumbar vertebrae and their dorsal elements and increase of mineralization in a skull and arms. An increase of the sizes of a number of internal organs is revealed as well. The shifts formed during adaptation in human body and animals are adequate to new conditions of existence. However, it is not clear yet as far as they are durable. The physiological measure of protection against adverse influence of microgravity on the expiration of acute period of adaptation appear sufficient for an establishment of relative balance in system organism - environment and maintenance of an adequate level of capacity for work in these conditions.

CONCLUSION

In microgravity conditions functional load on various systems is redistributed that renders influence on regulation of homeostasis of organism. First of all increased load on a number of regulatory systems, directed on cupping of sensory conflicts, and also on an establishment of a new level of functioning of the basic systems and maintenance of homeostasis. A functional load on bone and muscle systems and on some parts of cardiovascular system is reduced, that provokes the development of deconditioning in these systems. In result there is loss of a number properties, acquired by the person during individual development and life in conditions of earthly force of weight. It conducts to reduction of functional opportunities of human body after long-term stay in microgravity and to development of readaptive gravitational syndrom.

STRATEGY OF PRESERVATION OF HEALTH OF COSMONAUTS IN PROLONGED AND SUPERPROLONGED SPACE FLIGHTS.

A.I.Grigoriev¹, V.V.Polyakov¹, A.D.Egorov¹

¹State scientific centre - Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

In prolonged and superprolonged space flights the problem is the maintenance of health and capacity for work at a level, appropriate to fulfillment of the program of flight and promoting high efficiency of activity of crew in case of occurrence non-standard situations. In this connection the paramount importance gets creation adequate loads on all systems of human body in conditions of microgravity and maintenance of an earthly spectrum of distribution of body fluids and afferent impulse flows. It is natural, that the uniform method of the decision of all these problems does not at the moment exist. It follows that there is the problem of determination of strategic lines of researches, directed on the decision of listed problems.

METHODS

Currently using means and some results of medical monitoring and countermeasures in long-term space flights as well as of postflight rehabilitation are studied by method of the theoretico-physiological analysis. On this basis the main directions on further investigations and points of the application of countermeasures are determined and substantiated.

RESULTS

The leading role in creation of adequate load on human body in conditions of microgravity belongs to artificial force of weight. However, the practical realization of this method is connected to large technical difficulties and financial charges. At the moment in this direction extensive researches in our country, and abroad are carried out. Simultaneously, researches develop principles and new methods of non-gravitational countermeasures with reference to space flights increased durations. Thus the major importance has determination of points of the application of countermeasures for the most effective their influence with the minimum expense of time and development of methods of an objective estimation of a level of physical condition of each member of crew with the purpose of a choice on this basis of an adequate mode (regime) of trainings. From here follows necessity of conducting of monitoring not only condition of health of crew, but also degree of physical condition of each crewmember, including rational use of means of countermeasures. The medical monitoring in long-term manned space flights includes: the current control, estimation and diagnostics of adverse condition; prediction of changes in crewmembers' health in different phases of flight and after landing; assessment of the possibility to continue flight; planning and controlling of medical examination and countermeasures during the flight. The rehabilitation is founded on the following principles: local and general therapeutic influence on human body; active participation of patients in realization of procedures; selection of certain recovery methods and means and sequence of their application depending on cosmonauts' general state and fitness and phase of readaptation; regularity and required duration carrying-out of procedures; gradual increase of loads; complex, continuity and proper sequence of rehabilitation measures during all phases of readaptation; regular medical monitoring during the whole period of readaptation; complete restoration (renewal) the functional state of organism.

CONCLUSION

The preservation of health of cosmonauts in prolonged and superprolonged flights in a broad sense these word is connected to realization of monitoring, creation of conditions for normal ability to live, maintenance with the help of various methods of physical and mental health and capacity for work of crews at all stages of preparation, in flight and in early postflight period.

REHABILITATION OF COSMONAUTS' HEALTH FOLLOWING LONG-TERM SPACE MISSIONS

V. V. Bogomolov*, I. B. Kozlovskaya*, V. I. Pochuev**

*Institute for Biomedical Problems, **Gagarin's Crew Training Center,
Moscow, Russia

Return of cosmonauts from extended space missions (SM) to the Earth's gravity gives rise to alteration of the functional state of various body systems as compared with pre- and in-flight indices. Shifts are observed in circulation, neurological status, neuromuscular apparatus, processes of bone mineralization, hematological, immunologic, and metabolic parameters. These deviations are associated with changes in the regulatory systems of the body and generally treated as adaptive or functional. On the other hand, some investigators approach the severity of these shifts as a factor which may limit further prolongation of piloted SM.

In view of the experience of medical support for long-term SALYUT and MIR space missions lasting from several months up to 438 days and analysis of the readaptive shifts, we can state it as a fact that their depth and severity are not as much dependent on SM length as flight conditions, and, what is of paramount importance, on the intense and intelligent use of the Russian system of countermeasures against the unfavorable changes in cosmonaut's body developed for extended SM.

System of the postflight medical recovery developed and applied within the Russian program of piloted cosmonautics includes a set of therapeutic/rehabilitative measures to be used in a stepwise fashion and based on the functional methods of rehabilitation. On the initial phase (first 3 weeks) the goal of rehabilitation boils down to blocking the symptoms of asthenization, vestibular and orthostatic instability, locomotor and coordination disorders, normalization of functioning of the main body systems. Phase two (21-35-day rest in sanatoria and health resorts) results in the most complete recovery of the functional systems, the velocity/strength properties of muscles and coordination, fitness and endurance, and, possibly, more effective recovery of the reserve abilities and psychological status of cosmonauts. After many months on SM, the active rehabilitative programs takes two months. Over this period, functioning of the main body systems regains its preflight level although a number of hematological, biochemical indices and changes in bone tissue in some cosmonauts returns to the norm at later time points.

The report focuses on the time frame needed for the postflight readaptive shifts to be eliminated and functioning of cosmonaut's body following long-term SM (including repeated ones) recovered with allowance for individual patterns of readaptation and character of countermeasures administered in SM. Plans, methods, and criteria of adequacy of the rehabilitative measures are presented.

PERFECT COSMONAUT: SOME FEATURES OF BIO-PORTRAIT

N.G. Lacota, I.M. Larina, V.V. Polyakov

Institute for Biomedical Problems, Khoroshevskoye shosse 76-a
Moscow, 123007 Russia. Phone: (7-095) 195-2363, Fax: (7-095) 195-2253

The human data were obtained using the techniques simulate of space mission effects: exposures in snow-pit (48 hours - 6 man), suit immersion (3 hours...3 days - 46 man, including 18 cosmonauts and candidats), swimming in ice-water (6...20 hour - 20 man), bed rest (14...120 days - 36 man and 8 women), isolation by "HUBES" (135 days - 3 candidats) and "ECO-PSY" (90 days - 3 man). All exposures were complicated by the operative (including visual-motor programs), vestibular, orthostatic and physical provocative test. The part of volunteers was observed in the various and repeated experiments. The special autothermometric study was carried out onboard Orbital Complex "Mir" by 2 scientist cosmonauts (12 and 174 flight days), who had participated in suit immersion exposures.

The analyses of results have shown the following features of a perfect cosmonaut: a) low thermal sensibility; b) low hydro-ionic sensibility; c) the norepinephrine-type (NE-type) of sympathoadrenal system (SAS) functioning; d) high sensitivity serotonin-responsive structures which corresponds to low basal serotonin-concentration in blood; e) constitutional type of person should be like a sprinter which corresponds to high anaerobical qouta in total energy expenditure; f) minimal deviation of biomechanical parameters of respiration; g) vestibuloresistance by I. Bryanov-test.

Physiological role of thermal and hydro-ionic sensibility, unfinding out in usual life-work state is increased under experimental models significantly. If the space is unload, the direct correlation of the heat sensibility and the hydro-ionic sensibility is infringed and vestibuloresistance is correlated weakly to them. For example, the extremely wide range of individual thermal and water-salt sensibility was revealed in suit immersion. The motion sickness of 0-I class (A) was determined by: short period of thermogomeastatics resulted in a decrease of oral temperature to 0.2-0.4 deg. C; maintenance of blood osmolarity and pressure. The motion sickness syndrom of III-IV class (B) was determined by: a nonsteady heat state with decreased oral T by one deg. C, body mass loss, negative water balance, associated with hyperventilation, disorder adrenosympathetic circadian rhythm and hyperactivity of water-salt regulating hormones. Among 46 subjects the ratio of "A" and "B" reaction was 1:4 during suit immersion. The baseline stability to physical loads (PWC-170 test) and endurance to work with constant power (0.76 PWC-170 is "Individual tolerance" test) kept approximately for 4-5 from 30 subjects after 1-3 days of suit immersion (average decrease is equal to 1/4 and 1/2 of background). Only these 4-5 participants had the features determining the bioportrait of perfect cosmonaut. Their psychophysiological capability was confirmed by the successful work in space missions from the first up to the last day (including super long-term flight).

Wednesday, June 11

Session WA2
Room 2
8:30 - 11:30 a.m.

516-51

074144

10P.

326974

**Plant and Animal Gravitational
Biology - 2**

THE ASYMMETRICAL GROWTH OF OTOLITHS IN FISH IS AFFECTED BY ALTERED GRAVITY AND CAUSES KINETOSIS

R. H. Anken, T. Kappel, and H. Rahmann

Zoological Institute, University of Stuttgart-Hohenheim, Garbenstr. 30, D-70593 Stuttgart, Germany

INTRODUCTION

Immediately after having been subjected to microgravity conditions (e.g. in the course of parabolic aircraft flights), many human individuals reveal behavioural abnormalities regarding posture reflexes, ocular counterrolling, nystagmus and others. Given the case that such abnormalities occur, the respective person is apt to suffer space motion sickness (SMS), which is a particular kind of kinetosis-generated nausea including vomiting in the course of a prolonged stay under weightlessness. The basis of SMS (like motion sickness in general) is most likely due to non-matching visual, proprioceptive and vestibular cues in the central nervous system. A classic, exclusively theoretical concept presumes that such mismatches may be based on asymmetrically (from side to side) weighted inner ear utricular otoliths, which may be compensated for at 1g earth gravity by central nervous mechanisms (vestibular compensation), but may be disclosed in weightlessness, thus generating a secondary asymmetry on the level of the brain.

Many individuals of a given batch of larval fish, that are kept at modest hypergravity (3g; centrifuge) during their early ontogenetic development, reveal a kinetotic behaviour (so-called loop-swimming) as soon as they must face 1g conditions like it is observed at the transition from 1g to microgravity. This is possibly due to imprinting-like phenomena at higher g-levels, adjusting the central nervous integration of visual and vestibular cues.

Therefore, larvae after hyper-g experience can serve as model systems to investigate, if SMS might be caused by asymmetrical utricular otoliths.

METHODS

Larval cichlid fish were subjected to hypergravity from hatch until their yolk-sacs were completely resorbed (free swimming stage). After the experiment, the hypergravity animals were divided into a group of motion sick, i.e. looping samples and normally behaving individuals. The functional capacity of otoliths (utricular and saccular otolith, i.e. lapillus and sagitta, respectively; the former is involved in the perception of gravity, whereas the latter plays its role in hearing) was determined by measuring the maximum radius (r_{\max}), as it is common in fisheries science when the interesting otoliths are too small to be weighted. Consequently, the absolute differences in r_{\max} between the left and right sides (asymmetry) were determined and the two experimental groups were compared with each other and with 1g controls.

RESULTS AND DISCUSSION

Hypergravity reared samples yielded significantly smaller otoliths (regarding absolute r_{\max}) than 1g normal earth gravity controls: The sagittae of hypergravity animals were by moderate 14.1 % smaller than those of 1g control animals (Fig. 1a; $p < 0.0001$). The lapilli, however, were even by 33.2 % smaller in hyper-g fish than in controls (Fig. 1a; $p < 0.0001$).

Calculating in addition the asymmetry, we found that sagittae revealed a tremendously increased asymmetry after hypergravity (Fig. 1b; $p < 0.0001$). In contrast, the asymmetry of hyper-g lapilli was significantly decreased (Fig. 1b; $p < 0.0001$).

Both the absolute r_{\max} and the respective asymmetries of sagittae and lapilli as found in hyper-g animals were not concomitantly seen in any developmental stage (the average r_{\max} of hyper-g sagittae, e.g., was seen in stage 18 of normally developing fish, whereas the average r_{\max} of hyper-g lapilli was seen in stage 16, and the average asymmetry of hyper-g sagittae was about three times higher than the most prominent asymmetry found during the normal development; the respective data will be available at presentation): Thus, our present findings do not indicate any general effect of altered gravity (i.e. general environmental stress). In fact, they indicate a differential adjustment of lapilli and sagittae in their growth towards the altered gravitational environment. Under increased gravitational conditions, otoliths have a higher physical impact on the sensory epithelia. We propose that the fish compensate the resulting increased bilateral impact on the sensory epithelia by developing much smaller otoliths. Since the sagittae will not be used for the perception of gravity in free swimming fish, there will no adaptive mechanism be capable of decreasing any given asymmetry, as it should be the case concerning lapilli.

Calculating the asymmetry of sagittae, we found no statistically significant difference between looping and non-looping fish after hyper-g experience (Fig. 2). Individuals, which showed a motion-sick behaviour after transfer from hypergravity to normal 1g earth gravity, however, exhibited a significantly higher lapillar asymmetry than normally behaving hypergravity samples (Fig. 2; $p < 0.05$).

Our data are the first experimentally derived evidence in support of the theoretical concept mentioned in the introduction, according to which kinetoses might be based on asymmetrical (utricle) otoliths.

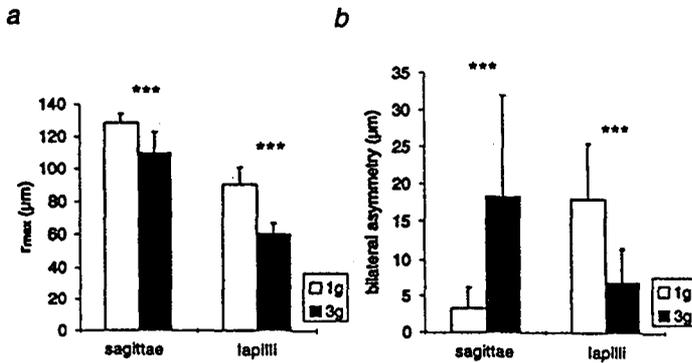


Fig. 1. Effects of altered gravity on the growth of inner ear otoliths of cichlid fish, which had been raised under 3g within a centrifuge, in comparison to 1g controls. sagittae: saccular otoliths (hearing); lapilli: utricular otoliths (perception of gravity). a, Size (maximum radius, r_{max}). ***: $p < 0.0001$. b, Asymmetry (absolute bilateral difference in r_{max} between the left and the right side otoliths). ***: $p < 0.0001$.

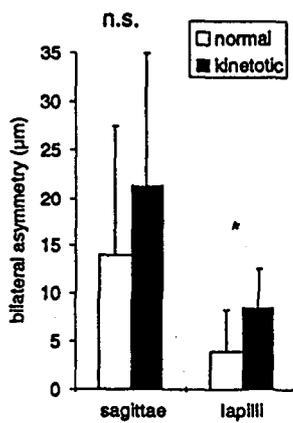


Fig. 2. Otolith asymmetry in kinetotic (loop-swimming) and normal behaving cichlid fish, which had been raised at 3g hypergravity. *: $p < 0.05$; n.s.: not significant. sagittae: saccular otoliths (hearing); lapilli: utricular otoliths (perception of gravity).

CONCLUSION

The differential effect of altered gravity on different otoliths (i.e. lapilli and sagittae) implies the existence of a hitherto unknown centrally guided feedback mechanism, which adjusts the functional capacity of otoliths towards the requirements for spatial orientation.

ACKNOWLEDGMENT

This work was financially supported by the German Space Agency DARA (FKZ: 50 WB 9533).

NEUROBIOLOGICAL RESPONSES OF FISH TO ALTERED GRAVITY CONDITIONS: A REVIEW

H. Rahmann, and R. H. Anken

Zoological Institute, University of Stuttgart-Hohenheim, Garbenstr. 30, D-70593 Stuttgart, Germany

INTRODUCTION

An alteration of sensory modalities such as gravity, that serve a fish for orientation, results in a changed behavior: A transfer from normal gravity to microgravity in the course of parabolic aircraft flights and spaceflights, respectively, results in a so-called loop-swimming behaviour in adult fishes. A qualitatively similar loop-swimming- (or somersaulting-) behaviour can also be observed in larval fish during parabolic flights.

Most interestingly, a transfer from a long lasting stay under hyper-gravity (centrifuge) conditions to normal 1g earth gravity results in a loop-swimming-behaviour in larval fish, which could still be observed after five days under 1g conditions.

As a matter of fact, the basis of the "loop-swimming" and related aberrative behaviours might be searched for in the central nervous system, where a signal-transduction from the inner ear related signal internalisation to the signal response (i.e. behaviour) takes place.

Thus, the present paper is intended to provide a review on our investigations upon neuroplastic reactivities of fish to altered gravitational environments, comprising behavioural, biochemical, histochemical and electronmicroscopical-cytochemical results, which have been achieved by our working group for some ten years on the search for the understanding of space-sickness in fish in order to contribute to the understanding of the neuronal basis of motion sickness in man.

METHODS

Several developmental stages of cichlid fish *Oreochromis mossambicus* and swordtail fish *Xiphophorus helleri* were subjected to hyper-gravity (3g in laboratory centrifuges), hypo-gravity ($>10^{-2}$ g in a fast-rotating clinostat) and to near weightlessness (10^{-4} g aboard the spacelab D-2 mission). After the end of the gravitational relevant experiments, the samples recovered were processed for further behavioural, biochemical, histochemical and electronmicroscopical analyses.

The swimming behavior of the animals was qualitatively observed during altered gravity. A quantitative evaluation of the swimming behaviour (quantification of swimming traces) was performed after the experiments by means of a computer-based video analyser.

Subsequently, samples were dissected for further neurobiological investigations: **Biochemically**, the total brain activity of glucose-6-phosphate dehydrogenase (G6PDH, cytosolic pentose phosphate pathway), succinate dehydrogenase (SDH, mitochondrial tricarboxylic cycle), cytochrome oxidase (CO, mitochondrial respiratory chain), cytosolic, plasma membrane located and mitochondrial creatine kinase (CK, creatine phosphoryl circuit), $\text{Ca}^{2+}/\text{Mg}^{2+}$ -ATPases and sialidase (membrane metabolism) was analysed. For **histochemical analyses**, the reactivity of succinate dehydrogenase was determined in various brain nuclei. On **electronmicroscopical** level, the reactivity of cytochrome oxidase was determined both in a vestibular brain nucleus and in inner ear epithelia. (Details of the methods used will be available at presentation.)

RESULTS AND DISCUSSION

Regarding behaviour, larval fish did not show any aberrative movements during hyper-gravity. After hyper-gravity as well as under microgravity, many of the animals performed a loop-swimming-behaviour. In the case of subadult and adult fish, qualitative and quantitative analyses of the behaviour after hyper-gravity experience (no abnormal behaviour observed during hyper-gravity exposure) did not yield a marked effect. These results strongly indicate, that a given gravitational environment results in imprinting-like phenomena on the level of the brain, disclosing an aberrative behaviour only when gravity is reduced.

Biochemically, G6PDH- and SDH- activities in the brains of larvae were significantly increased by hyper-gravity exposure. The cytosolic and membrane-located CK- activity as well as the activity of sialidase was decreased after hyper-gravity, whereas the activity of the mitochondrial membrane-located isoform of CK was slightly increased. Microgravity yielded the opposite effects. The brains of adult fish did not show a significant effect of altered gravity. Altered gravity did not yield any significant effect both on larval and adult fish regarding the activities of CO and $\text{Ca}^{2+}/\text{Mg}^{2+}$ -ATPases.

In order to gain some insights into the anatomical substratum of the gross-biochemical results, according to which SDH was strongly affected by altered gravity, the light-microscopical, **histochemical approach** was undertaken. Hyper-gravity resulted in an augmented enzyme reactivity within entire brains of larvae (entire sections were densitometrically investigated as a whole and "all over brain" reactivities were calculated) and

within vestibular brain nuclei, whereas non-vestibular nuclei revealed no effect. Weightlessness yielded the opposite results. Corresponding effects (hyper-gravity only) were obtained in the case of adult fish. The effect of altered gravity, however, was much less significant as compared to the circumstances observed in developing fish. The histochemical data strongly indicate, that the gross-biochemical results may represent sum-up effects of vestibulum related brain structures. However, an additional, general impact of altered gravity on the CNS (e.g. via the hormone system) cannot yet be excluded. Since the effect of altered gravity was much more distinct in larval animals than in adults (the range of the neuronal plasticity in larvae is generally higher than that in adults), the alteration of enzyme activities due to altered gravity might represent imprinting-like and adaptational processes

Concerning the brain, **ultramicroscopically** demonstrated cytochrome oxidase (CO)- reactivity in the vestibular Nucleus magnocellularis was increased after hyper-gravity and slightly decreased after microgravity. This is in complete agreement with the histochemical data. Ultramicroscopically demonstrated CO in the inner ear epithelia yielded the following findings: Weightlessness resulted in a decrease of CO- reactivity within the utricle, but not in the saccule as compared to 1g controls. The utricle is responsible for the internalisation of gravitational information, whereas the saccule of fish is believed in hearing. Interestingly, hyper-gravity had no effect on inner ear epithelia. This is in contrast to the findings on the level of the vestibular brain nuclei. An explanation could be as follows: The CO- reactivity in the inner ear epithelia at 1g seems to be close to the possible maximum activity. Any hyper-g effect thus is likely to have been overlooked. Additionally, it is possible to assume, that hyper-g facilitates the signal transmission of the inner ear, transmitting a respective rate of action potentials towards the vestibular brain nuclei without a concomitantly increased energy production. Further studies are sorely needed to clarify this topic.

CONCLUSION

All data taken together clearly demonstrate, that altered gravity affects developing fish on all levels of organismal organization investigated. The results obtained most possibly reflect adaptational phenomena to the altered gravity environments, i.e. imprinting-like processes. The gross-biochemical results probably resemble sum-up effects of particular vestibulum-related brain centers. However, an additional, general impact of altered gravity, e.g. stress related phenomena, cannot be excluded. The cellular activity of macular cells is not clearly correlated with the acceleration provided in contrast to higher order neuronal cells. This speaks in favour of the assumption, that especially hyper-gravity induces a facilitation of synapses in inner ear epithelia. The aberrative behaviour when long-term provided gravitational forces are reduced suggests, that imprinted brain structures cannot immediately handle with the actual, new input from the inner ears, possibly due to asymmetric otolith weights, as has already been proposed earlier. Our results regarding adult fish suggest that, as compared to developing fish, adult fish do not as heavily respond to altered gravitational forces, possibly due to a partial loss in neuronal plasticity.

Summarized, fish subjected to altered gravity seem to be a valuable model for the investigation of neuronal plasticity in general, and moreover, may provide clues and insights regarding the neuronal basis of kinetosis in man.

ACKNOWLEDGMENT

This work was financially supported by the German Space Agency DARA (FKZ: 50 WB 9533).

AN AGE-DEPENDENT SENSITIVITY OF THE ROLL-INDUCED VESTIBULOOCULAR REFLEX TO HYPERGRAVITY EXPOSURE OF SEVERAL DAYS IN AN AMPHIBIAN (*XENOPUS LAEVIS*)

C. Sebastian and E. Horn

Department of Neurology, Gravitational Physiology, University of Ulm, D-89081 Ulm, Germany

INTRODUCTION

Exposure of amphibian tadpoles to altered gravitational forces affected the development of the roll-induced static vestibulo-ocular reflex (rVOR). It was shown that for maximal postural changes, the appearance of the rVOR during development is an important milestone for the development of adaptive properties of the underlying neuronal network (Horn, Sebastian, Neurosci Lett 216:25-28, 1996). In *Xenopus* tadpoles with 3g-experience, we have tested the question, whether this observation is also valid if the animals were tested by small roll angles during 1g-readaptation.

METHODS

Hypergravity was induced by centrifugation of the animals and started at different developmental stages, two of them before (stages 6-9 and 33-36), and one of them (stage 45) after stage 42 at which the rVOR appeared for the first time. Duration of 3g was 9 to 12 days. Recordings of the rVOR started 24 hrs after termination of the 3g-period. The tadpoles were rolled either by 15° or by a complete 360° lateral roll around their longitudinal axis. From the latter stimulation procedure, the response amplitude was determined which is the peak-to-peak excursion of the rVOR characteristic recorded during a complete 360° roll.

RESULTS

Within 6 to 11 days after termination of the 3g-period, the rVOR induced by a 15° or by a complete 360° roll was similarly affected by the preceding 3g-exposure. For both the 6/9- and the 33/36-sample, the rVOR of 3g-reared tadpoles did not change significantly within this readaptation period while the rVOR recorded from the 1g-reared controls did so. In contrast, the rVOR increased significantly in the stage 45-group for both the 3g- and the 1g-groups for the small as well as for the complete roll angle during readaptation (complete roll: from 37.1 to 54.4° in the 3g-group, from 50.9 to 70.4° in the 1g-control; 15°-roll: from 4.4 to 7.6° in the 3g-group and from 6.6 to 10.2° in the 1g-control). The only difference of the rVOR induced by the 15° roll to that recorded during a complete roll was its faster 1g-readaptation (15°-roll, last: 3g vs 1g is n.s.; complete roll, last: 3g vs 1g is significant with $p < 0.01$).

g-level	15°-Roll						Complete roll					
	Stages 6-9		Stages 33-36		Stage 45		Stages 6-9		Stages 33-36		Stage 45	
	3g	1g	3g	1g	3g	1g	3g	1g	3g	1g	3g	1g
first	4.5°	4.7°	2.8°	4.9°	4.4°	6.6°	33.4°	36.7°	26.1°	36.9°	37.1°	50.9°
last	3.1°	8.2°	1.7°	8.4°	7.6°	10.2°	33.1°	48.3°	35.6°	55.2°	54.4°	70.4°
last/first	0.68	1.74	0.62	1.73	1.75	1.54	0.99	1.32	1.36	1.50	1.47	1.38
period [days]	6	6	11	11	10	10	6	6	11	11	10	10
significances	n.s.	<0.01	n.s.	<0.01	<0.01	<0.01	n.s.	<0.01	n.s.	<0.01	<0.01	<0.01

first (last), median rVOR obtained at the first (last) recording day; *last/first*, ratio between these data; *period [days]*, number of days between first and last; *significances*, statistical difference between first and last

CONCLUSION

The developmental stage at which the rVOR appears for the first time is an important milestone in the development of the gravity sensitive system. For small as well as large postural displacements by a passive roll, the rVOR is affected in a characteristic manner by a 9- to 12-days lasting 3g-period. It is likely that there are two components involved: (i) readaptation to 1g is faster the younger the tadpoles were at onset of 3g; this high plasticity is also known from the vestibular compensation. (ii) Slowly developing but long-lasting effective neuroanatomical changes exist, which affect the physiological connections between the central nuclei involved in the control of the rVOR.

Supported by the German Space Agency (DARA), grant no. 50WB9543-7 and the Deutsche Forschungsgemeinschaft (DFG), grant no. Ho664/16-1 to E. Horn.

MECHANICALLY-INDUCED MEMBRANE WOUNDING DURING PARABOLIC FLIGHT.

M.S.F. Clarke¹ and D.L. Feedback², ¹Division of Space Life Sciences, Universities Space Research Association, 3600 Bay Area Blvd., Houston, TX 77058; ²Life Sciences Research Laboratories, NASA/JSC, Houston, TX 77058.

INTRODUCTION

Mechanical load induces transient disruptions or "wounds" of the plasma membrane of skeletal muscle cells both *in vivo* and *in vitro*. We have previously shown that such wounding results in the release of fibroblast growth factor (FGF) from the sarcoplasm of both skeletal myofibers and cardiac myocytes *in vivo*. In addition, using a mechanically active tissue culture environment we have shown that there is a linear relationship between the amount of mechanical load placed on differentiated human skeletal myotubes (analogous to myofibers *in vivo*), the degree of membrane wounding and the amount of FGF released into the tissue culture medium. Furthermore, we have also demonstrated that the muscle growth response induced by mechanical load can be specifically inhibited by a site-directed, anti-FGF neutralizing antibody added to the tissue culture medium. Based on these and other results, we have formulated the hypothesis that microgravity exposure may result in the disruption of this mechanically-reactive, signaling pathway within skeletal muscle tissue and postulate that a microgravity-induced reduction in wound-mediated FGF release may contribute to skeletal muscle atrophy. Using the experimental conditions generated aboard NASA's KC-135 parabolic flight aircraft we have investigated whether or not microgravity *per se* alters the membrane wound response of human skeletal muscle cells at the cellular level. We have previously illustrated the utility of mechanically-induced membrane wounding as a highly efficient mechanism for the transfer of genetic material into primary human cells, a process termed "transfection". Transfection efficiency has proven to be an important rate limiting step in several human gene therapy protocols, such as transfection of the dystrophin gene into the muscle cells of Duchenne muscular dystrophy patients. Therefore, we also investigated whether the microgravity environment can be utilized to enhance transfection efficiencies in primary human skeletal myoblasts cultures using two different plasmid DNA constructs.

METHODS

Reproducible levels of mechanical load were applied to the sarcoplasmic membrane of cultured human skeletal muscle cells using a novel, impact-mediated loading (IML) procedure (Clarke *et al.*, 1994; *Biotechniques* 17:1118-1125) carried out during KC-135 parabolic flight. Wounding levels were assessed by: 1) determining cell survival using a DNA assay and 2) determining the amount of different Mr-sized fluorescent cytoplasmic wound markers (FITC-linked dextrans) present in the cytoplasm of surviving cells using flow cytometry. Transfection efficiencies were calculated using either: 1) cell counting after transfection with the pSV β plasmid construct encoding for bacterial β -galactosidase or 2) determination of enzyme activity after transfection with the pSVCAT plasmid construct encoding for the acetyl CoA transferase enzyme. The effects of parabolic flight on plasma membrane/intracellular vesicle fusion efficiency was measured after PMA stimulation in differentiated HL-60 cells (i.e. granulocyte-like cells) by the amount of β -glucuronidase enzyme released upon primary granule fusion with the plasma membrane.

RESULTS

Wounding inflicted during microgravity resulted in a significant ($p < 0.004$; $n = 31$ per condition) reduction in cell survival compared to that observed after wounding inflicted in either the normal or hypergravity phases of parabolic flight (Figure 1). When dextran size was varied from 10 kD to 2 million kD, the degree of membrane wounding, determined by the mean fluorescence value (MFV) of the surviving cells, indicated that the reduction in cell survival observed after wounding in microgravity was not due to an increase in membrane wound size but an inhibition of the membrane wound resealing process (Figure 2).

Figure 1

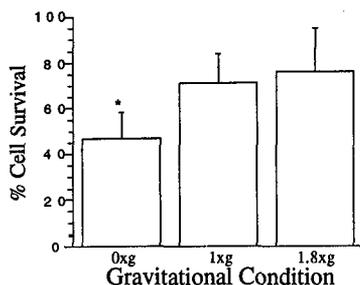
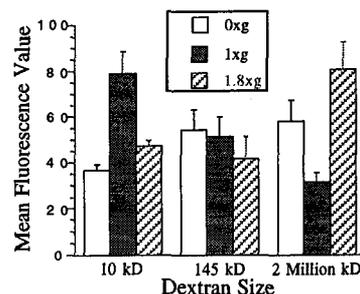
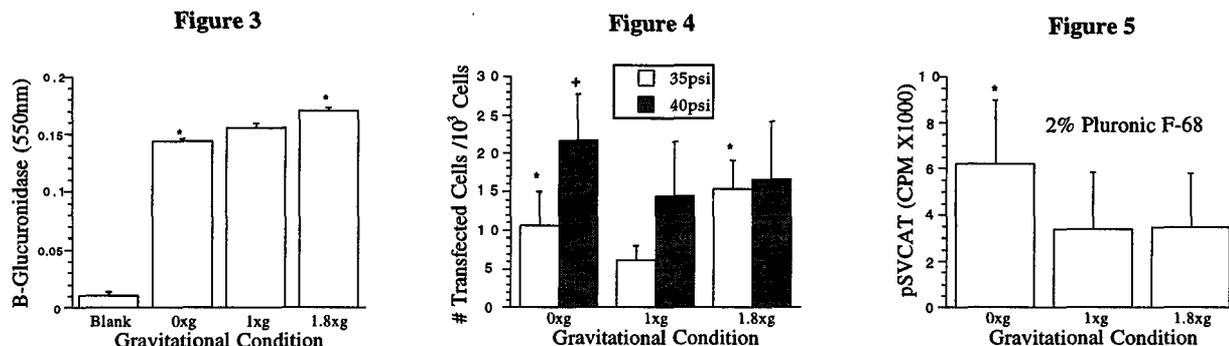


Figure 2



This conclusion was confirmed by the experimental observation that intracellular vesicle fusion with the plasma membrane in PMA-stimulated HL-60 cells, a process essential for resealing of a membrane wound, was significantly ($p < 0.001$; $n = 4$ per condition) inhibited in microgravity but enhanced in hypergravity (Figure 3). No significant amount of β -glucuronidase was released by unstimulated control cells exposed to parabolic flight (Figure 3). Transfection efficiencies of primary human skeletal muscle cells with the pSV β plasmid construct were significantly ($* - p < 0.01$; $n = 20$ per condition) enhanced in microgravity and hypergravity compared to normal gravity. When a greater impact pressure (i.e. 40 psi vs. 35 psi) was used, the transfection efficiency remained significantly ($+ - p < 0.01$; $n = 20$ per condition) higher in microgravity than under either normal or hypergravity conditions (Figure 4). Using a quantitative enzyme assay for the product of the pSVCAT plasmid construct, we determined that the membrane active agent PF-68, previously shown to enhance both resealing of membrane wounds and transfection rates in ground-based studies, significantly ($p < 0.05$; $n = 20$ per condition) increased primary human skeletal myocyte transfection in microgravity compared to normal or hypergravity conditions (Figure 5).



CONCLUSIONS

Our results indicate that microgravity *per se* has an effect upon the resealing process of mechanically-induced plasma membrane wounds. We have previously shown in ground-based experiments that membrane resealing is linked to the physical properties of the plasma membrane, such as membrane fluidity and tensile strength. Alterations in these parameters have also been shown to alter the fusogenic properties of the plasma membrane. The disruption of stimulated primary granule fusion in differentiated HL-60 cells by microgravity, the same intracellular membrane/plasma membrane fusion process required for membrane wound resealing, indicates that microgravity may effect the macromolecular structure of the plasma membrane in some fashion. Such changes in plasma membrane properties may explain why tissue cultured human skeletal muscle cells appear to be more susceptible to plasma membrane damage when mechanical load is imposed during microgravity compared to the levels of damage observed when load is applied under normal or hypergravity conditions..

Although preliminary, these experimental observations have several operational implications. These include the possibility that excessive mechanical load placed on muscle tissue in microgravity may result in greater levels of muscle damage than anticipated from ground-based models. A second implication is that membrane adaptation during space flight may result in membranes which have attenuated function upon return to normal gravity. In addition, during the adaptation period, biological membranes may exhibit abnormal function. These include inhibition of membrane fusion and inhibition of cell-cell signaling associated with membrane-associated channels and receptors. Examples of such processes include neuronal transmitter release at the synapse which could lead directly to alterations in motor neuron activity, cognitive function and peripheral vascular tone. A third implication is that an altered gravity environment (i.e. microgravity or hypergravity) can be utilized to enhance the transfer of genetic material into primary human cells by modulating the effectiveness of membrane wound-mediated transfection.

ERYTHROPOIETIN STIMULATES INCREASED F CELL NUMBERS IN BONE MARROW CULTURES ESTABLISHED IN GRAVITY AND MICROGRAVITY CONDITIONS

D. Houston-Hawkins¹, O. M. Hurst¹, S. Oduntan¹, and S. O. Fadulu¹,

¹The Department of Biology, Texas Southern University, Houston, TX 77004

INTRODUCTION

The induced anemia associated with space travel greater than 8 days compromises the oxygenation of the various tissues throughout the body. Davis and his colleagues (1996) report that after eight days of space travel, the number of erythrocytes is reduced by greater than 83% and corpuscular volume is significantly diminished. Mental acuity and physical performance are impaired by the physiological change of tissue hypoxia. Efforts in our laboratory are directed towards inducing the production of fetal hemoglobin (HbF) by the hemopoietic system. Fetal hemoglobin (HbF) has been shown to have a higher affinity for oxygen, and its post natal production is thought to be a countermeasure that improves tissue oxygenation. We are currently testing the efficacy of erythropoietin to induce the differentiation of uncommitted stem cells in bone marrow cultures towards the erythroid line. The derived erythroblasts are called F-cells, because 10 - 25% of their hemoglobin is fetal hemoglobin. Image analysis will be used to quantitate F-cell numbers while protein electrophoresis will be used to measure the variations in fetal hemoglobin expression.

METHODS

Four milliliters (4ml) of normal human bone marrow was resuspended in 36 ml of IMDM with 10% fetal calf serum, 10% horse serum, and 5ul/ml of penicillin streptomycin. Cell count and viability was obtained by using a hemacytometer and the trypan blue dye exclusion method. Ten mL of this mixture was placed into the 10 ml HARV vessel to the *Synthecon* Bioreactor, while 2 aliquots of 10 ml of the same were plated into 2 X 75cm³ tissue culture flasks. The remaining mixture was distributed and plated into 25cm³ tissue culture flasks, 25cm³ tissue culture plates, and 6 well tissue culture microtiter plates. Erythropoietin (human recombinant, from Sigma, St. Louis, MO.) was added, at 2U/ml, to half the cultures under gravity conditions and to the culture in the bioreactor. An untreated microgravity cultures were established seven days later. The cultures were maintained in a 5% CO₂ tissue culture incubator at a temperature of 37°C and a humidity > 99%. After one week in culture, three (3) homogeneous, 50 ul aliquots were removed from each treatment condition and image analysis and protein electrophoresis were conducted. Standard cell counts were also taken.

RESULTS

Provisional results (N=3) show that under microgravity conditions, the three (3) parameters measured showed a decrease in values over initial values at the establishment of the cultures. The total cell count decreased by 86% in the untreated cultures, while total cell counts in the EPO treated, microgravity cultures showed an 82% decrease. A diminished HbF band over baseline was seen for both the EPO treated and untreated cultures in microgravity, as observed on the cellulose acetate blot. (Densitometry of the HbF bands are forthcoming). Using image analysis (Advance Logic Research, Inc., Irvine, CA), the F-Cell count in 5 randomly selected fields showed a decrease of 2.5% and 1.5% in untreated and EPO treated cultures in microgravity, respectively. The count was based on equivalent total cell counts for both culture conditions of microgravity and gravity. Under gravity conditions, the total cell count was increased 39% and 42% in the untreated and EPO treated cultures, respectively. Cellulose acetate blots for the protein electrophoresis, showed a visible increase in HbF in the EPO treated cultures over the untreated cultures. For 5 randomly selected fields, the EPO treated cultures showed increased of 5.5% in the number of F-cells, while the untreated cultures only showed a 1.0% increase in observable, large nucleated F-cells. Other remarkable observations were noticeable cell volume differences in the microgravity and gravity established cultures. The microgravity culture cells visibly appeared to have less cellular volume than those of the gravity established cultures.

CONCLUSION

Our current series of experiments have been to develop a protocol to stimulate uncommitted bone marrow stem cells to differentiated into F-Cells. While microgravity has diminished the proliferation of the total bone marrow cell count, erythropoietin (EPO) appears to significantly increase the F-cell count and fetal hemoglobin expression as measured by protein electrophoresis in cultures under the influence of gravity. Although the total cell count was significantly decreased in the microgravity cultures, EPO treatment appeared to induce a greater number of F-cells than untreated cultures in microgravity cultures. Future studies will be to gather more definitive results from our

erythropoietin studies and to further induce differentiated cultures to express higher fetal hemoglobin. The Extract NXO6999 has been clinically shown to increase blood serum levels of fetal hemoglobin in sickle cell and thalassemia patients (Fadulu, 1995). Development of a prophylactic drug regime, proposed by our research finding, might be effective in inducing an increased production of fetal hemoglobin. Such a development should counterbalance the erythropoietic deficit and ameliorate the anemic conditions experienced by astronauts involved in lengthy space travel. The results of these studies should also improve the anemic conditions and oxygenation deficits experienced by sickle cell and beta thalassemia sufferers.

Acknowledgements:

This research is funded by a National Aeronautics and Space Administration grant "Microgravity and Sickle Cell Anemia" Grant Number: NAG 9-862. Special thanks to Astronaut Ellen Baker, MD. , the technical advisor for this project.

References

Chang J, Morgenstern G, Deakin D, Testa N, Coutinho L, Scarffe J, Harrison C, and Dexter T. "Reconstitution of Haemopoietic Systems With Autologous Marrow taken During Relapse of Acute Myeloblastic Leukaemia and Grown in Long-Term Culture"(1986): *Lancet* 1: 294-5.

Davis TA, Wiesmann W, Kidwell W, Cannon T, Kerns L, Serke C, Delaplaine T, Pranger A, and Lee K. "Effect of Spaceflight on Human Stem Cell Hemoatopoiesis: Suppression of erythropoiesis and Myelopoiesis"(1996): *J. of Leukocyte Biology* 60 : 69-76.

Fadulu SO. "Composition and Method for Treatment of Hemoglobinopathies", (1995) United States Patent: 5,447,720 September 5, 1995.

Wednesday, June 11

Session WA3
Room 3
8:30 - 11:30 a.m.

517-52

074197

141.

3 26975

Technology - 1

PHYSIOLAB A CARDIO VASCULAR LABORATORY

D. Cauquil¹, C. Laffaye¹, A-L. Camus¹, V. Gratchev², I. Alferova², A. Kotovskaya², G. Weerts³

¹Centre National d'Etudes Spatiales, Toulouse, France

²Institute of Biomedical Problems

³Institut de Médecine et Physiologie Spatiales

PHYSIOLAB is a cardio vascular laboratory designed by CNES in cooperation with IMBP, with both scientific and medical objectives :

- to gain a better understanding of the basic mechanisms involved in blood pressure and heart rate regulation, in order to better predict and control the phenomenon of cardio vascular deconditioning
- to provide real-time monitoring of cosmonauts during functional tests

This laboratory was launched to the MIR station in 96, and it was set up and used for the first time by Claudie ANDRE-DESHAYS during the French mission CASSIOPEE (August 96).

The scientific program is performed pre, in and post flight to study phenomena related to the transition to microgravity and to the return to Earth conditions.

Particular emphases was laid on the development of real-time telemetry to monitor LBNP test. During these tests, physiological signals are sent to the MIR control center (TSOUP) and displayed in real-time on a dedicated computer. This function was successfully demonstrated during the CASSIOPEE mission, this providing the medical team at TSOUP with efficient means to control the physiological state of the cosmonaut.

Based on the results of this first mission, IBMP and CNES will continue to use PHYSIOLAB on the Russian crews. CNES also intends to take advantage of the forthcoming French mission on MIR to improve this system, with the perspective of developing a new laboratory for the Space Station.

MEDEX: A FLEXIBLE MODULAR PHYSIOLOGICAL LABORATORY

J. Kass and G. Kampfer

PANKOSMOS GmbH, Medical and Space Technology, Munich, Germany

INTRODUCTION

MEDEX is an advanced medical experiment support system designed for space applications, whose first spaceborn application shall be during the German-Russian mission MIR'97. This paper will describe the system and its operation philosophy; it will also present how the system can be expanded with additional modules as required.

SYSTEM OVERVIEW

The Medex design concept is based on the integration of medical instruments into small, battery powered Measurement Modules, which transmit physiological data via an infrared link or via cables to a Central Data Unit (CDU). A laptop computer serves as an intelligent terminal of the CDU offering capabilities for numerical and graphical display of procedures and data as well as for command input via keyboard. The Central Data Unit provides for data acquisition and extensive real-time processing capabilities as well as high data storage capacity. Although interfaces to the MIR orbit-to-ground data links are available, the prominent feature of the system is its ability to support medical experiments without ground-based assistance.

At present there are five modules consisting of a Basic Measurement Module (ECG, Respiration, arterial blood pressure, temperature, EMG) an Impedance Measurement Module including Electrical Impedance Tomography, a Micro-Circulation Diagnostic Module, Portapres, a Stressor Module (pressure cuffs for the thighs, static ergometer, and LBNP pump control), Cranial Doppler. There is also a Vest for carrying some of the miniaturised modules about the test subject. All modules have a power interface connector, and may be supplied by an accu pack or by a central power supply.

OPERATIONAL PHILOSOPHY

The Central Data Unit allows for easy access to the various circuit boards, which makes exchange of specific interface boards for future reconfiguration of the system a relatively simple task. This unit also includes a power converter and a battery charging device for the accumulators. A second power converter is designated for peripheral units with high power dissipation like a pump system for the LBNPD, a Cranial Doppler Module and a Stressor Module, as required for the specific experiment scenario.

The experiment operation is supported by the laptop computer. As soon as the computer is switched on the test subject is permanently guided by the experiment procedure being displayed on the screen of the computer. For each step the subject is prompted and has to verify his activity by pressing ENTER. Errors or critical parameters are visually and acoustically indicated. All relevant physiological signals are acquired, analyzed and displayed on-line, thus allowing the subject at every moment to be fully aware of the ongoing experiment. The reaching of a hazardous condition will immediately lead to an automatic shutdown of the stimulation device or the whole experiment.

Beside the preprogrammed nominal mode there are capabilities for the test subject to intervene himself. He can deliberately change preset parameters within the allowed ranges. He can switch to off-nominal experiment procedures and repeat or skip certain experiment phases.

This concept allows for the test subject being able to perform most activities of even complex experiments all by himself and with very little risk of operational failures. Thus, the extremely precious resource of crew time can be reduced to a minimum.

MODULAR PHILOSOPHY AND FUTURE PLANS

Because the Medex system is conceived and built in a modular manner, it is possible to run it with any combination of modules, which are linked together with Daisy Chains. In this manner not only is the set-up and operation simplified depending on its application, but it is possible to extend the system in the future. In the past, complex systems have been built at great cost for a space mission, to become obsolete before a chance of reflight offers itself. With Medex, it is possible to add a new module or replace an outdated module relatively simply; an identical system exists on the ground where such changes can easily be tested and verified. Some new modules being considered for the future are a dedicated EMG module and an EEG module,

Mailing Address:

Dr. J. Kass
PanKosmos GmbH
Robert-Koch-Strasse 2
82152 Planegg, Germany

Phone/ Fax: +49 - 89 - 899 342 44

A Sensate Liner for Personnel Monitoring Applications

Dr. Eric J. Lind
NRaD, San Diego, Ca.

Dr. Sundaresan Jayaraman
Dr. Rangaswamy Rajamanickam
Ms. Sungmee Park
Georgia Institute of Technology, Atlanta, Georgia

Dr. Robert Eisler
Mission Research Corporation, Fountain Valley, Ca.

Mr. Gil Baird
Mr. Dave Cadogan
Mr. Tony McKee
ILC Dover, Frederica, De.

This program develops and demonstrates technologies useful for implementing a manageable cost effective systems approach to monitoring the medical condition of personnel by way of an instrumented uniform hereafter referred to as a *Sensate Liner* (SL). The SL consists of a form fitting garment which contains and interconnects sensing elements and devices to an electronics pack containing a processor and transmitter. The SL prototype requires fiber, textile and garment development. The SL textile consists of a mesh of electrically and optically conductive fibers integrated into the normal structure (woven or knitted) of fibers and yarns selected for comfort and durability. A suite of SL garment compatible embedded biological and physical sensors are then integrated into the SL. The initial SL sensor suite is selected to improve triage for combat casualties. This mesh forms a conductive backplane hosting and integrating sensors for biological phenomenon such as blood pressure, pulse rate (heart rate), etc.; physical sensors including - barrier penetration, motion, position etc.; environmental sensors such as temperature, etc.; while including ultra low power alert and monitoring technologies. The initial proof of concept suite includes sense modalities for heart rate, respiration, torso penetration (occurrence, classification and localization), and motion. Of particular interest is the detection and location of high speed projectiles penetrating the human body. Experimental results utilizing polymer acoustic transducer arrays indicate entrance wound locations can be detected with an acceptable degree of accuracy. Additional concepts for SL sensors for medical monitoring will be discussed. The SL, while individually tailored, will utilize computer automated design technologies such as laser scanning amenable to custom mass production. This work is sponsored by the Defense Science Office of the Defense Advanced Research Projects Agency, as well as the Defense Logistics Agency.

SECURE REMOTE ACCESS TO PHYSIOLOGICAL DATA

Dr. Rex E. Gantenbein

Department of Computer Science, University of Wyoming, Laramie WY 82071-3682

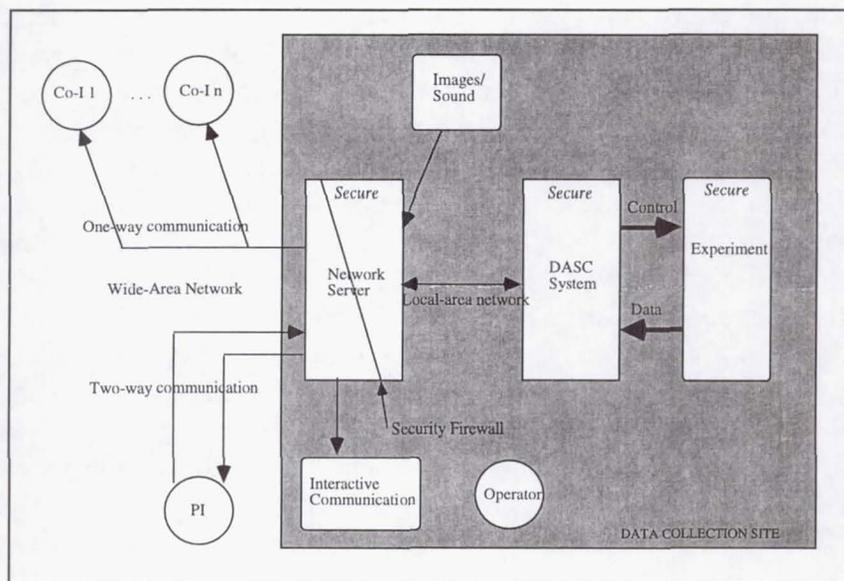
INTRODUCTION

Given the geographically distributed nature of space-based physiological experimentation, particularly in light of the International Space Station Alpha science programs, improving technologies for remote access to scientific data is an extremely important task. Freeing scientists from the need to be physically present at an experiment site allows scientific data acquisition to be more mobile and cost-effective. In addition, multiple investigators can simultaneously access and analyze acquired data, thus improving results dissemination and furthering collaboration.

However, when open technologies like the Internet are used to provide computer access to experimental data, maintaining the integrity and privacy of that data is a significant problem. Our work combines the high-quality delivery of computer-collected physiological data over networks with mechanisms to ensure the security of such data. Our approach is based on *distributed computing*, which involves using multiple computers, connected by a network, in a coordinated manner. In most stand-alone physiological experiments, data collected at a site can either be analyzed in real time by an attending experimenter, or it can be stored and forwarded to other scientists for off-line review. While the collected data can be analyzed in this latter situation, the "immediacy" of the data and the associated value of real-time review of the data and feedback among the observers is lost.

RESEARCH DESCRIPTION

A distributed data acquisition system, as shown below, uses Internet technology to link computers located at an experiment site with other computers to transfer the acquired data (as well as video or sound) from the site to laboratories or offices in near-real time, providing remote observers with digital display images and audio/video communication links to the site. This allows scientists with connections to the site to inobtrusively observe the subject and the images or data being acquired without being present at the site, as well as remotely interact with an operator, the subject, or even the equipment used to acquire the data.



To maintain security in this distributed system, the data acquisition and stimulus control (DASC) computer is separated from the network server, as shown in the figure. Using a *request broker* architecture that isolates all data acquisition processes from the network, a "firewall" is created that can only be crossed with proper authorization. In this way, network access is strictly controlled. Varying levels of access (including both one-way observation and two-way communication and control of the DASC system) can be provided using this architecture.

RESULTS

A prototype for a secure, remotely accessible data acquisition system is currently being implemented on a network of computers in the Distributed Computing Laboratory at the University of Wyoming, in cooperation with the Life Sciences Research Laboratories at NASA Johnson Space Center. The DASC system, which was created during the author's sabbatical at JSC, runs on a Power Macintosh using National Instruments' data acquisition hardware and Labview software. The network server is implemented on a Gateway 2000 486 machine using Windows NT and the TCP/IP network protocol. Remote access is tested on a Macintosh IIfx using viewer software, also written in Labview, that is connected to the experiment site through an Internet link and can both display acquired data from a file located on the server and start, stop, and configure the experiment on the DASC system from the remote site.

A description of the completed prototype, including performance data and security test results, will be presented at the conference.

CONCLUSION

The request broker approach to designing distributed data acquisition systems aids the development of secure systems for remote access to physiological data. With increasing emphasis in space science on improving the accessibility of data gathered from humans in space and maintaining the privacy and integrity of that data, this work has significant potential. The prototype will provide both a testbed for the evaluation of the approach and a template for development of other systems of this kind.

DARA VESTIBULAR EQUIPMENT ONBOARD MIR

P. Hofmann¹, A. Kellig¹, H.-U. Hoffmann², G. Ruyters²

¹Kayser-Threde GmbH, Wolfratshauser Str. 48, D-81379 München;

²Deutsche Agentur für Raumfahrtangelegenheiten (DARA, German Space Agency) GmbH, Königswinterer Str. 522-524, D-53227 Bonn

INTRODUCTION

In space, the weightless environment provides a different stimulus to the otolith organs of the vestibular system, and the resulting signals no longer correspond with the visual and other sensory signals sent to the brain. This signal conflict causes disorientation. To study this and also to understand the vestibular adaptation to weightlessness, DARA has developed scientific equipment for vestibular and visuo-oculomotoric investigations. Especially, two video-oculography systems (monocular – VOG – and binocular – BIVOG, respectively) as well as stimuli such as an optokinetic stimulation device have successfully been employed onboard MIR in the frame of national and European missions since 1992.

The monocular VOG was used by Klaus Flade during the MIR '92 mission, by Dr. V. Polyakov during his record 15 months stay onboard MIR in 1993/94 as well as Dr. Ulf Merbold during EUROMIR '94. The binocular version was used by Thomas Reiter and Sergej Avdeyev during the 6 months EUROMIR '95 mission. PIs of the various experiments include H. Scherer and A. Clarke (FU Berlin), M. Dietrich and S. Krafczyk (LMU München) from Germany as well as C.H. Markham and S. Diamond from the United States.

VOG and BIVOG

The video-oculographic MIR hardware has been developed by Kayser-Threde in close cooperation with the ENT Laboratory of the Free University of Berlin (Prof. H. Scherer, Dr. A. Clarke), software for evaluation by Sensomotoric Instruments (SMI, Teltow). The BIVOG system, to be described in more detail, is an upgraded version of the monocular VOG MIR '92, which allowed video images of one eye to be recorded by a CCD camera mounted on a lightweight face mask. Now both eye images are obtained employing ray tracing via infrared mirrors. Thus, free-field-of-view, as well as experiments in which visible light is occluded are possible.

The video pictures are recorded on a professional studio quality Betacam recorder, which has been modified to be able to simultaneously record two monochrome images. Acceleration and rate sensors are mounted on a head frame and the data are recorded. A dictaphone (to guide the experimenter), an eye monitor (to focus) and a calibration unit are part of the new BIVOG system. A biteboard can be attached to fix the camera to the skull.

Much development effort was invested into the new binocular face mask (IR mirrors and coatings, diodes and illumination arrangements, selection of a small IR sensitive camera, optical arrangements etc).

OUTLOOK

We also will present new prototype-developments for a next generation BIVOG, which may - as part of NASA's Human Research Facility - become the 3D eye tracking system for the early utilisation phase of the International Space Station.

THE KINELITE PROJECT : A NEW POWERFUL MOTION ANALYSIS SYSTEM FOR SPACELAB MISSION

M. Venet¹, H. Pinard², J. Mc Intyre³, A. Berthoz³, F. Lacquaniti⁴

¹Centre National d'Etudes Spatiales, Toulouse, France

²Matra Marconi Space, Toulouse, France,

³Laboratoire de Physiologie de la Perception et de l'Action, CNRS-Collège de France, Paris, France

⁴Instituto di Neuroscienze e Bio immagini, CNR, Roma, Italy

INTRODUCTION

The goal of the Kinelite project is to develop a space qualified motion analysis system to be used by the scientific community, mainly to support neuroscience protocols.

The first flight opportunity will be the Neurolab mission when the Kinelite is installed inside the Spacelab module to support the experiment "Ball Catching" (Principal Investigator : Pr. A. Berthoz, Co Investigators : J. Mc Intyre, F. lacquaniti).

HARDWARE DESCRIPTION

The main equipment, developed by Matra company, is a motion analysis system (Kinesigraph) based on real time data processing of video signals generated by CCD cameras. The points of interest are identified by small, light weight, reflective markers worn by the subject performing the experiment ; additional markers are attached to other important elements, such as the ball for the "ball catching" experiment. The markers are lighted by infra red flashes synchronized with the cameras. The system, in real time, at 200 Hz, detects the markers, computes and records on a removable hardisk, the two dimensional (in each camera CCD plane coordinate) position of these markers.

- The marker detection is based on a 2D cross correlation filtering technique giving a very good rejection of false markers (e.g. light reflection on screen).

- The marker position computation is based on a barycentric algorithm giving a sub pixel accuracy.

The three-dimensional trajectories of the markers are derived from the two-dimensional recorded positions using camera calibration data. This calibration is achieved in two steps : cameras are first precalibrated on ground, to determine the parameters relative to lenses and CCD position ; cameras position relative to each others (translations and rotations) are then determined by filming a small reference object (200 mm sized square) in the field of view. This 2 steps procedure has been developed to facilitate calibration operation in microgravity.

Other equipments, developed to support the "ball catching" experiment, include :

- an analog signal conditioner, used to acquire EMG and acceleration data

- a automatic ball launcher, able to throw a 400g silicone covered ball at various speeds from 0,5 to 3 m/s.

- a foldable seat, used to give the subject performing the experiment a comfortable and reproducible position.

Algorithms used in the system are based on the commercial ELITE™ system developed and sold by Bioengineering Technology and System company (BTS in Milano, Italy).

KINELITE MAIN CHARACTERISTICS

- Camera field of view : 45°

- Number of camera : 2 to 8 (4 for Neurolab)

- Acquisition frequency : 200 Hz

- 3D accuracy : 2 mm

- Other acquired signals (at 800 Hz) : 3 acceleration and 8 EMG signals

- Main dimensions : 45 cm x 45 cm x 30 cm

- Mass : 23 kg

- Power consumption : less than 200 W

THE EXPERIMENT

The "Ball Catching" experiment objective is to examine the internal reference frames and models used by the Central Nervous System (CNS) for the interpretation of sensory informations and the coordination of motor outputs during a task of catching a falling ball.

On ground, with a 1g accelerated ball trajectory, the anticipation movement of the subject to catch the ball is linked to the initial speed of the ball, as perceived by vision.

In flight, in 0g, the ball trajectory (constant speed) will be modified compared to what the subject use to know and the CNS will have to re-learn the correct way to catch it.

Practically, the subject will be seated in a foldable seat to give reference and a 400g soft ball will be thrown toward him at various speed ; upper and lower limb movements, synchronized with muscle activities will be recorded to study the re-learn process.

CONCLUSION

By now, three complete sets of Kinelite have been delivered for Neurolab : one for training, one for the Principal Investigator, one for flight. Besides the Neurolab mission, the intent of CNES developing this equipment is to propose it for various other experiments, scientific or technological (e.g. in the robotics field) inside Spacelab, the MIR Russian station or the International Space Station Alpha (ISSA).

THE TECHNICAL EVOLUTION OF THE FRENCH NEUROSCIENCES MULTIPURPOSE INSTRUMENTS ONBOARD THE MIR STATION

J. M. Bois,¹ Y. Matsakis,² J. McIntyre,³ and A. Shulenin⁴

¹Centre National d'Etudes Spatiales, 18 avenue Edouard Belin, Toulouse, France, ²MEDES, 18 avenue Edouard Belin, Toulouse, France, ³Laboratoire de Physiologie de la Perception et de l'Action, CNRS-Collège de France, Paris, France, ⁴Institute for Biomedical Problems, Moscow, Russia

Since the first French flight in 1982, the CNES has developed a wide range of instruments, especially in the Neurosciences. More specifically, the instrument designed for the French mission on the Russian station focused on the study of the adaptation of cognitive processes, together with the French and Russian laboratories.

This cooperation, on the one hand, between the scientists and the engineers, and on the other hand, between the French and Russian space communities, will continue during the next four-month mission in 1999.

The scientific needs that provide the basis for the development of these instruments, mainly deal with the analysis of the mechanisms employed by the central nervous system during perception of visual images, manual forces, or intervals of time, and the evaluation of the adaptive capacities of the brain when reconstructing the global perception of the body in microgravity.

The design of these instruments has considerably evolved from rather simple equipment to much more sophisticated tools that are being studied for future missions. Four steps can be defined:

- from a simple adaptation of an echograph to carry on the first neurosciences experiment (the ARAGATZ mission)
- the ILLUSIONS and VIMINAL instruments during the ANTARES and ALTAIR missions
- the COGNILAB instrument developed for the CASIOPEE mission and reused in 1997
- to the preliminary design of the 1999 mission payload, including virtual realities concepts.

These instruments include the following subsystems:

- the visual stimulation systems (from a narrow screen to a flat 8 x 8 inches LCD matrix, and to the virtual realities)
- the force feedback systems (from the first 2-axes hand controller used in the laboratories to a 3-axes instrument onboard the Mir station)
- the body restraint systems (from some straps to a complex seat with a lot of accessories)
- the hardware and software systems (from a little computer to a biprocessor computer with more than 100,000 lines of code).

Besides the evolution of scientific requirements, the experience gained during the flights led to progressive improvements of these different parts. The long-duration mission in 1999 should open a new experimental area with the implementation of virtual reality concepts.

EXTENDED GROUND-BASED RESEARCH IN PREPARATION FOR LIFE SCIENCES EXPERIMENTS

M. Schuber, D. Seibt, J. Zange
DLR, Microgravity User Support Center (MUSC), D-51147 Köln

INTRODUCTION

For many years the DLR Microgravity User Support Center (MUSC) has supported external scientists in the fields of life and material sciences. For Spacelab and MIR flights scientists were supported pre-, in- and post-flight for preparing, performing and evaluating their experiments. For the support of biological and biomedical research the MUSC has set up infrastructure for experimentation in Cell and Molecular Biology, Plant and Animal Biology as well as in Human Physiology, which is offered to international scientists for extended ground based research and the preparation of flight experiments.

RESEARCH TOPICS AND DEDICATED MUSC INFRASTRUCTURE

For 0-g simulations, hypergravity experiments and extended ground based research different facilities can be utilized for integrated scientific investigations. Research topics and dedicated devices are described in the following.

For gravity related questions, MUSC offers to use equipment covering the interests both below as above 1 g, to answer scientific questions on stimulus-reaction chains on the cellular or individual level of biological samples. Clinostats can be used for the simulation of μg conditions by rotating samples perpendicular to the earth's g vector. On-line observations of small organisms will be performed with microscopical clinostats (e.g. fast rotating clinostats with CCD cameras). Larger sample volumes (as cell suspensions) are to be treated by cuvette clinostats. The Slow Rotating Centrifuge Microscope (NIZEMI), with on-line observation, is available for hyper-g applications from 1 g to 5 g. Samples can range from very small organisms (single cells, tissues etc.) or physico-chemical systems up to samples of approx. 4 cm in diameter.

Different incubation devices ($10^\circ - 36.5^\circ \text{C}$) are available for research in the fields of gravitational biology and biological processing, e.g. cell cultures, aquatic vertebrate larvae, protoplasts, fungi and plants can be investigated. Microscopical observation is enabled by a workbench with a microscope with standard techniques. Electrofusion of different cell types (protoplasts, animal cell cultures etc.) can be done.

Apart from gravitational biology research, equipment, especially suited for photochemical and photobiological studies, is available to investigate the influence of other environmental parameters on organisms or materials. The extreme environment simulation facilities are designed to expose cellular systems or biomolecules to a combination of controlled environmental conditions, such as different kinds of radiation, high or low pressure, high or low temperature, and defined atmosphere composition, and to analyze the responses to the selected parameters. Combined studies on the interaction of gravity and environmental aspects are possible.

Magnetic Resonance Spectroscopy is a non-invasive and non-hazardous tool for investigations on metabolic processes. In vivo MR spectroscopy (MRS) promotes understanding of biochemical metabolic regulations and bioenergetics in intact cells, perfused organs, animals and man. With the aid of continuously recorded ^{31}P -MR spectra changes in steady state concentrations of intermediate products of the energy metabolism like phosphagen, ATP, and inorganic phosphate can be measured. Precise intracellular pH values can be measured as an indicator for lactic acid formation and cellular acid-base regulations. For experiments on small invertebrates, thin tissue preparations or plant material the 5 mm ^1H , ^{31}P -solenoid probe head can be utilized.

Magnetic Resonance Imaging (MRI) is capable of demonstrating anatomical structures and pathologies in details. Our equipment can be used for whole body studies on animals up to the size of an adult rat. For the identification and quantitative examination of anatomical structures different standard MRI techniques are available. Qualitative and quantitative changes, i.e. regional capillary blood volume or temperature, in tissues of intact organisms can be measured by functional imaging method based on the Snapshot-FLASH method.

For all acquired experimental data in the a.m. fields of research, capabilities and tools can be offered to evaluate the raw measurements by video processing, image analysis, database techniques and statistics.

MEDES CLINICAL RESEARCH FACILITY AS A TOOL TO PREPARE ISSA SPACE FLIGHTS

A. Maillet, A. Pavy-Le Traon

Clinique Spatiale - MEDES, CHU Rangueil, 1 avenue Jean Poulhès, F-31054 Toulouse Cedex, France
Phone : (+33) 562.174.950, Fax : (+33) 562.174.951 and E-mail Alain.Maillet@cst.cnes.fr.

INTRODUCTION

Space research in Life Sciences is usually embedded in larger research programs related to scientific or clinical issues of health management. In the field of human physiology, this is illustrated by the main following examples: adaptive physiology, where space research deals with upcoming scientist issues and has a global approach of physiology; preventive medicine, where space medicine is beyond current achievements in occupational medicine and develops innovative countermeasures for physical fitness or health rehabilitation; clinical research, where ground based research and support to space experiments need complex and integrated multicentric studies (bed-rests, immobilization, confinement...); development of new services, such as Telemedicine in remote sites; development of new hardware and medical procedures.

MAIN CHARACTERISTICS

MEDES is an Economic Group of Interest created in 1989 by French institutions involved in manned space flights. The main shareholders are the French Space Agency and Toulouse Hospital. Other partners are two Sports Physiology Research and Training Centers (Toulouse and Aix-Marseille), the French Nuclear Research Commission (CEA) and several universities, all of them involved in space scientific programs. MEDES relies on the scientific and medical skills of its partners to ensure: Medical activities related to French and European manned space flights; Implementation of ground based simulations (studies on physiological and psychological adaptation, evaluation of countermeasures); Transfer of the skills gained in Space research to applications in Health, as for instance Telemedicine projects in remote sites, managed by MEDES; Development of links between Space research and Health industries (The OSTEOPOROSIS Project as part of the European Space agency Application Program).

The Clinical Research Facility (CRF) is a 1000 m² multipurpose facility located within the Toulouse Rangueil Hospital. The CRF has been designed to host most of the ground based clinical or human factors experimental research necessary to conduct space research, as for instance: simulation of effects of space environment (bed-rest, confinement, circadian rhythms...); performance of experiment test-beds; ground based control experiments; equipment and/or procedures assessment; medical screening and check-up for healthy volunteers; training courses of students and hosting of Ph.D. students. Similar support will be proposed to Health professionals.

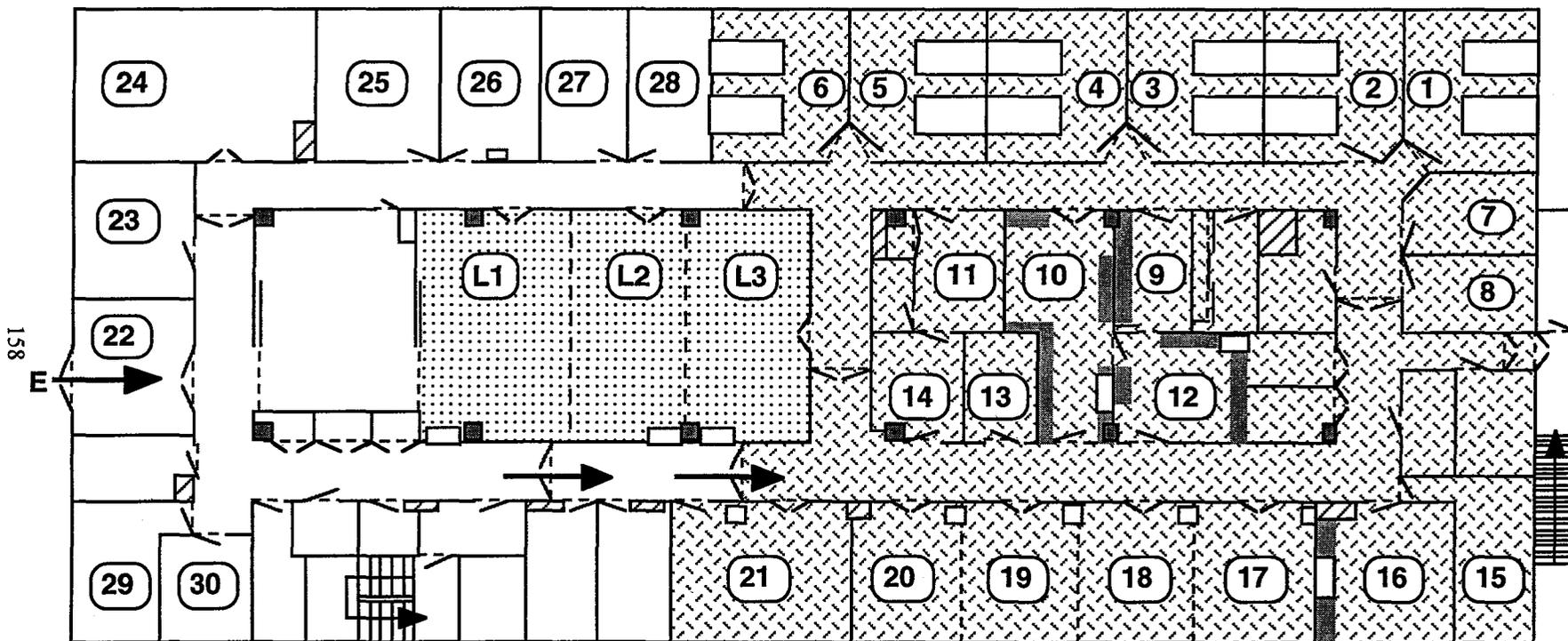
CRF has access to the biomedical facilities of a high standard hospital (NMR - CT scan - biological analyses...) and its own internal equipment includes the main required devices : to test and monitor specific physiological functions (LBNP - tilt table - rotating chair...); to handle biological samples. It allows monitoring of the main environmental parameters or linked to the subject such as : diet, activity (24 h video monitoring), temperature 20-25°C ± 0,5°C, acoustics (isolation of 60 dB from external environment, background less than 35 dB), and light (natural / artificial ranging from 0 to 500 Lux). CRF capacity ranges from : 4 beds for strictly controlled sleep or alertness studies, enabling blood sampling and physiological recordings without disturbing the patient, 20 beds for bed-rest studies, up to 26 beds for miscellaneous tests.

CRF is served by highly skilled professionals matching the requirements of good clinical and good laboratory practices. Services will be strictly tailored to the needs. They can be limited to a simple logistics accommodation, hosting of researchers and go up to the co-ordination of international multicentric studies.

CONCLUSION

In the frame of future long-term space flights and ISSA missions, MEDES has already co-ordinated and organized a 42 days bed-rest study, performed on behalf of CNES and ESA with the participation of 15 European research groups. Building space research on robust ground based research, developing synergies between space and health, opening space research to the widest health professionals community and therefore contribute to develop the benefits from space research are now possible objectives with the availability of a permanent and sophisticated space laboratory. MEDES, with the CRF is willing to contribute to the development of a successful utilization program of the International Space Station.

MEDES - CRF LAYOUT



MEDES Clinical Research Facility (CRF) including three areas : 1- Office area (white part, from 22 to 30) and the main entrance (E); 2- Multipurpose laboratory zone (dotted area : L1-L3, is a 120 m² or 1,300 square feet) with entrance fitted for large size objects (2,50 m x 2,50 m or 8.20 to 8.20 feet); 3- The experimental zone with controlled environment (hatched area) : rooms 1-6, high quality chambers; rooms 7-8, psychomotor test laboratories; logistics zone (rooms 9-14 and 15-16); modular rooms (17-20: standing for 4 chambers, 4 laboratories or one bigger laboratory); room 21 is a specific laboratory where orthostatic tests (tilt and lower body negative pressure tests or Coriolis stress tests - on rotating chair - can be performed).

Wednesday, June 11

Session WP1
Room 1
2:30 - 5:30 p.m.

518-53
074329
11r.
326976

**Human Behaviour in Long-Term
Missions**

Psychological Support for International Space Station Missions

O.P. Kozerenko¹, O.O. Ryumin², A.D. Sled¹, and A.W. Holland³

¹Institute for Biomedical Problems, Moscow; ²Gagarin Cosmonaut Training Center, Moscow Region; ³NASA Johnson Space Center, Houston

The exclusive use of multinational crews on the International Space Station requires that attention be directed to the increased role of psychological, social and cultural factors in influencing morale, performance and interpersonal and inter-group cooperation. The implementation of an effective Psychological Support (PS) system will be critical. PS is defined as a complex system of psychological methods, means and actions to be implemented preflight, in-flight and postflight by the ground support team controlling the mission, with an objective to maintaining the crew in good health, optimal emotional and performance status, and effective interactions. A wide range of PS activities influence the crewmember's psychological status and adaptation, including, but not limited to, regulating the impact of information, teaching self-regulation and team behavior skills, compensation for insufficient social communication, 'reconstruction' of the ambient environment to prevent monotony, and provision of multicultural interaction skills.

The joint Mir-NASA program, which has been in place since 1995, adopted the fundamental principles of the Russian PS system and modified them for an international crew. This experience has resulted in a number of 'lessons learned' and demonstrated the effectiveness of psychological correction based on the PS system. A number of changes in the PS system were made over the course of the multiple joint missions. These are discussed, as are the methods and means needed to effectively address the larger number of cultures that will be working together on the International Space Station.

PSYCHO-SOCIAL TRAINING FOR MAN IN SPACE

R. Kass¹ and J. Kass²

¹ Concordia University, Department of Applied Social Science, Montreal, Canada

² PANKOSMOS GmbH, Medical and Space Technology, Munich, Germany

INTRODUCTION

In preparation for the international manned space station various international and national space agencies are already participating with the Russian MIR programme with short, medium, and long term presence on the MIR station. Although selection criteria for all crew include careful psychological screening, with some effort also regarding team build-up, little or no effort is expended in the area of psycho-social- or team training.

In this paper our thesis regarding psycho-social training for manned space flight shall be propounded, and it shall be argued why such training is necessary for long-duration flight. Furthermore, an overview will be presented of how such a training programme will look like with examples of past applications given.

THE PROBLEM

It has been observed in past long duration space missions that despite major effort expended regarding crew selection and teaming, compatibility statistics are at best mediocre. It has also been observed that this tends to impair the efficiency of work done on board, as well as increase operational errors. This not only has a deleterious effect on the scientific and technical work on board, but could endanger the safety of the station.

With the makeup of the crew becoming more and more multi-cultural, moreover coming from very differing professional backgrounds, the consequences of incompatibility and the accompanying costs in decreased effectivity and safety are aggravated as the potential for psycho-social problems increases, thus begging that this growing problem be addressed.

THE SOLUTION

To date, nothing much has been done on all sides in the area of psycho-social and team-work training. Our thesis is that training in Human Relations and team-work is important and should take place. Such training would provide the crew with tools to use during the mission as it unfolds and problems arise; it gives them skills that help them avoid the problems from arising in the first place, and then, if they do, to prevent them becoming acute. The training would focus on such areas as morale, norms, decision-making, handling conflicts, and leadership struggles. Moreover, such training increases the crew's effectiveness as a team both in the preparation and training phase as well as during the space mission.

Mailing Address:

Professor R. Kass
Concordia University
Department of Applied Social Science
c/o 2177 Lincoln Street, Apt. 10
Montreal, H3H-1J2
CANADA

Phone/ Fax: (001) 514 -932 0827 / -932 3948

STUDY OF THE PSYCHOLOGICAL ADAPTATION OF THE CREW DURING A 135-DAY SPACE SIMULATION

E. Rosnet,¹ G. Cazes,¹ A. Vinokhodova²

¹Laboratoire de Psychologie Appliquée de l'Université de Reims 57 rue Taittinger, 51096 Reims Cedex France,

²IBMP, Moscow, Russia

Three Russian subjects stayed in a chamber for 135 days during the HUBES space simulation held in Moscow in 1994-1995. Our purpose was to examine human adaptation to specific stress factors such as isolation and confinement and to compare and validate psychological methods for monitoring and support in flight.

Quantitative and qualitative psychological tests were completed before (baseline data), during and just after the simulation. These tests included free reports, free discussions, group problem solving, evaluation questionnaires on crew members, sociometric questionnaires, and the Matrix of Inter and Intra Processes in Group Test and Personal Choices Questionnaire. Content analysis was processed for the qualitative tests and statistical processes for repeated measures, when possible, for the quantitative tests.

The main findings concern i) the sensitivity of the subjects to the stress factors, ii) the interrelations within the crew and between the crew and the ground support, and iii) the consequences of individual reactions upon the group behavior. Surprisingly, isolation was not a key factor for the subjects who were more concerned by recreational activities, family, and work. When difficulties occurred, individuals chose to project their problems on the others ("I'm well, but the others don't see me that way"). At the end of the simulation, one of the crew members was considered as less integrated to the group by the other two subjects, who, however, acted to protect (successfully) the general cohesion and mood of the crew. The three subjects developed a weak tendency to "group thinking." There was an opposition with one ground support team member, although this conflict was rather limited and didn't seem to have any consequence on the crew efficiency.

Baseline data predicted that difficulties could occur in the crew member who did not integrate well into the group. Both quantitative and qualitative tools were adequate, although qualitative tests gave a closer approach to the actual situation that developed during the simulation.

INTERPERSONAL RELATIONSHIPS IN SPACE SIMULATION : THE LONG-TERM BED REST IN HEAD-DOWN TILT POSITION

WEISS, Karine & MOSER, Gabriel

LABORATOIRE DE PSYCHOLOGIE ENVIRONNEMENTALE (CNRS - URA 1270)
Université Paris V - Institut de Psychologie
28, Rue Serpente
75006 Paris - FRANCE
Tel. : 1.40.51.99.18
Fax : 1.40.51.99.19
e-mail : weiss@msh-paris.fr

Symposium topic area : human factors

The long-term bed-rest has been organised by ESA and CNES*, in order to simulate physiological effects of weightlessness: eight volunteers had to stay during 42 days in bed, in head down tilt position (- 6°). There were two subjects in a room, they could not be alone and it was difficult for them to have their own personal space and intimacy. Like in outer space, in that circumstances, interpersonal relationships were of prime importance, and we proposed to study what effects isolation and confinement stress had on social relationships.

This situation has allowed, from a systematic observation, the study of the evolution of the relational behaviour in dyads, and to quote some social indicators of adaptation. Results show an important withdrawal, and the time passed alone is marked by the emergence, during the experiment, of specific preferential activities. A behavioural contagion is observed in each dyad (people have the same activities at the same time), excepting the unique case of abandon. Moreover, the most important rates of inactivity and withdrawal were noted in this case of giving up. Verbal indicators were useful to comment these results and showed that, for all the dyads, one of the two subjects was always playing a regulating role by expressing a very positive perception of the situation.

With this set of results, we emphasize the importance of psychosociological factors in isolation and confinement. Thus, it appears that different modalities of interpersonal relationships, and not only verbal interactions, play a significant role in adaptation to stress situations.

* ESA : European Space Agency
CNES : Centre National d'Etudes Spatiales (France)

PSYCHOLOGICAL ADAPTATION IN GROUPS OF VARYING SIZES AND ENVIRONMENTS

J. Wood¹, D. Lugg², D. Eksuzian¹, D.L. Harm* and M. Shepanek³

¹KRUG Life Sciences Inc., ²Australian Antarctic Division, ³NASA HQ, Washington DC, ⁴NASA/Johnson Space Center

INTRODUCTION

Several incidents of friction among crewmembers, tensions between ground and space crews, and lapses in judgment have been reported in both the Russian and U.S. space programs (Collins, 1985; Cooper, 1976; Bluth, 1980, Newkirk, 1990). In some cases, these lapses were judged to be potentially dangerous. As other space agencies gain more experience in long-duration space flight on the International Space Station, they can expect similar incidents. A number of factors are presumed to account for behavioral problems that occur in space. Common factors on all space flights are isolation and confinement, and the accompanying psychological discomfort they can cause. Similar feelings of hostility and occurrences of interpersonal tensions have also been reported in other isolated and confined environments (Gunderson, 1963; Lugg, 1977; Weybrew, 1963). The overall goal of the present research is to identify changes in psychological variables and to track adaptation in persons living and working in extreme, isolated environments. Data from twelve groups in diverse analogue environments will be summarized and compared in this presentation.

METHODS

Computerized questionnaires were administered twice weekly to crewmembers throughout the duration of their exposure to the extreme environments in which they were living and working. Data were collected from two 100-day Antarctic science traverses, one 60-day Antarctic construction traverse with a multi-cultural crew, seven Antarctic winter stations (260+ days), and two (30- and 60-days) crews in the Early Human Testing Facility. Groups ranged in size from 4 to 20 members. The traverse teams were all male, while all other groups were of mixed gender.

RESULTS

Individual and group differences in interpersonal tensions, individual morale, perceptions of the social and work climates of the various groups were examined. Results of time series regressions suggest that personal factors of the individual crewmembers, and local events are the primary causes for the changes observed in these varied groups.

CONCLUSION

Data from these twelve groups demonstrate the need for additional research in selecting and composing teams for long-duration space missions. The approach demonstrated in the current research has the potential to identify the events and personal characteristics that affect individual psychological adaptation and group functioning, in order to answer some of these important questions.

REFERENCES

- Bluth, B.J. Social and psychological problems of extended space mission. American Institute of Aeronautics and Astronautics, International Meeting and Technical Display on Global Technology 2000; 1980 May 6-8; Baltimore MD 7p A80-32854.
- Collins, D.L. Psychological issues relevant to astronaut selection for long-duration space flight: a review of the literature. 1985. Technical report for the Air Force Institute of Technology, Human Resources Laboratory, Houston, TX; AFMRL-TP-84-41.
- Cooper, H.S.F. A house in space. New York: Bantam Books; 1976.
- Gunderson, E.D.; Nelson, P.D. Adaptation of small groups to extreme environments. *Aerospace Medicine*, 34: 1111-1115; 1963.
- Lugg, D.J. Physiological adaptation and health of an expedition in Antarctica, with comment on behavioral adaptation. ANARE scientific report. Series B (4) medical science. Publication No. 126. 1977; 188p. Canberra, Australia.
- Weybrew, B.B. psychological problems of prolonged submergence. In Burns, N.M.; Chambers, R.M.; Henchler, E (eds). Unusual environments and human behavior – physiological and psychological problems of men in space. New York: MacMillan Company; 1963

DEVIANCE AMONG EXPEDITIONERS: DEFINING THE OFF-NOMINAL ACT IN SPACE AND POLAR FIELD ANALOGS

M. Dudley-Rowley

Sociology Department, The University of South Carolina, Columbia, South Carolina 29208 and OPS-Alaska, 2664 Montana Road, Fairbanks, Alaska 99709

INTRODUCTION

A review of the record of those living and working in extreme environments like space, under the seas, and the polar regions demonstrates that deviant acts do occur and take a number of forms. These run the gamut from a crewmember's show of frustration in communication with ground control or base, to his/her not using a piece of equipment in the prescribed way by the manufacturer, to delaying to report a critical piece of information, to expressed hostilities among the crew, to the display of mental disorders. However, what behaviors are off-nominal in the extreme environment have never been defined with any precision.

Such an understanding is imperative now that humans verge on permanent societies in space. This paper reports the results of a reliability pre-test administered to both academic sociologists with only a general interest in deviance and to social and behavioral scientists working with deviance in extreme environments. The purpose of the pre-test was to lead to a standard definition of off-nominal behavior in isolated and confined environments (ICE). A sociological examination of deviance in the extreme environment is key to understanding the psychosocial human factors of space and space-like environments. Deviance relates to several questions about human behavior in space and space analog environments which have emerged in the past two decades.

Extracting off-nominal acts in their order of occurrence from diaries, logs, participant accounts, reports, and personal interviews can facilitate answering the following research questions: 1) What is the relationship between the number of off-nominal acts occurring during missions and crew size? 2) What is the relationship between the number of off-nominal acts occurring during missions and crew heterogeneity? 3) What is the relationship between the number of off-nominal acts occurring during missions and mission duration? 4) Is there really a "third-quarter phenomenon", where the number of off-nominal acts increases dramatically after the half-way point of the mission is reached? 5) If there are relationships among off-nominality and crew size, heterogeneity, and mission duration, are the relationships similar for space and polar field environments?

METHODS

The pre-test was provided to 6 participants, 3 social and behavioral scientists who have published extensively on human behavior in extreme environments, and 3 sociologists who were not familiar with the topic. It consisted of a number of passages of narrative drawn from four isolated and confined settings: 1) a Russian space station, 2) an American space flight, 3) an Arctic venture of the 1920s, and 4) a modern Antarctic field expedition. Passages were selected to depict a wide variety of behaviors. The purpose of the pre-test was stated in the instructions, that its aim was to arrive at a standard definition of the off-nominal act in the extreme environment. No presumed definition of what comprised an off-nominal act was advanced to the participants, except to suggest that it was an interaction among crew which prevented optimal functioning and ran the gamut from a minor incident to one of larger proportion. Participants were instructed to name any off-nominal acts they could discern in the passages and to number them. No participant was told the name of any other participant and they were all asked not to discuss the test with others interested in deviance in extreme environments.

RESULTS

Respondents fell into two discrete clusters: 1) those who extracted every item of deviant behavior possible from the passages, from trivial to life-threatening, and 2) those who discounted possible off-nominal acts owing to the extremity of circumstances, physical illness, or the cultural background of the actors. However, there was uniformity of agreement in labeling off-nominal those behaviors which involved mental disorder, poor hygiene, or were enacted by a distant base or ground control without due consideration for the position of the crew in the field.

CONCLUSION

Although the response to the pre-test did not issue a unanimous statement about off-nominality in extreme environments, it provided insight into elements that must be included in a standard definition and lent direction to a follow-up stage of testing to accomplish that goal. This phase of testing, in progress, is described, as is further research designed to use the operationalized definition of off-nominal acts in extreme environments.

GETTING EFFECTIVE SLEEP IN THE SPACE-STATION ENVIRONMENT

Wayne Rhodes

Rhodes & Associates Inc., Toronto, Canada, M2H 2Z3

INTRODUCTION

Getting enough sleep is important for all human beings who must function in the world. Sleep has particular significance, where a person's level of performance is critical to system safety. Therefore, establishing an effective system for ensuring sleep while aboard space-stations is surely a goal worth pursuing. In light of the 12-hour shifts and demanding tasks faced by space-station crew, sleep will be a very necessary element, not only for the safe operation of the space-station, but also for the health and well-being of the crew. The nature of sleep within the space-station environment, and the strategies which could be considered to counter-act the problems of sleeping in a space-station, are discussed.

FOCUS OF THE PRESENTATION

This is a discussion paper which reviews research on sleep, as applied within the aviation, transportation, processing industries, and in extreme environments. Information on sleep problems encountered, work arrangements that are effective, scheduling, core human factors concerns, personal coping strategies and interventions which can help alleviate problems, will all be addressed.

RESEARCH TO DATE

Research on shiftwork, hours of work, sleep patterns and functioning, sleep hygiene, and various strategies and countermeasures against fatigue (napping, drug therapy, light, lifestyle counselling) all point toward the need for a systematic approach to managing sleep. Sleepiness and fatigue have been compared with drunkenness, the resultant impact on performance showing that severe impairment indeed happens much too often, as reflected in North American accident statistics. An individual's ability to cope with fatigue and working shifts appears to decline with advancing age. The quality and quantity of sleep have been shown to correlate significantly with performance on standard cognitive tests. Various accounts from astronauts indicate that long work hours and reduced sleep periods, as well as decreased quality of sleep, all affect work performance. The sleep environment is clearly an important factor in promoting sleep and maintaining it. Preparation for sleep, a dark, quiet room, absence of stimulants and increased levels of melatonin in the body, and a comfortable sleeping position, all are necessary to allow a person to achieve sleep quickly and throughout the specified sleep period. Finally, the day-night cycle is an important factor in regulating sleep. Circadian effects will impact the success in getting to sleep and maintaining it.

RECOMMENDATIONS FOR SLEEPING IN THE SPACE-STATION

Recommendations for sleeping in a space-station environment include:

- ▶ astronaut training requiring knowledge about sleep hygiene, working shifts, relaxation techniques, dietary effects etc.
- ▶ provision of comfortable and effective sleeping quarters.
- ▶ application of strategic napping, task rotation, and other strategies for alleviating boredom and fatigue
- ▶ staffing on space-station that allows off-duty personnel freedom from responsibility, except in extreme cases.
- ▶ scheduling of shifts which is consistent with the circadian rhythm.
- ▶ introduction of artificial day/night cycles which are strong enough to set the circadian rhythm.

HUMAN SLEEP AND CIRCADIAN RHYTHMS ARE ALTERED DURING SPACEFLIGHT

A. Gundel, V.V. Polyakov¹

DLR Institute of Aerospace Medicine, Cologne, Germany; ¹Institute for Biomedical Problems, Moscow, Russia

INTRODUCTION

Numerous anecdotes in the past suggest the concept that sleep disturbances in astronauts occur more frequently during spaceflight than on ground. Such disturbances may be caused in part by exogenous factors, but also an altered physiological state under microgravity may add to reducing sleep quality in a spacecraft. The presented investigations aimed at a better understanding of possible sleep disturbances under microgravity. For the first time, experiments were conducted in which sleep and circadian regulation could be assessed simultaneously in space.

METHODS

Four astronauts took part in this study aboard the Russian MIR station. Sleep was recorded polygraphically on tape together with body temperature. For a comparison, the same parameters were measured during baseline periods preceding the flights.

RESULTS

The circadian phase of body temperature was found to be delayed by about two hours in space compared to baseline data. A free-run was not observed during the first 30 days in space. Sleep was shorter and more disturbed than on earth. In addition, the structure of sleep was significantly altered. In space, the latency to the first REM episode was shorter, and slow-wave sleep was redistributed from the first to the second sleep cycle.

CONCLUSIONS

Several mechanisms may be responsible for these alterations in sleep regulation and circadian phase. Most likely, altered circadian zeitgebers on MIR and a deficiency in the process S of Borbély's sleep model cause the observed findings. The change in process S may be related to changes in physical activity due to weightlessness.

METHODOLOGICAL APPROACH TO STUDY OF COSMONAUTS ERRORS AND ITS INSTRUMENTAL SUPPORT

A.P.Nechaev¹, V.I.Myasnikov¹, S.I.Stepanova¹, O.P.Kozerenko¹, G.F.Isaev², S.V.Bronnikov²

¹Institute of Biomedical Problems, Moscow, Russia, ²Rocket-Space Corporation "Energiya", Koroljov, Moscow Region, Russia

INTRODUCTION

The methodological basis of the proposed approach is the idea of system essence of human-operator's error. In accordance with this principle an error is result of many causes associated with both operator and conditions, process and tools of performance. In our study¹ an error is considered in psychophysiological aspect. In the framework of Human-Operator Reliability Problem such approach is topical since psychophysiological state is integral characteristic reflecting the result of interaction between external (environmental) factors and internal (mental, physiological, physic features and qualities of human) factors.

METHODS

The method includes procedures of the collection, identification and analysis of information gained in the course of medical and psychological support of space flights. Indirect character of inflight data received mainly through radio and TV channels causes the necessity of application of expert evaluations method for their identification. This procedure is carried out by experts with using the following parameters:

- CREW ERRORS: causes and consequences;
- PSYCHOPHYSIOLOGICAL STATE: behavior, motor activity, speech and sleep disturbances, mood, emotional reactions, psychosensory disturbances, will-power, dominant interests, deprivation phenomena, suggestions/complaints, general condition;
- PECULIARITIES OF WORK-REST SCHEDULE: sleep-wake rhythm disturbances, crew workload, symptoms of the psychosomatic discomfort;
- GROUP PHENOMENA: group cohesion, intragroup guidance, group interaction.

The parameters of psychophysiological state, work-rest schedule and group behavior are evaluated with the scales reflecting power of negative symptoms. According to these scales the symptoms with the highest psychophysiological "cost" have the highest evaluations. The integral parameters of psychophysiological state and work-rest schedule tensity are calculated by adding up all separate evaluations. The method of correlation analysis is used for evaluation of interrelanion between crew errors and other parameters. Accumulation, systematization and processing of inflight information are supported by data base which is instrumental component of the present method. Its operanion does not require special preparation of users due to usage of friendly interface and dialogue mode of work.

RESULTS

The results of the analysis of interrelanion among crew errors, cosmonauts psychophysiological state, work-rest schedule tensity and group characteristics in several flights on "Mir" Station are presented in the paper.

CONCLUSION

We consider that the results obtained using the present approach will allow to expand our knowledge about a nature of cosmonauts errors and may be utilized in the practice of the space flights support, cosmonauts training and manned spacecrafts design.

¹ This work is supported in part by contract NAS-15-10110

Wednesday, June 11

519-54
074624

Session WP2
Room 2
2:30 - 5:30 p.m.

326977
71.

Human Factors Research
Under Ground-Based and Space
Conditions - 2

**TRAINING ASTRONAUTS USING THREE-DIMENSIONAL VISUALIZATIONS
OF THE INTERNATIONAL SPACE STATION**

R. Bagaoutdinov³, Barker¹, G. Bodrikov³, Y. Borodin³, M. Cheburkov³, E. Dahlstrom¹, D. Ivanov³,
P. Karpunin³, R. Katargin³, A. Kiselyev³, Y. Kotlayarevsky³, N. Maris¹, D. Nelles¹, M. Rycroft²,
A. Schetinnikov³, and F. Tyerlov³

1. Maris Multimedia Limited, 99 Mansell Street, London, E1 8AX, U. K.

2. International Space University, Boulevard Gonthier d'Andernach, 67400 Illkirch, France

3. Maris Limited, Kaliningrad, Russia

Recent advances in Personal Computer technology have led to the development of relatively low-cost software to generate high resolution three-dimensional images. The capability both to rotate and zoom in on these images superposed on appropriate background images enables high-quality movies to be created. These developments have been used to produce realistic simulations of the International Space Station on CD-ROM. This product will be described and its potentialities demonstrated. With successive launches, the ISS is gradually built up, and visualized over a rotating Earth against the star background. It is anticipated that this product's capability will be useful when training astronauts to carry out EVAs around the ISS. Simulations inside the ISS are also very realistic. These should prove invaluable when familiarizing the ISS crew with their future workplace and home. Operating procedures can be taught and perfected. "What if" scenario models can be explored and this facility should be useful when training the crew to deal with emergency situations which might arise. This CD-ROM product will also be used to make the general public more aware of, and hence enthusiastic about, the International Space Station program.

MEASUREMENT AND VALIDATION OF BIDIRECTIONAL REFLECTANCE OF SHUTTLE AND SPACE STATION MATERIALS FOR COMPUTERIZED LIGHTING MODELS

L. Fletcher³, A. Aldridge², C. Wheelwright², and J. Maida¹. ¹Lyndon B. Johnson Space Center, Houston, TX
²Lockheed Martin Engineering and Sciences Co. (LME&SC), Houston, TX, ³LME&SC, Moffet Field, CA

INTRODUCTION

Awareness of surroundings critically impacts an astronaut's ability to carry out assigned tasks. Evaluation of lighting conditions for performance of on-orbit tasks and training with realistic lighting are important to successful shuttle missions and for the assembly of Space Station. Since the Gemini program, NASA's Johnson Space Center has used ground-based mockup testing and scale models to evaluate on-orbit illumination and to provide training for astronauts. Some of these procedures are very expensive to carry out and only partially simulate the actual conditions. In order to evaluate lighting conditions which cannot easily be simulated on Earth, the Graphics Research and Analysis Facility (GRAF) has been developing the capability to provide computerized simulations of various illumination conditions using the ray tracing program, Radiance, developed by Greg Ward at Lawrence Berkeley Laboratory. This capability permits the computational prediction of light levels on surfaces in complex configurations for visibility or viewing analysis. The sun, diffuse earth shine, and/or a collection of vehicle-based lights may be used as illumination sources. Computed lighting levels (luminance from surfaces and illumination on surfaces) were validated by comparing computed values to measurements made during ground-based lighting tests.

MATERIAL REFLECTANCES

Successful use of the GRAF lighting modeling depends on having material properties that describe the reflection of light from various spacecraft structures (overall reflectivity of the surface, the distribution of the reflected light in each direction from the material surface, and the distribution of the incident light being reflected.) The reflectivity of a material is the ratio of the reflected light intensity to the incident light intensity at any angle in a hemisphere above the plane of the reflecting surface (Bidirectional Reflectance, BR). BR depends on the material reflectance and the angle of the reflected light. The Bidirectional Reflectance Distribution Function (BRDF), the ratio of the reflected luminance to its incident illumination, is constant at all angles for a perfectly diffuse material, but will have a peak at the angle of incidence equal to the angle of reflection when the material also has a specular component. The measured reflectance data can be described with three parameters: the total reflectance, the amount of this reflection which is specular, and the angular width of the specular distribution.

BR and BRDF can be measured with a gonireflectometer, which collects reflected values from a material sample over the angles in a hemisphere. The constant diffuse component was determined by averaging values from a hemispherical sweep in 5 degree steps. A high resolution sweep in 0.5 degree increments was then run around the approximate peak of reflectance to determine the peak value, peak location, and width of the specular reflectance.

The averaged diffuse reflectance component was important because this constant was integrated over the hemisphere when calculating the total reflectance and was also subtracted from the specular peak during the process of fitting a Gaussian curve to the data. A computer program was written to process the hemispherical sweep data and produce the constant diffuse reflectance component by averaging points in the data set.

Once the diffuse reflectance component was determined, the fine angular sweep was used to determine the width and height of the specular component by plotting the intensity for each point against the angle between the peak angle and the vector, yielding a 2D plot. The best Gaussian fit to the data was found, after subtracting the constant diffuse value. This "best fit" Gaussian peak amplitude and width, along with the constant diffuse component were used to generate the actual parameters needed for Radiance. The half width at half maximum (HWHM) is calculated by finding the angle in the Gaussian fit where the BRDF value is half the value at the Gaussian peak.

VALIDATION OF COMPUTER LUMINANCE CALCULATION

When accurate lamp and material properties, along with accurate geometric objects, are incorporated into the Radiance lighting calculation, the computer calculation of the luminance from each surface in the scene should agree with measured luminance values within the limits of accuracy of the model and the measurements. Limitations of comparisons between calculated and measured values are: light sources may not have uniformly regular distributions, lamp intensities degrade over time, material surfaces may be non-uniform, and slight errors in orientation of lamps or surfaces can result in significant differences in measured luminance values.

Three earth-based tests have been used to check the luminance calculations against measured values. These three tests provided validation of the modeling under different lighting conditions. The first test used the solar simulator to model the effects of direct sun light on the docking target used in the Shuttle-MIR docking. The second test used shuttle Remote Manipulator Assembly (RMA) lights on the docking module to simulate exterior shuttle lights for

night time Shuttle-MIR docking. The third test used interior station fluorescent lighting in a mockup of the International Space Station Habitation Module where multiple reflections from surfaces are important.

RESULTS

The reflected distribution of light from more than 70 samples including 42 interior and exterior Shuttle and ISS paints, Shuttle Tiles and Thermal Blankets used to protect the Shuttle during re-entry, materials for the Hubble Space Telescope, materials used for ISS structures and thermal protection, and material from the Russian MIR Space Station were collected. A process was developed to convert this data into Radiance Parameters forming a data base which includes the total reflectance from the surface, the percent of the total reflectance that is specular, and the angular width of the specular distribution for each material. It was found that the measured specular widths of the paint samples could be grouped according to the type of finish: gloss, semi-gloss, or flat. A statistical analysis of these samples found a mean HWHM of 1.64 ± 0.20 degrees for all gloss samples, and 5.464 ± 2.06 degrees for semi-gloss samples. All flat samples were treated as being entirely diffuse. From the results of the gloss samples, it is clear that as long as the paint is thick enough to completely cover the surface to prevent reflections from the material surface on which the paint is applied, then the under surface can be ignored.

A data base of light values was also compiled for most of the luminaries in the Shuttle and Space Station programs which included part number, location/use, size, power, peak illumination, and beam width.

CONCLUSION

Methods of predicting luminance levels have been shown to be reasonably accurate for a variety of lighting conditions including direct sun light and artificial lighting. The Radiance calculations have shown good results for both exterior and interior lighting environments.

These luminance calculated images are being displayed using algorithms which model Shuttle camera parameters to produce accurate simulations of the Shuttle and ISS cameras in order to determine light levels that are adequate for camera viewing. The figure below shows an actual downlink video image from STS-80(left) and a computed image generated 2 months before launch.

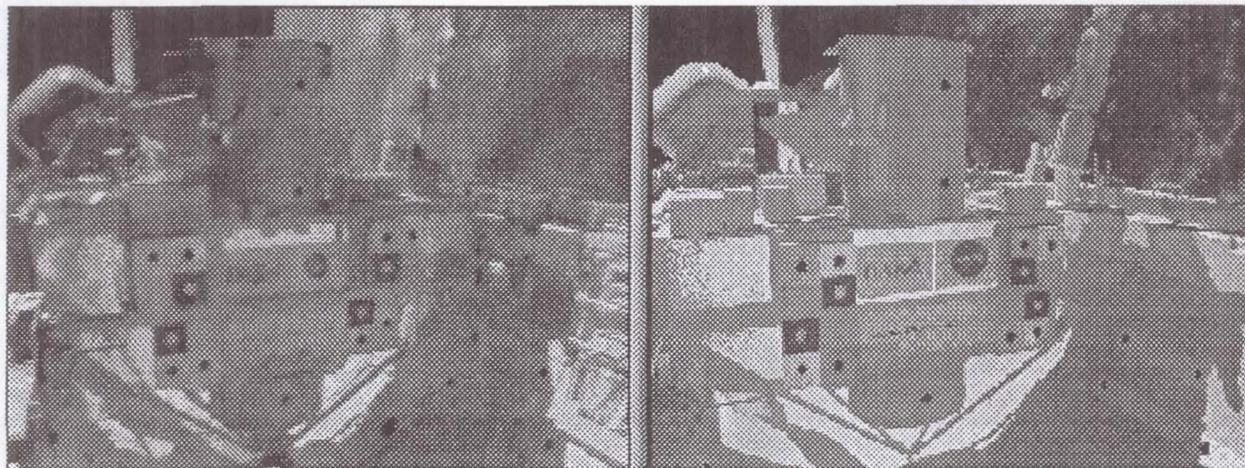


Figure: Image on left is downlink video from STS-80. The image of the right is computer generated, two months before launch. Slight differences in beta angle, geometry, and time do not have a major impact on the basic luminance image.

EFFECTS OF ENVIRONMENTAL COLOR ON MOOD AND PERFORMANCE OF ASTRONAUTS IN ISS

N. Kwallek

Environmental Design Research Center, Division of Interior Design, The University of Texas at Austin, Austin, TX
78712

INTRODUCTION

Effects of the interior environment on astronauts' feelings of well-being, morale, and productivity are important—especially when considering upcoming long-term space flights on the International Space Station (ISS). Varied social-cultural backgrounds of crew members may affect their mood and performance while living/working together in the confined space of the habitation module. On earth or in space, interior color can have a great environmental effect on individuals. However, individuals differ in their ability to screen out environmental stimuli. Individual sensitivity within a particular environment might hinder performance. On the other hand, some individuals, having a higher threshold level, might need more environmental stimuli to perform at optimum level.

METHODS

The purpose of this study was to examine the impact of three color schemes in confined spaces on mood, worker productivity, and performance over a 4-day work week relative to individual differences in environmental sensitivity. Matched on relevant variables, 90 subjects were randomly assigned to one of three confined spaces. Each confined space was painted either predominantly bright red, light blue-green, or the white color used by NASA for the habitation module mock-up at JSC. The bright red and light blue-green color schemes were derived from the conclusions of a NASA sponsored literature review on the effects of interior color on individual characteristics such as mood, performance, and productivity. Data on a series of experiments were collected. The first involved data on individual mood characteristics which were collected twice daily. Short-term productivity tasks based on 30 minutes of standardized clerical tasks were administered on the first and the fourth work day. A major phase examined the impact of color on longer-term office tasks such as proofreading and typing administered at intervals for 1 hour and 15 minutes each workday.

RESULTS

For mood, on average, higher scores for Confusion and Tension were reported by workers in the red space than in the blue-green, while higher scores for Vigor were reported in the blue-green than in the red. Low screeners scored higher on Depression in the white space than high screeners. In terms of performance, primarily on the third and fourth days, subjects made more errors on proofreading and typing in the blue-green color, and to a lesser degree in the red space than in the white space. This was true regardless of stimulus screening ability. On the first and second work days, workers with high screening ability in the predominantly red color performing the long-term proofreading and typing tasks were more productive than workers with low screening ability. Conversely, on the first and second work days, workers with low screening ability were more productive on the long-term proofreading and typing tasks than high screeners in the light blue-green space. This was similar to the findings on short-term clerical tasks.

CONCLUSION

In examining the effects of the three different schemes on productivity and performance, the results suggest that individual stimulus screening ability may act as a moderating variable influencing how individuals experience a particular interior color. Implications about mood, performance, and productivity of astronauts during long-term space flight on ISS' habitation module will be discussed.

The study was developed under a grant sponsored by the Institute of Business Designers Foundation (IBDF) and funded by BASF Corporation and Interface Flooring Systems, Inc.

PSYCHOPHYSICAL MEASURES OF MOTION AND ORIENTATION: IMPLICATIONS FOR HUMAN INTERFACE DESIGN

A.M. Mead and B.D. Lawson.

Naval Aerospace Medical Research Laboratory, Pensacola, FL 32508; amead@namrl.navy.mil.

INTRODUCTION

Numerous methods have been used to elicit precise information from a subject regarding the orientation and motion he experiences in a dynamic motion environment. Finding the best method for a given situation is crucial to understanding problems such as spatial disorientation and for designing human-machine interfaces. NAMRL has embarked on a multi-year research effort, dedicated in part to evaluating various psychophysical measures of spatial orientation.

METHODS

In our first study, each upright subject (S) received a range of linear x-axis oscillations on a linear track, with resultant y-axis force angles of 15° and 30°. As a control, Ss were exposed to angular oscillation using the same frequencies and true y-axis pitch angles. We explored a variety of static and dynamic approaches to collecting body orientation estimates, including retrospective and concurrent verbal reporting of tilt and retrospective and concurrent laser horizon tracking. In our second study, Ss were exposed to head-centered y-axis rotation which progressed from 6 to 30 rpm in incremental steps and their responses were elicited every 30 seconds using one-to-three word queries and replies about motion and orientation. In our third study, Ss were rotated off-center at resultant gravito-inertial force angles of 45° or 60° in tangential-facing and in center-facing orientations. Subjects gave dynamic estimates of the perceived earth horizontal using a line of light and also provided retrospective verbal estimates of tilt.

RESULTS

Subjects tended to underestimate the resultant force angle in all measures during linear and angular oscillation. However, subjects came closer to accurately estimating the resultant force vector with some methods than others. The most to least accurate methods were: retrospective verbal report, subjective vertical tracking, laser retrospective horizon tracking, and laser concurrent tracking. For eliciting responses regarding movement illusions in our first two studies, verbal subjective reporting was the most consistent measure. Subjects' dynamic estimates during off-center rotation in two tangential headings were eventually tilted by about the same amount as the resultant force angle, but Ss tended to underestimate the resultant force angle during center-facing runs. In general, verbal and line-of-light estimates were well correlated for the center-facing stimulus and both tended to lag behind the stimulus during initial acceleration.

CONCLUSION

We conclude that the psychophysical method one employs to estimate orientation perceptions is important to the findings obtained. Different measures are appropriate to different stimuli and, indeed, may assess different aspects of an individual's orientation system. Attempts to standardize measures across studies must take this into account. While much of our data confirm early perceptual findings, the *dynamics* of tilt perception are a relatively unstudied aspect of the data that yield new interpretations. We will discuss our interpretations and their implications for the design of multimodal (visual, tactile, auditory) flight displays.

THE SOPITE SYNDROME REVISITED: DROWSINESS AND MOOD CHANGES IN STUDENT AVIATORS

B.D. Lawson¹, A.M. Mead¹, A. Apple², and L. Barton²

¹Naval Aerospace Medical Research Laboratory, ²Naval Operational Medicine Institute, Pensacola, Florida 32508 blawson@namrl.navy.mil

INTRODUCTION

Graybiel and Knepton coined the term *Sopite Syndrome* more than 20 years ago to describe the extreme drowsiness and mood depression they saw in subjects riding aboard the Pensacola Slow Rotation Room. They observed the syndrome even in subjects who had otherwise adapted to the motion and no longer experienced nausea. This motion-related syndrome has gone largely unexplored in recent years; we are initiating research into the Sopite Syndrome and seeking to determine its incidence in situations relevant to aerospace training and operations.

METHODS

We surveyed 1,945 aviation students who trained aboard the Multi-Station Disorientation Demonstrator (MSDD) and 40 airsick students referred to the Self-Paced Airsickness Desensitization Program (SPAD). These two studies are described below:

1) The MSDD consists of avection projector and 10 capsules that rotate off-center. We queried each student's symptoms before, during, and after a 15-min MSDD training session. MSDD Survey #1 ($n = 1585$) was open-ended and relied upon the student to recall his specific symptoms. We looked for post-hoc evidence of the Sopite Syndrome (i.e., motion-induced drowsiness increases and/or the appearance of unusual mood states defined by Graybiel and Knepton). MSDD Survey #2 ($n = 360$) was designed to yield a better estimate of drowsiness (the cardinal symptom of Sopite). We scored drowsiness using the Stanford Sleepiness Scale (1 = wide awake; 7 = falling asleep); motion sickness (MS) was scored similarly (1 = no symptoms, 7 = extreme discomfort). An increase over the baseline rating was counted as a possible incidence of MS or Sopite in that individual.

2) Student aviators who got airsick during their initial training flights were referred to the SPAD for treatment, many of whom were successfully returned to flight training afterwards. The SPAD required the participant to adapt to repeated head movements in four directions during gradually increasing rates of on-center rotation. Our SPAD Survey ($n = 40$, still ongoing) consisted of a battery of six different scales designed to detect changes in arousal and affect that could be indicative of the Sopite Syndrome. Incidence of Sopite was defined and coded using a similar strategy to MSDD Survey #2.

RESULTS

	MSDD Survey #1	MSDD Survey #2	SPAD Survey
Sopite frequency	3.7% of all students	28% of all students	77% of all students
Freq. of Sopite w/o other symptoms	19% of subgroup above	21% of subgroup above	3% of subgroup above

CONCLUSIONS

Our research has two main implications: (a) The Sopite Syndrome occurs frequently enough in two different motion environments to warrant further consideration; (b) the Sopite Syndrome appears to be the sole manifestation of motion sickness for some individuals. We conclude that this motion-related syndrome represents a poorly understood threat to performance that is not presently accounted for in most studies of sleep and fatigue during aerospace operations.

Wednesday, June 11

Session WP3
Room 3
2:30 - 5:30 p.m.

520-52
074625

326978

Technology - 2

12P

MONITORING PHYSIOLOGICAL VARIABLES WITH MEMBRANE PROBES

E. M. Janle, L. Yang and P. T. Kissinger
 Bioanalytical Systems, Inc., West Lafayette, Indiana 47906

INTRODUCTION

Successful long-term ventures of humans into space will require a complete understanding of the effects of microgravity on physiological systems and development of effective countermeasures to the deleterious effects of long-term residence under these conditions. Accomplishing this task will require a significant amount of in vivo research. Some of this can be ground-based simulations but much will have to be done in space. We have developed membrane probes and technologies which will facilitate obtaining and processing samples both in ground-based simulations and in on-board studies. Membrane probes also provide a method of studying physiological changes in different tissues simultaneously and therefore provide more complete physiological information than blood sampling alone.

Microdialysis and ultrafiltration probes employ hollow fibers, which can be implanted in living tissue for sample collection. In microdialysis, an isosmotic perfusion fluid is passed through the fiber. Substances in the tissue, with a smaller size than the molecular weight cut off of the membrane, diffuse across the membrane into the perfusion fluid and are collected. In ultrafiltration, a negative pressure is applied to the fiber and interstitial fluid is passed through the membrane, into the lumen and out of the animal.

In this project, we have validated microdialysis and ultrafiltration probes by in vitro recovery tests for electrolytes sodium, potassium, and chloride and for the metabolites glucose and lactate. The use of these probes in simulated microgravity research was demonstrated in the rodent mode.

METHODS

The ultrafiltration probe consisted of three 12-cm hollow fibers in a loop configuration bonded to a fluid conduction tube. The microdialysis probe consisted of a 5-cm membrane in loop configuration, bonded at each end to a fluid conduction tube. In vitro recovery tests were done by placing probes in a stirred solution of the analyte, which was maintained at 37° C. Samples obtained from the probes were compared with samples of the original solution. The range of concentrations investigated included the physiologically normal as well as pathologically high and low concentrations.

Rats were implanted with subcutaneous microdialysis and ultrafiltration probes and jugular catheters. After collecting baseline samples, the rats were placed in a suspension system with heads down and hind legs elevated to simulate the fluid shifts of microgravity. After one to two weeks in the suspension system, the rats were returned to the normal position for one week. Microdialysis samples were collected every two hours; ultrafiltration samples were collected twice a day. Blood samples were collected daily until catheters failed. Samples were analyzed for sodium, potassium, chloride, glucose, and lactate.

RESULTS

In vitro recoveries for each analyte are listed in table I.

Table I. In Vitro Recoveries

Analyte	Ultrafiltration	Microdialysis
Sodium	101% ± 2%	101% ± 2%
Potassium	94% ± 13%	106% ± 4%
Chloride	96% ± 4%	95% ± 7%
Glucose	99% ± 3%	90% ± 10%
Lactate	94% ± 5%	95% ± 7%

The implanted membrane probes provide a method for continuously monitoring changes in body chemistry. Since no cells are removed there is no limit to the number of samples which can be obtained as there is with blood sampling. Figure 1 illustrates the changes in subcutaneous and plasma sodium concentration during a baseline control period, after suspension and during recovery. Sodium levels are stable during the baseline period. After suspension there is an immediate decline in sodium below baseline followed by an elevation above baseline. When suspension is ended, the concentrations return to baseline values during the recovery period.

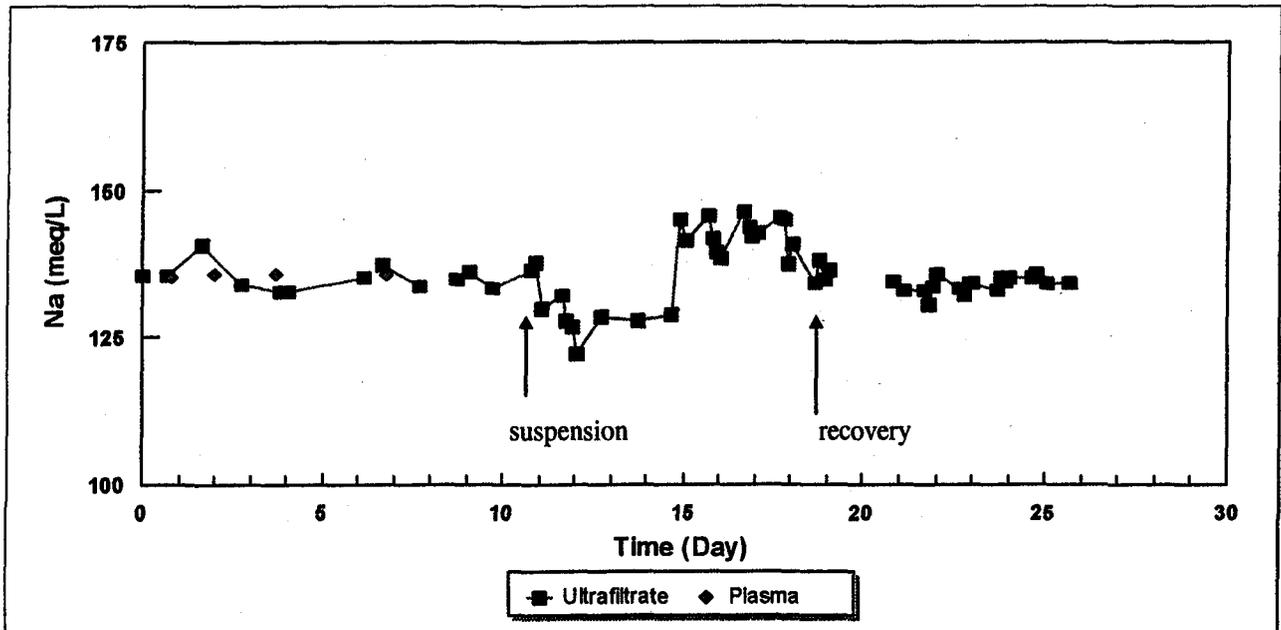


Figure 1. Subcutaneous ultrafiltrate and sodium concentrations in the rat during baseline control, head-down suspension, and recovery.

CONCLUSIONS

The *in vitro* recoveries indicate that the microdialysis and ultrafiltration probes are suitable for use in sampling these analytes.

The *in vivo* studies have demonstrated the potential of these techniques to obtain physiological data from animal models. These probes have the potential to be coupled with on-line sensors which would make it possible to acquire physiological data from animals in space without astronauts having to collect and store or process samples. This will facilitate the study of the physiological effects of weightlessness and the development of countermeasures.

REAL TIME CONFOCAL LASER SCANNING MICROSCOPY: POTENTIAL APPLICATIONS IN SPACE MEDICINE AND CELL BIOLOGY

Ana Rollan & Anthony P. McHale

Biotechnology Research Group, School of Applied Biological and Chemical Sciences, University of Ulster, Coleraine, Co. Londonderry BT52 1SA, Northern Ireland.

INTRODUCTION

In more recent times technological advances in medicine have tended towards developing non-invasive treatment modalities to replace more conventional invasive surgical procedures. One example of this has been the development of photodynamic therapy for the relatively non-invasive removal of abnormal tissues. This treatment modality involves the systemic administration of a preparation known as a photosensitizer. This material is taken up by abnormal tissues and subsequent irradiation of those tissues using low energy laser radiation results in non-thermal activation of the photosensitizer and resultant cell death at the treated site. In laboratory-based studies on photodynamic therapy (PDT) lasers such as low energy HeNe lasers are used in conjunction with tissue culture systems. One problem associated with this approach is that events occurring in real time at a microscopic level may not be visualized. Here we report on the use of a real-time confocal laser scanning microscope system (CLSM) in conjunction with photosensitized erythrocytes and we discuss its possible applications in space medicine and cell biology.

METHODS

In these studies human erythrocytes were harvested from fresh blood, washed twice in phosphate buffered saline and subsequently exposed to the photosensitizer (HPD) for 2 hours. The cells were then washed and placed on microscope slides together with coverslips. These were placed on the stage of a Nikon Optiphot microscope equipped with a x60 objective lens. This was coupled to an Odyssey confocal laser scanning system (ODYSSEY, Noran Instruments Ltd., UK) with real time imaging facilities in order to facilitate direct examination of the specimen during photodynamic activation. Activation was accomplished during exposure to the visualizing scanning beam emitted by an Argon laser with multi-line emission at 458nm/488nm/514nm/529nm. The microscope and scanning system were controlled by the Odyssey software package loaded into a 486 IBM compatible PC, driven by Microsoft Windows MS-DOS system. Images of events occurring during photoactivation could be captured using a conventional VCR system.

RESULTS

When non-photosensitized samples of erythrocytes were examined using the confocal system it was found that the cells remained unchanged over a period of 1 hour, after which drying of the samples contributed to distortions. However when samples were applied to the system and the emission wavelength of that beam was set at 529nm a very dramatic disruptive event was found to occur within 5 seconds exposure and all cells within the field had disappeared within a 10-second period from the onset of exposure to the scanning beam. This suggested that the system was capable of observing events at a microscopic level during photodynamic activation. These results did not however give any indication as to whether or not the observed events, recorded at a microscopic level, could be quantified. We therefore decided to determine whether the disruptive event could be quantified with respect to photosensitizer concentration and the intensity of the laser scanning beam. It was therefore decided to

expose cells to three different photosensitizer concentrations and to subsequently visualize the samples on the CLSM at various scanning beam intensities. The end point for this study was chosen as the time taken for the onset of the disruptive event to occur once the samples were exposed to the scanning beam. The results demonstrated that increasing the scanning beam intensity decreased the time taken for photoactivation to occur. In addition, when the photosensitizer concentration increased, the time taken for photoactivation to occur also decreased. These results indicated a clear relationship between the events observed in real time using the CLSM and both laser beam intensity and photosensitizer concentration.

In addition to carrying out these studies with erythrocytes, we have also used the CLSM to examine living human HeLa cells which have been exposed to photosensitizers. In these studies cells were also exposed to fluorescent probes which are only taken up by cells with damaged membranes. The results from these studies will also be presented at the Symposium as will potential applications of the system in space medicine and cell biology.

CONCLUSIONS

In ground-based studies, the CLSM system is capable of observing events which occur during photodynamic activation in real time at a cellular level. Those events, in relations to our studies with human erythrocytes may be quantified with respect to scanning beam dose and photosensitizer dose. In the context of long and intermediate duration space flight we envisage that modifications of the existing system offer significant potential both in studying basic cellular function in a microgravity environment and capturing those events in real time for subsequent transmission to ground-based laboratories. Because control of the basic system is computer-based, the degree of expertise required by on-board personnel would be minimal and extensive manipulation of the system could be ground-based. We believe that such a system would have certain attractions for inclusion on-board the International Space Station. In the context of space medicine we believe that the CLSM offers the potential for developing non-invasive, remote medical procedures which would not necessitate return of on-board personnel to Earth. It is also worth noting that the system offers the possibility of carrying our tissue removal at a microscopic level and that removal may be monitored in real time at a microscopic level. The system as outlined above with human erythrocytes has already been suggested to offer potential as a drug delivery system in ground-based medical procedures [Refs. 1 & 2]. We would intend to discuss the above possibilities in more detail at the Symposium.

REFERENCES

1. Flynn, G., McHale, L. & McHale, A.P. 1994, Methotrexate-loaded, photosensitized erythrocytes: a photoactivatable carrier/delivery system for use in cancer therapy. *Cancer Letts.* 82, 225-229.
2. Flynn, G., Hackett, T.J., McHale, L. & McHale, A.P. 1994, Encapsulation of the thrombolytic enzyme brinase, in photosensitized erythrocytes: a novel thrombolytic system based on photodynamic activation. *J. Photochem. Photobiol. B - Biol.* 26, 193 - 196.

OPTIMUM VERSUS UNIVERSAL PLANETARY AND INTERPLANETARY HABITATS

Marc M. Cohen, Arch.D., Advanced Projects Branch, Space Projects Division, Mail Stop 244-14, NASA-Ames Research Center, Moffett Field, CA 94035-1000
(415) 604-0068, FAX (415) 604-0763, mcohen@mail.arc.nasa.gov

INTRODUCTION

Habitats designed for interplanetary vehicles and planetary bases pose the challenge of substantial and significant differences in each application. These differences encompass a wide range of functions and accommodations, including radiation shielding, reliability strategy, gravity orientation, EVA airlock, life support system closure, laboratory facilities, countermeasures against weightlessness, pressure ports, and inflatable structures. This comparison, detailed in Table 1, shows that these differences are very substantial and raise the question whether a single habitat design can adequately perform the functions of supporting a human crew both in transit to Mars and on the Mars surface.

UNIVERSAL HABITAT PRESSURE VESSEL

Despite these differences in functions and accommodations, it is unlikely that NASA could justify designing and building two separate designs for large, human-rated pressure vessels. Estimates for planetary habitat pressure vessels --conceived as a squat cylinder range from six to ten meters in diameter and from five to twelve meters in height. Estimates for optimized interplanetary habitats -- conceived as a sphere or a nearly spherical ellipsoid -- range from seven to ten meters in diameter and from five to ten meters high. This paper will examine ways in which it may be possible to design a single "universal habitat" pressure vessel module, that is easy to adapt to either interplanetary or planetary use. This study will show the optimized, separate designs for planetary and interplanetary habitat applications. It will propose and examine options for creating a "universal" habitat module that meets the demands of both applications, without forcing unacceptable compromises upon either one.

PRESSURE VESSEL GEOMETRY

One key to successful pressure vessel design for these habitats is careful attention to the ellipsoidal geometry of the end domes. By designing a dome of the most useful and appropriate depth and curvature, it is possible to meet many of the mission demands without compromising essential capabilities. The primary cost comes in sacrificing some modularity and standardization in interior secondary structures, stowage volumes and tankage.

CONCLUSION

This design research suggests that it is possible to create a near-optimized pressure vessel geometry that can support both planetary and interplanetary crewed missions to Mars with minimum compromise to the capabilities of either. The key to implementing this approach will be to treat planned customization as normal use, rather than as an anomaly that requires waivers and special review.

OPTIMUM VERSUS UNIVERSAL PLANETARY AND INTERPLANETARY HABITATS

TABLE 1. INTERPLANETARY VEHICLE AND PLANETARY HABITAT PARAMETERS

MISSION DESIGN IMPLICATIONS

Design Parameter	Interplanetary Vehicle	Planetary Surface Habitat
1. Radiation Shielding	Must launch to LEO, don't want to drag it down to planet surface.	Can extract water from Mars atmosphere or excavate regolith.
2. Reliability Strategy	Propulsive character demands .99999 reliability.	Availability, resupply & repair complement standard reliability approaches.
3. Gravity Orientation	Optimize for zero-gravity IVA operations.	Optimize for partial-g operations.
4. EVA Airlock	Landing in interplanetary vehicle requires integration of heavy airlock into Habitat.	Separately landed habitat & airlock allows on-surface assembly.
5. Life Support System Closure	Plan for physical / chemical closed-loop regenerative system, with possible plant-growth unit.	Plan for physical /chemical system that includes local resources (atmosphere) with CELSS component.
6. Laboratory Facilities	No use for the Lab Facilities going to Mars, minimal use on return voyage.	Laboratory will provide the center of the Working Environment.
7. Countermeasures Against Weightlessness	Countermeasures such as a small diameter, human-powered centrifuge are essential to maintain crew health.	Zero-gravity countermeasures will be less important in the .38 G gravity field on Mars.
8. Pressure Ports	2 Ports at distal axial ends	4 or more peripheral ports w/ dust control
9. Inflatable Structures	No likely application	Greenhouses, auxiliary and supplementary facilities.

Application of Remote Sensing and Geographic Information System Technologies to the Prevention of Diarrheal Diseases In Nigeria

Philip C. Njemanze¹, Sheri W. Dister², Brad M. Lobitz², Louisa R. Beck², Byron L. Wood²

¹Institute of Space Medicine and Terrestrial Science, Chidicon Medical Center Owerri, Imo State, Nigeria

²Center for Health Applications of Aerospace Related Technologies, JCI, NASA Ames Research Center, Moffett Field CA

Abstract

Among the poor in developing countries up to 20% of an infant life experience may be spent suffering from diarrheal illness, and up to one-third of deaths among children less than 2 years of age are due to complications of diarrheal illness. This problem is spatially related to the lack of pure water at different sites. Identification of the areas with poor water facilities and high incidence of diarrhea is crucial to solving this problem. Conventional approaches used in Nigeria do not take into account the spatial relationship between water availability and disease patterns. This project will use remote sensing and geographic information system (GIS) technologies to determine the optimal location for boreholes and other clean water resources to prevent diseases. The initial study will focus on Imo and Anambara States, Nigeria. The RS images of this area will be used to map landcover, landuse, hydrology, towns, villages, and the major transportation networks. The GIS database will also include spatial and quantitative information on diarrheal disease patterns, population data, transportation infrastructure, existing clean water facilities, human waste dumps, industrial pollution sites, and other sources of contamination of water supply locations. The location of potential clean water resources will be determined based on the analysis of the database. Computer modeling will enable determination of the impact of contamination, infrastructure malfunction, population changes, and seasonal fluctuations. The experience gained in this study could be used on a regional scale to guide funding agencies to implement water development schemes. Such an approach could significantly reduce infant mortality due to diarrheal diseases.

A SMALL G LOADING HUMAN CENTRIFUGE FOR SPACE STATION ERA

K. Yajima, K. Iwasaki, R. Murai, T. Nakazato, M. Itoh, K. Hirayanagi, A. Miyamoto and M. Igarashi

Department of Hygiene/Space Medicine, School of Medicine, Nihon University

INTRODUCTION

Human centrifugations were conducted using a short arm (1.8 m radius) centrifuge (First Medical Co. Japan). Long-duration exposure to the microgravity environment in space would produce various biomedical problems including cardiovascular deconditioning, bone-demineralization, muscle atrophy, etc. Usefulness of a short-radius human centrifuge is expected when it is used in space as a countermeasure against these problems. Especially, centrifugation has been considered as an only solution in a long term micro gravity exposure to prevent a calcium loss from the bone. However almost nothing is well established regarding the most desirable program for artificial G application. Moreover, we definitely need to understand more details about the effects of long duration small +Gz(1-3G) on human. We have studied for many years to solve these points using a short arm centrifuge on the ground. This is an overview of our experiments from the early stage up to the present.

METHODS

Nihon university's short-radius human centrifuge was used for 6 study series. 151 healthy male subjects aged 21 - 39 were informed and chosen for this series of experiments. They received G load along the body's +z axis. The data were collected on sitting position during the load. Electrocardiogram (ECG) was obtained from the third lead and systolic blood pressure (SBP) and diastolic blood pressure (DBP) were obtained with Life Scope 8 (Nihon-Koden). We also observe Arterial Oxygen Saturation by a pulse oximeter since Series B. Sympathetic and parasympathetic activities were evaluated with R-R interval spectral analysis.

In these studies the G load was discontinued when the subject complained of the symptoms by the G load or when the experimenter judged to discontinue based on his evaluation of the subject's physical condition.

RESULTS

The acceleration protocol, G level, and exposure time, the total number of subjects and the number of subjects who completed the exposure time are shown in table I.

The number of subjects who could not tolerate the load, and the causes of discontinue are shown in table II.

A, B, C, D, E and F are the series timely sequenced, and G parameters, such as acceleration protocol, acceleration period, G level and exposure time, have been changed by the previous results, aiming to get the more G and the longer exposure time. By the same reason, the centrifuge itself and its inner devices also have been improved year by year according to the time pass. Then we could gradually neglect the side effects of our short-radius human centrifuge, such as nausea or vertigo.

CONCLUSION

We have studied for many years to understand more details about the effects of long duration small +Gz on human, using short-radius centrifuge on the ground. We have improved our centrifuge and program of artificial G application. Then we could gradually neglect the side effects. However, when we study the usefulness of a short-radius centrifuge, the potential effects of various factors in space need to be considered as well.

USE OF THE BICYCLE ERGOMETER ON THE INTERNATIONAL SPACE STATION AND ITS INFLUENCE ON THE MICROGRAVITY ENVIRONMENT

N. Penley¹ and G. Banta²

¹Microgravity Payloads Office (0Z4), Johnson Space Center, Houston, Texas 77058, ²Science Applications International Corporation

INTRODUCTION

A number of exercise techniques have been employed routinely aboard Shuttle and MIR. These same techniques and others are planned for use aboard the International Space Station (ISS) for extended space missions. Peddling on a bicycle ergometer, an endurance exercise, is one exercise technique that will be used to maintain Astronaut respiratory capacity, minimize loss in work capacity, and perhaps increase circulating blood volume.

Operation of the ergometer has however, stimulated some concern for the Space Station Payload Office. Those concerns relate to whether ergometer operation and its location will have an influence on the microgravity payload environment. The microgravity environment generally requires acquiescence. To properly address these concerns, review of isolated and non-isolated ergometer operations are necessary.

METHODS

To assess potential loads (microgravity disturbance) that might be generated for the ergometer aboard the ISS, data from both KC-135 parabolic flights (non-isolated) and two Orbiter flights (isolated) were reviewed. The Orbiter flight tests used both a Passive Cycle Isolation System (PCIS) and an Inertial Vibration Isolation System (IVIS). KC-135 flights to collect microgravity disturbance of an isolated ergometer are under consideration for early spring. The test criteria and data will be compared to the KC-135 non-isolated tests.

RESULTS

KC-135 test data (non-isolated) was assessed by frequency range and amplitude for the MIR ergometer, the Orbiter ergometer, and a proposed ISS ergometer. Disturbances ranged from 0.05 to 5.5 Hz. A wide range of microgravity environment disturbances can also be seen for the two Orbiter flights depending on location and subject peddling technique. These data as well as results of KC-135 isolated ergometer tests, if flown, will be reviewed and presented.

CONCLUSION

Preliminary data analysis from KC-135 non-isolated and Shuttle isolated bicycle ergometer testing suggests potential for microgravity environment disturbance aboard the ISS. These disturbances may be accentuated by location of the ergometer as well as the time period of its use. This type of information will aid ISS research planners in determining the best location of the exercise equipment, methods of its use, and periods of its operation as related to other essential microgravity payloads.

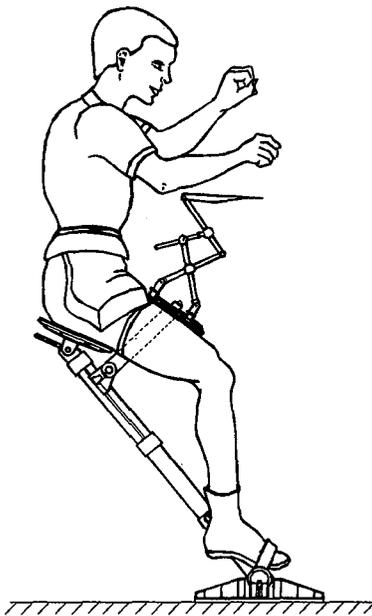
MUNICH SPACE CHAIR (MSC) - A NEXT GENERATION BODY RESTRAINT SYSTEM FOR ASTRONAUTS

E. Igenbergs¹, W. Naumann¹, P. Eckart¹, E. Pfeiffer²

¹Institute of Astronautics, Technical University of Munich, 85747 Garching; ²Kayser-Threde GmbH, Munich
email office@asterix.lrt.mw.tu-muenchen.de

INTRODUCTION

The microgravity environment onboard orbital facilities greatly influences working conditions. On the one hand, the lack of gravitation facilitates the moving from one place to another; on the other hand it makes it more difficult to rest in a stable position. As a prevention from floating away, astronauts have to hold with one hand a grip or handrail, or clamp another part of their body between available facilities. To avoid this and to lower the restrictions due to 0-g, many different body restraint systems have been developed and used onboard spacecrafts and space stations. The most common ones are footloops and handrails. Unlike most of these different restraint systems, the Munich Space Chair (MSC) gives astronauts the possibility to fix their bodies very rigidly while staying relaxed even during work under high muscular strain and long working conditions.



Munich Space Chair with adjustable work table

table for the MSC was also sent up to MIR in a PROGRESS cargo spacecraft. During the EUROMIR'95 mission, the MSC was used for experimental activities, writing and typing. Moreover, it was tried to verify an improvement of concentration abilities and precise movements using the MSC for the DLR experiment PSY-15 D, which requires precise work with both hands under high concentration over a long period of time. German Astronaut Thomas Reiter, who spent 6 months onboard MIR, confirmed the expected improvements compared to other restraints for this kind of application. Another MSC main duty onboard MIR, the support of the mechanical PELIKAN manipulator arm operation, has not yet begun.

OUTLOOK

Presently, several components of the MSC are adapted for future use onboard the International Space Station (ISS). Especially, the floor connection unit is redesigned to enable a connection to the seat tracks inside the ISS. The use of the MSC onboard the ISS will complete the required range of restraint systems.

FIXATION PRINCIPLE

The concept of the MSC is based on ergonomic aspects. It fixes a human body in its neutral 0-g position without the need for additional supports like belts, e.g. The sitting posture of the MSC is combined with a simple fixation principle. As depicted in the figure, the human body is fixed between foot bar, thigh plate and seat plate. The astronaut only has to press his thigh against the thigh plate by stretching his foot and spanning his calf muscles, respectively. Due to the leverage of the thigh plate, the back is pressed onto the seat plate. The whole lower part is fixed while the upper part of the body with the arms keeps its freedom. Depending only on the muscle employment of the astronaut, it is possible to „sit“ in the Chair being fixed very tightly or rather loosely or „free floating“ within the three fixing points. So the fixation can be easily varied for different tasks. Furthermore the MSC can be adapted to all body sizes.

DEVELOPMENT AND APPLICATION ON MIR

The MSC was tested in three parabolic flight campaigns and optimised according to the results. A detailed load analysis was performed to get the limit loads induced to the MSC by the astronaut. In 1995, more than 10 years after the invention of the space chair, the MSC was launched to Space Station MIR and installed inside the SPEKTR module. In October 1995, an adjustable and foldable work

THERMOELECTRIC HUMAN-BODY COOLING UNITS USED BY NASA SPACE SHUTTLE ASTRONAUTS

Pat Heenan¹, Roy Theisen¹, B. MathiPrakasam¹, Stephanie Walker², and Bruce Sauser²

¹Midwest Research Institute, Kansas City, USA; ²NASA Johnson Space Center, Houston, USA

INTRODUCTION

The US National Aeronautics and Space Administration (NASA) realized a need for a cooling system that can provide body cooling to the space shuttle astronauts and thus reduce heat stress while they wear the Launch Entry Suit during shuttle launch and reentry. Midwest Research Institute (MRI) developed thermoelectric (TE) cooling units to meet this need. First generation cooling units developed by MRI are being used by the astronauts during the last three years. Second generation cooling units are currently under development and will become available for 1997 missions. The cooling units are used in conjunction with NASA-furnished tube-type cooling garments. The paper will discuss the technical details of body cooling needs of astronauts, second generation TE cooling units, and the performance results.

BODY COOLING NEEDS

The metabolic heat produced by an average astronaut's body is about 100 watts. Since the astronauts wear the Launch Entry Suits for survival reasons during shuttle launch and reentry, the produced heat cannot be rejected to the cabin air. Body cooling is done by wearing a special tubes-sown garment adjacent to the body skin and by circulating a chilled fluid through the garment tubes. A cooling unit is required to re chill the warm liquid returning from the garment.

COOLING UNITS

The second generation TE cooling units are compact, lightweight, and efficient. Each unit weighs about 6.5 lb and has a size of 4 X 5 X 8.5 in. The principal components of a unit are (1) a cooler core, (2) a fan, (3) a fluid pump, (4) an electronic PC board, and (5) an enclosure. The core contains the TE modules, fluid cooling channels, and heat sinks. In operation, power is applied to the TE modules, fan, and pump. The warm fluid returning from the garment is pumped through the cooling channels of the core and thus cooled. The fan circulates cabin air through the heat sinks to remove the heat rejected by the TE modules. A 10-position wired-remote switch is used by each astronaut to regulate the power applied to the TE modules and thus vary the cooling delivered to the body.

PERFORMANCE RESULTS

The cooling unit is capable of delivering up to 150 watts of cooling in a 75° F cabin temperature. The maximum delivered cooling reduces to about 105 watts (and is still sufficient to balance the metabolic heat produced by an average astronaut) when the cabin temperature increases to 90° F. To deliver 100 cooling watts, the electrical power requirements of the cooling unit at 28 VDC are 25 and 60 watts respectively at 75° F and 90° F cabin temperature.

Wednesday, June 11

Session WP4
Room 4
2:30 - 5:30 p.m.

521-72
074626
141.
326979

**Radiation: Physical Characterization
and Environmental Measurements**

PRODUCTION OF NEUTRONS FROM INTERACTIONS OF GCR-LIKE PARTICLES

L. Heilbronn

Lawrence Berkeley National Laboratory, Berkeley, CA 94720

In order to accurately determine the radiation risk to astronauts from galactic cosmic radiation (GCR), the nature of the secondary radiation field produced by the interactions of the GCR in shielding materials and tissue must be understood. Neutrons are an important component of the secondary radiation field, especially behind the thick shielding anticipated for lunar or Martian bases^{1,2} (Fig. 1). The predominant source of these neutrons is nuclear interactions of GCR protons and heavier nuclei in shielding. Some studies have been conducted at ground-based accelerator facilities on the production of neutrons from interactions of GCR-like particles, but because accelerator resources are limited and because neutron experiments require a large amount of time at those accelerators, the best approach to the problem of determining the amount of neutron radiation behind shielding is through calculations such as the ones reported in references 1-3. From the viewpoint of the experimentalist, the key questions are (1) What are the critical data needed by theorists for the development and verification of their calculations, and (2) What data sets already exist that can be applied to the problem?

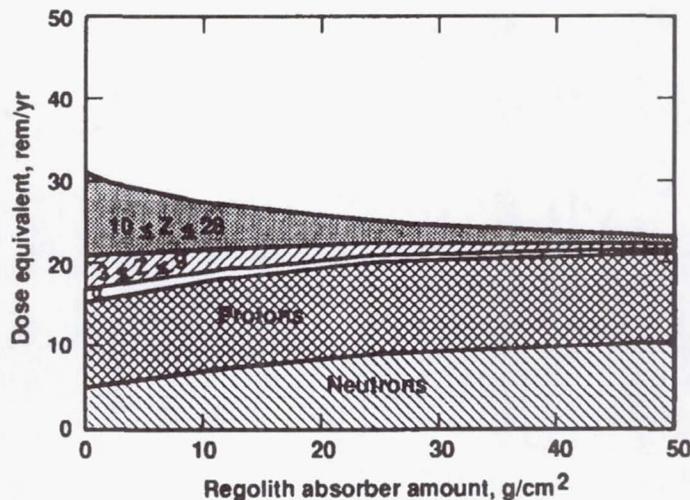


Figure 1. Calculated contributions to the annual dose equivalent to the blood-forming organs from neutrons, protons and heavier nuclei as a function of depth in Martian regolith, for the GCR flux at solar minimum after transport through the Martian atmosphere ($16 \text{ g/cm}^2 \text{ CO}_2$). (From reference 2.)

In answer to question (1), data are needed on total neutron production, angular distributions, and energy distributions. Details on the systematics of neutron production as a function of projectile mass and energy and target mass will be needed. The projectiles include protons, helium, and heavy ions with atomic number as large as 26 (iron). The projectile energies should span the range of energies from 100 MeV/nucleon to 2 GeV/nucleon. Targets should include possible shielding materials such as aluminum, water, and regolith components, as well as tissue components such as water, carbon, and nitrogen.

The production of neutrons by GCR nuclei ($Z=2$ and greater) is important. One calculation³ predicts that about 15% of the neutron flux behind 50 g/cm^2 of water comes from helium interactions, and another 16% comes from interactions of heavier nuclei. However, the heavy ion neutron data base has a scant amount of applicable data. To our knowledge, there is only one reference on neutron production from heavy ion GCR-like particles stopping in shielding materials. (177.5 MeV/nucleon and 160 MeV/nucleon helium particles stopping in C, Pb, steel, and water.⁴) There is little thin target neutron cross section data that is relevant to GCR-like interactions.

In order to fill in some of the gaps in the heavy ion neutron data base we have done two sets of accelerator-based experiments that have measured neutrons from heavy ion interactions. One experiment measured the yield of neutrons resulting from 272 and 435 MeV/nucleon Nb ions stopping in Nb and Al targets. The other experiment has measured the yield of neutrons from 155 MeV/nucleon C and He ions stopping in Al targets. Figure 2 shows neutron energy spectra at 3°, 9°, 16°, 28°, 48° and 80° for the 435 MeV/nucleon Nb + Nb system. The solid lines are BUU (Boltzmann-Uehling-Uhlenbeck) model calculations of the data.

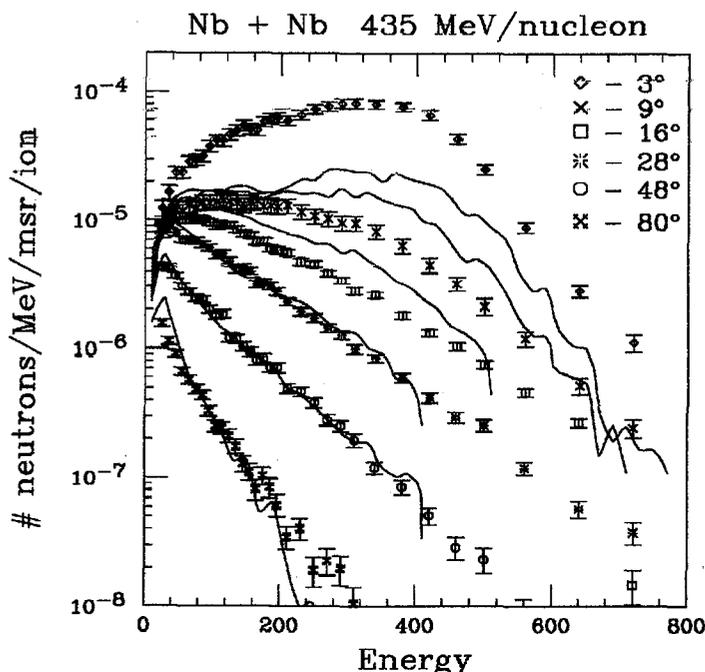


Figure 2. Neutron production as a function of angle and energy in 435 MeV/nucleon Nb + Nb collisions. The solid line is the result of a BUU model calculation.

As can be seen, BUU is unable to fit the entire range of data (nor can other current models), indicating that more work is needed on the development of models that predict neutron production in heavy ion interactions. The experimental data presently available are insufficient to resolve the discrepancies between data and model calculations. For the data set above, acquiring cross section data for the same system and other projectile energies would aid the model development. Additional thick-target and cross section data from a wide range of systems is also needed.

REFERENCES

1. L. C. Simonsen and J.E. Nealy, Radiation Protection for Human Missions to the Moon and Mars, *NASA TP 3079*, 1991.
2. L. C. Simonsen, J. E. Nealy, L. W. Townsend and J. W. Wilson, Space Radiation Shielding for a Martian Habitat, *SAE Technical Paper 901346*, 1990.
3. F.A. Cucinotta, Calculations of Cosmic-Ray Helium Transport in Shielding Materials, *NASA TP 3354*, 1993.
4. R. A. Cecil, B. D. Anderson, A. R. Baldwin, R. Madey, A. Galonsky, P. Miller, L. Young, and F. M. Waterman, Neutron angular and energy distributions from 710-MeV alphas stopping in water, carbon, steel, and lead, and 640-MeV alphas stopping in lead, *Phys. Rev. C* 21, 2471-2484 (1980).

SOLAR PARTICLE EVENT DOSE DISTRIBUTIONS: PARAMETERIZATION OF DOSE-TIME PROFILES

E. N. Zapp¹, C. R. Ramsey¹, L. W. Townsend¹, and G.D. Badhwar²

¹Department of Nuclear Engineering, The University of Tennessee, Knoxville, TN 37996-2300, ²Space Radiation Analysis Group, NASA Johnson Space Center, Houston, TX 77058

INTRODUCTION

In order to provide adequate warning to deep space astronauts to terminate extravehicular activities or surface operations and to seek protective shelter, methods of accurately predicting the time development of dose buildup from measurements of doses in the early stays of a large solar particle event (SPE) must be provided. We have developed an inventory of dose-time profile calculations for all major SPEs that occurred from January 1986 through April 1994. This inventory of SPE dose-time profiles provides a database for further model development focused on predicting the future buildup of radiation doses from a limited number of observations of absorbed dose spread over time relatively early in a large solar particle event.

METHODS

A typical SPE dose-time profile is displayed in Figure 1. The shapes of the curves are typical for a major event and can be represented by a Weibull function of the form

$$D(t) = D_{\infty} \left\{ - \exp \left[- \alpha (t - t_0)^{\gamma} \right] \right\} \quad (1)$$

where D_{∞} , α , γ are fitting parameters and $t-t_0$ is the time since protons began arriving. The procedure is to determine these fitting parameters for the inventory of SPE dose-time profiles using least squares regression analysis methods.

RESULTS

Weibull function fits for the fifteen SPEs in the inventory have been made. The fitting parameters for each event will be available at presentation. A typical fit to a dose-time profile is displayed in the figure for the large SPE which began on September 29, 1989.

CONCLUSIONS

A parameterization of dose buildup over time, based upon a Weibull function, appears promising as a computer model for predicting cumulative doses and times to reach various dose limits from a limited number of measurements of absorbed dose spread in time.

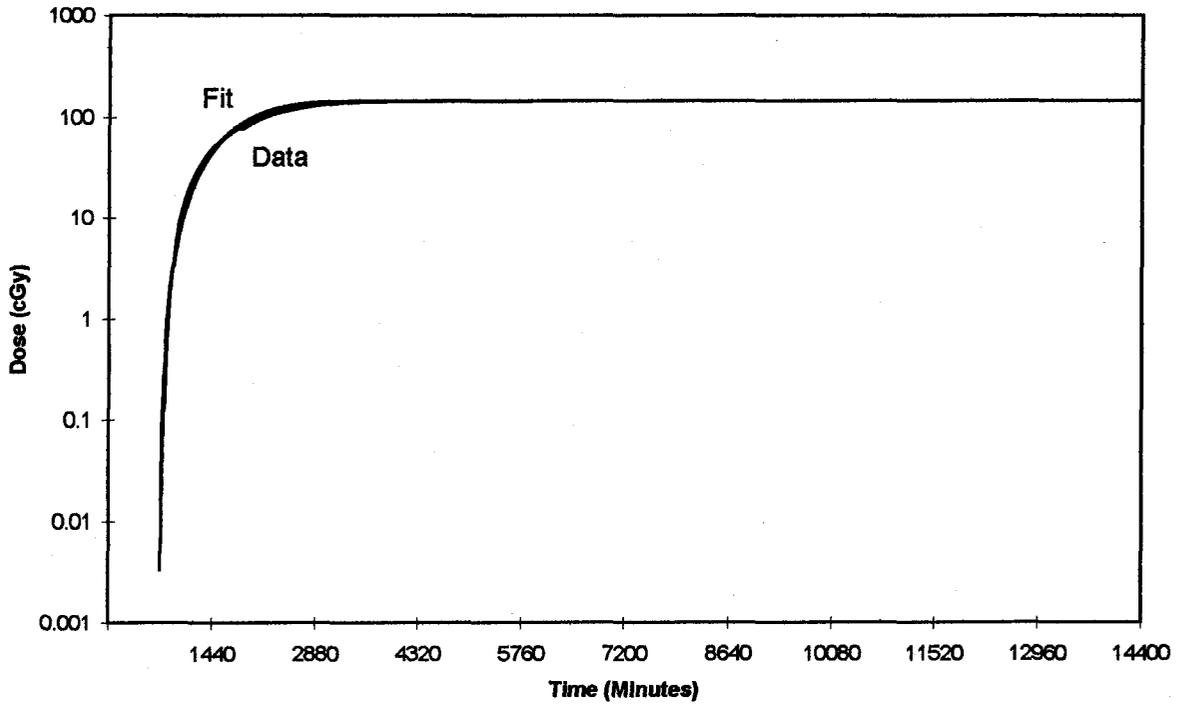


Figure 1. Fit for Skin Doses from the solar particle event on 9/29/89 to 10/9/89 located at S26/W90.

ASSESSMENT OF NUCLEAR EVENTS IN THE BODY PRODUCED BY NEUTRONS AND HIGH-ENERGY CHARGED PARTICLES

R. A. Noulty,¹ H. Ing,¹ E. T. H. Clifford,¹ B. Selkirk,¹ J. Gamero,¹ and A. Mortimer²

¹Bubble Technology Industries, Chalk River, Ontario, ²Space Life Sciences, Canadian Space Agency, Ottawa, Ontario

SUMMARY

Nuclear fragmentation, which is of concern for radiation protection of astronauts, can be produced by neutrons and high-energy charged particles in space. An experiment is being planned to determine the relative importance of the two modes of interactions. The experiment is based on coincidence counting between a bubble detector and a plastic scintillator which is used as a coincidence shield. This information is needed to interpret properly past measurements of space radiation with various detectors, including the bubble detector, and will lead to a better understanding of the source of the radiation with the potential of reducing the biological risk from such radiation effects. The experimental equipment which is being built for this measurement will be useful for other studies involving active detectors.

INTRODUCTION

The neutron bubble detector¹ is a popular personal dosimeter which provides a good assessment of biological detriment from neutrons found in various radiation environments on earth.^{2,3,4} There are reasons to believe⁵ that such a detector may also be a good indicator of biological detriment for high-energy particles in space.

In our previous measurements of neutron spectra in biosatellites⁶ and the space station Mir, we have interpreted⁷ the readings of bubble detectors as being caused by high-energy neutrons. This interpretation was based on data from an earlier experiment where high-energy protons from the Orsay cyclotron were used to irradiate bubble detectors and produced negligible response.

Charged particles interact with matter predominantly via the Coulomb force with the electron cloud surrounding the nucleus, rather than with the nucleus itself. In fact, the interaction of charged particles with the nucleus is so rare that it is usually neglected in the computation of charged particle behaviour in a medium to derive characteristic parameters such as penetrating depth, stopping powers, etc. For radiation dosimetry on earth, the calculations of those and biological effect treat charged particles very differently from those for neutrons and photons because of their vastly different interaction modes with matter.

SIMILARITY OF CHARGED PARTICLES AND NEUTRONS AT HIGH ENERGY

However, as charged particles increase in energy, they can interact with the nucleus more readily and can create nuclear fragmentations similar to high energy neutrons. Despite the rarity of such events compared to electron interactions, nuclear fragmentation by charged particles may play a crucial role in producing biological damage in a space environment. Since the target nucleus – whether it be a radiation detector or tissue – usually cannot distinguish the nature of the impinging projectile and the net effect is similar, there is reasonable justification to consider lumping high-energy charged particles and neutrons together from the viewpoint of biological effect associated with the nuclear fragmentation process.

SEPARATION OF NUCLEAR EVENTS

Despite the apparent capability of the bubble detector to respond to neutrons and high-energy charged particles on an equal basis, it is nevertheless scientifically interesting to determine the relative importance of these two different interaction processes in the bubble detector. This information would allow us to confirm our earlier interpretation of bubble detector data from space. Also the information has other implications such as the possibility of allowing certain procedures to be implemented to reduce radiation exposure to the crew.

For example, since neutrons are not a direct component of cosmic rays in space, their presence is due to secondary sources of radiation production which can be modified by judicious choice of environmental materials such as those

used in the construction of the space vehicle. Also, if a significant fraction of nuclear fragmentation events are caused by high-energy charged particles, it may be possible to consider shielding the crew from radiation hazard – especially in the event of anomalously high radiation activity.

EXPERIMENT TO SEPARATE NEUTRONS AND CHARGED PARTICLES

Equipment is being built for an experiment to assess the relative contribution to nuclear fragmentation processes due to neutrons and charged particles in space. The equipment is intended to be flown in the Mir space station in late 1997.

The apparatus consists essentially of a bubble detector surrounded by a plastic scintillator coincidence counter. The bubble detector is fitted with an acoustic detection system to register electronically the formation of bubbles induced by space particles. The plastic scintillators are housed in a light-tight assembly and viewed with two photomultipliers.

When a bubble formed in the bubble detector is created by a high-energy charged particle, its formation would be accompanied by a signal in the plastic scintillator since the particle would have traversed the outer scintillator giving off light in order to reach the central bubble detector. However, if the bubble is formed by a neutron, so signal would be expected from the scintillator since neutrons would normally penetrate the outer scintillator without interaction. Thus, comparison of the total number of bubbles and the fraction of these which are accompanied by coincidence signals in the plastic scintillator will yield the desired information.

EQUIPMENT DETAILS

The design of the equipment has taken into account the space environment in the performance of the experiment. The size of the scintillator was kept to a minimum, consistent with producing adequate light signal for minimum ionizing radiation. Since high counting rates are anticipated in traversing the South Atlantic Anomaly, the timing circuits have been designed to achieve acceptable randoms to reals ratio over this region. Special boards are made to provide high voltage to the photomultipliers and bubble acoustic sensors and to process the digitized signals. A programmable microprocessor (Intel 8031) is used to control the signals and handle data display and storage. The instrument is designed to be low weight, resistant to noise and powered by the 28 volt supply of the space station.

After completion of this experiment, the equipment would be available for other experiments of scientific interest. The plastic scintillator “coincidence shield” could be used with other types of active radiation sensors that fit within the cavity, designed to house the bubble detector for this experiment.

REFERENCES

- ¹H. Ing and H. C. Birnboim, “A Bubble-Damage Polymer Detector for Neutrons,” *Nucl. Tracks Rad. Meas.* 8 (1984) 285-288.
- ²P. Broussard and L. B. Pascale, “Radiological Protection at PWR Plants in Service,” *RGN International Edition*, Vol. A. (1993) p. 55-56.
- ³J. Shulze, R. Rosenstock, and H. L. Kronholz, “Measurements of Fast Neutrons by Bubble Detectors,” *Radiat. Prot. Dosim.* 44 (1992) 351-354.
- ⁴B. J. Lewis, R. Kosierb, T. Cousins, D. Hudson, and G. Guery, “Measurement of Neutron Radiation Exposure of Commercial Airline Pilots Using Bubble Detectors,” *Proc. Intern. Nuclear Congress (INC93)*, Toronto, Canada, 3-6 October 1993, Cl. 3, 1-9.
- ⁵H. Ing, T. D. McLean, R. A. Noulty, and A. Mortimer, “Bubble Detectors and the Assessment of Biological Risk from Space Radiation,” *Radiat. Prot. Dosim.* (in press).
- ⁶H. Ing and A. Mortimer, “Space Radiation Dosimetry Using Bubble Detectors,” *Adv. Space Res.* 14 (1999) (10)73- (10)76.
- ⁷H. Ing, T. D. McLean, R. A. Noulty, and A. Mortimer, “Measurements of Space Radiation Using Bubble Detectors,” *Proc. Spacebound/93*, May 16-18, Ottawa, Ontario (1993) 9-10.

GROUND-BASED SIMULATIONS OF COSMIC RAY HEAVY ION INTERACTIONS IN SPACECRAFT AND PLANETARY HABITAT SHIELDING MATERIALS

J. Miller¹, C. Zeitlin¹, L. Heilbronn¹, T. Borak², T. Carter³, K. A. Frankel¹, S. E. Rademacher² and C. Stronach³

¹Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

²Colorado State University, Fort Collins, CO 80523, USA

³Virginia State University, Petersburg, VA 23806, USA

INTRODUCTION

One of the constraints on the design of spacecraft and future planetary habitats is the effect of the structural materials on the radiation environment inside the spacecraft. High energy heavy charged particles are relatively small in number in space, but because of their highly ionizing character they may have significant biological effects, and the fact that they can fragment in matter complicates the problem. It will obviously be impractical to verify the shielding and transport properties of every candidate material and configuration under actual space flight conditions, and for this reason shielding designers will need accurate models of radiation transport in matter. These models require experimental data for their development and verification. The data needed are of two general types: (1) cross sections, which are probabilities that an ion with a given charge, mass and energy incident on a given target nucleus will produce a fragment with a particular set of properties (charge, mass, energy, angle); (2) fluences, which are numbers of fragments produced at depth in shielding. Cross sections more directly reflect the dynamics of the high energy nucleus-nucleus interactions, and are fundamental information which must be incorporated in heavy ion transport models. Fluence measurements are used to test the ability of a given model to account for the many different interactions which can occur in a thick target such as a spacecraft wall or the human body. We have made a series of measurements at particle accelerators with heavy ion projectiles incident on shielding and tissue-equivalent materials, including aluminum, polyethylene, water, graphite and composite materials.

EXPERIMENTAL METHODS

Charge and energy spectra were obtained using a particle spectrometer (Figure 1), the major components of which are solid state (silicon) detectors of several different thicknesses. The number and type of detectors is adjusted according to the beam ion and energy. Position sensitive detectors (PSD's) provide position information.

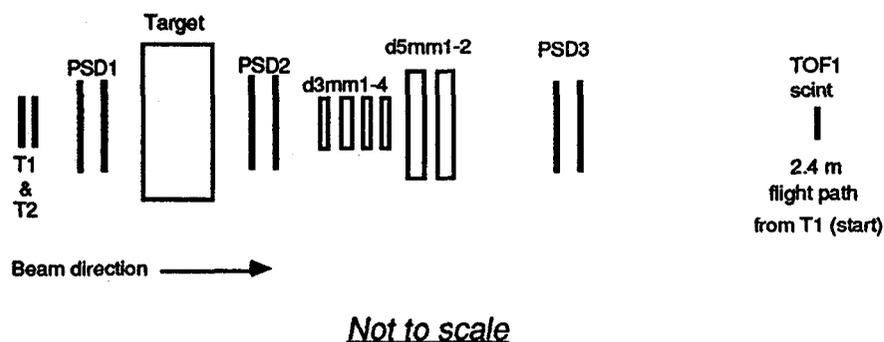


Fig. 1. Charged particle spectrometer used for beam characterization at the BNL AGS.

RESULTS AND DISCUSSION

Figure 2 shows a sample of data taken at the Brookhaven National Laboratory Alternating Gradient Synchrotron (BNL AGS) for fragment fluence spectra produced by 1 GeV/nucleon ⁵⁶Fe in aluminum and two different thicknesses

of graphite-epoxy, one possible shielding material. The primary iron beam produces the large peak at the right in each spectrum, and discrete energy loss peaks for charges from the primary ($Z=26$) down to at least $Z=4$ can be identified by eye. This simple example shows the similarity in the fragmentation properties of 2.54 cm aluminum and 5 cm graphite-epoxy, and the effects of doubling the thickness of graphite-epoxy from 5 to 10 cm: note the slightly increased energy loss at 10 cm (due to the slowing of the beam) and the increased fragmentation—evidenced in the increased height of the fragment peaks relative to the primary iron. The data can be readily converted into separate energy spectra for each fragment, and analytical techniques using the information from additional detectors have extended the range to $Z=2$ and in some cases 1.

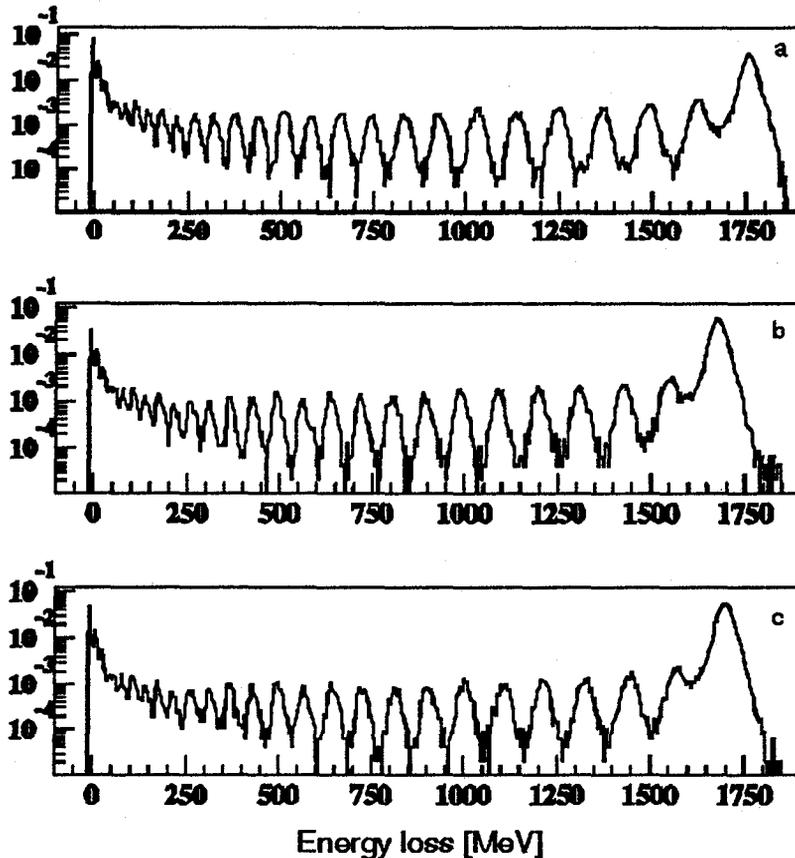


Fig. 2. Energy loss spectra from 1 GeV/nucleon ^{56}Fe fragmenting in three different shielding material targets. a) 10 cm graphite-epoxy; b) 5 cm graphite-epoxy; c) 2.54 cm aluminum. The ordinate is number of counts (unnormalized). The abscissa is the summed energy loss (in MeV) in two 3 mm thick silicon detectors.

CONCLUSIONS

Accelerator experiments generate high statistics data in a controlled setting with well-defined beams. While they cannot simulate the complex radiation fields found in space, they can be used to test model performance for selected critical sets of parameters, *e.g.* for particular incident particle charges, masses and energies and target compositions and thicknesses. They can also be used at various stages of the shielding design process to test the response of candidate materials to a representative subset of space radiation components.

This work was supported in part by the NASA Space Radiation Health Program under Contract No. L14230C through the U.S. Department of Energy under Contract No. DE-AC03076SF00098.

RADIATION MEASUREMENTS IN SPACE MISSIONS

G. Reitz,¹ I. Apathy,² R. Beaujean,³ S. Deme,² C. Heilmann,⁴ J. Kopp,³ M. Leicher,³ and K. Strauch¹

¹DLR, Institut für Luft-und Raumfahrtmedizin, Abteilung Strahlenbiologie, D-51140 Köln, ²KFKI Atomic Energy Research Institute, Health Physics Dept., H-1525 Budapest, ³Universität Kiel, Institut für Reine und Angewandte Kernphysik, D-24118 Kiel, ⁴CRN, GADVI, F-67037 Strasbourg Cedex 02

Detector packages consisting of plastic nuclear track detectors, nuclear emulsions, and thermoluminescence detectors were exposed at different locations inside the Shuttle and at the astronauts' body and in different sections of the Mir space station. Total dose measurements, particle fluence rate and linear energy transfer (LET) spectra of heavy ions, number of nuclear disintegrations and fast neutron fluence rate from these exposures were obtained. Additionally, results from a particle telescope with two silicon detectors, first used inside Biorack on STS-76 and absorbed doses from TLD readings obtained with an onboard TLD-Reader during Euro-Mir 95 will be discussed. The dose equivalent received by the astronauts was calculated from the measurements.

RADIATION MEASUREMENTS IN CIVIL AIRCRAFT

R. Beaujean,¹ J. Kopp,¹ F. Roos,¹ G. Reitz²

¹Universität Kiel, Institut für Reine und Angewandte Kernphysik, D-24118 Kiel

²DLR, Institut für Luft-und Raumfahrtmedizin, Abteilung Strahlenbiologie, D-51140 Köln

The instrument DOSTEL, which was developed for dosimetry measurements in manned space flights and contains two planar silicon detectors for the registration of charged particles, was used to monitor the level of the ionizing radiation aboard German airline aircraft.

Results from recent flights in 1996 and 1997 will be presented. Data include count rates, dose rates and LET spectra from different altitudes and latitudes. Deduced radiation quality factors and dose equivalent values will be discussed.

ANALYSIS OF THE PRE-FLIGHT AND POST-FLIGHT CALIBRATION PROCEDURES PERFORMED ON THE LIULIN SPACE RADIATION DOSIMETER

Ts. Dachev*, J. Semkova*, V. Petrov#, V. Redko#, V. Bengin#,
T. Kostereva#, J. Miller+, L. Heilbronn+, C. Zeitlin+

* Solar-Terrestrial Influences Laboratory, 1113 Sofia, Bulgaria

Institute of Biomedical Problems, 123007 Moscow, Russia

+ Lawrence Berkeley National Laboratory, Berkeley, CA 94720

ABSTRACT

LIULIN, a dosimetry-radiometry system, was developed to satisfy the requirements for active flux and dose rate measurements for the flight of the second Bulgarian cosmonaut in 1988. The system consists of a compact battery-operated detector unit and a read/write microcomputer and telemetry unit. The detector unit contains a silicon solid state detector (SSD), with an active area of 200 mm and thickness of 306 μm . The instrument worked successfully on board the Mir space station from 1988 through 1994 and was returned to Earth in 1995. After pre-flight electronics tests the instrument was calibrated using radioactive sources and accelerated 170 MeV/nucleon proton and alpha particles at the Dubna, Russia accelerator. Analysis of the results obtained at Dubna showed that the instrument sensitivity was overestimated by factor of 2 during the electronics tests. A comparison with data obtained on MIR with the French-built tissue equivalent LET spectrometer NAUSICAA shows that at high latitudes the tissue-equivalent absorbed dose measurements are typically two times greater than the doses measured by Liulin. The NAUSICAA flux data are usually underestimated in comparison with LIULIN SSD data and in comparison with theoretical predictions of the number of protons required to produce the observed absorbed dose. Differences up to a factor of two can be explained by differences in the shielding of the instruments on board the MIR station. In order to study the response of the detector to heavier charged particles post-flight calibrations were recently performed with 1 GeV/nucleon ^{56}Fe ions at the Brookhaven National Laboratory AGS accelerator. At the AGS, the instrument was mounted in tandem with several thin position-sensitive silicon detectors behind a stopping target of lead and graphite-epoxy. Since the LET of the primary beam exceeded the upper limit of LIULIN's sensitive range, the calibration was performed using the lower LET charged fragments produced by nuclear interactions of the primary ^{56}Fe in the aluminum. The silicon detectors provided charge and energy identification for the surviving charged nuclear fragments for which the flux and absorbed dose were recorded by LIULIN.

RADIATION ENVIRONMENT MONITORING FOR ASTRONAUTS

G. Mackay¹, I. Thomson¹, N. Sultan², Alfred Ng², and Pat Sullivan²

¹ Thomson & Nielsen Electronics Ltd., 25E Northside Rd., Nepean, Ontario, Canada K2H 8S1.

² Canadian Space Agency, St-Hubert, Quebec, Canada J3Y 8Y9.

INTRODUCTION

The radiation environment in space, particularly Low Earth Orbit (LEO), can be hazardous to the well being of the mission crew. Radiation doses measured inside MIR and STS are considerably higher than those found in occupational situations on earth. Computer simulations also indicate that astronauts in Extra Vehicle Activity (EVA) can be exposed to even higher dose levels, especially to their skin, and eyes where cataract formation is of concern. On-board radiation monitoring for future crew safety, especially during EVA is of extreme importance. This paper discusses the results of two passive experiments, flown on MIR and BION-10, and the resulting development of a real time astronaut monitor developed for the Canadian Space Agency.

METHODS

Computer simulations of the radiation environment were carried out to determine the dose, not only to crew members in shielded areas, but also to crew involved in Extra Vehicle Activity (EVA). The need for radiation measurements on-board the spacecraft has been demonstrated by these simulations. This is especially true of crew involved in EVA. As a result, prototype radiation monitoring instruments based on semiconductor MOSFET dosimeters were developed. The simulations also showed the need to measure three types of dose to humans, viz. skin, ocular and blood-forming organs (BFO). These doses are defined at different depths in the human body.

Instruments which measured the radiation dose both inside and outside a spacecraft were flown on MIR space station as well as the Russian recoverable satellite BION-10. A further experiment was designed and built for a flight on BION-11 which is expected to be recovered early in 1997. As a result of these flight experiences, an astronaut dosimetry system has been developed which can be used for on-board measurements of crew radiation dose.

RESULTS

Simulations of radiation inside MIR show that the environment inside the spacecraft is dominated by high energy protons and the dose to crew members is about 0.3 mSv/day (110 mSv/yr). This calculation was confirmed in experiments using integrating electronic dosimeters on missions of 96 days, 268 days and 430 days durations. This result should be compared with radiation workers in terrestrial occupations who are allowed a maximum dose of 20 mSv/yr.

Computer simulations also predict that higher radiation doses will be received by astronauts in EVA and the organs at greatest risk are the skin and eye lens. Daily skin doses of up to 100 mSv could be encountered in EVA in the Space Station Alpha orbit. In contrast with the doses inside the spacecraft, EVA doses are dominated by high energy electrons.

Figure 1 shows the recently developed Astronaut Radiation Monitor (ARM), which has sensor technology based on the two passive models flown on MIR, BION-10 and BION-11. The ARM is a battery powered real time monitor capable of measuring dose to an astronaut skin, eye and BFO. Such doses are measured using appropriate shielding which surround three MOSFET dosimeters. In addition to measuring dose to the skin, eye and BFO, the ARM has a semiconductor dose rate monitor capable of detecting radiation at rates as low as 0.01 mSv/hr. The latter feature is designed to warn astronauts when high radiation levels are encountered, thereby giving them time to take protective measures. All measurements are time stamped and stored in electronic memory, which can be downloaded later for detailed analysis. The ARM makes dose measurements (skin, eye and BFO) once per hour and dose rate measurements once per minute, with a storage capability of 40 days. In the future, personal dosimeter badges may be interfaced with the ARM, providing a dose record for the individual astronaut during his mission. Monitor parameters are listed in table 1.

Table 1 Astronaut Radiation Monitor Specifications.

PARAMETER	
size	21 cm x12 cm x 5 cm (L x W x H)
mass	2.1 kg
power	10.8 V (0.3 W)
type of dose measurement	skin, eye and blood forming organ
maximum dose measurement	2.0 Sv
minimum dose measurement	0.40 mSv
dose rate detection limit	0.01 mSv/hr
output	RS232

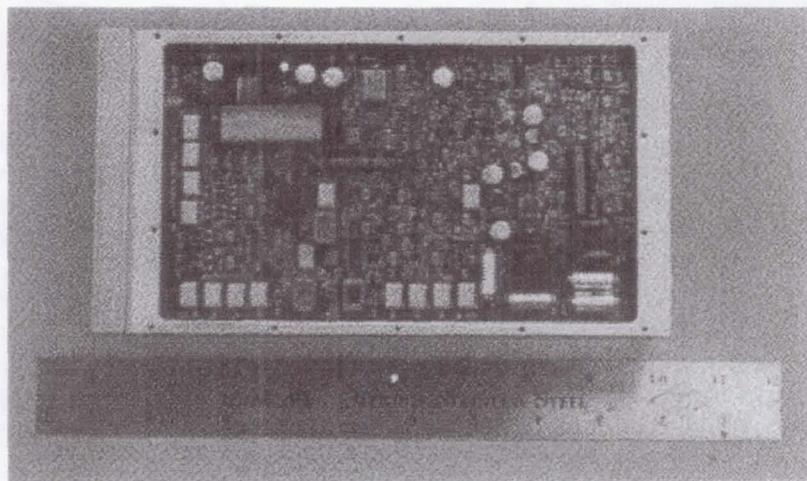


Figure 1 Astronaut Radiation Monitor.

CONCLUSIONS

It has been demonstrated by simulation and experiment that the dose to crew members in long duration missions can be considerably higher than for terrestrial radiation workers and the need for on-board radiation dosimeters has been demonstrated. The need for differentiating measurements, especially in EVA, for skin and eye doses as well as whole body doses has been demonstrated. In addition, the feasibility of using integrating electronic dosimeters on-board the spacecraft has been demonstrated. A dosimetry system which will measure doses to organs at risk (skin, eye, BFO) has been developed as a result of this work and will be tested in future missions.

The ultimate goal is for each astronaut to have his/ her own radiation protection badge which can be interfaced with the ARM. In this manner each astronaut can record his/ her eye, skin and BFO dose during the entire mission, including EVA, thereby giving ample time for protective measures to be taken by the crew members if dose levels become dangerous.

Wednesday, June 11

omit PD
P205

Session WP5
Room 5
2:30 - 5:30 p.m.

**The National Space Biomedical
Research Institute**

The National Space Biomedical Research Institute

L. R. Young, R. J. White, and B. R. Alford
National Space Biomedical Research Institute and Baylor College of Medicine
Houston, TX

On March 14, 1997, the National Aeronautics and Space Administration (NASA) selected a Consortium of nonprofit academic institutions, led and coordinated by Baylor College of Medicine, Texas Medical Center, Houston, Texas, to establish the National Space Biomedical Research Institute (NSBRI). In addition to Baylor College of Medicine, the Consortium includes Harvard Medical School, The Johns Hopkins University, Massachusetts Institute of Technology, Morehouse School of Medicine, Rice University, and Texas A&M University. The mission of the NSBRI, as stated by NASA, is to lead a National effort to accomplish the integrated, critical path biomedical research necessary to support the long-term human presence, development, and exploration of space, and to enhance the quality of life on earth by effectively applying the advances in human knowledge and technology acquired through living and working in space. NASA funding for the NSBRI is expected to continue for 20 years and will be \$10,000,000 annually, at least until 2001.

In this Session, NSBRI officials Laurence Young, Director, Ronald White, Associate Director, and Bobby Alford, Chairman of the Board, will present the vision and plan for this enterprise. While the specific research agendas and educational activities are still being defined at this time, eight major research areas have been identified and the general research strategy for each area will be discussed by the NSBRI Team Leaders or their representatives: Neurovestibular Adaptation (C. Oman, MIT), Cardiovascular Alterations (R. Cohen, MIT), Muscle Alterations and Atrophy (R. Schwartz, Baylor College of Medicine), Bone Demineralization/Calcium Metabolism (J. Shapiro, Johns Hopkins), Hematology, Immunology, and Infection (F. Rudolph, Rice) Human Performance Factors, Sleep, and Chronobiology (C. Czeisler, Harvard), Radiation Effects: DNA Damage and Repair (J. Dicello, Johns Hopkins) and Technology Development (V. Pisacane, Johns Hopkins).

Opportunities for cooperation in research and technology transfer with other universities and with current and future industrial affiliates will be discussed, as will joint extramural funding programs, currently under definition, with the National Science Foundation and National Institutes of Health.

Thursday, June 12

Session JA1
Room 1
8:30 - 11:30 a.m.

522-54

074627

12P.

326980

Studies Relating to EVA

THE STAGED DECOMPRESSION TO THE HYPOBARIC ATMOSPHERE AS A PROPHYLACTIC MEASURE AGAINST DECOMPRESSION SICKNESS DURING REPETITIVE EVA

V.I. CHADOV, S.N. FILIPENKOV, L.R. ISSEEV, S.R. KISLYHIN, A.J. MEDNIH, V.V. POLYAKOV, G.F. VOROBIEV

All-Russian Centre for Disaster Medicine "ZASCHITA"(PROTECTION), Moscow

The risk of decompression sickness (DCS) inherent in extra-vehicular activity (EVA) is reduced through the exposure in the hypobaric normoxic atmosphere. The safety of decompression protocols was evaluated as a result of EVA simulation in pressure chamber complex (PCC-270). The goal of the staged decompression investigations was to identify an optimal protocol that would provide protection against DCS during repetitive EVA in the Russian space suit with nominal pressure mode 280 mm Hg and emergency pressure mode 220 mm Hg.

A review of test exposures in hypobaric atmosphere with total pressure 450-700 mm Hg indicated good correlation of DCS risk with R value or ratio of tissue nitrogen partial pressure over final pressure. These experiments included a high incidence of venous bubbles (49%) detected by an ultrasound Doppler detector at nominal schedule of decompression with 30-minutes prebreathe and a lower than anticipated incidence of gas bubbling after 24-hours exposure at the pressures 550-600 mm Hg (6 % and 12 % correspondly). There was decreasing in the incidence of venous bubbles and DCS symptoms during repetitive EVA simulation.

This paper presents experimental data base to verify the safety of repetitive EVA sorties from the orbital space stations

A NEW PREOXYGENATION PROCEDURE FOR EXTRAVEHICULAR ACTIVITY (EVA)

James T. Webb¹, Ph.D. and Andrew A. Pilmanis², Ph.D.

Currently, all crewmembers undergo a 10.2 psi staged-decompression schedule (“camp-out procedure”) or a 4-hour preoxygenation at 14.7 psi prior to EVA to reduce decompression sickness (DCS) risk. The staged-decompression procedure is long (12 hours minimum), involves decompression of the whole Shuttle crew, and impacts computer/electronics cooling. Recent research at the Armstrong Laboratory exposed human volunteers to several altitude chamber profiles designed to demonstrate the effectiveness of exercise during preoxygenation on prevention of DCS. The results showed that a 1-hour resting preoxygenation followed by a 4-hour, 4.3 psi exposure resulted in 77% DCS risk (N=26), while the same profile beginning with 10 min of exercise at 75% of VO_{2peak} during preoxygenation reduced the DCS risk to 42% (P<.05; N=26). A 4-hour preoxygenation without exercise followed by the 4.3 psi exposure resulted in 41% DCS risk (N=22; preliminary). The 1-hour preoxygenation with exercise and the 4-hour preoxygenation without exercise tests were not significantly different. Elimination of either 3 hours of preoxygenation or 12 hours of staged-decompression are compelling reasons to consider incorporation of exercise-enhanced preoxygenation. A 1-hour alternative to the current procedures with no difference in DCS risk represents an enormous cost/time savings, particularly at the beginning of each Shuttle/Space Station construction mission.

¹ KRUG Life Sciences Inc. c/o AL/CFTS, 2504 Gillingham Drive, Suite 25, Brooks AFB, TX 78235-5104

² AL/CFTS, 2504 Gillingham Drive, Suite 25, Brooks AFB, TX 78235-5104

METABOLIC ASSESSMENTS DURING EXTRA-VEHICULAR ACTIVITY

Yu.Yu. Osipov¹, A.N. Spichkov¹ and S.N. Filipenkov²

¹Institute for Biomedical Problem, ²All-Russian Center for Disaster Medicine "Zaschita"

INTRODUCTION

Extra-vehicular activity (EVA) has a significant role during extended space flights. It demonstrates that humans can survive and perform useful work outside the Orbital Space Stations (OSS) while wearing the protective space suits (SS). When International Space Station 'Alpha' (ISSA) is fully operational, EVA assembly, installation, maintenance and repair operations will become everyday repetitive work activity in space. It needs new ergonomic evaluation of work/rest schedule for an increasing of the labor amount per EVA hour. The metabolism assessment is a helpful method to control the productivity of the EVA astronaut and to optimize the work/rest regime.

METHODS

Three following methods were used in Russia to estimate real-time metabolic rates during EVA:

1. The oxygen consumption, computed from the pressure drop in a high pressure bottle per unit time (with actual thermodynamic oxygen properties under high pressure and oxygen leakage taken into account).
2. The carbon dioxide production, computed from CO₂ concentration at the contaminant control cartridge and gas flow rate in the life support subsystem closed loop (nominal mode) or gas leakage in the SS open loop (emergency mode).
3. The heat removal, computed from the difference between the temperatures of coolant water or gas and its flow rate in a unit of time (with assumed humidity and wet oxygen state taken into account).

RESULTS

Comparison of heat removal values with metabolic rates enables us to determine the thermal balance during an operative medical control of EVA at "Salut-6", "Salut-7" and "Mir"OSS. Complex analysis of metabolism, body temperature and heat rate supports a differential diagnosis between emotional and thermal components of stress during EVA.

CONCLUSION

It gives a qualitative prognosis of human homeostasis during EVA. Available information has been acquired into EVA data base which is an effective tool for ergonomical optimization.

EVALUATION OF SAFETY OF HYPOBARIC DECOMPRESSIONS AND EVA FROM POSITIONS OF PROBABILISTIC THEORY

V.P. Nikolaev

Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

The current methods of decompression sickness (DCS) risk evaluation in humans during hyperbaric and hypobaric decompressions are based on classical mathematical models of gas bubbles dynamics in body tissues, and on models of washin and washout of inert gas from the body. Nevertheless, in reality bubbling process in the body (formation and further bubbles growth together with their aggregation, dividing into parts, and migration) during decompression is casual by its nature. Hence, a more realistic approach toward DCS risk evaluation is likely to be based on the original probabilistic theory of decompression safety being developed by us. This theory is based on stochastic modeling of bubbling process in the body and on the concept of critical volume of a free gas phase. The accuracy of this DCS risk evaluation method significantly depends upon the precision of calculations of initial nitrogen tension in the "worst" body tissues. Based on the positions of the mentioned theory, this work is aimed at the search for adequate estimation of nitrogen washout half time from these tissues, DCS risk evaluation during based ground shirt-sleeves EVA simulation, and the reasoning of real and simulated EVA decompression safety differences.

METHODS

According to our theory of decompression safety, the probability of the DCS incidence in subjects exposed to single-stage reduction of ambient pressure can be identified with the size of area under distribution curve of possible values of nucleation efficiency (k) inherent in the "worst" body tissues right from the critical value $k = k_m$ determined by the initial nitrogen tension in these tissues and rate of its washout, as well as by the level of final pressure, time of exposure, and composition of a breathing gas mixture at this pressure. The parameters of log-normal distribution of k values which have dimension $pressure^{-1} \cdot volume^{-1}$ and the parameters of normal distribution of non-dimensional value $z = \log \gamma k$ (where γ - some constant with dimension $pressure \cdot volume$ which gives evaluation scale for z and $z_m = \log \gamma k_m$ in conditional units) depend on character and intensity of subject physical activity before, during and after decompression as well as on hardware ergonomic characteristics. At known or assumed probability of safety for two distinct single-stage decompressions the method of evaluation of DCS risk mentioned allows to determine the parameters of z values distribution and to conduct ranking of all possible decompressions of this type based on the extent of their safety.

RESULTS

The analysis of DCS risk during exposures to different hypobaric pressure levels after preliminary denitrogenation at various duration based on data described in publications provides us to consider that the traditional evaluation of nitrogen washout half time for the "worst" human tissues is underestimated. The value of this parameter is not 360 min, but at least 480 min. Therefore, it may be expected that the initial values of nitrogen tissue ratio in Russian cosmonauts and NASA astronauts during EVA performance are 1.92 and 1.87 respectively. On the other hand, the indices z_m inherent in this tissues equal to 2.55 and 2.52 respectively. Given the parameters of z value distribution that are calculated on the basis of empirical results of Conkin et al (1987), these indices z_m indicate that DCS risk during based ground shirt-sleeve simulation of Russian and U.S. protocols of EVA are 19.2% and 23.4% respectively. Resulting from the microgravity factor influence, space suit rigidity, and increase of average energy expenditures at real EVA, the distribution mode of possible z values for cosmonauts and astronauts in open space is shifted to the left, and the critical value z_m - to the right if compared to their positions for usual subjects during ground based unsuited tests. This is reflected in comparative increase of decompression safety of real EVA.

CONCLUSION

The results of this work confirm the point that the value of nitrogen tissue ratio is not an adequate criterion of decompression safety extent. During based ground shirt-sleeves tests of the Russian EVA protocol with physical load that is used at simulation of the U.S. protocol of EVA the risk of DCS should be 19.2% instead of 42% as predicted by empirical model Conkin et al (1987).

This work is supported in part by the Russian Foundation for Basic Research grant N 95-04-11892 and in part by contract NAS-15-10110.

FATTY ACID COMPOSITION OF PLASMA LIPIDS AND ERYTHROCYTE MEMBRANES DURING SIMULATION OF EXTRAVEHICULAR ACTIVITY

M.A.Skedina, L.B.Buravkova, V.P.Katuntsev and V.P. Naidina.

State Scientific Center of RF - the Institute of Biomedical Problems, Moscow, 123007, Russia

INTRODUCTION

During extravehicular activity (EVA) cosmonauts are affected by a number of extremal factors: hyperoxia, hypobaria, weightlessness, intensive physical loading, emotional stress, which can cause reversible or irreversible changes in the structural and functional state of the cellular membranes. In the altitude chamber EVA model investigations (308 mm Hg - 6 hs duration, 230 mm Hg - 2 hs duration) we didn't reveal any rough alterations in erythrocyte membranes affecting their osmotic resistance or sedimentation rate (Buravkova, Katuntsev et al., 1990, 1994, 1996). However, the cellular membrane fatty acid composition under such conditions is still unknown.

METHODS

In 32 experiments which have been analyzed 10 subjects (healthy male volunteers in age from 27 to 41 years) participated. The individuals were decompressed from ground level to 7000-8100 m (308 - 263 mm Hg) in altitude chamber. At the final pressure all subjects breathed 100% oxygen by mask and performed repeated cycles of exercises: lifting dumb-bells and turning a cycle ergometer. Biomedical monitoring included a record of electrocardiogram, heart rate, breathing frequency, blood pressure and Doppler ultrasonic detection of circulating microbubbles (CMB) in the venous vessels of extremities and pulmonary artery on subjects at regular intervals during the entire period of stay at altitude. Decompression sickness (DCS) was diagnosed on the basis of subject's complaints of skin manifestations, musculoskeletal pains, respiratory disturbances and other abnormalities, results of medical observation and biomedical monitoring during hypobaric exposures in altitude chamber. CMB were aurally detected by the ultrasonic Doppler equipment, recorded on magnetic tape and graded according to the Spencer Scale modified. Each subject was exposed to altitude twice with a two - five days interval. To study the dynamics in the fatty acid composition of the total plasma lipids and erythrocyte membranes we've obtained 57 venous blood samples before and after repeated decompression sessions.

RESULTS

There were 7 episodes of DCS (2 cases during exposure to pressure of 308 mm Hg and 5 cases during exposure to pressure of 263 mm Hg). CMB were detected in 27 cases (84,4%). The intensity of bubble signals in pulmonary artery was 3-4 balls in 24 cases and 1-3 balls in 3 cases.

After the first session (308 mm Hg) we didn't observe any significant changes in the fatty acid composition of plasma and erythrocyte membranes. However, by the beginning of the second session (263 mm Hg) the total lipid in erythrocyte membranes decreased from 54,6 mg% to 40,4 mg % in the group without DCS signs (5 subjects), and from 51,2 mg% to 35,2 mg % ($P < 0,05$) in the group with DCS manifestations (5 subjects). The same subjects had a tendency to elevated level of saturated fatty acids (16:0, 18:0) along with a tendency to decreased level of polyunsaturated linolic acid (18:2); similar results were obtained in the animal study under the conditions of intensive gas formation (Skruopsky et al, 1994). The content of arachidonic acid (20:4) in erythrocyte membranes decreased after each pressure session and significantly increased between the sessions ($P < 0,05$) in the group with DCS signs. This decrease of arachidonic acid level and decrease of total lipids level could be manifestation of disturbed peroxide lipid oxidation in the cellular membranes under experimental conditions. The increase of arachidonic acid content before the following session could be a reversibility sign of the structural and functional changes in membranes, as well as activation of the enzyme system defending cellular membranes under the conditions of hyperoxia and increased metabolism. Insignificant changes in fatty acid composition of plasma lipids were registered in both groups; DCS group showed the tendency to decreased total lipids level in each following measurement, which may also indicate activated peroxide lipid oxidation.

CONCLUSION

The results of present study suggest that DCS risk increase (from 12,5% to 31,3%) during repeated decompression sessions according to reduction of final pressure. The obtained biochemical data show that the simulated EVA conditions can induce alterations in plasma lipid metabolism, as well as reversible changes in the structural and functional state of the erythrocyte membranes, in particular in case of CMB appearance and DCS development.

BIOMEDICAL STUDIES RELATING TO DECOMPRESSION STRESS WITH SIMULATED EVA: OVERVIEW

B.D. Butler,¹ T. Little,¹ M. Powell,² R.R. Robinson¹

¹Baromedical Laboratory, Department of Anesthesiology, University of Texas Medical School 6431 Fannin, 5020 MSB, Houston, Tx 77030 and ²NASA, Johnson Space Center, Life Sciences Laboratories, SD3, Houston, TX 77058

INTRODUCTION

Astronauts are exposed to reductions in ambient pressure from the Space Shuttle or Space Station environment of 14.7 -10.2 psi, to that of suit pressure (4.3 psi) when conducting extravehicular activities (EVA). Ground-based studies simulating these pressure reductions have demonstrated that the formation of venous gas emboli (VGE) and decompression sickness (DCS) can occur. The symptoms of DCS usually are limited to localized joint pain but can include circulatory, nervous system or pulmonary effects, some of which can be life threatening. Avoidance of decompression-induced VGE and DCS can be achieved with multi-hour oxygen prebreathe protocols or prebreathe combined with staged decompression from 14.7 psi to 10.2 psi to suit pressure (4.3 psi). Decompression-induced VGE are usually detected by recording the bubble signals from the precordial or subclavian site using Doppler ultrasound. Previous studies in humans have suggested a correlation between the detected VGE using Doppler and subsequent DCS. In recent studies we have focused on several topics relating to the effects of (VGE) formation that can occur with decompression for simulated EVA. These topics include the evaluation of cardiovascular, pulmonary, biochemical and cellular pathophysiology associated with decompression-induced VGE. Of particular interest are the increases in bioactive mediators that may occur as a result of blood/bubble (VGE) interactions and that can play a principal role in local inflammatory responses and ultimately in lung pathophysiology following more severe cases of DCS. These results may help delineate some of the mechanisms of DCS related symptoms as well as provide a biochemical indicator for VGE formation.

METHODS

To evaluate decompression-induced VGE pathophysiology we have developed both an instrumented rat model for simulating the fluid shifts and cardiovascular adjustments detected in microgravity as well as canine models for evaluating the changes in bioactive inflammatory mediators. In the first series, Sprague-Dawley rats were surgically instrumented with ultrasonic flow and thickness transducers for chronic recordings of blood pressure, cardiac output, myocardial ventricular wall thickness (contractility) measurements, heart rate and vascular resistance measurements. Post decompression or VGE tissue, blood and fluid analyses included pulmonary edema assessment and white blood cell counts. To simulate the cardiovascular deconditioning that occurs as a result of fluid shifts in microgravity, we subjected the rats to a head-down (30°) tilt protocol, commonly used for simulation purposes. Canine models were used for evaluation of the effects of decompression-induced VGE on eicosanoid (leukotriene and thromboxane) production in blood, broncho-alveolar lavage (BAL) and urine. Analyses were made using enzyme immunoassay (EIA) techniques. Moderate decompression exposures were used to simulate operational conditions. In both types of exposure, VGE formation was similar to human ground-based studies and little or no circulatory effects were detected. Both hyperbaric

and hypobaric decompression-induced VGE were detected using transesophageal echo ultrasound. All studies were approved by the UTH-HSC Institutional Animal Care and Use Committee.

RESULTS

The results of the rat study examining the combined effects of cardiovascular deconditioning (e.g. simulated microgravity) and VGE, demonstrated that tail-suspension attenuated both the pulmonary edema formation and the decrease in cardiac output commonly observed with VGE alone. Blood pressure, heart rate and systemic vascular resistance measurements showed no difference between tail-suspended (cardiovascular deconditioned) rats receiving VGE and those receiving VGE alone. Myocardial contractility and differential cell counts were unchanged.

Maximal changes in eicosanoid production in canines after Hyperbaric decompression were as follows: ARTERIAL PLASMA levels of leukotriene E4 (LKE4) were increased by 45%, thromboxane B2 (TXB2) and 11 dehydrothromboxane B2 (11dhTXB2) levels were unchanged; BAL levels of LKE4 were increased by 171%, TXB2 and 11dhTXB2 levels were unchanged; URINE levels were increased of LKE4 by 50%, TXB2 levels by 267%, ($p < 0.05$) and 11dhTXB2 levels by 332%, ($P < 0.05$). With Hypobaric decompression, significant increases ($p < 0.05$) were detected in URINE LKE4 (111%), TXB2 (177%) and 11dhTXB2 (133%). Significant amounts of pulmonary edema and increases in BAL protein levels were detected.

CONCLUSIONS

From an operational standpoint, the EVA's currently performed by US and Russian astronauts entail pressure reductions which, when simulated in ground-based altitude chamber studies, produce VGE and in some cases DCS. Conservative oxygen prebreathe protocols or a microgravity-related effect on VGE formation, may account for the absence of symptoms in astronauts performing EVAs to date. However, operational desires to decrease oxygen prebreathe time may result in an increased appearance of VGE in the future. The results from our studies suggest that some degree of protection from the pulmonary effects of VGE are afforded as a result of the fluid shift mechanisms involved in the simulated microgravity conditions of tail-suspension in the rat. The results further suggest that post-exposure evidence of decompression-induced VGE can be detected in bodily fluids, including urine, using a biochemical assay for the VGE-induced changes in inflammatory mediators. Supported in part by NASA NAGW 4479, NCC9-20.

THE JOINT ANGLE AND MUSCLE SIGNATURE (JAMS) SYSTEM - CURRENT USES AND FUTURE APPLICATIONS

C. U. Ranniger¹ and D.L. Akin²

¹ Graduate Research Assistant, University of Maryland; Zonta Foundation Amelia Earhart Scholar

² Director, Space Systems Laboratory; Associate Professor, Departments of Aerospace Engineering, Applied Mathematics, and Institute for Systems Research, University of Maryland at College Park

INTRODUCTION

The Joint Angle and Muscle Signature (JAMS) System developed at the University of Maryland Space Systems Laboratory is designed to provide accurate, quantitative information describing joint motion of the hand and muscle activity of the associated extensor and flexor groups in the forearm during extravehicular activities (EVA). The system was built to aid in understanding the biomechanics of the EVA-gloved hand/forearm, from both a kinematic and neuromuscular standpoint. The purpose of this presentation is to describe the system and its uses, to report on results of neutral buoyancy suit simulation experiments conducted at Marshall Space Flight Center (MSFC) in September, 1996, and to describe the potential applications of this system to EVA biomechanics research and EVA mission planning.

Space Station-related construction and maintenance operations requiring EVA will increase in frequency, complexity, and duration throughout the next decades. To maximize the productivity of these EVAs, the efficiency of all aspects of these missions - training, operations, and equipment - must be enhanced to the greatest extent possible. The EVA astronaut's unique capabilities rest in the eyes, brain, and particularly the hands, which are used to perform a variety of dexterous, compliant tasks. In order to improve performance, it is important to understand not only the biomechanics of the hand itself, but also of the glove-hand system, as the bulky, protective EVA glove diminishes sensation, range of motion, and force output of the hand. Of particular interest in EVA studies is the manifestation of muscle fatigue in the hand and forearm. Excessive muscle fatigue can inhibit worksite closeout, reduce productivity, and pose a safety threat to the extravehicular astronauts. Use of muscle activity data such as that collected by the JAMS System to determine and predict muscle fatigue relative to joint motion and hand activity will enhance the evaluation of new glove designs, new tools, and EVA task procedures by providing insight into the dynamic state of the human system as well.

JAMS SYSTEM DESCRIPTION

The JAMS system noninvasively monitors joint motion of the right hand and muscle activity of the large hand flexors and extensors, and is compact and lightweight enough to be used within an extravehicular mobility unit (EMU). The JAMS system, shown in Figure 1, is completely self-contained, requiring no external power or data lines. Noninvasive surface electrodes are placed on the large extensor and flexor muscle groups of the hand, located in the forearm, to monitor muscle electrical activity. Fiberoptic cables which transmit light in inverse proportion to fiber deflection are used to track composite joint angles in each of the five digits. Data conditioning, acquisition, and storage units are mounted on a vest which is worn within the hard upper torso (HUT) of the EMU. The system is capable of collecting data for approximately one hour total; currently the limiting factor is the size of the flash RAM data storage card. Data acquisition is controlled via a reed switch located inside the soft lower torso assembly (LTA) where an externally-placed magnet can be used to activate the system after suit ingress. System status, including data acquisition activity, processor, power, and sensor status, is displayed to the suited subject via an LED panel mounted on the communications carrier cap.

JAMS TESTING METHODOLOGY

The JAMS System was used to collect data describing hand motion and muscle activity during simulated EVA operations in the Neutral Buoyancy Simulator (NBS) at MSFC in August-September, 1996. Taskboard-based activities incorporating simple tasks (gripping tools and turning knobs) and complex activities (j-hook operation and beam assembly) were completed by all subjects. JAMS data was acquired during the first and last 20-25 minute taskboard cycles of each ~3 hour test session. Six right-handed male volunteers, ages 20-40, participated in the study. Of these, three test subjects had experience in EVA suits while the remainder were novices.

RESULTS

Examination of muscle activity patterns during early and late taskboard cycles permits comparison of 'fresh' and fatigued electromyograms (EMGs) and joint positions during various activities. Changes in both EMG magnitude and signal frequency content are evaluated for indications of fatigue, and are compared to joint position and motion to extract altered kinematic behaviors which result from increasing fatigue. Previous researchers have shown that the

fatiguing process during isometric, constant force exertion (such as grasping a handgrip) is reflected in changes in the EMG signal's spectral content, specifically as a decrease in the signal's mean frequency. Additional, but less specific fatigue-related changes include variations in signal magnitude. Unpublished research by the authors has shown that similar changes are seen during repetitive (dynamic) gripping tasks.

Examination of EMG signal during 40% maximum voluntary force (MVC) sustained and repetitive handgripping tasks from a single subject (#4) shows significant changes between first and last taskboard cycles. Mean power frequency (MPF) of the flexor EMG signal, collected during an isometric 20-sec handgripping task from the first taskboard cycle, decreases throughout the contraction as expected; however, during the late taskboard cycle the MPF decreases during early contraction and stabilizes during the latter half (Fig 2). The MPF determined from the late contractions is at all times higher than that of the original, unfatigued EMG signal. While flexor EMG magnitude of the task remained constant throughout the first taskboard cycle, as is consistent with a constant-force, unfatigued muscle exertion, the EMG magnitude of the last taskboard cycle was initially smaller, but subsequently increased during the latter half of the contraction. Possible explanations for the magnitude and spectral changes in the later task cycle include lower initial gripping pressure (incomplete closure of the springloaded gripper) with subsequent repositioning of the hand to achieve closure, or increased neuronal stimulation with recruitment of additional muscle fibers as initially-active fibers fail.

Comparison of repetitive-handgripping tasks performed during early and late taskboard cycles yields less conclusive results. Average EMG magnitude increased during late-cycle repetitions, and MPF during peak contraction was greater during late-cycle repetitions. However, the expected reduction in MPF within taskboard cycles was not found. The authors postulate that the time-frequency resolution conflict inherent in Fourier frequency analysis prohibits examination of the frequency spectrum at the time of peak contraction alone. The authors propose the use of wavelet-based frequency analysis to elicit temporally-compact frequency spectra of the signal.

FUTURE JAMS APPLICATIONS

The JAMS System provides a unique window onto the EVA system during working conditions. Fatigue analysis of individual tasks, such as those presented here, can be used with kinematic (joint) analyses to develop task-based fatigue metrics. Metrics describing the rate and extent of fatigue resulting from simple activities such as squeezing a handgrip or twisting knobs can subsequently be used to aid in fatigue prediction of more complex tasks which incorporate these or similar simple motions. The ability to predict fatigue and recovery rates during typical EVA tasks will enable development of operations which minimize fatigue by interleaving high-intensity tasks with recovery periods or less-demanding activities.

The JAMS System has the potential to aid in the global understanding of the EVA subject by supporting the development of an experimentally-validated model describing the relationship between body position and orientation, exorable force and torque, and muscle activity and fatigue of the EVA astronaut. Expansion of the JAMS System to incorporate major joints and muscle groups of the body will enable data collection describing postural, kinematic, and dynamic responses and capabilities of the body in the EVA environment. A quantitative relationship between maximum force/torque vs. body orientation or joint extension will enable prediction of optimal workspace location, including foot restraint placement, handhold placement, and tool design. A quantitative understanding of the limitations which EVA suits place on activity will enable better design of advanced EVA suits for the next century.

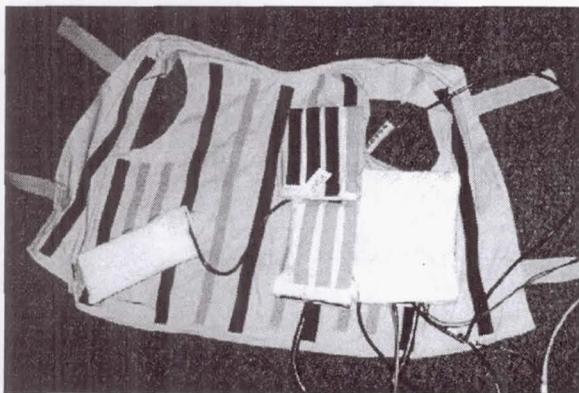


Figure 1: JAMS System Hardware and Vest

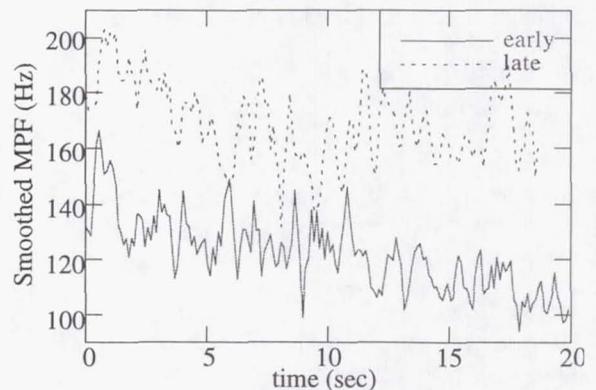


Figure 2: Mean Power Frequency during isometric handgrip in early and late taskboard cycles

EXPERIMENTAL INVESTIGATION OF COOPERATIVE HUMAN-ROBOTIC ROLES IN AN EVA WORK SITE

D. L. Akin

Space Systems Laboratory, University of Maryland, College Park, MD 20742

INTRODUCTION

With the advent of the International Space Station (ISS), the demand for human extravehicular activity (EVA) will increase by an order of magnitude from the peak activity over the history of the space program. This increased demand will require a limitation of current levels of EVA training, as the flight pace and limited training resources will be spread over many more EVA hours. In addition, NASA studies have indicated that the Space Station could reach a point, prior to assembly completion, where all available EVA hours will be spent repairing failures to the existing hardware, with no time remaining to complete station assembly activities.

With these factors in mind, extravehicular telerobotics play an increasing role in maintaining an effective and productive space presence. Orbital replacement units (ORUs) which have to be changed on a regular basis on ISS are designed to be maintained using the Canadian Special Purpose Dexterous Manipulator (SPDM). However, this represents only a small fraction of the total maintenance items on the station, and designs for robotic servicing have to be substantially altered to deal with the extremely limited dexterity of the SPDM.

This paper presents results from extensive testing by the University of Maryland Space Systems Laboratory on potential cooperative roles of humans and machines to accomplish exterior activities in microgravity. Over the last decade and a series of increasingly sophisticated telerobots, the useful robotic roles have changed from simplistic assistant to the EVA human, to the current level of near-equivalent performance.

HISTORICAL BACKGROUND

Human-robotic EVA interaction in space to date has been limited to the use of foot restraints on the end of the shuttle Remote Manipulator System (RMS). This pairing is used to provide stabilization for the astronaut, who may be thought of as a truly dexterous end effector for the RMS.

In the Space Systems Laboratory, robotic interaction with EVA subjects has been an active experimental topic since the development of the first SSL teleoperator in 1984. In the most extensive series of tests, the Beam Assembly Teleoperator was used for solitary and cooperative servicing of the Hubble Space Telescope training mockup (Figure 1). These tests indicated the utility of a robot to assist the EVA crew, even if the robotic manipulative capability is severely limited. Other robotic systems were tested in a variety of roles, including concepts such as the Astronaut Support Vehicle for supporting human presence in space beyond the orbital limitations of the Space Shuttle and ISS.

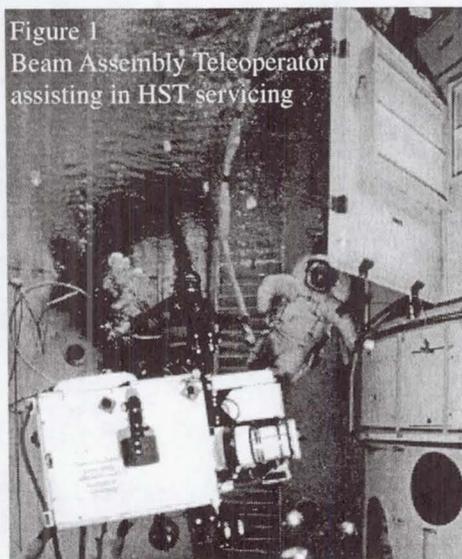


Figure 1
Beam Assembly Teleoperator
assisting in HST servicing

FREE-FLYING CAMERAS AND EVA

The Supplemental Camera and Mobility Platform (SCAMP) was developed in the SSL as a remotely controllable free-flying camera platform. Views of space activities to date have been largely from internal points of view, since exterior views are not easily attainable. SCAMP was developed to provide exterior views of remote work sites, to be used with either EVA or dexterous robotic operations.

To date, SCAMP has performed flawlessly in this visual monitoring capability. It has been used in the NASA Johnson Space Center Weightless Environment Training Facility (WETF) to monitor astronaut training for EVA (Figure 2), including close proximity to suited operations. During tests at the NASA Marshall Space Flight Center, SCAMP was used with remote satellite control from JSC and the University of Maryland to monitor EVA simulations. In one interesting application, an EVA subject performing Hubble Space Telescope servicing was directed to incorrectly close out a work site. The remote SCAMP operator was able to instantly spot the deficiency and direct the EVA subject to correctly complete the task.

The demonstrated performance of SCAMP, along with a newly



Figure 2
SCAMP monitoring EVA
training for STS-80

recognized need for visual coverage of the extensive ISS hardware, has led the Johnson Space Center to develop a free-flying camera for space flight demonstration. The Autonomous EVA Camera (AERCAM) Sprint mission will fly in late 1997, and will provide a variety of external views of EVA operations in the space shuttle.

DEXTEROUS ROBOTS AND EVA

With the lessons learned from two decades of experience with human EVA and space robotics, the SSL has developed a telerobotic system to approach the dexterity of a suited astronaut. Ranger has been designed to perform all spacecraft servicing tasks planned or considered for EVA, and represents a highly capable vehicle in its own right. In a recent series of tests at NASA MSFC, Ranger was used in cooperative activities with EVA subjects performing HST servicing tasks and structural assembly. In these tests, Ranger passed tools and ORUs back and forth to the human subject (Figure 3), and cooperated in extended servicing tasks. In one of the most interesting tests, Ranger prepared the HST work site by opening the access panel and emplacing portable foot restraints (Figure 4), then stood by to monitor and assist the EVA crew in the actual ORU replacement. Following the servicing, Ranger then closed out the work site after the departure of the EVA crew.

FUTURE RESEARCH

Much work remains to fully identify the useful cooperative roles between humans and robots in space operations. The neutrally buoyant Ranger vehicle will be used extensively in the coming months to extend the knowledge base of human-robotic cooperation when highly dexterous robots are involved. These tests will provide continued information on multiple robot scenarios, as SCAMP is routinely used in Ranger and Ranger/EVA test scenarios. While these tests will provide critical data on orbital operations, the entire field of cooperative human/robotic EVA operations on planetary surfaces is waiting for the first critical experiments.



Figure 3
ORU hand-off
between Ranger
and EVA crew
with SCAMP
monitoring

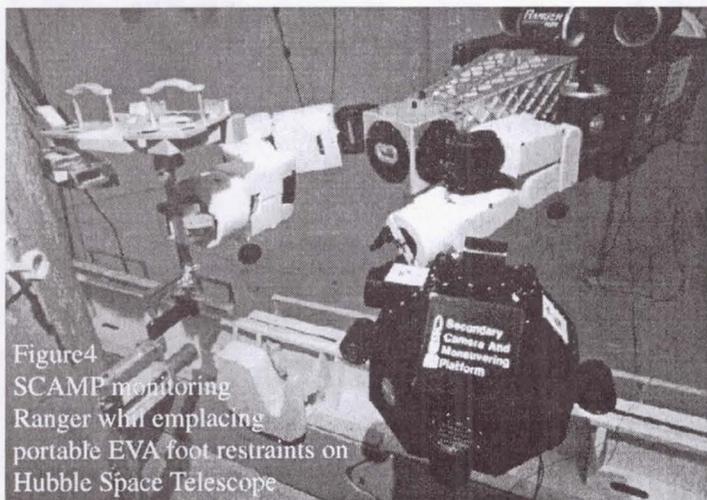


Figure 4
SCAMP monitoring
Ranger when emplacing
portable EVA foot restraints on
Hubble Space Telescope

CONCLUSIONS

Every experience indicates that a cooperating team of humans and robots in the EVA work site is significantly more productive than either system working alone. In the words of the NASA EVA Program Manager, "Humans and robots in EVA are symbiotic, if not synonymous." If an era of highly aggressive space operations is to prove successful, in the future the term "EVA" will come to automatically mean a team of humans and robots working together.

Thursday, June 12

523-52

074628

Session JA2

Room 2

8:30 - 11:30 a.m.

326981

19A.

**Body Fluid Regulation and
Hemopoiesis in Space Flight**

BODYMASS AND FLUID DISTRIBUTION DURING LONGTERM SPACEFLIGHT WITH AND WITHOUT COUNTERMEASURES

K. A. Kirsch, F. Baartz, H.-Ch. Gunga, E. Koralewski and B. Johannes
Dept. of Physiology, Free University Berlin, 14195 Berlin, Arnimallee 22, Germany

INTRODUCTION

Exposure to micro-g is followed by a fluid shift from the lower limbs towards the upper part of the body and simultaneously a fluid loss occurs. We therefore studied the dynamics of the fluid shift in relation to the fluid loss during short and long term spaceflights. In the latter case countermeasures were applied to prevent a fluid mobilisation from the lower limbs.

METHODS

8 male subjects took part in the study during 5 different space missions. Two subjects were on the D-2 Mission, 6 were on the Mir-Station. In the short term flights (4 subjects) no countermeasures like cuffs around the thighs were used. In the long term flights (33 - 436 days) countermeasures were applied. The tissues thickness (TT) was measured in superficial tissues by ultrasound probes attached along the tibia and in the front. Pre-, In- and postflight data were collected. During long term flights Body Mass (BM) was taken together with the TT values.

RESULTS

During all missions facial tissue swellings appeared within the first hours but tended to diminish during the flight. The shrinking of the limb tissues (- 15%) was more outspoken than the tissue swellings in the front (+ 7 %) and remained unchanged throughout the flight as observed during the short term missions. In the long term flights the application of the cuffs prevented a fluid mobilisation from the lower limbs but not the swelling of the facial tissues. In the front between the BM changes and the TT changes in flight always a strong correlation existed ($p < 0.01$).

CONCLUSIONS

Swellings of the facial tissues during space flight are dependent from the water balance of the body, they can not be prevented by countermeasures.

PLASMA VOLUME, EXTRACELLULAR FLUID VOLUME, AND REGULATORY HORMONES DURING LONG-TERM SPACE FLIGHT H.W. Lane, B.V. Morukov, I.M. Larina, S.M. Smith, A.I. Grigoriev, C.S. Leach. NASA Johnson Space Center, Houston, TX; Institute for Biomedical Problems, Moscow, Russia.

Exposure to microgravity causes headward fluid shifts, and it is hypothesized that the body perceives this as an increased circulatory volume. Within hours of entering microgravity, a 12-15% decrease in plasma volume (PV) and a 10% decrease in extracellular fluid (ECF) occur. The PV decreases through a shift of plasma out of the vascular compartment, initially to the extravascular ECF and then to the intracellular compartment. The net result is a shift of fluid from the ECF to the intracellular fluid compartment. Concurrently, erythropoiesis is downregulated resulting in a 12-15% decrease in red blood cell mass, with an overall 12-15% reduction in blood volume. These observations have been well characterized in short-term space flight. We report here data from a 115-d mission aboard the Mir space station.

Three male subjects participated in these studies (age 47 ± 12 years, mean \pm SD; body weight 77.9 ± 7.2 kg). Plasma volume was measured before flight and on landing day using the carbon monoxide rebreathing technique. Extracellular fluid volume was determined before and during flight using the bromide dilution technique. Blood and urine samples were collected, aliquoted, and frozen until postflight analysis, except for blood sodium and potassium, which were determined in "real-time" with a portable clinical blood analyzer. Plasma levels of aldosterone, antidiuretic hormone (ADH), and atrial natriuretic peptide (ANP) were determined before flight and after 110 d of flight. Results are shown below; all data are mean \pm SD.

<u>Analyte</u>	<u>Preflight</u>	<u>Inflight</u>
Plasma Volume (L)	3.16 ± 0.15	$3.01 \pm 0.08^*$
Extracellular Fluid Volume (L)	19.53 ± 2.16	15.56 ± 1.80
Aldosterone (pg/ml)	109 ± 34	73 ± 29
ADH (pg/ml)	2.6 ± 1.3	0.9 ± 0.4
ANP (pg/ml)	20.0 ± 12.7	12.6 ± 11.6

* Landing day data

The decreases in plasma volume and extracellular fluid volume are similar to changes found in 14-d Shuttle flights. After 110 days of flight, plasma ADH concentrations of all crewmembers and ANP of 2 of the 3 had decreased compared to preflight values. The initial changes in fluid volumes that occur during space flight appear to remain throughout long-term flight. This indicates that these are not transient effects, but rather reflect an adaptation to space flight which occurs within the first days to weeks of flight.

EFFECT OF MICROGRAVITY AND ITS GROUND-BASED MODELS ON FLUID VOLUMES AND HEMOCIRCULATORY VOLUMES

V.I. Lobachik, V.V. Polyakov, S.A. Chupushtanov, S.F. Voronov
State Scientific Center RF— Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

Despite certain achievements of space exploration, many important problems of space medicine remain unresolved. There is no clear scientifically validated concept of the pathogenesis of the effect of space flight (SF) factors upon the human body; its most vulnerable functions and systems have not been identified; the compensatory reserve of the body remains undetermined. All this prevents further increase of space flight duration, prediction of the development of sub-pathological states as well as further optimisation of countermeasures and purposeful correction of the status of body functions. Among the unresolved problems of space medicine, the leading one are, in our view: the change, during SF, of the functioning of the circulatory system (CS) manifested as a decreased orthostatic tolerance of cosmonauts; disturbed cardiac rhythm, increased blood filling of parenchymatous organs during SF, the space anaemia syndrome; decreased content of fluids and hemocirculatory volumes. The subject of discussion in this work is a study of fluid and blood volumes. It is obvious that these studies require a complex approach and the use of modern measuring techniques. The most adequate are, in our view are stable and/or radioactive isotopes. Great experience has been accumulated of complex studies of fluid and blood volumes in various ground-based simulation experiments using a complex of stable and radioactive isotopes. However, scanty and fragmentary data obtained during space flight have not allowed to determine the identical nature of physiological effects seen during simulation experiments and SF. This could be resolved only by quantitative measurements of blood and fluid volumes directly during SF. After developing methods for delivery, means for investigation, and ways of returning the biomaterials to the Earth, these measurements were performed aboard the "Mir" orbital station during orbital missions (OM) 15—17 in 2 cosmonauts: the physician (OM 15—17) and commander of OM-16. The in-flight studies were performed by physician-cosmonaut.

METHODS

The following radioisotopes were used: tritium water and labelled albumin (J-131), as well as stable bromide. The following volumes were studied: total body water (TBW), intracellular water space (ICWS), extracellular fluid (ECF), and its fractions: plasma (PV) and the interstitial fluid (IFV), as well as blood and erythrocyte volumes (BV and EV). Studies were performed pre-flight, on flight days 4-5 (in physician and commander) and on day 434 (in physician) as well as during readaptation.

RESULTS

On days 4 and 5 of SF in physician and commander the TBW was lower than pre-flight by 4 and 5 % respectively. The ECF was lower than pre-flight by 9 and 10 % respectively. The ICWS within the SF duration was unchanged. BV in commander was lower than pre-flight by 8 % due to his own plasma. The erythrocyte mass volume was not decreased. Observation of physician on the SF day 434 revealed a decrease of ECF by 18 % as related to pre-flight. This was due both to plasma and to the interstitial fraction which changed more significantly. Ratios of fluid fractions changed insignificantly. The post-flight observation of commander on day 1 after completing his 158-day SF, revealed a decreased content of all fluids: TBW by 10 %, ECF by 23 %, ICWS by 5 % as related to the pre-flight value. The post-flight observation of physician on day 14 after landing demonstrated that the changes noted at the end of SF by the day of readaptation mentioned were slight. However, the changed ratio of the vascular and interstitial fractions was maintained. The work presents a comparative analysis of changes in hydrational homeostasis and hemocirculatory volume during microgravity and ground-based simulation experiments — clynostatic hypokinesia, head-down hypokinesia with a tilt angle of 5 and 15°, vertical immersion.

CONCLUSIONS

Due to the inadequate number of observations during SF, the conclusions are preliminary. On days 4 and 5 of adaptation to SF, a new level was formed of hydrational homeostasis and hemocirculatory volumes at a lower quantitative level most marked was the decrease of the extracellular fluid volume and its fractions. The intracellular fluid volume was unchanged, which disturbed their ratios. During a prolonged space flight in physician, the changes progressed. The most marked were also changes in the extracellular water space, mainly due to the interstitial fraction. During readaptation for 14 days, the changes noted in-flight, practically returned to pre-flight values. A comparative analysis of changes in fluid and blood volumes during microgravity and ground-based simulation experiments demonstrated that, preliminary, they have a common direction of changes. However, each of the above models has its peculiarities and differences.

SEVENTEEN WEEKS OF HORIZONTAL BED REST, LOWER BODY NEGATIVE PRESSURE TESTING, AND THE ASSOCIATED PLASMA VOLUME RESPONSE

Claire M. Lathers, Barr Laboratories Inc., Pomona, NY
John B. Charles, NASA Johnson Space Center, Houston, Texas

INTRODUCTION

Both space flight and BR are associated with a cephalad shift of body fluids, diuresis, a decrease in plasma volume (PV) and orthostatic intolerance. The loss of orthostatic tolerance can be documented during bed rest (BR) using lower body negative pressure (LBNP).

METHODS

This study was conducted in Methodist Hospital, Baylor College of Medicine, as an adjunct investigation to a primary study designed to document hypokinesia-induced Ca^{++} loss. We examined PV in 4 healthy male subjects before, during, and after 17 weeks of horizontal BR. LBNP was performed weekly to document orthostatic tolerance. The LBNP protocol consisted of a 10-min control period at ambient pressure; 5 mins each at 5, 10, and 20 mm Hg, but it increased at 30, 40, and 50 mm Hg LBNP. Pre-BR, peak HR was 97 ± 10 bpm, occurring at 50 mm Hg. After 3 days of BR, all HR responses, including values after release of LBNP, were only slightly elevated (ns) above pre-BR level. Peak HR was 118 ± 21 bpm at 50 mm Hg decompression (ns). After 3 weeks of BR, peak HR was 110 ± 16 bpm at 50 mm Hg decompression (ns). The slight increase (ns) in HR persisted throughout the 17 weeks of BR. A decrease in the duration of tolerance to LBNP occurred in 3 subjects. Mean PV was decreased 5% to 4% (sig different from almost all other days) on day 36 and 42 of BR, respectively. All other PV values did not vary much, ranging from -1.5% to 1% of control.

CONCLUSIONS

The data indicate that the HR changes associated with orthostatic instability develop early, after as few as 3 days of BR, and persist throughout the entire 17 weeks of horizontal BR. Sandler (NASA 1988 Technical Memorandum 88314) summarized data from many BR studies and reported that PV exhibited a rapid 8-10% loss over the first few days of BR. PV values were then stabilized at -15 to 20% between 14 to 28 days and exhibited decreases up to 30% when the duration of BR was from 100 to 200 days. Udden et al (Space Physiology and Medicine, Lea & Febiger, p 350, 1994) reported a 23% decrease in PV after 24 hours of space flight; values 9 days later, at landing, were only decreased by 10%. PV values returned to control six days after landing. In the 17 week BR study the peak magnitude of the PV decrease, (-5%) detected on day 36 of BR, was one-half that reported after 9 days of space flight. On day 15 of BR, PV values were no different from those at day 0. In conclusion, the data show a decrease in PV like other BR and space flight studies, but the magnitude of the decrease and the time frame in which the decrease occurred were different. In general, PV was maintained during the 17 weeks of horizontal BR. The data suggest that the slight decrease in PV did not, by itself, alter the HR changes associated with the orthostatic stress induced by LBNP.

EVAPORATIVE WATERLOSS IN SPACE THEORETICAL AND EXPERIMENTAL STUDIES.

F. Baartz, F. Castrucci, H.-Chr. Gunga, E. Koralewski and K. Kirsch
Dept.of Physiology, Free University Berlin, 14195 Berlin, Arnimallee 22, Germany

INTRODUCTION

During space flight often water loss occurs in man but it is unknown whether a reduced intake or an increased output is responsible for the fluid loss. In a theoretical study evaporative water loss (EVA) was estimated and compared with results obtained during head down tilt (HDT) studies.

METHODS

In the theoretical study besides the usual climate factors prevailing in a space craft micro-g conditions were assumed which would exclude thermal convection.

Experimental studies were performed in 12 male subjects measuring EVA in supine and HDT conditions. EVA was measured with an evaporimeter (Servo-Med Sweden) in 8 points along body axis.

RESULTS

The theoretical study revealed an evaporative loss of $6.1 \text{ g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$, which is a very low rate compared to data seen on ground.

Subjects with high ($n = 4$) and low ($n = 6$) EVA rates during rest in supine position were seen. During HDT the subjects with high resting EVA rates responded with significantly reduced EVA values ($p < 0.01$). The individual type of subject seen in supine position determined the EVA rate rather than the HDT manoeuvre.

CONCLUSIONS

Theoretically low EVA rates in micro-g can be expected. Simulated micro-g can affect EVA depending on individual. Whether this plays a role under stress conditions like in space remains to be determined. Only direct measurements in space can solve the problem.

ERYTHROPOIETIN UNDER REAL AND SIMULATED MICRO-G CONDITIONS IN HUMANS

H.-C. GUNGA¹, K. KIRSCH¹, A. MAILLET², F. BAARTZ¹, C. GHARIB², W. NALISHITI³, I. RICH⁴, L. RÖCKER¹

1) Department of Physiology, Free University of Berlin, Amimallee 22, D 14 195 Berlin, Germany; 2) Laboratoire de Physiologie de l'Environnement, Faculté de Médecine Lyon Grange-Blanche, 8 Avenue Rockefeller, F-69373 Lyon, France; 3) ZPK, 14160 Star City, Moscow, Russia; 4) German Red Cross, University Ulm, Helmholtzstraße 10, 89081 Ulm, Germany

INTRODUCTION

It was the aim of this study 1) to analyze the time course of erythropoietin during earth-bound micro-g simulations such as bed-rest, isolation and confinement, head-down tilt (-6°), and immersion so as to evaluate 2) which factors could contribute to alterations found in erythropoietin under real micro-g conditions during and after short- (<10 days) and long-term (>6 months) space-flights.

METHODS

Serum and plasma samples were taken and analysed for erythropoietin by radioimmunoassay and enzyme linked immunoassays before, during and after the following test settings: bed-rest (N=10, male, 24 hrs); isolation and confinement (N = 4; 1 female, 3 male, 8 weeks); head-down tilt (-6°) (N = 8, male, 42 days); immersion (N = 8, male, 1 hr); short- (N = 4, male, 10 days) and long-term (N = 1, male, 135 days) space-flight.

RESULTS

During bed-rest (24 hrs) no significant changes in erythropoietin could be observed. The subjects confined in a diving chamber facility for 8 weeks showed, after 3 weeks inside the chamber, an erythropoietin decrease until the last week inside the chamber. In the recovery period a slight increase was observed, but erythropoietin concentrations did not reach the pre-isolation control level. In the control period before head-down tilt (-6°) the subjects showed normal resting values for erythropoietin, but already on the 2nd day of head-down tilt the erythropoietin concentrations were decreased ($P < 0.01$). During the following weeks the erythropoietin levels remained below the control value and were increased during the 1st week post-head-down tilt ($P < 0.05$). After immersion (1 hr) the erythropoietin values were unchanged, whereas 24 hrs later a significant increase could be determined ($P < 0.05$). During the German *D-2* mission, a short-term space-flight (10 days), the astronauts showed pre-flight normal resting erythropoietin levels (9.3 ± 2.2 mU . ml⁻¹). In-flight (4th day) the erythropoietin concentrations were decreased (6.0 ± 5.1 mU . ml⁻¹): two astronauts had very low erythropoietin levels (subject A 0.3 mU . ml⁻¹; subject D 3.3 mU . ml⁻¹) while the other ones showed nearly unchanged concentrations. On the recovery day the erythropoietin concentrations were slightly further decreased (5.6 ± 3.3 mU . ml⁻¹) and increased slowly towards control level in the post-flight phase (7th day 7.4 ± 3.4 mU . ml⁻¹; 15th day 10.9 ± 2.1 mU . ml⁻¹). During the *EUROMIR'94-E* mission, a long-term space-flight (135 days), the cosmonaut showed pre-flight normal resting erythropoietin levels (14.4 mU . ml⁻¹). One day after the recovery the erythropoietin concentration was slightly elevated, but in the normal range (19.4 mU . ml⁻¹). In the following post-flight phase the erythropoietin values increased markedly (2nd day 46.3 mU . ml⁻¹) and remained elevated (5th day 43.1 mU . ml⁻¹).

CONCLUSION

It is concluded that 1) head-down tilt (-6°) causes a rapid erythropoietin decrease in man; 2) isolation and confinement *per se* lead to diminished erythropoietin concentrations; 3) during a short-duration spaceflight (<10 days) extremely low erythropoietin concentrations were observed in-flight in two out of four astronauts, whereas in the other ones unchanged erythropoietin concentrations were determined. After two weeks post-flight all subjects showed normal erythropoietin concentration; 4) increased erythropoietin concentrations above control range were found immediately after long-term space flights; 5) changes in central blood volume, i.e. central venous pressure, might be involved in the modulation of erythropoietin production and release under simulated and real micro-g conditions; and 6) the head-down tilt (-6°) earth-bound simulation reflects most likely the changes in erythropoietin production and release observed under micro-g conditions in man.

VERTEBRAL BONE MARROW CHANGES FOLLOWING SPACE FLIGHT

A. LeBlanc¹, C. Lin¹, H. Evans², L. Shackelford³, S. West¹, T. Hedricks¹

¹Baylor College of Medicine, ²Krug life sciences, ³Johnson space Center, Houston Tx.

INTRODUCTION

It is known from bone biopsies that marrow fat increases 100% during the first 20 weeks of paralysis. The exact function of marrow adipose cells and their relation to bone metabolism and hematopoiesis is unknown, however, it is known that bone marrow adipose cells have a reciprocal relationship to hematopoietic tissue. As the hematopoietic tissue expands the lipid fraction of the adipose cells decreases while the opposite occurs during decreases in hematopoiesis. A number of studies suggest linkage between the bone marrow microenvironment and osteoblastic activity. With magnetic resonance spectroscopy (MRS), the possibility exists to examine these changes in vivo. One objective of our Life and Microgravity Spacelab (LMS) experiment, flown in July of 1996, was to document this expected change in the marrow composition using a noninvasive MRS technique developed in our laboratory.

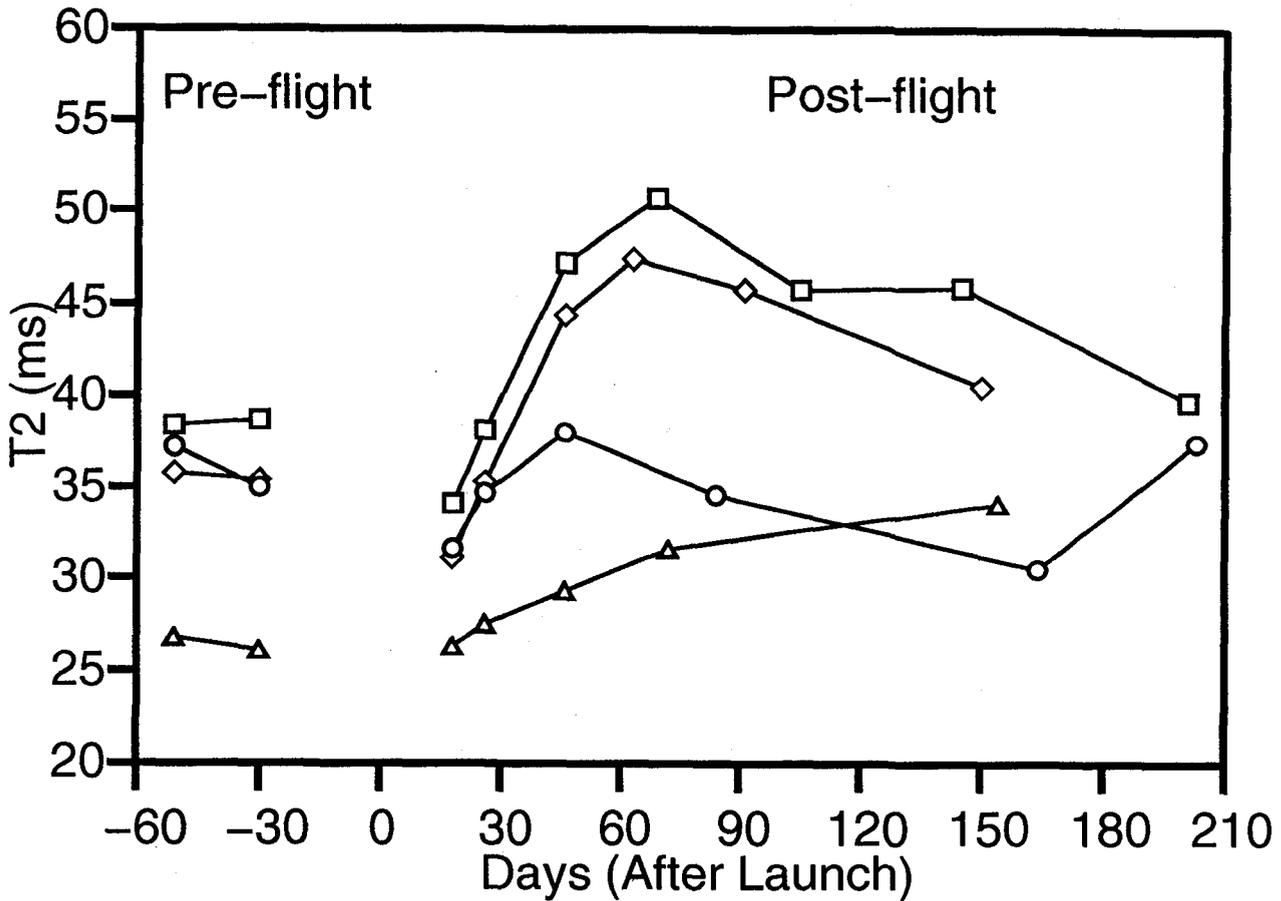
METHODS

LMS was a 17 day Spacelab mission dedicated to life and microgravity research. The 4 payload crewmembers participated in the magnetic resonance experiment which involved MRS scanning at L-60, L-30, R+2, R+14 and R+30 days. To measure the fat to water ratio in vertebral bone marrow, volume selective proton spectra were obtained using a surface receive coil. A cubic volume of interest of 15mm x 15mm x 15mm located in the center the L3 vertebral body was selected based on the initial scan of the spine region. A Gradient Inversion Spectroscopy technique was used to acquire spectra at TE = 12, 18, 24, and 30 ms with TR = 2s. The images were corrected for T2 weighting by exponential extrapolation of the spectra obtained at various TE. The intensities of fat and water were calculated by integrating the areas under the fat and water peaks after baseline correction. Bone marrow cellularity was determined from the fat to water ratio.

RESULTS

Immediately post-flight no significant change in the fraction of the water (cellular) component was found although subsequent post-flight measurements may indicate some change. There appeared to be a small decrease in the T2 of the cellular component post-flight, but what was surprising was the increase in T2 in all crewmembers that was clearly evident by the final data collection point at 30 days post-flight. We obtained IRB and astronaut permission to obtain additional measurements when the crewmember's time and schedule permitted. The data collected to date are shown in figure 1. For 3 of the 4 crewmembers, the T2 remains elevated above baseline 130 days after landing. There was no change in the T2 of the fat component. The T2 of the fat and water components for three volunteers measured over a one year interval overlapping the time when the flight data was collected showed no significant change.

Figure 1



DISCUSSION

Since the fraction of the cellular portion of the marrow is changing only slightly if at all, implies that the observed T2 change in the cellular component represents a change in the cellular composition of the marrow. One explanation is increased hematopoiesis to replace lost red cells following flight since the loss of red cell mass during short duration weightlessness is documented. However, the time frame of the T2 response is much longer than needed to replace lost red cells which should be completed in about one month after flight. Another explanation for the post-flight T2 response might be increased osteoblastic activity which might be expected to have a longer time frame. Our 17 week bed rest studies demonstrated an increase in bone formation markers compared to pre-bed rest after reambulation; alkaline phosphatase by 50% and osteocalcin by 33%.

CONCLUSION

There are significant T2 changes in the vertebral bone marrow observed with MRS after short duration flight (17 days). These changes demonstrate a time course lasting several months suggesting accelerated osteoblastic activity after return to earth's gravity. These findings have significant implications for medical research on earth as well as microgravity.

Thursday, June 12

524-52

074629

Session JA3

Room 3

12P.

8:30 - 11:30 a.m.

326982

**Effect of Real and Simulated
Microgravity on Muscle Function**

CHANGES IN CALF MUSCLE PERFORMANCE, ENERGY METABOLISM, AND MUSCLE VOLUME CAUSED BY LONG TERM STAY ON SPACE STATION MIR

J. Zange¹, K. Müller¹, M. Schuber¹, H. Wackerhage², U. Hoffmann², R.W. Günther³, G. Adam³, J.M. Neuerburg³, A.O. Bacharev⁴, V.E. Sinitsyn⁴, and O.I. Belichenko⁴

¹Institute of Aerospace Medicine, DLR, Cologne, Germany; ²German Sports University Cologne, Germany; ³RWTH-Aachen, Germany; ⁴Cardiology Research Centre, Moscow, Russia

INTRODUCTION

The decrease in performance of anti gravitational muscles due to space flight conditions has been studied by several groups of scientists in terms of tissue mass, muscle performance, and neuro-muscular characteristics (1, 2, 3). However, the role of changes in energy metabolism, determined by the ratio of oxidative and glycolytic muscle fibres and their densities in mitochondria and glycolytic enzymes, is still unclear. For this reason, we have used ³¹P magnetic resonance spectroscopy to monitor the energy metabolism in resting, working, and recovering calf muscle before and after space flight in the scope of the space missions EuroMIR'94 and '95.

SUBJECTS AND METHODS

3 to 6 times pre-flight and 3 times post flight (return +4,+9 to 11, and +30 days) examinations were performed on the right lower leg of one cosmonaut, who was on Mir for one month, and on three cosmonauts, who stayed on Mir for 6 months. Space flight conditions are characterized by unloading due to microgravity and by the Russian countermeasure program containing treadmill and velo ergometer exercise for approximately 2 hours per day. The cross-sectional areas and the volumes of the plantar flexors were determined from T1-weighted magnetic resonance images acquired at 1.5 Tesla. Energy metabolism was monitored by ³¹P-MR spectroscopy at 4.7 or 1.5 Tesla, respectively. Spectra were obtained in intervals of 20 s during an exercise protocol containing three periods of 3 min isometric foot plantarflexion with increasing muscle tension (20, 40, and 60% of current maximum voluntary contraction force, MVC) on a pedal ergometer each followed by 5 min of recovery. Spectra were analysed for phosphomonoesters (e.g. glucose-6-phosphate), inorganic phosphate, phosphocreatine (PCr), adenosine triphosphate (ATP), and intracellular pH. The time constant of PCr repletion in recovery from exercise was assessed in order to characterize the oxidative metabolism in calf muscle (4). Since muscle forces equal to, or higher than, 60% MVC cause a functional ischemia, the overall energy turnover was calculated from the rate of PCr depletion at the very onset of contraction. Glycolytic ATP formation was calculated from the difference between the initial and final rates of PCr depletion 60% MVC (5).

RESULTS

In all cosmonauts volumes of plantar flexors in the calf were decreased by 6 to 20%, as compared to average pre-flight values. MVC was unchanged after one months in space but decreased by 20% to 48% after 6 months. Reductions in force could not be correlated with the decrease in muscle volumes.

After return from a 1 month space flight all three exercise steps were executed as nominally required. The oxidative PCr recovery after contraction was delayed and glycolytic ATP formation at high forces (60% MVC) was reduced.

After 6 months in space, the 60% MVC step of isometric contraction test was terminated after 1 to 1.5 min, instead of the demanded 3 min, because of muscle pain. However, pain occurred after little exercise in absolute terms resulting in only small depletion of PCr stores by 20% to 65% and an intracellular acidification which was less than 0.1 to 0.2 pH-units. PCr and pHi kinetics did not indicate changes in the capacities of oxidative and glycolytic metabolism compared with pre flight conditions. However, in subject metabolic efficiency (total ATP turnover versus force time integral) was decreased by 33%. About 1 month post flight all investigated parameters had returned to normal in all subjects, independent from flight duration.

DISCUSSION

Post-flight changes in aerobic and anaerobic work capacities were only observed in one subject who was in space for 1 month.. However, after 6 months in space, 3 subjects did not show any change in their aerobic and anaerobic metabolic capacities. The single case after one month in space might be representing a transition state during long term space flight or was more probably due to intense exercise one day before examination. This will be studied in

the scope of the German - Russian space mission MIR'97. Furthermore, in 1997, present findings for a 6 months long space flight will be proved on further 3 subject in the scope of MIR'97 and EuroMIR-E.

The decrease in calf muscle performance observed in early post-flight examinations in EuroMIR'94/ '95 cosmonauts cannot only be explained on the basis of a decrease in muscle volume. Furthermore, early painful fatigue due to isometric contraction, which occurred after 6 months in space, was clearly not induced by energy depletion or acidification. Effects of space flight conditions on the capacities of energy metabolism are of little or no physiological relevance for the reduction in muscle performance. Although long term static contraction of the calf muscles did almost not occur under microgravity, endurance kinetic exercise e.g. on the treadmill seemed to be sufficient to conserve the relative fraction of red muscle fibres.

The decrease in maximum and endurance muscle performance after 6 months space flight may result from a decrease in the solidity of the muscle tissue and in consequence a different mechanical behaviour during contraction detected by mechanoreceptors.

OUTLOOK

In the scope of MIR'97 and EuroMIR-E we will examine passive and active fluid shifts in resting and exercising calf muscles using MRI in combination with a lower leg differential pressure device. This device simulates fluid shifts which are normally driven by the gravitational field and different body positions. A decrease in muscle solidity will be determined as an increase in fluid uptake of resting muscle tissue at a given pressure. First pre-flight results have shown that at negative pressure the volume of muscle tissue is swelling almost to the same extent as the whole lower leg. This means, on earth distinct fluid shifts do not only occur in subcutaneous tissues but to the same extent in muscle. As a powerful tool MRI will contribute to this systemphysiological approach on muscle physiology.

REFERENCES

1. Bachl N., Baron R., Tschan H., Mossaheb M., Bumba W., Hildebrand F., Knauf M., Witt M., Albrecht R., Kozlovskaya I.E., Charitonov N.: [Principles of muscle efficiency in weightlessness]. *Wien med Wschr* 143: 588-610, 1993.
2. Dudley G. A., Hather B. M., Buchanan P.: Skeletal muscle responses to unloading with special reference to man. *J Fla Med Assoc* 79: 525-529, 1992.
3. Jaweed M.M.: Muscle structure and function. in: Nicogossian A.E., Huntoon C.L., Pool S.L. (eds.): *Space physiology and medicine*. Philadelphia, Lea & Febiger, 1994, pp 317-326.
4. Kemp G. J., Radda. G. K.: Quantitative interpretation of bioenergetic data from ^{31}P and ^1H magnetic resonance spectroscopic studies of skeletal muscle: an analytical review. *Magn Reson Q* 10: 43-63, 1994.
5. Wackerhage H., Zange J., Müller K., Hoffmann U., Essfeld D.: Glycolytic ATP production during ischemic exercise measured by ^{31}P -MRS in vivo. *MAG MA* 4: 1996, in press.

VIBROGRAFIC SIGNS OF AUTONOMOUS MUSCLE TONE STUDIED IN LONG TERM SPACE MISSIONS

E. Gallasch¹, T. Kenner¹, IB. Kozlovskaya²

¹University of Graz, Dept. Physiology, Austria, ²Institute for Biomedical Problems, Moscow, Russia

INTRODUCTION

Questions concerning the regulation of autonomous muscle tone in relaxed and postural states of the human peripheral motor system are still a matter of debate. Basmajian/de Luca [1] for example found no myographic evidence for muscle activity in relaxed limbs and Lakie et al [2] found that stiffening in a relaxed muscle is produced by a thixotropic behaviour of muscle tissue. On the other hand additional musculoskeletal relaxation was found in REM sleep [3], and cardiac produced 'microvibrations' (MV) of the body showed sensitive to the direction of optokinetic stimulation [4], indicating a mechanism underlying muscle tone. It was therefore of interest to study signs of muscle tone in the absence of gravitational forces as well as after a long term flights during the readaptation phase.

METHODS

Muscle tone of the arm was assessed by vibrographic signals (accelerometers) in six cosmonauts staying 4 - 6 months in space and in one cosmonaut staying 14 months in space. In the relaxed (free floating) state of the body microvibrations (MV) over muscle tissue (M. brachioradialis) were investigated. The experimental protocol was: maximal relaxation, activation of respiratory muscles and slightly extending the arm. In the postural states of the arms physiological tremor (PT) was studied over bony tissue. The experimental protocol was: keep the arm forward, close eyes, reach both hands and use an elastic band to load both arms isotonically. To determine the relation of the vibrographic signals to the cardiac cycle an electrocardiogram was recorded simultaneously.

RESULTS

Accelerometric recorded forearm MV in 1 g showed the typical 7-13 Hz oscillations triggered by the heart beat. In 0 g, during the fully relaxed state, these oscillations were decreased in amplitude and shifted to lower frequency. Activation of respiratory muscles had little effect, whereas slight extension of the arm in 0 g resulted in a similar MV amplitude and frequency as in 1 g during the relaxed state. No postflight effects were found. PT showed an irregular waveform in 1 g. In 0 g tremor amplitude was reduced and postflight the amplitude was increased in relation to preflight. Closure of eyes and reaching both arms showed no effect, whereas stretching of the elastic band produced large tremor oscillations postflight. Further the resistance to fatigue was reduced postflight.

CONCLUSION

Signs of muscle tone in the relaxed state (MV) were generally decreased in 0 g, but when muscle tone was produced voluntarily in the 0 g environment a similar MV occurs as in 1 g. This indicates that actually some kind of resting muscle tone is present in 1 g, producing the 7 -13 Hz component of MV. Multijoint musculoskeletal stiffness is proposed as mechanism to convert resting muscle tone into 7-13 oscillations in response to the cardiac impact.

The reason for the decrease of tremor amplitude in 0 g is mainly given by the fact that no muscular contraction is necessary to compensate gravitational forces. The increases of tremor amplitude postflight, indicates a reduction of stability in the motor system. At the moment it is unclear whether peripheral or central adaptation processes are responsible for these effects.

REFERENCES

- [1] Basmajian, De Luca: *Muscles alive*. Editor: John Buttler, Williams&Wilkins Inc. Baltimore-USA (1985)
- [2] Lakie M et al: Resonance at the wrist demonstrated by the use of a torque motor: an instrumental analysis of muscle tone in man. *J Physiol* 353, 265-285 (1984)
- [3] Gallasch E et al: Sleep state dependent effects on microvibration and muscle tone in infants (in German). *Z EEG-EMG* 28 (1997)
- [4] Shirabe S, O Tokunaga, K Yasuda: Microvibration related responses to optokinetic stimulation. *Auris-Nasus-Larynx* 13: 81-85 (1986)

REDUCTION OF MUSCLE STRENGTH AFTER LONG DURATION SPACE FLIGHTS IS ASSOCIATED PRIMARILY WITH CHANGES IN NEUROMUSCULAR FUNCTION.

S. F. Siconolfi¹, I. B. Kozlovskaya², Neurosciences' Neuromuscular Laboratory, NASA Johnson Space Center¹ (Houston, TX), State Scientific Center - Institute for Biomedical Problems² (Moscow, Russia).

INTRODUCTION

Decreases in muscle strength after long duration space flight could result from alterations in neural control. Siconolfi et al. (1996) reported increases in the electromyographic response during maximal contractions after the Mir 18 flight (115 days). Koryak et al. (1997) reported that one subject had 8% and 35% decreases in maximal tetanic and voluntary contractions, respectively, after the 115 days of the Mir 18 flight. Siconolfi et al (1997) reported decreases in peak running speed 5-6 days after the Mir 18 flight while oxygen uptake was not changed. Peak running speed returned to near preflight levels 18-19 days after return to earth. This study presents the integration of these reports with the post-flight decreases in peak (of 3 contractions) concentric knee strength at different velocities (below) in 5 crewmembers from Mir 18 and 19 (77 days) space flights.

METHODS

Strength was assessed on a LIDO Multi-joint Isokinetic Dynamometer. Crewmembers performed various levels of in-flight exercise. One crewmember (C) performed minimal exercise during flight while the others exercised on a treadmill, cycle with or without resistance exercise. Two of the exercising crewmembers completed 70% and 90% of the prescribed treadmill exercise (TE) protocol but only at <70% of the recommended exercise intensity. The other two crewmembers performed treadmill, bicycle and resistive exercise (TBRE) at >80% of prescribed exercise volume and intensity.

RESULTS

	C-Mir 18		70%TE-Mir 18		90%TE-Mir 18		TBRE-Mir 19		TBRE-Mir 19	
	Flex	Extend	Flex	Extend	Flex	Extend	Flex	Extend	Flex	Extend
C-0	-27%	-32%	-39%	-24%	3%	-1%	-25%	3%	2%	16%
C-30	-31%	-35%	-65%	-65%	NA	NA	-11%	-2%	16%	-5%
C-60	-35%	-38%	-72%	-69%	NA	NA	-3%	-15%	18%	-11%
C-120	-43%	-30%	-66%	-65%	-23%	-21%	12%	4%	-3%	-13%
C-180	-57%	-48%	-63%	-66%	-24%	-27%	14%	-11%	8%	-14%

The general trend for larger reductions in knee strength at the higher limb velocities suggests that inadequate time for motor unit recruitment or altered recruitment patterns were present in all subjects after space flight. Increasing the volume and intensity of in-flight exercise, modulated the size of the decrease, but did not affect the general trend. Shenkman et al (1997) reported that Mir 19 cosmonauts had little change (-13.8 to 6.7%) in post flight muscle cross-sectional areas (vastus lateralis biopsy), yet these crewmembers still exhibited the same general trend for reductions in strength at higher limb velocities.

CONCLUSION

We concluded that changes in post flight muscle strength are primarily influenced by alterations in neural control.

Yu. Koryak, Ph.D.
Institute of Biomedical Problems
76-A Khoroshevskoye Shosse
Moscow D-7 123007
Russia

THE EFFECTS OF A 115-DAY SPACEFLIGHT ON NEUROMUSCULAR FUNCTION IN CREWMAN

Yu. Koryak, I.B. Kozlovskaya

Institute of Biomedical Problems, 123007 Moscow D-7, Russia

As a result of simulated spaceflight effect (120-day period of bed-rest, 7-day "dry" immersion), contractile properties of the triceps surae muscle (TS) in response to disuse change considerably (Koryak, *Eur. J. Appl. Physiol.* 1995; *Aviat. Space Environ. Med.* A60. 1995). We examined maximal twitch response (Pt), maximal voluntary contraction (MVC), maximal force (Po) of isometric contraction elicited by electrical stimulation of tibialis nerve with a supramaximal force and at a frequency of 150 Hz (Koryak, 1978), time-to-peak tension (TPT), a half-relaxation (1/2HR), and time of force development both during voluntary and evoked contractions to 25%, 50%, 75% of maximal before (60-days) and after (6-days) the MIR-18 mission. Force deficit were evaluated as well. TPT increased by 19.1%, 1/2HR by 8.2%, and Pt decreased by 32.9%. Slow and fast MVC, and Po decreased by 35.5%, 26.8%, and 8.2%, respectively. The value Po/Pt ratio increased by 27%. Force deficit increased by 30.3%. The rate of rise a voluntary tension development decreased by 47.8%, 62.5%, and 43.1%, respectively. However, electrical evoked tetanic development not differ substantially from the initial data. These findings indicate relative less functional alterations of the TS compared to those observed after a 120-days bed-rest that may be related to countermeasure compliance.

EFFECTS OF 17-DAY SPACEFLIGHT ON HUMAN TRICEPS SURAE ELECTRICALLY-EVOKED CONTRACTIONS

M.V. Narici¹, B. Kayser², P. Barattini, and P. Cerretelli^{1,2}

¹Istituto di Tecnologie Biomediche Avanzate, Consiglio Nazionale Ricerche, Milan, Italy

²Dept. Physiologie, Centre Medical Universitaire, Université de Genève, Switzerland

INTRODUCTION

Skeletal muscle wasting and weakness have been frequently reported after spaceflight (1). The loss of voluntary muscle strength seems partly explained by atrophy but also by neural adaptations (2). Therefore, the aim of the present study was to investigate the effects of spaceflight on muscle function by-passing changes in neural control through direct electrical stimulation of the muscle.

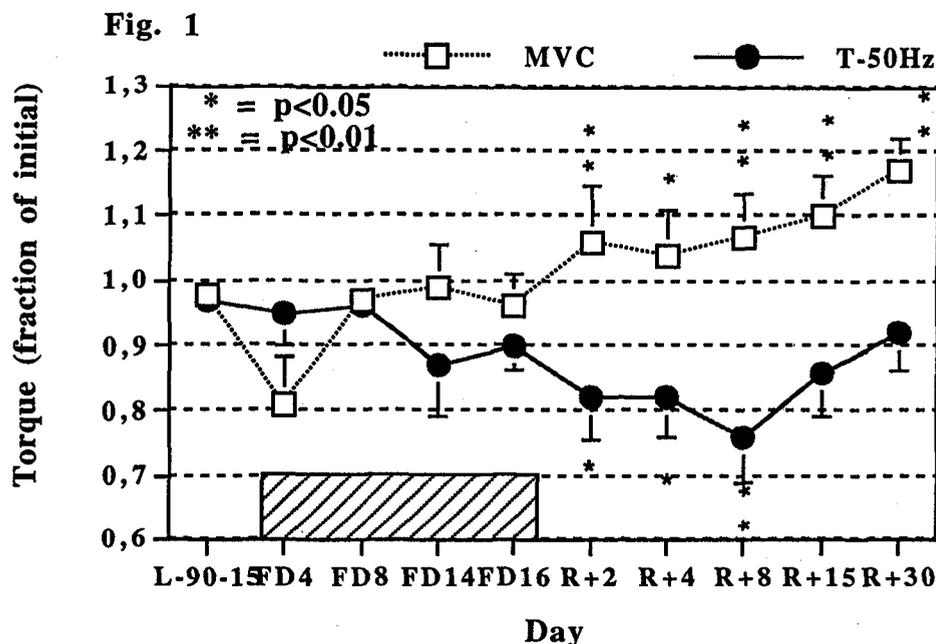
METHODS

The contractile properties of the human Triceps surae (TS) were investigated on four crew members (age 44.3 ± 3.4 yr., mass 81.0 ± 6.7 kg, height 1.82 ± 0.07 m) of the Life and Microgravity Science (LMS) STS-78 Spacelab mission. Measurements were made before the flight, on days 90, 60, 30, and 15 (L-90, L-60, L-30, L-15), during the flight, on days 4, 8, 14 and 16 (FD4, FD8, FD14, FD16) and during recovery on days 2, 4, 8, 15 and 30 (R+2, R+4, R+8, R+15 and R+30). Time-to peak torque (TPT), half-relaxation time (1/2 RT), rate of rise of torque (dT/dt), and twitch peak torque (PT_{tw}) at 20, 15 and 5 deg of dorsiflexion (DF) and at 5, 15, 25 and 30 deg of plantarflexion (PF) were assessed during supramaximal percutaneous electrical stimulation of the Triceps Surae (TS) using the PEMS stimulator (C.I.R., Gals, Switzerland) of the European Space Agency (ESA). Maximum voluntary contraction (MVC) was measured using the twitch-occlusion technique. A current intensity of 60% of the supramaximal level was used to investigate the frequency-torque relation (FTR), during stimulation at 1, 10, 20, 30 and 50 Hz, and the fatigability during intermittent TS stimulation at 20 Hz with 350 ms trains every second for 2 min. A fatigue index (F.I.) was calculated as the ratio of the final over the initial torque. All torque measurements were performed on the left leg in isometric conditions using the Torque-Velocity-Dynamometer (TVD, E.T.H., Zurich, Switzerland) of ESA. To complement the muscle function data, the muscle plus bone cross-sectional area (CSAm+b) of the calf at mid-tibia was evaluated from anthropometric circumference and skinfolds measurements of the calf.

Values are presented as means \pm S.E.M.; statistical significance of differences was assessed with repeated ANOVA followed by the Fisher's protected least significance difference test.

RESULTS

TS tetanic torque at 50 Hz (T_{50Hz}) significantly decreased during the flight and recovery, dropping by $24.0 \pm 7.0\%$ ($p < 0.01$) on R+8 (Fig. 1). Contrary to the loss of tetanic torque, MVC did not change significantly during the flight but progressively increased during recovery reaching a maximum of $17.0\% \pm 0.05\%$ on R+30 ($p < 0.01$) (Fig. 1). This increase in MVC was accompanied by an improvement in twitch-occlusion in some of the crew members after the flight. The decrease in T_{50Hz} was significantly correlated ($P < 0.01$) with a decrease in calf CSAm+b except for values on R+8 at which the loss of torque ($24.0 \pm 7.0\%$, $p < 0.01$) was far greater than that of CSAm+b ($7.1 \pm 1.1\%$, $p < 0.01$). On R+15, CSAm+b was still below that of pre-flight by $5.0 \pm 1.3\%$ and by R+30 differences were no longer significant. The force/CSA of the TS, calculated by expressing the force at 50 Hz per unit of anatomical CSAm+b, decreased by $16.0 \pm 9.5\%$ ($p < 0.01$) on R+8. Changes in twitch characteristics, frequency-torque relation and fatigability are being presently analysed



CONCLUSIONS

The present results show that a significant loss of tetanic torque and cross-sectional area of the Triceps surae occurs during 17 days of spaceflight. It is noteworthy that the tetanic torque continues to decline during the first week of recovery showing a 24% decrease on R+8. This loss of electrically evoked torque was accompanied by a significant decrease in F/CSA which reached its nadir during the reloading phase. A decrease in muscle fibres specific tension (3, 4), muscle damage (5,6), and a change in muscle architecture (5) are proposed as possible explanations for this finding. The maintenance of MVC during spaceflight and an increase during recovery could be due to either: 1) an incomplete motor units activation before the flight and bedrest, supported by the finding of an incomplete twitch-occlusion, 2) a decrease in the co-activation of antagonist muscles, as suggested by EMG recordings of the Tibialis anterior and TS muscles (LMS experiment E-407), and 3) the activation of synergistic and accessory muscles. The present results also suggest that MVC perhaps is not the paradigm of choice for an objective evaluation of muscle deterioration in actual and simulated microgravity.

REFERENCES

- 1 Thornton, W.E., and J.A. Rummel. Muscular deconditioning and its prevention in spaceflight. In: Biomedical results from Skylab, edited by R.S. Johnston and L.F. Dietlein. Washington DC: NASA 1977, p. 191-197. (Publ. S-377 NASA).
- 2 Edgerton V.R., and R.R. Roy. Neuromuscular adaptations to actual and simulated spaceflight. In: Handbook of Physiology - Adaptation to the Environment. Bethesda, MD: Am. Physiol. Soc. Chapter 32, p. 721-763, 1996.
- 3 Larsson L., Li X., Berg H.E., and W.R. Frontera. Effect of removal of weight-bearing function on contractility and myosin isoform composition in single human skeletal muscle cells. *Pflügers Arch* 432: 320-328, 1996.
- 4 McDonald K.S., and R.H. Fitts. Effect of hindlimb unloading on rat soleus fibre force, stiffness, and calcium sensitivity. *J Appl Physiol* 79: 1796-1802, 1995
- 5 Hikida R.S., Gollnick P.D., Dudley G.A., Convertino V.A., and P. Buchanan. Structural and metabolic characteristics of human skeletal muscle following 30 days of simulated microgravity. *Aviat Space Environ Med* 60: 664-670, 1989.
- 6 Kasper, C.E.: Sarcolemmal disruption in reloaded atrophic skeletal muscle. *J Appl Physiol* 79: 607-614.
- 7 Phillips S.K., Bruce S.A., Newton D., and R.C. Woledge. The weakness of old age is not due to failure of muscle activation. *J Gerontol: Med Sci* 47: M45-49.

EFFECTS OF MUSCLE UNLOADING ON EMG SPECTRAL PARAMETERS

S.H. Roy, E.J. Kupa, C.J. De Luca, S.C. Kandarian*, and P. Bonato
NeuroMuscular Research Center and *Department of Health Sciences, Boston University, Boston, MA, 02215, U.S.A.

INTRODUCTION

Non-invasive, quantitative techniques are needed to monitor the effects of microgravity on the neuromuscular system. Muscle adaptation to zero gravity and the effectiveness of countermeasures may be assessable by surface electromyographic (EMG) signal techniques [1]. This possibility is primarily based on secondary information, both theoretical and empirical, which have demonstrated that the EMG signal waveform and its propagation velocity are related to muscle fiber cross sectional area (CSA) and metabolite production at the muscle membrane [2]. Changes to these morphological and biochemical properties of muscle have been reported for spaceflight and simulated microgravity [3]. In this study, an *in vitro* technique was utilized to compare changes in muscle fiber morphology and histochemistry with spectral parameters of the EMG signal in antigravity muscles exposed to short- and long-term unloading.

METHODS

A tail-suspension procedure [4] was used to induce hindlimb unloading in female Wistar rats, aged approximately 2 months (150-175g). Animals in the experimental group ($n=12$) were suspended for either seven or twenty-one days. Equal numbers of control animals were included. Neuromuscular preparations of the soleus muscle were extracted at the end of these interventions and placed in an oxygenated isothermal Krebs bath. Preparations were supramaximally stimulated via the nerve at 40 Hz to induce tetanic contractions for a maximum of 30 s. M-waves were recorded using a multielectrode array (O.D. 0.5 mm, interelectrode spacing 2.3 mm) placed against the muscle belly. Signals were sampled at 2048 Hz and then averaged over 0.25 s epochs before calculation of the median frequency by fast fourier transform techniques. The median frequency (MF) is the half-power frequency of the signal spectrum and is used to monitor alterations in the EMG signal that result from changes in the generation and conduction of action potentials at the muscle membrane [2]. We studied two MF parameters: the initial MF, which is the value of MF for the first few epochs of EMG data, and the Δ MF, which is the change in MF between the beginning and end of the 30 s contraction. These parameters are used to describe the EMG signal before and after the effects of fatigue, respectively. Following the experiment, muscles were frozen for later histochemical analysis to measure CSA and fiber type content by myosin ATPase staining. All procedures were conducted following approval by our Institutional Animal Care and Use Committee.

RESULTS

Tests for significant differences between means were based on a probability of $p<0.05$. Average muscle fiber CSA was significantly decreased when compared to controls at 7 days and 21 days of unloading (Figure 1). There was also a significant increase in the percentage by area of fast fibers, but only for muscles unloaded for 21 days. Initial MF significantly decreased after 7 days of unloading and was further decreased by 21 days of unloading, whereas no significant changes were observed for control muscles (Figure 2). Δ MF was not obtainable for all muscles, and therefore individual data points are shown in this figure rather than grouped data. Unloading did not appear to have an effect on this parameter, although the variability and small sample size preclude a conclusive finding.

CONCLUSION

The similar pattern of change between the muscle CSA and the initial MF suggests that this EMG parameter is sensitive to the presence of muscle atrophy following muscle unloading. The most likely mechanism for this association is that muscles with a smaller mean CSA have lower muscle fiber conduction velocities which prolong the EMG signal waveform, thereby compressing the spectral content of the signal to lower frequencies. Somewhat unexpectedly, the MF parameters appeared to be insensitive to changes in fiber type because the increase in % fast fibers at 21 days of unloading did not result in an

increase in either initial MF or Δ MF. Such changes have been reported in previous studies comparing normally loaded muscles of different fiber type proportions [5]. It may be that the change in myosin ATPase that occurred following unloading did not involve muscle metabolic factors that could alter the M-wave (e.g. Na^+ - K^+ or H^+ ion concentration at the sarcolemma).

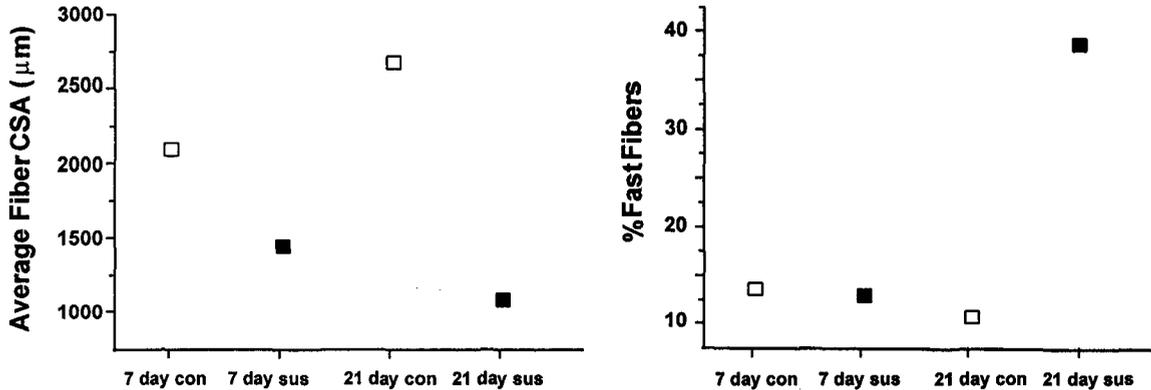


Figure 1: Average muscle fiber cross sectional area (CSA) [left plot] and percentage of fast fibers by area [right plot] are shown for control (open squares) and experimental (filled squares) groups at 7 and 21 days. Standard deviation bars are not shown because their magnitude is smaller than the dimensions of the data point symbols.

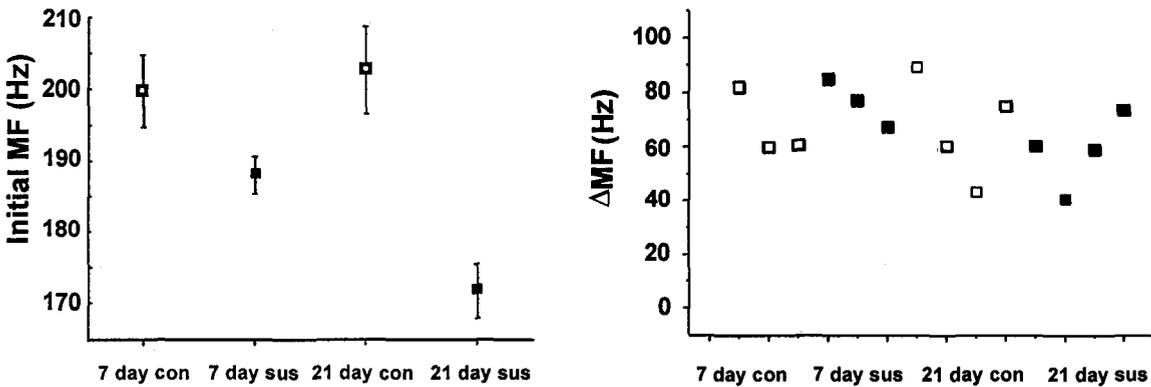


Figure 2: Mean (SD bars) of the initial MF for M-waves elicited from control muscles (open squares) and unloaded muscles (filled squares) at 7 and 21 days [left plot]. Change in MF (Δ MF) following the 30 s contraction for several samples of control (open squares) and unloaded (filled squares) muscles at 7 and 21 days [right plot].

REFERENCES

- [1] Young L. et al. *Journal of Vestibular Research*, 3:231-239, 1993.
- [2] De Luca C.J. *Critical Reviews of Biomedical Engineering*, 11:251-279, 1985.
- [3] Roy R.R. et al. *Exercise and Sports Science Reviews*, 19:269-312, 1992.
- [4] Thomason D.B. and Booth F.W. *Journal of Applied Physiology*, 68(1):1-12, 1990.
- [5] Kupa E.J. et al. *Journal of Applied Physiology*, 79(1):22-32, 1995.

This work was supported in part by the Liberty Mutual Insurance Company.

MYOFIBER WOUND-MEDIATED FGF RELEASE AND MUSCLE ATROPHY DURING BEDREST.

M.S.F. Clarke¹, M.M. Bamman² and D.L. Feedback³, ¹Division of Space Life Sciences, Universities Space Research Association, 3600 Bay Area Blvd., Houston, TX 77058; ²Department of Human Studies, University of Alabama, Birmingham, AL 35294; ³Life Sciences Research Laboratories, NASA/JSC, Houston, TX 77058.

INTRODUCTION

We have previously shown that there is a linear relationship between the amount of mechanical load placed on muscle tissue and the amount of myofiber fibroblast growth factor (FGF) (acidic and basic isoforms) released into the extracellular environment both *in vivo* and *in vitro*. In addition, we have demonstrated *in vitro* that the growth-promoting effect of mechanical load upon human skeletal myotube cultures (analogous to myofibers *in vivo*) can be specifically inhibited by the presence of a site-directed anti-FGF antibody in the tissue culture medium. We postulate that a reduction in mechanical load-induced myofiber wounding and a consequent decrease in wound-mediated release of FGF under microgravity conditions contributes to the initiation of skeletal muscle atrophy during spaceflight. Our hypothesis is supported by experimental data gathered from Space Shuttle crew-members which indicates that circulating levels of a skeletal myofiber-specific wound marker, the MM isoform of creatine kinase (CKMM), is significantly reduced after short duration spaceflight. We have tested our hypothesis utilizing a terrestrial model of human adaptation to spaceflight (i.e. 14 days of 6° degree head-down tilt bedrest) and determined the amount of myofiber wounding and FGF release which occurs during mechanical unloading of the human body. In addition, a resistive exercise protocol was incorporated into the experimental design in order to test the efficacy of resistive exercise as a countermeasure to skeletal muscle atrophy induced by mechanical unloading.

METHODS

The level of myofiber wounding in bedrest subjects with, and without, resistive exercise was assessed by determining the amount of the CKMM isoform present in the serum before and after 14 days of 6° head-down tilt bedrest. Total CK activity was determined using a commercially available assay for CK based upon the conversion of NADP to NADPH (Roche Diagnostic Systems, Inc., NJ) measured at 340 nm using a Cobas Mira Chemical Analyzer (Roche Diagnostic Systems, Inc., NJ). In addition, CK isoenzyme profiles were also determined from the same samples using the commercially available automated Paragon Gel System (Beckman, Fullerton, CA). This system separates CK isoforms using agarose gel electrophoresis followed by incubation of the gel in CK substrate buffer containing creatine phosphate, hexokinase, ATP, D-glucose, glucose-6-phosphate and NADP as the major components, followed by fluorescent densitometry as described by the manufacturer. Serum levels of both acidic and basic FGF were also determined before and after bedrest using a previously described ELISA protocol developed in this laboratory (Clarke and Feedback, 1996: FASEB J.10: 502-509). In addition, a needle biopsy was performed on the same region of the *m. vastus lateralis* of each subject before and after bedrest. Muscle samples were snap-frozen in liquid nitrogen-cooled isopentane, cryosectioned and myofiber cross-sectional area was determined using quantitative image analysis. A small amount of each muscle biopsy sample (i.e. 50 µg) was homogenized and the amount of FGF present in the soluble protein fraction was determined by ELISA. A third experimental group underwent resistive exercise but was not bedrested. These ambulatory, resistive exercise-trained subjects were used as positive controls for mechanical load-induced myofiber wounding but did not undergo the muscle biopsy procedure.

RESULTS

Bedrest alone caused a significant ($p < 0.05$; $n=8$) decrease in myofiber size of the *m. vastus lateralis* (Figure 1). Muscle atrophy was paralleled by significant ($p < 0.05$; $n=8$) reductions in the serum levels of both CKMM (Figure 2) and aFGF (Figure 3). In contrast, bedrest plus resistive exercise resulted in the reversal of unloading-induced skeletal muscle atrophy (Figure 1). This reversal was paralleled by significant ($p < 0.05$; $n=8$) increases in the serum levels of both CKMM (Figure 2) and aFGF (Figure 3). In addition, exercise-induced reversal of myofiber atrophy in the *m. vastus lateralis* was paralleled by a significant ($p < 0.05$; $n=8$) increase in the amount of myofiber-associated aFGF (Figure 4) detected in the soluble protein fraction of homogenized muscle biopsy material. No significant changes were detected in serum or myofiber-associated bFGF levels in the three experimental groups (data not shown). As expected, resistive exercise in ambulatory subjects resulted in a significant ($p < 0.05$; $n=6$) increase (i.e. a 50% increase) in serum CKMM levels (Figure 2), although no significant increase in the amount of FGF released into the serum was noted in these subjects (Figure 3). However, bedrest plus resistive exercise caused significantly ($p < 0.05$; $n=8$) greater amounts of CKMM to be released into the serum (i.e. a 450% increase) than would be predicted based on the levels released in the ambulatory exercised group (Figure 2).

Figure 1

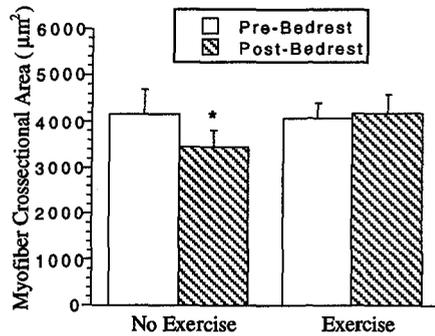


Figure 2

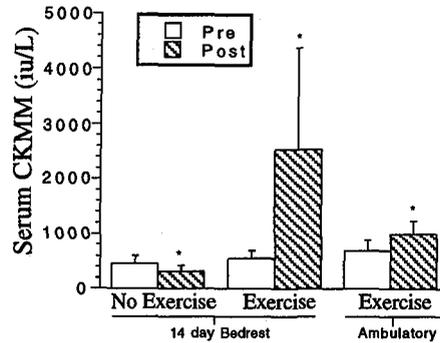


Figure 3

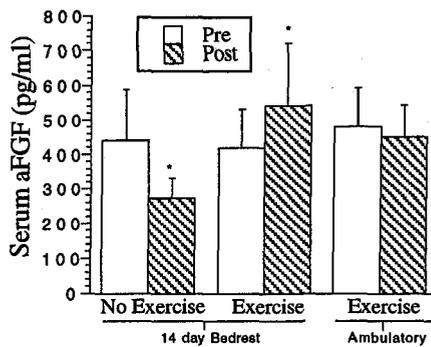
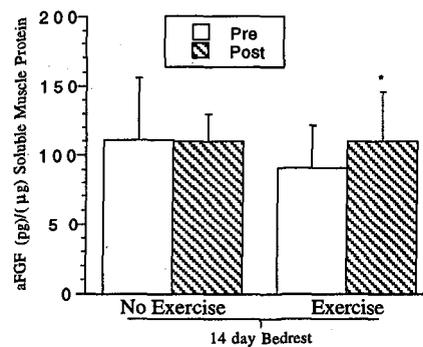


Figure 4



CONCLUSIONS

Our experimental results in a bedrest model of microgravity-induced skeletal muscle atrophy indicate that a reduction in mechanical-induced myofiber wounding and disruption of wound-mediated FGF release from the myofiber cytoplasm plays a central role in the initiation of muscle atrophy. Our results indicate that mechanical unloading inhibits FGF release, rather than FGF content, in skeletal muscle tissue. Whether or not FGF is the only growth factor involved in skeletal muscle atrophy remains unclear. However, sarcolemmal wounding and consequent membrane wound-mediated FGF release is a mechanically-reactive signaling pathway which can be directly linked to a muscle growth response. As such, it is a leading candidate for potential disruption during spaceflight. In addition, FGF may have a series of direct and indirect effects upon several other components of skeletal muscle tissue, all of which play a role in the maintenance of skeletal muscle mass. For example, FGF is capable of modulating the function of other muscle growth factors, such as insulin-like growth factor-1 (IGF-1) where FGF upregulates the expression of IGF-1 protein and its receptors in human muscle cells. A second example of the importance of FGF is its role in the maintenance of neuronal cell function and integrity, where FGF is responsible for the upregulation of nerve growth factor (NGF) protein and its receptors. In addition, FGF is a potent angiogenic factor for microvascular endothelial cells within the muscle capillary bed.

Our experimental observations in bedrest plus resistive exercise subjects indicate that skeletal myofibers are more prone to mechanical load-induced sarcolemmal damage after a period of unloading than ambulatory, resistive exercised individuals. These data suggest that not only is there a myofibrillar remodeling component involved in the adaptive muscle response to mechanical unloading, but that there is an additional membrane remodeling component. We are now in the process of analyzing the lipid composition of sarcolemma membranes isolated from bedrest muscle biopsy material to determine if this is the case. It is still unclear whether membrane remodeling occurs before or after myofibrillar protein remodeling, or whether both occur at the same time during the adaptive response.

In conclusion, it is interesting to speculate that a microgravity-induced reduction in mechanically-induced, membrane wound-mediated FGF release from skeletal myofibers may lead not only to myofiber atrophy, but that disruption of this signaling pathway may also play a role in the disruption of other signaling pathways involved in the maintenance of muscle mass, such as neuromuscular function and maintenance of muscle capillarity.

Thursday, June 12

Session JA4

Room 4

Education and Space:
NASA Reaches for the Stars

Session Overview

Rosalind A Grymes, Manager, Space Life Sciences Outreach Program, Life Sciences Division, NASA Ames Research Center, Moffett Field, California

James Pagliasotti, Office of Lieutenant Governor, 130 State Capital, Denver, Colorado 80203

NASA's Life Sciences Division recognizes the imperative of public outreach in order to positively impact national priorities (telecommunications, health care, biomedical advances, education, science literacy and enfranchisement), to return to our citizens the benefits of their investment, and to develop broad based advocacy for life sciences research and technology development and human space exploration. In order to expand its offerings, and provide increased efficacy through coordination of activities, the Life Sciences Division established an Outreach Program in 1995. Direct experience and evidence from public surveys indicates that support for any country's national space effort derives from a combination of current perceived benefits and futuristic dreams. In this session, we will present and discuss demonstrated programs that deliver to public audiences the 'human experience' of spaceflight, the challenge of space exploration, and the tangible benefits of space-related research. The contribution of space, thematically and realistically, to national education goals will be highlighted.

The article reproduced below is taken from *CBE Views* (1997;20(3):93), and is used with permission of the Council of Biology Editors. It illustrates programs and approaches to be presented in greater detail in this session. In addition to these efforts, outreach associated directly with space missions will be presented. Spaceflight is at the core of the public's interest in, and excitement about, the space program. Neurolab, a Space Shuttle mission dedicated to research on the nervous system and behavior, is a joint venture of six space agencies and seven U.S. research agencies. Researchers from nine countries will carry out thirty one studies on board Neurolab. Outreach activities will include an extensive on-line component (NeurOn); traditional hardcopy and video materials, multimedia products, and the capability to offer 'virtual' tours of a mock-up facility used for crew training (Virtual Neurolab). STS 87, a joint U.S.-Ukraine Shuttle mission planned for launched in October 1997, will carry a set of plant biology investigations collectively known as the Collaborative Ukrainian Experiment (CUE). An integrated educational project will provide curriculum supplements and teacher training for classroom experiments that will parallel flight experiments in real time.

This session is jointly sponsored by the Life Sciences Division's Outreach Program and the Office of the Lt. Governor of Colorado. These organizations have collaborated for years, and share many goals that are being realized through the application of space themes and telecommunications solutions. The format of this session will involve multiple short presentations and several keynote speeches. Information on the creation, implementation, and administration of outreach activities will be presented. Speakers will also discuss the practical outcomes of outreach efforts, from personal experience. The session's overarching themes of science and technology education, for traditional student audiences and for general public literacy, will be presented with a recognition of the international nature of this conference, as the challenge of creating advocacy for space efforts is a challenge shared by every space agency and all investigators interested in space research. Opportunity for open discussion among all attendees will be provided.

NASA: Reaching for the Stars

The article reproduced below is taken from *CBE Views* (1997;20(3):93), and is used with permission of the Council of Biology Editors.

Rosalind A Grymes, Manager, Space Life Sciences Outreach Program, Life Sciences Division, NASA Ames Research Center, Moffett Field, California

The NASA Life Sciences Division Outreach Program has innovated a diverse and comprehensive suite of projects designed to communicate science to its shareholders, the American public. Several ongoing projects provide training to teachers (grades K-12 plus community colleges) and demonstrate singular approaches we hope others will adopt. Our STELLAR workshop brings teachers into laboratories at Ames Research Center as colleagues of life-science researchers and engineers. This experience enhances the capabilities of classroom educators and so is unusual and receives remarkable enthusiasm among both teacher and mentor participants. STELLAR also engages the teachers in creating, evaluating, and refining classroom activities based on their NASA experience which are disseminated (hardcopy and electronically) nationwide, increasing the number of teachers who receive the STELLAR experience.

The teachers' workshop in the Johnson Space Center's Life Sciences Electronic Classroom combines space life-sciences information and activities for the classroom with training and support in the current ways to share information. NASA works at the information-systems frontier; daily we use personal computers, distributed systems, remotely acquired data, and video and teleconferencing. Our familiarity with these technologies and communications skills matches precisely the needs of K-12 teachers, particularly those serving remote rural communities. To help underserved communities, this project highlights partnerships with schools serving Native American students.

Other projects bring NASA to the public. The Scott Carpenter Research Station is a space/ocean analog demonstration habitat being constructed at Kennedy Space Center. It will bring live research to public and classroom audiences. Completely contained and transportable, the Habitat will be installed at Florida's Sea World; the aquanaut inhabitant will simultaneously be in communication with classroom participants (and to astronauts aboard the Shuttle, as downlink time allows). These real-time exchanges can foster comparisons between the undersea Habitat and the Space Transportation System that remind students of the challenges that beckon us onboard Spaceship Earth and beyond.

Telecommunications are the key to a project bringing NASA's Life Sciences expertise to the Navajo Reservation. Navajo Community College, a tribally controlled community college, serves a 26 000 square-mile area with campuses and ancillary sites and is a resource central to the Navajo people. After implementing effective Internet and intranet hardware connections, we are now in the 2nd phase of the project funded by the Air Force Office of Scientific Research. In this phase, we are concentrating on matching Space Life Science interests in remote learning and telemedicine with the needs and capabilities of the community college.

Our major effort to distribute the results of the Space Life Sciences enterprise to our shareholders uses the Internet. In designing and populating our Website (<http://weboflife.arc.nasa.gov>) we tried to illustrate human exploration themes and provide 1) relevant materials to educators, 2) interesting, timely, and informative articles, 3) selective links, 4) a scientific and technical newsroom, and 5) interactive projects for space-flight missions (check out <http://quest.arc.nasa.gov/smore>). Our Website is continuously under improvement; watch this site, and pardon our (interstellar) dust.

In these projects, and more, partnership is the key to success. Partners leverage resources, invigorate ideas, broaden support, and reach complementary audiences. We welcome new partners; contact the author via rgrymes@mail.arc.nasa.gov or call 415-604-3239.

Thursday, June 12

**Session JA5
Room 5**

525-52

074630

9P.

326983

**Neurolab - A Space Shuttle Mission
Dedicated to Neuroscience Research**

NASA/NIH Neurolab Collaborations

by

James B. Snow, Jr., M.D.

Director

National Institute on Deafness and Other Communication Disorders

June 12, 1997

The National Institutes of Health (NIH) is the nation's steward for biomedical and behavioral research while the National Aeronautics and Space Administration (NASA) is the nation's steward for civilian aeronautical and space research programs. Together, NIH and NASA have the opportunity to conduct biomedical research related to the changes in living organisms associated with spaceflight; research on earth that could benefit from the application or transfer of technologies specifically developed for space-related purposes; and research in space or spacelike environments that could improve knowledge of the normal function of human biologic systems on earth. This collaborative research can ultimately contribute to better health for many Americans as well as safeguard the health of space travelers. Several NIH institutes, centers and divisions have become active partners with NASA, developing research that will be conducted on the 1998 Neurolab space shuttle mission. Those research efforts, which include studies of circadian rhythms, neural plasticity, aging, the effects of microgravity on the vestibular system and on the development of the mammalian nervous system and autonomic control of human blood pressure, will be highlighted.

Neurolab Mission An Example of International Cooperation

Antonio Guell, DP/MP/SC - CNES, 18, avenue Edouard Belin, 31401-Toulouse Cedex 4

In July 1993, an International Announcement of Opportunity for the SLS₄ mission dedicated to Neurosciences was issued. More than 160 proposals coming from 13 countries were received covering the 5 Neurosciences following fields:

1. Developmental neurobiology
2. Cellular and molecular neurobiology
3. Sensori and motor systems
4. Behavior, cognition and performances
5. Nervous system homeostasis and adaptation

In a first step, a scientific merit evaluation was made by an appropriate peer review group convened by the NIH. The second step consisted in a technical evaluation made by ARC (animal research and biology) and JSC (human physiology).

After these evaluations, 8 scientific teams, involving each one several research groups, were created: the objectives of these were to provide an overview of the experimental objectives of their team integrated protocols: autonomic nervous system, sensory motor and performance, sleep, vestibular, aquatic, adult neuronal plasticity, mammalian development, neurobiology.

At the same time, a preselection and selection of 4 payloads specialists (2 flights and 2 back-up) was made.

All these processes will be discussed, criticized and proposals will be made for the ISSA.

NEUROLAB: AN OVERVIEW OF THE PLANNED SCIENTIFIC INVESTIGATIONS

J. L. Homick

Medical Sciences Division, NASA Johnson Space Center, Houston, Texas 77058

Neurolab is a NASA Spacelab mission with multinational participation that is dedicated to research on the nervous system. The nervous systems of all animal species have evolved in a one-g environment and are functionally influenced by the presence of gravity. The environmental stressors encountered during space flight, particularly the absence of gravity, present unique opportunities to gain new insights into basic neurologic functions as well as an enhanced understanding of physiological and behavioral responses mediated by the nervous system. The primary goal of Neurolab is to expand our understanding of how the nervous system develops, functions in and adapts to microgravity space flight.

During the Neurolab flight, the crew will serve as both subjects and operators in carrying out a diverse complement of 26 investigations divided into 8 scientific discipline teams. Four of the teams, with a total of 11 experiments will use the astronauts as subjects and 4 teams with a total of 15 experiments will use non-human subjects. Within the complement of human studies, the Autonomic Nervous System Team will determine the effects of microgravity on autonomic control of the cardiovascular system, as well as the consequences of adaptation by the autonomic nervous system on cardiovascular function after return from space flight. This team will use a number of techniques to apply stressors to the cardiovascular system and will measure a variety of responses to these stressors which are regulated by the autonomic nervous system. The Sensory Motor and Performance Team will investigate the effects of adaptation to the microgravity environment on human perception and motor function. The experiments to be performed by this team range from assessments of adaptive changes in eye-hand coordination to the use of a virtual environment generator to determine how microgravity alters self orientation and the perception of objects. The Sleep Team will evaluate the sleep patterns of crewmembers before, during, and after space flight to identify factors that contribute to sleep disturbances that may be associated with space flight. The influence of the naturally occurring hormone, melatonin, on sleep and performance will be included in these evaluations. Alterations in respiratory function in microgravity and their effects on sleep will also be investigated by this team. The Vestibular Team will investigate the fundamental question of how spatial orientation of the vestibulo-ocular reflex and the optokinetic response are altered in microgravity. These investigations will use a rotating chair to provide stimuli to the inner ear vestibular system. Reflexive eye movements will be measured with an infrared camera system.

Within the highly integrated complement of non-human studies, the Adult Neuronal Plasticity Team will study neural and physiological changes that occur during space flight to determine the adaptive responses of the adult rodent's central nervous system to microgravity. The primary focus of this team will be assessments of neural plasticity of the vestibular system and related spatial and motor integration processes. Investigators on this team will also use behavioral and histochemical techniques to assess the effects of microgravity on the ability of rodents to maintain circadian rhythms and homeostatic regulation. The Aquatic Team will carry out two experiments, each using different aquatic species housed in separate facilities. This team will investigate the

effects of microgravity on the development and activation of gravity-sensing organs in the vestibular systems of saltwater and freshwater animals. The Mammalian Development Team will study the effects of space flight on the normal development of the central nervous system. The series of experiments to be conducted by this team will involve the use of anatomical, physiological, molecular, and biochemical techniques to assess the processes essential for normal development of the central nervous system and motor systems. The Neurobiology Team will study the effects of microgravity on the development of gravity receptors in an invertebrate, the cricket.

Elements of the knowledge acquired from the Neurolab mission will be applicable to enhancing the well being and performance of future long duration space travelers. Additionally, the new information to be gained will contribute to our understanding of normal and pathological functioning of the nervous system and may be applied by the medical community to enhance the health of humans on Earth. The cooperative nature of the mission, involving multiple domestic and international agencies, will serve as a model for the scientific collaboration and agency cooperation that will be necessary to carry out high-quality neuroscience and biomedical research on the International Space Station.

ABSTRACT

EDEN : A payload for NEUROLAB, dedicated to Neuro Vestibular Research

Frederic Bellossi - AEROSPATIALE Espace & Defense, BP11, F33165 Saint-Médard-en-Jalles, France

INTRODUCTION

The major aim of the ATLAS experiment (Adaptation To Linear Acceleration in Space), to be performed on-board the Neurolab mission in early 1998, is to investigate the basic question of how spatial orientation of the vestibulo-ocular reflex and optokinetic response are altered in micro gravity. The investigators proposing this research (1) aim to improve understanding of the contribution of spatial orientation to oculomotor and postural function on earth, and to determine the oculomotor and perceptual consequences of plastically modifying and adapting this orientation by adaptation to microgravity.

To achieve this purpose, they will use the "Visual and Vestibular Investigation System" (VVIS). This facility is currently under development by AEROSPATIALE, as part of the contribution of ESA to the Neurolab mission (ESA Programme EDEN : ESA Developed Elements for Neurolab).

VVIS REQUIREMENTS

The ATLAS experiment will stimulate the vestibular and visual systems of human subjects and record and analyse the effects of these stimuli with three-dimensional measurements of eye movements.

The VVIS facility provides these functions through the simultaneous use of three main units which are accurately synchronised and managed through a central computer :

- An Off-Axis Rotator, that can apply inertial accelerations of 0.5g or 1g, to a subject seated in yaw and roll positions.
- An Eyes Stimulation System, that can present an optokinetic stimulus or a smooth pursuit stimulus to a subject. The stimuli are binocular and cover a large field of view in all directions (more than $\pm 40^\circ$).
- An Eye Movement Recording System, which will measure the horizontal, vertical and torsional components of movements of both eyes simultaneously. Real-time measurements at 60 Hz can be made, but the final accuracy will be reached through post-flight analysis of the video recorded images.

DISCUSSION

For the first time, the VVIS will enable application of well-controlled linear accelerations to the vestibular system combined with wide-field, binocular eye movement recordings. This will be achieved through the use of new technology and through the development of the specific pieces of equipment which are described and discussed in this paper, together with the experiments presentation. Possible use to prepare next neurophysiology science works for the future International Space Station will be proposed as a conclusion.

REFERENCES

1. Gilles CLEMENT, Ph.D.
CNRS - Cerveau et Cognition, Université Paul Sabatier - Toulouse - France
Experiment : Visual-Otolithic Interactions in Microgravity

Bernard COHEN, M.D.
Department of Neurology, Box 1135, Mount Sinai School of Medicine - New-York
Experiment : Spatial Orientation of the Vestibulo-ocular Reflex and Velocity storage

Neurolab Experiments on the Role of Visual Cues in Microgravity Spatial Orientation

Charles M. Oman¹, Ian P. Howard², Ted Carpenter Smith³, and Andrew C. Beall¹

¹Man Vehicle Laboratory, Center for Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139 USA

²Human Performance Laboratory, Institute for Space and Terrestrial Sciences, North York, Ontario M3J 1P3, Canada

³Emerging Technologies Applications Group, Andersen Consulting Education, St. Charles, IL 60174, USA

Working in space, astronauts often move in 3 dimensions, and view the spacecraft interior and each other from a variety of different body orientations. The “down” cue is absent to the body’s gravity receptors, such as the otolith organs of the inner ear and muscle and joint receptors. Crew members are therefore reliant on vision to maintain their orientation. Many report occasional difficulty their spatial orientation due to the inherent ambiguities in visual cues available in certain situations. Most experience striking but labile “visual orientation illusions”, which can trigger space sickness in some individuals, and to cause disorientation and a variety of space human factors problems. The goal of our Neurolab experiment is to study how humans perceive their own orientation and that of surrounding objects, and the interdependence of self-and object-orientation perception in microgravity, using quantitative methods. Previous Spacelab experiments studied illusory self rotation (“circular-vection”), but did not explore the role of scene content on the perception of “down”, illusory self-translation (“linear-vection”), or the effect of perceived orientation on object recognition and interpretation of shading gradients, which are the focus of our specific experiments. To provide controlled visual stimuli, we use NASA’s “Virtual Environment Generator” (VEG): Our astronaut subjects wear a wide field of view head mounted display to view color stereo scenes rendered by a 3D graphics computer. The VEG is equipped with an optical head tracker, so the scene appears stable when the head moves. In some portions of our experiment, our subjects also wear a constant force spring harness to provide artificial “down” cues to their muscle and joint receptors. Our findings will help NASA human factors engineers design the next generation of spacecraft; suggest new types of preflight training techniques which could reduce the incidence of disorientation and in flight space sickness; and better understand the relative role of vision in human spatial orientation not only in space but also in our daily lives on Earth.

Supported by NASA Contract NAS-9-19536 and the Canadian Space Agency.

The Role of Space in the Exploration of the Mammalian Vestibular System

Muriel D. Ross, Biocomputation Center, NASA Ames Research Center, Moffett Field, CA
94035-1000

Results of two spaceflight experiments are revealing the importance of space research in exploring gravity sensor organization, adaptability to altered-G, and function. Gravity sensors respond to gravitational and translational linear accelerations acting on the head. In space, the bias of gravitational acceleration is virtually absent but translational accelerations are still effective. The hypothesis tested by the research presented here is that the synapses of the rat gravity sensing cells (hair cells) will be modified during adaptation to the space environment. The rat utricular gravity sensor is used as the model system. Ultrastructural and statistical studies employed 50-100 serial sections in which the organization of the sensor was reconstructed in 3-D, changes in voltage were simulated, and ribbon synapses in hair cells were counted and analyzed. The results were as follows. 1) Ground-based research showed that peripheral gravity sensors have a dual circuit organization that includes local feedback as well as feedforward microcircuitry. The sensors are comparable in organization to retina, olfactory system, cerebellum and cerebral cortex. Of the two types of hair cells, type I cells are inserted into direct circuits and type II cells into local circuits. 2) Synaptic ribbons doubled in number in type II cells in microgravity and changes in ribbon morphology and distribution also occurred. Type I cells were only subtly affected. 3) Computer simulations demonstrated that the morphology of neuronal endings is related to their output. Interpretations of the findings are: 1) Gravity sensor morphology indicates that the preprocessing of acceleratory information occurs at the gravity sensor level. Local circuits shape the final output which induces behavioral responses. Thus, adaptation to microgravity should largely occur in local circuits, which it does, 2) Type II hair cells appear to be sensitive to gravity and type I cells to translational accelerations. The continuum of mix type I and type II hair cells in receptive fields of gravity sensors could be related to the continuum of physiological responses. 3) Simulations of voltage changes in single neuronal endings indicate that morphology affects discharge frequency and latency. Changing the direction of input alters output in multicalyx endings. Distal spread of voltage from the spike initiating zone briefly shuts off synaptic input. This mechanism could be essential to sense gravity, a continuous stimulus that neuronal systems learn to ignore. Thus, space exploration has made significant contributions to our understanding of gravity sensor organization and adaptive capabilities. We now need correlated physiological and behavioral studies, and a better understanding of the molecular mechanisms involved in inducing synaptic changes. Thus, space research will continue to play a major role in the exploration of the vestibular system, particularly as the era of the space station arrives and prolonged exposure to microgravity becomes a reality.

Thursday, June 12

Session JP1
Room 1
2:30 - 5:30 p.m.

526-52
074631
9P.
306984

Medical, Psychophysiological, and
Human Performance Problems During
Extended EVA

NEW DEVELOPMENTS IN THE ASSESMENT OF THE RISK OF DECOMPRESSION SICKNESS IN NULL GRAVITY DURING EXTRAVEHICULAR ACTIVITY

M. R. Powell

NASA Johnson Space Center, Medical Sciences Division, Houston, Texas 77058

INTRODUCTION

It has been noted that the risk of decompression sickness (DCS) during extravehicular activity (EVA) is less than would be expected from ground-based experiments testing the oxygen prebreathe protocols. We have conducted a series of experiments over the past several years to examine the hypothesis of lower body adynamia (as would be encountered in 0-g) as a mitigating condition in DCS formation. This would be a result of the reduction in formation of tissue gas micronuclei that are the "seeds" which grow into pain-causing bubbles during decompression.

METHODS

Test subjects have been exposed to reductions of pressure in an altitude chamber in both the seated and standing posture. In some cases, subjects performed oxygen prebreathe before the altitude expose; in some subjects, mild arm and leg exercise was performed).

RESULTS

Data indicates that the reduction in gas bubble production and decompression sickness is significantly reduced (approximately by an order of magnitude) in the seated (adynamic) subjects. These experiments further indicated that tissue micronuclei have lifetimes on the order of several hours, not weeks or months as previously thought. We now have data from other laboratories both in the United Sates and Europe that corroborate our original NASA hypothesis. This concept of mild exercise during prebreathe in adynamic subjects is now being further explored to develop oxygen prebreathe schedules of one to two hours duration.

DISCUSSION

This work is being combined with examinations of the DCS/prebreathe algorithms to develop schedules that combine the time course and intensity of musculoskeletal activity and inert gas washout with oxygen.

THE DYNAMIC OF PHYSIOLOGICAL REACTIONS OF COSMONAUTS UNDER THE INFLUENCE OF REPEATED EVA WORKOUTS: THE RUSSIAN EXPERIENCE.

A.S. Barer, N.K. Gnoevaia, V.P. Katunczev, and U.U. Osipov
Svezda Corporation, Moscow, Russia

INTRODUCTION

Extravehicular activities continue to be one of the most dangerous and emotionally stressful operations of cosmic flight. This situation is primarily due to a lack of individual and cumulative experience regarding arduous mechanical (physical) work in microgravity conditions. In addition, the space suit is the final technical barrier and the only protective countermeasure against the deep vacuum of space. The visual information received by individuals during EVA regarding the infinity of space appears to enhance an emotional state similar to the typically observed "altitude fear." Together with the unusual microclimate of the space suit, the specific gas environment and the principles of thermoregulation of the suit system result in pronounced physiological reactions by many bodily systems.

RESULTS AND CONCLUSIONS

The accumulation of individual experience during on-ground training in vacuum chambers, in modeled microgravity, and in actual EVA have enabled the normalization of physiological reactions, increased work capacity effectiveness, and simultaneously decreased the metabolic cost for cosmonauts engaged in EVA. The opinion of the cosmonauts is that the most advisable regime of repeated walkouts is at 4-7 day intervals. In emergency situations, it is possible to carry out EVA with a 2-3 day interval. There is a significant amount of important scientific and practical information that can be gained by analyzing physiological reactions during EVA. Therefore, it is highly advisable to develop standardized methods for monitoring the status of the cosmonaut during EVA based on the cumulative experience of Russian and American specialists from on-ground training and actual EVA.

MEDICAL EMERGENCIES IN SPACE

S. L. Pool

Medical Sciences Division, NASA Johnson Space Center, Houston Texas 77058

INTRODUCTION

Predicting and ranking the probability of occurrence of medical contingencies (e.g., illness or injury) during space missions is difficult, in part because the database is too small to allow definitive conclusions. Moreover, medical risk assessments derived from surrogate populations will be imprecise, and the associated magnitude of error is nearly impossible to estimate accurately. Attempts by physicians and epidemiologists to analyze the results collected to date and use those analyses to generate risk "scores" are an overextension of data sources and should be viewed skeptically.

DISCUSSION

Another approach to assessing medical emergencies in space is to focus on the adequacy of in-flight medical care and the ability to return crews safely. NASA's efforts to design a Health Maintenance Clinic for space are well underway. Many of the technologies to be used in this Clinic have been identified, and competing technologies are being evaluated. Many established technologies used routinely on Earth cannot be adapted readily to the space flight environment, particularly those used in imaging and in clinical laboratory equipment. Emergency scenarios generated from space flight experience and risk assessments have been developed and studied. These and other scenarios will be helpful in determining how well Earth-based diagnosis and treatment paradigms can be applied in combination with the clinical resources planned for space.

THE EVOLUTION FROM 'PHYSIOLOGICAL ADEQUACY' TO 'PHYSIOLOGICAL TUNING.'

P.A. Hancock and V. S. Koscheyev
Human Factors Research Laboratory, University of Minnesota, Minneapolis, Minnesota 55455

The challenge of the first wave of space exploration was the sustenance of life in the face of the unforgiving circumstances of extraterrestrial conditions. The prime imperative was the support of the astronaut in terms of providing short-term, micro-environments that permitted undisturbed physiological functioning. It was assumed that where conditions were physiologically tolerable, astronaut performance would remain unimpaired. This concept of physiological adequacy, although demonstrably flawed, served as an unacknowledged design foundation. At the turn of the century, we are in the beginning stages of the second wave of space exploration including the planning of long-term planetary missions and extended residence in space. Today, the imperatives are the uses of space and in particular the unique human role in space development. Consequently, our design strategy has to turn from physiological support to physiological tuning. By this we mean the use of knowledge of physiological systems to subserve and promote optimal performance capability. Given the cost of the sustenance of human residence in space, it is no longer sufficient to simply ensure tolerable conditions. Rather, using NASA's human-centered design innovations, we seek to promote increases in performance efficiency and particularly the reduction of human error in an error intolerant environment. The underlying model which permits the linkage between physiological response patterns and performance efficiency is an extended-U innovation which draws direct parallels between success and failure in physiological and psychological functioning. How performance error may be reduced and performance efficiency increased using the tenets of this approach will be adumbrated.

FIVE ZONES OF SYMMETRICAL AND ASYMMETRICAL CONFLICTING TEMPERATURES ON THE HUMAN BODY: PHYSIOLOGICAL CONSEQUENCES

V. S. Koscheyev

School of Kinesiology and Leisure Studies, University of Minnesota, Minneapolis, Minnesota 55455

INTRODUCTION

This investigation assessed conflicting temperatures on the body surface to evaluate how signals from differing receptor fields determine total body heat status, and the nature of the processes in the thermoregulatory center that manage the stabilization of heat balance. The aim of this program of research is to provide better information on how to manage and protect the body when conflicting temperatures occur during EVA, diving, or in other extreme activities.

METHOD

A cooling/warming suit was constructed with five different zones on each side of the body for cooling and warming the body surface. The suit is divided sagittally so the same five focal areas on the left and right halves of the body can receive the same (symmetrical) or differing (asymmetrical) thermal input, depending on the particular experimental condition. The input of simultaneous warming and cooling to different focal zones results in a body mosaic of conflicting temperatures on the legs, feet, hands, torso and arm, and head. Physiological status was evaluated by electrocardiogram, blood pressure, and thermoregulatory assessment (inlet and outlet heat evaluation, surface and core temperature monitoring, rate of sweating).

RESULTS AND CONCLUSIONS

Comparison of physiological reactions to different sizes and different regimes of warming/cooling panels distributed on the body surface indicated the following: 1. the greater the number of panels with conflicting temperatures on the surface, the more difficult it is for the thermoregulatory center to recognize the existing heat content and heat balance and undertake protective reactions; 2. sweat distribution manifests a mosaic topography that follows the temperature redistribution; 3. sagittally symmetrical and nonsymmetrical distributions of cold and warm panels have a significantly different influence on thermoregulation; 4. it is difficult for subjects to discriminate conflicting temperatures on the surface of the head.

HUMAN PERFORMANCE AND SUBJECTIVE PERCEPTION IN NONUNIFORM THERMAL CONDITIONS

G. R. Leon

Department of Psychology, University of Minnesota, Minneapolis, Minnesota 55455

INTRODUCTION

Marked changes in the microclimate within the space suit may occur during extended duration EVA as a result of physical exertion and differential exposure of different parts of the body to thermal extremes. Nonuniform thermal conditions within the space suit affect overall physiological status; these conditions may also have a significant effect on work performance during EVA. Greater knowledge about the nature of changes in work performance and subjective state has direct relevance to more accurately monitoring the safety of the astronaut and enhancing task effectiveness.

METHOD

Four male and four female volunteers were each evaluated in eight different protocols of nonuniform thermal conditions. The experimental paradigm involved the development and use of a sagittally divided heating/cooling tube suit enabling differential variation of temperature on each side of the body. Core and skin temperature were continuously monitored on numerous sites of the body. A vigilance task was used to measure reaction time and other attentional parameters at periodic intervals across each session. Subjective ratings were obtained of perceptions of heat and cold on the left and right sides of the body and the body as a whole. Overall perception of alertness, tension, and psychological comfort were also measured.

RESULTS

Marked individual differences were demonstrated across subjects in response to nonuniform thermal conditions. Several subjects showed no change in reaction time irrespective of the particular differential temperature condition they were experiencing. However, other subjects exhibited decrements in reaction time with the experience of significant heating on one side of the body. Cold on one side of the body had a greater influence on ratings of overall thermal state than did heat. Some subjects had difficulty discriminating between differential cold temperatures on the two sides of the body when one side of the body was significantly cooled in comparison to the other side. Shifts in the direction of extreme cold were associated with a decrease in ratings of overall alertness and psychological comfort, and an increase in ratings of tension. Differential changes in diastolic and systolic blood pressure on each side of the body were also demonstrated in nonuniform thermal conditions.

DISCUSSION AND CONCLUSIONS

The findings of this investigation point to the possibility of decrements in the work performance of astronauts during extended EVA in nonuniform thermal conditions. Changes in vigilance, inaccurate perception of thermal status of different parts of the body, and decrements in overall psychological comfort and alertness are of concern to mission success. The individual differences noted across subjects in responsiveness to nonuniform thermal conditions suggests the need to evaluate these factors in the management of EVA, and to develop countermeasures to mitigate the effects of these conditions.

THE HAND AS A CONTROL SYSTEM: IMPLICATIONS FOR HAND-FINGER DEXTERITY DURING EXTENDED EVA

Thomas J. Smith and Michael G. Wade

Human Factors Research Laboratory, School of Kinesiology and Leisure Studies, University of Minnesota, Minneapolis, Minnesota 55455

There is broad agreement that the emergence and evolution of species *Homo* was closely associated with the phylogenetic emergence of prehensile hands as advanced, articulated movement systems specialized for complex expressive, social, and instrumental control behaviors. The most recent stage of human social, occupational, and technological evolution into space environments has been accompanied by new challenges to effective behavioral control and use of the hands and upper extremities for the performance of useful work. This paper analyzes the hand as a behavioral control system and explores the implications of this perspective for understanding sources of, and possible solutions to, problems via the dexterous use of hands to perform work during extravehicular activity (EVA) by suited astronauts in space.

Our understanding of the hand as a control system is best seen as a dynamic interaction between task, performer and the environment. Optimal performance of reaching and grasping requires information directly perceived from the "object to be grasped" which mediates both the kinematic and kinetic requisites of the reach and grasp activity. Postural configuration and support is a critical requirement for a successful coordinated reach and grasp activity. Appropriate postural support permits effective use of both the spatial, temporal, and force requirements to complete the task. The coordinated activities of the arm, wrist, hand, and finger system permit a wide range of manipulanda, dexterous, and forceful skill based activities.

From the initial information derived primarily via visual perception, a variety of feedback systems enrich the interaction of the hand-finger system and the object, permitting essentially, a closed loop monitoring of the performance. The system must detect the invariant properties of objects to be manipulated, transported, or torqued via a variety of feedback information that includes haptic and visual information, as well as proprioceptive, tactile, and thermal changes which will allow for optimal or near optimal performance. Such behavior will permit the exercise of a broad repertoire of skillful and force based activities that include grasping, seizing, tracking, steering, reaching, placing, tracing, pointing, beckoning, waving, pushing, pulling, turning, twisting, pinching, squeezing, punching, lifting, supporting, throwing, pivoting, smashing, cutting, tearing, shearing, piercing, pressing, shaping, forming, smoothing, padding, and tapping unilateral and bilateral functions of the hands. Numerous allusions in the lexicon to hand functions underscore the richness of hand movement behaviors that are involved in diverse forms of expressive, gestural, symbolic, social, and tool using activities.

During extended EVA, behavioral control of hand movements typically is compromised for a variety of reasons. The space suit and gloves reduce range of movement and articulation of the arm, wrist, and fingers. Micro gravity conditions may reduce the control stability of postural and transport movements. Integration of hand movements with control of visual, auditory, and social feedback may be compromised because of EVA related perturbations in these latter sensory feedback modalities. Peripheral cooling of the upper extremities may also undermine all modes of movement and sensory feedback. Research evidence indicates that when movement is impaired, control of sensory feedback suffers and effective behavioral control of motor performance is compromised. We may therefore anticipate that during extended EVA the fidelity of dexterous hand control behaviors for routine tool use, expressive, gestural, and social interactive purposes will be constrained. The present report outlines research strategies for delineating the nature and extent of this problem area and will suggest possible approaches to problem abatement.

UNDERSTANDING THE SKILL OF EXTRAVEHICULAR MASS HANDLING

P. V. McDonald¹, G. E. Riccio¹, B. T. Peters², C. S. Layne², and J. J. Bloomberg³

¹Nascent Technologies Ltd., Dayton OH, ²KRUG Life Sciences Inc., Houston TX, ³Life Sciences Research Lab, NASA Johnson Space Center, Houston TX

INTRODUCTION

Our approach to understanding mass handling during extravehicular activities(EVA) is fundamentally empirical and analytically open to the peculiarities of adaptive and intentional control by humans of human-machine systems. We view extravehicular mass handling as a whole-body skill with a domain of adaptability that currently is not well understood. Documentation such as the EVA Lessons Learned [1,2] indicate to us that it is at least as important to understand this adaptability as it is to understand simply what a crewmember can reach. To gain some insight on this capacity for adaptability a ground based investigation of extravehicular mass handling was designed and performed utilizing the Precision Air Bearing Floor at NASA Johnson Space Center.

METHODS

Subjects were suited in a Shuttle extravehicular mobility unit (EMU), pressurized to 4.3 psi. They were placed in a recumbent orientation, left hand down, and supported by a frame attached to the portable life support system (PLSS). This frame was fitted with bearings located along an axis which ran through the center of mass of the human-EMU system and sat in a "cradle" device so as to permit body yaw rotation. The yaw axis cradle-EMU assembly was supported on an air bearing sled. The subjects feet were affixed to a foot restraint (PFR) which was attached to a rigid, immovable structure. Thus the subject, restrained at the feet, could pitch and yaw, and translate in the anterior-posterior and superior-inferior axes by virtue of the air bearing sled and the yaw-axis cradle. In this configuration, subjects' performed an orbital replacement unit (ORU) docking task, maneuvering a 5 degree of freedom (on air bearings) ORU into a docking structure. Trials were repeated with the PFR placed in 6 different locations relative to the docking structure, with varying degrees of freedom permitted for body motion, varying ORU translation trajectories, and under two conditions of docking accuracy. During all of the trials, force and moment data were collected at the PFR and the ORU handle. A video based tracking system was also used to track the motion of the EMU and the ORU relative to the PFR and the docking structure.

RESULTS

We will report data to argue that the essential aspects of mass-handling skill include: (a) management of the tradeoff between postural stability and mobility; (b) control of multiaxis postural perturbations resulting from noncoplanar force couples between ORU and restraints; and (c) sensitivity to the postural and ORU inertia tensors with respect to the ORU trajectory and with respect to the location and orientation of restraints, EMU, and ORU.

CONCLUSION

These data are undergoing analyses in an effort to yield insights that will increase the generalizability of past investigations and current Detailed Technical Objectives (DTOs). The application of these insights is intended to facilitate planning for future EVAs that exploit the skills of crewmembers for whole-body coordination and adaptation.

REFERENCES

- [1]. Fullerton, R.K. (1993/1994). EVA Lessons Learned: Volume I-, Revision A. EVA Section/DF42 (JSC-26055:I). NASA-JSC: MOD, Systems Division.
- [2]. Fullerton, R.K. (1993/1994). EVA Lessons Learned: Volume II-, Revision A. EVA Section/DF42 (JSC-26055:I). NASA-JSC: MOD, Systems Division.

Thursday, June 12

527-52

074632

Session JP2

Room 2

2:30 - 5:30 p.m.

326985

71.

**Metabolic and Regulatory Systems in
Space Flight**

THE DYNAMICS OF BLOOD BIOCHEMICAL PARAMETERS IN COSMONAUTS DURING LONG-TERM SPACE FLIGHTS

Valery Polyakov, Andrei Markin, Lubov Strogonova, Timoty Tigner
State Scientific Center of Russian Federation - Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

Long-term stay under conditions of space flight accompanied by forming in man lipid, carbohydrates, protein, and energetic metabolism alterations. The most part of studies of cosmonauts metabolic state had been carried out in post-flight period. In this connection, all conclusions, concerned of metabolism peculiarities during space flight, had probabilistic character.

The purpose of our work was study of metabolism in cosmonauts right during long-term space flights.

METHODS

in capillary blood taken from the finger, by biochemical analyzer "Reflotron IV" (Boehringer Mannheim Co., Germany), which work based on principle of "dry chemistry", activity of GOT, GPT, CK, gamma-GT, total and pancreatic amylase, as well as concentration of hemoglobin, glucose, total bilirubin, uric acid, urea, creatinine, total, HDL- and LDL cholesterol, triglycerides had been determined. HDL/LDL cholesterol ratio also was computed. Crewmembers of 6 basal missions, 17 persons total, had been tested. Biochemical studies carried out 30-60 days before launch, at the 25 - 423 day of flight, at the 1 and 14-th day of recovery.

RESULTS

In cosmonauts during space flight had been found tendency to increase, in compare with basal level, GOT, GPT, total amylase activity, glucose and total cholesterol concentration, and tendency to decrease of CK activity, hemoglobin, HDL-cholesterol concentration, and HDL/LDL cholesterol ratio. Some definite trends in alterations of other determined biochemical parameters had not been found.

CONCLUSION

The same directions of alterations GOT, GPT, total amylase, CK, glucose, total and HDL-cholesterol values, and HDL/LDL-cholesterol ratio allows to suppose existence of connection between noted metabolic alterations with influence of space flight condition upon cosmonaut's body. Alterations of other studied blood biochemical parameters depends on, probably, pure individual causes.

All data, illustrating noted hypotheses will be discussed in the report.

EFFICIENCY OF FUNCTIONAL LOADING TEST FOR INVESTIGATIONS OF METABOLIC RESPONSES TO WEIGHTLESSNESS.

Popova I.A., Zabolotskaya I.V., Balashov O.I., Buravkova L.B.
State Scientific Center - Institute of Biomedical Problems, Moscow, 123007, Russia.

INTRODUCTION

Biochemical research performed in manned space missions, simulated and in-flight animal experiments to develop and concretize the concept of metabolic balance in microgravity environment indicated that the total metabolic balance in weightlessness is dependent upon the polyhormonal influence of the regulatory systems the function which is reduced to a minimum under these conditions. A specific manifestation of the metabolic balance is the mobilization of the endogenic substrates resulting from the proteins and lipids destruction while inhibition the synthesis of the metabolites, the desintegration of the metabolic cycles with an activation of the deport processes of many substances and the increase of excreting the ballast metabolic products from. The acute periods of adaptation and readaptation to the effect of gravitational factor are aggravated by the development of the stress-reactions having insignificant specificity.

The aim of the present investigation is to examine the advantages of applying the physical load test for men and women metabolism investigation under ground-base simulations of the space flight factors and study of the possibility to using of a stepwise incremental grades load (GPL) on the bicycle ergometer to investigate the metabolic responses of human to a weightless environment during a long-term space mission.

METHODS

The studies with the use of the GPL-test have been done in the experiment with the long-term head-down tilt bed-rest (HDT-BR) with participation of 8 female and 8 male volunteers once before bed rest, respectively on day 60 and day 128 during HDT-BR. The studies with the use of the GPL-test have been performed also with participation of 6 crew members of the prime and back-up spacecrews once pre-flight and post-flight. In the studies there has been used the following GPL-test: a steppers incremental graded leg bicycle ergometry performed in the supine position, with the standard load of 150 W in capacity at the last stage and with total time of pedaling which amounts to 15 min. In conducting the GPL-test, three times - 10 min prior to testing, immediately after completing the bicycle ergometry and within 30 min of rest blood sampling through the catheter inserted into the antecubital vein has been done. In the collected specimens of the blood serum there has been determined the broad spectrum of the biochemical indices characterizing the state of energy metabolism judging from the content of the carbohydrate and lipid substrates and the blood activity of energy - producing enzymes. The studies are performed by using of the biochemical analyzer Technicon RA 1000 with the Boehringer Mannheim commercial test-kits. The data is subjected to multifactorial differential analysis with the fixed effects.

RESULTS

The data of applying the GPL-test in men under ground-based simulation of weightlessness effects are more informative as compared to the performance of biochemical investigations at rest. When studied the effects of long-term HDT-BR on the woman metabolism, the use of GPL-test was also more informative as compared to the at-rest studies. Absolute majority of the observed changes in metabolism is manifested a significant dependence on he level of physical activity of the test-subjects. Physical loads indicated that of 20 blood parameters characterizing the state of carbohydrate and lipid metabolism the 14 indices were reliably changed during experiment. In this case, the maximum amount of changes is revealed with the use of GPT and only 9 indices were registered in the rest state of test subjects. GPL-test has been used for studying the peculiarities of metabolism in cosmonauts of the 18-th crew expedition.

CONCLUSION

The performed studies were the clean demonstration of the high efficiency of applying the GPL-test for studying the peculiarities of metabolism during ground-based simulation of the effects of microgravity both in men and women. The biochemical studies of blood samples taken during GPL-testing are more informative than the investigations performed under at-rest conditions and on this basis have been used for studying the peculiarities of metabolism in a space mission.

Human cellular immunity and space flight .

A. Lesnyak., G. Mitirev, I. Vorotnikova, E. Antropova, G. Levicheva, I. Konstantinova.

State Scientific Center Institute of Biomedical Problems

Space flight factors may influence many human systems and functions, and in particular, the immune system. In work are presented results of peripheral blood lymphocyte subpopulations studies at cosmonauts, taken part in space flights at the period of 1987-1994, as well as at volunteers, having been in hypokinesia experiments conditions. The flow cytometry method was used to quantify CD3+, CD4+, CD8+, Leu7+ and HLA-DR+ cells. The lymphocyte ability to answer to the mitogen stimulation was studied in cell cultures.

It was shown that already before the flight the reduced contents of CD4+ cells was observed at cosmonauts. After long flights the contents of CD3+, CD8+ and Leu7+ cells was diminished. Lymphocyte functional activity was also decreased after the flight. At the long-duration space flight modeling by means of hypokinesia it was noted a reduction of CD4+ cell count at the beginning of the experiment and an increase of CD3+ cell contents at its end. After the experiment the changes were distinguish from usually observed after the flight. At first days after the end of the experiment it was noted an increase of all T-cell populations, but later a reduction of CD8+ cell amount was happened.

Thereby, the hypokinesia studies do not give a full belief about changes, occur in human immune status in space flight.

At present the methods of immunity evaluation in weightlessness are developed, which will allow to study the cosmonaut immune status right in conditions of space flight. Results of conducted studies are discussed.

This work is supported in part by contract NASA-15-10110

CYTOKINE PRODUCTION AND HEAD-DOWN TILT BED REST

D. A. Schmitt¹, A. Cogoli², M. Abbal³

¹International Space University, Strasbourg Central Campus, Illkirch-Graffenstaden, France ; ²Laboratoire d'Immunologie, Faculté de Médecine Rangueil, Toulouse, France ; ³Space Biology Group, ETH, Zurich, Switzerland

INTRODUCTION

Head-down tilt bed rest (HDT) is used as an analogue to study physiological effects mimicking those occurring in weightlessness during space flight. An unusual high frequency of infectious diseases during long duration HDT has been described along with a decreased natural killer cell activity.

METHODS

In the present study, 8 volunteers were subjected to a strict HDT of -6° for 42 days. Blood samples were obtained 12 days before, at day 14, 35, and 42 during and 14 and 35 days after HDT. Facscan analysis was used to determine cell subpopulations. Plasma was used to quantify various plasma hormone levels. Whole blood was also triggered with various activators such as LPS, PHA, PMA, anti-CD3, and anti-CD2 antibodies. Supernatants were collected and analysed for interleukin-1, 2, 6, 10, interferon gamma, and tumor necrosis factor alpha.

RESULTS

No significant changes in the percentage and total number of CD2, CD3, CD4 and CD8+ cells was observed. The percentage and absolute number of natural killer cells (CD2+/CD3-/CD56+) decreased in all subjects after 14 days of HDT. No differences in interleukin-2, 6, 10, and tumor necrosis factor-alpha were found. Other cytokine levels have still to be analysed. Hormone levels which might interact with the immune system have shown that 1,25-dihydroxyvitamin D3 and parathormone decreased significantly during HDT whereas cortisol, prolactin, TSH and growth hormone levels remained unchanged.

CONCLUSION

- These results might indicate that the decrease in natural killer cell activity during and after HDT :
- is not due to an increase in stress hormone levels such as cortisol
 - might be due to a decrease in the absolute number in natural killer cells
 - is probably not due to a decrease in cytokine production

PLASMA AND URINE AMINO ACIDS DURING HUMAN SPACE FLIGHT. T.P. Stein, M.J. Leskiw and M.D. Schluter. Department of Surgery, University of Medicine and Dentistry of New Jersey - SOM, Stratford, NJ, 08084.

We measured the plasma and urine amino acid distribution patterns before, during and after space flight on the Shuttle. The urine and plasma samples were collected on two separate flights of the space shuttle. The first flight lasted 9.5 days and the second flight 15 days. Urine was collected continuously for the period beginning 10 d before launch to 6 days after landing. venous blood samples were taken from a forearm vein from the four payload crew of the second mission after an over night fast. The blood samples were taken launch-45 (L-45), 15 (L-15) and 8 (L-8) days before flight, inflight on the flight day 2 (FD-2), 8th (FD-8) and 12th (FD-12) days and after flight on the day of return (R+0), and days 6 (R+6), 15 (R+15) and 45 (R+45) after return. Results: (i) Urinary amino acids: Overall the urinary amino acids showed little change with spaceflight. except for a marked decrease in all of the amino acids on FD1 ($p < 0.01$) and a reduction in isoleucine and valine on FD3 and FD4 ($p < 0.05$). (ii): Plasma amino acids. Most of the changes found pertained to the essential amino acids, particularly the branched chain amino acids. The plasma aminograms for FD's 8 and 12 were very similar and both aminograms were very different from the FD 2 aminogram. FD2 was not different from the preflight ground control. With increasing duration of time in space, there was an increase in the concentration of the essential amino acids in the plasma. Most of the increase found on FD's 8 and 12 relative to FD2 was due to increases in the branched chain amino acids all of which were significantly increased ($p < 0.05$). The concentration of the essential amino acids on landing were decreased. There was no correspondence between the last inflight measurement (FD12) and the sample collected immediately after landing.

DNA FINGERPRINTING: APPLICATIONS TO SPACE MICROBIOLOGY

Duane L. Pierson¹, Satish K. Mehta², Christian Brauning³, and George M. Weinstock³
¹NASA/Johnson Space Center, Houston, Texas 77058, ²Universities Space Research Association, and ³Department of Biochemistry and Molecular Biology, University of Texas Medical School, Houston, TX 77225

INTRODUCTION

DNA fingerprinting techniques have been used to study microbial transfer among crewmembers, microbial dissemination throughout the spacecraft, and to identify sources of contamination. DNA fingerprinting can distinguish different genotypes and provide a molecular identification system for microorganisms. DNA fingerprinting can be achieved by various methods including: restriction fragment length polymorphism (RFLP), Southern blot hybridization, repeated sequence PCR, ribotyping, and others.

METHODS

Microbiological specimens from crewmembers and the spacecraft environment were collected, and *Staphylococcus aureus*, the selected bacterial model, was isolated by standard methods. Crew specimens included nose, throat, skin, urine, and feces; environmental samples included air, surfaces, and water. DNA was extracted from the *S. aureus* isolates and fingerprinted by one or more of the following techniques: RFLP, RFLP with Southern blot hybridization, ribotyping, and repeated sequence PCR. RFLP and PCR products were separated by electrophoresis (pulsed-field, agarose, etc.). Following electrophoresis, the gels were stained (e.g., ethidium bromide) to visualize the banding patterns of the DNA fragments. *S. aureus* displaying the same DNA banding patterns were designated as the identical genotype.

RESULTS

RFLP analysis using Sma I restriction endonuclease demonstrated transfer of *S. aureus* between two crewmembers during a Space Shuttle mission. RFLP analysis following digestion with either EcoRI or HinfI in combination with Southern blot hybridization with repeat fragment 27A probe similarly demonstrated a transfer of *Candida albicans* between crewmembers. However, such transfers appeared to occur infrequently (<1 in 10 Shuttle missions) during the relatively short Space Shuttle missions (<15 days). Repeated sequence PCR analysis of *S. aureus* isolates from crewmembers of the Mir 18 and 19 missions also demonstrated transfer of the bacterium between crewmembers. Ribotyping was used to distinguish different genotypes of waterborne bacteria recovered from Shuttle and Mir water sources.

CONCLUSIONS

DNA fingerprinting proved to be a powerful tool for studying microbial dynamics in spacecraft. Transfer of microbes between crewmembers occurred during shorter duration missions aboard the Space Shuttle as well as during longer duration missions on the Mir Space Station. DNA fingerprinting technologies can be used to validate microbial contamination models. This technology can also serve as an invaluable epidemiological tool to investigate in-flight contamination events and infectious disease outbreaks.

Thursday, June 12

Session JP3
Room 3
2:30 - 5:30 p.m.

S28-51
074633

326986

13P.

**Gravitational Biology: The Rat
Model**

Morphology of brain, pituitary and thyroid in the rats exposed to altered gravity

I.B.Krasnov^{*,**}, L.N.Dyachkova^{*1}, E.I.Alexeev^{**}, V.I.Loginov^{**}, K.O'Mara^{*2}, W.Hinds^{*2}

State Scientific Center of Russian Federation —Institute of Biomedical Problems, Severtsev's Institute of Ecological and Evolutionary Problems RAS¹, Moscow, Russia; Ames Research Center NASA, Moffett Field, CA, USA²

Introduction

The presented data are results of two studies which have been carried out to elucidate the mechanism of altered gravity influence on animals. The first — morphological study of brain in the rats exposed to microgravity (μG) in space flight aboard SLS-2. The second — morphological study of pituitary and thyroid in the rats exposed to single and repeated hypergravity (HG).

Electron microscopic studies of brain cortex ultrastructure in the rats exposed to μG in 7-, 9- and 14-day space flights aboard Cosmos biosatellites and SLS-1 revealed the dynamics of adaptive changes of cortex ultrastructure in space flight. However, in these experiments the rats for 3—11 h after landing were in conditions of Earth gravity the influence of which on animals led to sharply increase in extero- and proprioceptive afferent flow entering the brain cortex. Therefore the aim of the first of presented studies was morphological investigation of brain somatosensory cortex in the rats exposed to μG and dissected during space flight aboard SLS-2 on purpose to avoid postflight Earth gravity influence on animals.

The results of vestibular studies in cosmonauts, repeatedly flown in space, and the data of ground-based experiments with animals, repeatedly rotated on centrifuge, point to decrease in response to micro- and hypergravity in each subsequent spaceflight or centrifuge rotation. These data are indicative of speeding up adaptation of vestibular apparatus, brain and hormonal system to functioning in conditions of repeated influence of altered gravity. However, the mechanism of accelerating these adaptive reactions remains unclear. In the second of presented studies for understanding the mechanism of speeding up adaptation of mammals to repeated prolonged alteration of gravity the pituitary and thyroid in the rats exposed to single and repeated hypergravity (HG) were studied by means of morphological methods.

Methods

The rats were dissected in flight aboard SLS-2 on day 13 of the mission. Brains from 5 rats were excised after decapitation, sagittally sectioned and halves from each brain were fixed by immersion in 2.5 % glutaraldehyde in 0.1 M cacodylate buffer pH 7.3, precooled at 4 °C. The fixed brains were kept during flight at 4 °C. After landing fixed brains were transferred to Ames Research Center where fragments of somatosensory cortex were excised, post-osmicated, dehydrated in ethanol, acetone and embedded in araldite. Embedded in araldite fragments of cortex and fixed in glutaraldehyde halves of brains were transferred to Moscow for morphological study. Brains of 5 ground control rats were processed with the same protocol. The structures of somatosensory cortex were studied by means of electron microscopy and morphometric analysis.

In experiment with the rats exposed to single and repeated HG the rotation of animals in peripheral cages of centrifuge, having a radius of 1.41 m, was used for prolonged 2 G influence. For estimation of Coriolis acceleration influence, the rats, rotated in the cage on the axis of centrifuge, with 1.1 G level, was studied also. Centrifuge was run constantly and stopped for 20 min each day to service. Vistar male rats (197 ± 2 g) were subdivided into 5 groups with 5 rats in each. The rats exposed to repeated 1.1 G and 2 G were rotated on centrifuge for 19 days and repeatedly — after a 30-day interruption — 5 days. The animals exposed to single 1.1 and 2 G were rotated on centrifuge for 5 days simultaneously with the rats repeatedly exposed. The rats were decapitated by guillotine. The pituitary and thyroid were fixed in Buen's liquid and embedded into histoplast. Pituitary sections were stained with paraldehyde-fuxin and Halmy's mixture aiming the development of somatotrophs and thyrotrophs. In each pituitary in 100 somatotrophs the cell and nucleus volume and in 100 thyrotrophs the cell and nucleus cross section area were measured by means of image analysing system. Thyroid sections were stained by Marais method to develop iodated thyroglobulines and by hematoxylin-eosin. In 100 follicles of each thyroid the thyrocyte nucleus volume, follicle epithelium height and follicle cross section area were measured with the help of image analysing system.

Results

Electron microscopic analysis of brain somatosensory cortex in rats exposed to μG aboard SLS-2 revealed in cortex layers II—IV the next changes of ultrastructure: 1) appearance of "light" presynaptic axonal terminals, which are characterized by low electron density of matrix and significant decrease in the number of synaptic vesicles; 2) decrease in electron density of pre- and postsynaptic membranes in axo-dendritic synapses formed

by "light" axonal terminals; 3) vacuolization of dendritic microtubules and destruction of spine apparatus in dendritic spines; 4) autophagocytosis in the middle and wide dendrites; 5) decrease in amount of axo-dendrite synapses; 6) increase in area occupied by glial cell processes. These data — on the basis of morpho-functional correlations — indicate the decrease in afferent flow entering the cortex in μG . It was found only single "light" and "dark" degenerating axonal terminals, described earlier in brain cortex of the rats exposed to μG in space flight and dissected postflight under Earth gravity in a few hours after landing. In some part of stellate and pyramidal neurons of layers II—IV the increase in amount of ribosomes and Golgi apparatus elements was found indicating the increase in functional activity of these cells. The state of ultrastructure in large majority of large pyramidal neurons in layer V point out the hypofunction of these neurons. The results of morphometric study conform these obtained data.

In ground-based experiment with the rats exposed to single and repeated HG the following results were received after pituitary and thyroid morphological study. In pituitary somatotrophs after single 2 G influence the content of hormonal product in cytoplasm, zones of its degranulation and volume of cells did not differ from those of vivarium control animals and only volume of nuclei exhibited a tendency to increase. After repeated 2 G in somatotrophs it was found the sharply decreased hormonal product content in cytoplasm together with large zones of product degranulation and increased dimensions of nuclei and nucleoli pointing out the intensification of growth hormone production and secretion. In pituitary thyrotrophs the single 2 G did not induce any significant morphological changes. After repeated 2 G the cytoplasm of thyrotrophs was filled with the hormonal product, the zones of product degranulation were hardly noticeable and dimension of cells were sharply increased, while the dimension of nuclei had a tendency to decrease. These data indicate the inhibition of thyrotropic hormone secretion in the rats exposed to repeated HG. The results of morphological study of somatotrophs and thyrotrophs after single and repeated 1.1 G point to the decrease in cell functional activity. In thyroid of rats exposed to single 2 G influence it was revealed the diminution of cross-sectional area of follicles (by 38 %), the signs of parenchyma proliferation and the increase in amount of perifollicular capillaries. In spite of unchanged content of iodinated thyroglobulines and thyrocyte nuclear volume the state of thyroid structure point to the increased functional activity of thyroid. After repeated 2 G the cross-sectional area of follicles was reduced by 51 %, amount of perifollicular capillaries was increased still more in comparison with single 2 G, thyrocyte nuclei had sharply expressed tendency to increase in volume and the content of iodinated thyroglobulins in colloid was significantly rose. In total these data indicate higher thyroid activity after repeated HG than after single one. However, processes of parenchyma proliferation were less pronounced and thyroid structure was more "in order".

Conclusion

The results of morphological study of brain somatosensory cortex in rats exposed to μG in space flight aboard SLS-2 and dissected during space flight on 13 day of the mission allow to conclude — on the basis of morpho-functional correlations — about decrease in afferent flow entering the somatosensory cortex in μG and point out the developed in μG hypofunction of large pyramidal neurons. The comparison of results of thyrotroph and thyroid morphological study in the rats exposed to repeated 2 G with the data of other authors about functional connection of thyrotrophs and thyrocytes allows to suppose than inhibition of thyrotropic hormone secretion following the repeated HG is conditioned by increase in activity of thyrocytes the influence of which on thyrotrophs is realized by feedback mechanism via thyroid hormones. The obtained data indicate the acceleration-of-pituitary somatotroph and thyroid cell reactions in response to repeated prolonged HG and point out the animal capability for memorizing of gravity alteration. The work devoted to morphological study of the rats exposed to single and repeated HG was partly supported by contract NAS 15-10110. * — SLS-2 experiment. ** — HG experiment.

BIOCHEMICAL PROPERTIES OF β ADRENOCEPTORS AFTER SPACEFLIGHT (LMS-ST578) OR HINDLIMB SUSPENSION IN RATS.

S. Fagette[°], L. Somody[°], F. Bouzeghrane[°], N. Gallo-Bona[°], L. Eward, M. Viso*, C. Gharib[°] and G. Gauquelin^{°*}
[°] Laboratoire de physiologie de l'Environnement, Faculté de médecine, 8 avenue Rockefeller, 69373 Lyon cedex 08 ; * CNES, 75038 Paris cedex 01.

INTRODUCTION

To complete our previous studies on the sympathetic nervous system (SNS) adaptation to microgravity, β adrenoceptor biochemical characteristics were determined in rats. This work was performed in two major peripheral organs involved in blood pressure regulation i.e. heart (atria and ventricles were separated) and kidneys of rats flown for 18 days onboard the NASA space shuttle and in 14-day-tail suspended rats to compare actual to simulated microgravity influences on this system.

METHODS

In each experiment, animals were divided into 2 groups : for spaceflight mission, 6 flight rats and 12 ground control rats (6 vivarium and 6 Animal Enclosure Module groups) were considered ; for hindlimb suspension study, 10 suspended rats (Morey's model) and 20 control animals (10 horizontally attached and 10 isolated rats) were used. In both investigations, the biochemical properties of β adrenoceptors were assessed using ¹²⁵I-pindolol binding followed by a Scatchard analysis to calculate the dissociation constant (Kd) and the maximal binding capacity (Bmax) of these receptors in both organs considered.

RESULTS

A 18-day-spaceflight did not significantly change any biochemical characteristics of cardiac and renal β adrenoceptors since Kd and Bmax values in flight rats were similar to those in ground control groups. The 14-day-tail suspension induced no significant alterations of β adrenoceptors Kd and Bmax values in heart and kidneys comparing to both control groups.

CONCLUSION

The spaceflight study evidenced the lack of modification in β adrenoceptor characteristics in the 2 peripheral organs considered after the mission. All these results do not allow us to conclude about the SNS adaptation pattern neither to actual microgravity nor to simulated microgravity. We have to take into account the necessity to develop inflight sacrifice protocols to avoid possible effects of reentry into Earth gravity which could mask the influence of microgravity on the SNS. That is why the international space station will be very useful to provide further information about the biological system adaptation to actual microgravity in animals.

INFLUENCE OF HYPERGRAVITY ON THE DEVELOPMENT OF MONOAMINERGIC SYSTEMS IN THE RAT SPINAL CORD

M. Giménez y Ribotta and A. Privat

INSERM U. 336, Université Montpellier II, 34095 Montpellier, FRANCE.

INTRODUCTION

The development of the Central Nervous System depends of the interaction of a genetic program with the environment. Gravity constitutes a major element of the environment and its influence is exerted on motor, sensory and autonomous functions. These functions are integrated in the spinal cord. Our aim was to study the influence of gravity on the development of a modulatory system of these functions -the monoaminergic medullary projections- by using an hypergravity model. We evaluated whether the structure and function of these descending systems are modified by this physical condition.

METHODS

Pregnant Sprague-Dawley rats from embryonic day 15 and their litter were submitted to hypergravity (1.8 g) until postnatal day 15. Animals simultaneously localized in the same room, but not submitted to hypergravity were used as controls. Two groups of animals were studied: at postnatal day 1 and at postnatal day 15.

Morphological evaluation: After intracardiac perfusion of animals with 5% glutaraldehyde in 50mM cacodylate buffer, spinal cords were removed and postfixed in the same fixative for 24h. Transverse vibratome sections (50µm) at thoracic and lumbar level were processed for serotonin (polyclonal antibody, 1:10000) or tyrosine hydroxylase (polyclonal antibody, 1:5000) immunodetection.

RESULTS

Postnatal day 1. Serotonergic system.

Control animals: Thin and varicose immunoreactives serotonergic fibers were observed invading the ventral horn, whereas a discrete and scarce innervation is observed in the intermediolateral columns.

Animals in hypergravity showed only an incipient serotonergic innervation in ventral funiculi.

Postnatal day 15. Serotonergic system.

Control animals: Serotonergic fibers were observed in the ventral horn concentrated around motoneuron somata, in the intermediolateral columns, and in the dorsal horn. This innervation pattern is reminiscent of the well defined pattern of the adult animal.

Animals in hypergravity showed a similar pattern of serotonergic fibres, but its distribution in the target areas was disorganized with sharp changes of orientation and many fibers appeared dystrophic.

Similar results were observed for tyrosine hydroxylase immunodetection, at both time intervals.

CONCLUSION

The influence of hypergravity on the motor, sensory and autonomous functions during development, leads to a delay in the developmental schedule of monoaminergic projections regulating these functions in the spinal cord. Moreover, an anarchic, disorganized and dystrophic innervation is observed in the target regions, which correspond to the precise levels of integration of sensory-motor and autonomous functions in the spinal cord.

A Vestibular Evoked Potentials (VsEPs) Study of the Function of the Otolith Organs in Different Head Orientations with respect to Earth Gravity Vector in the Rat

M. Plotnik¹, M. Mager², J. Elidan³ and H. Sohmer¹.

¹Dept. of Physiology, The Hebrew University Hadassah Medical School, ²Dept. of Electrical Engineering, ³Dept. of Otolaryngology, Head and Neck Surgery, Hadassah University Hospital. Jerusalem, Israel.

Recently we have successfully recorded short latency ($t < 12.7$ msec) VsEPs in response to linear acceleration impulses, using a new technique that was developed in our laboratory. The stimulating apparatus consisted of a horizontal sliding device (to which the rat was attached) that was linearly accelerated (nose forward) by force impulse generated by a solenoid. Stimulus intensity varied between 1-10g' (risetime: 1msec, displacement: 30 μ m). The electrical activity was recorded by needle electrodes and was analyzed (filtered: 300-1500 Hz, amplified and averaged: N=128) by a standard evoked potential system. Various control experiments suggested that the recorded response is initiated in the otolith organs. In this study we investigated the effect on the VsEPs of holding the head in different orientations with respect to the direction of earth gravity vector (EGV) while delivering the linear acceleration impulses. The amplitude of the first wave of the VsEPs to linear accelerations (4g') in 6 rats was significantly increased when the rat was in the upside down position, than when in the prone position. In 9 different rats VsEPs (4g' linear accelerations) were recorded in 7 different head orientations with respect to the EGV, all with bilateral symmetry with respect to the EGV. These included head perpendicular to the EGV (standard prone position); head parallel to the EGV, nose up; head parallel to the EGV, nose down; and 4 additional intermediate head orientations: 26° head down and up and 45° head down and up. The amplitude of the first wave of the VsEPs varied consistently among rats in the different head orientations, having a maximum at 45° head down and head up positions. The results of these experiments suggest that the amplitude of the first wave is proportional to the instantaneous superposition of the contributions of gravity and of the induced linear force impulse. These results provide further evidence that the VsEPs to linear acceleration are initiated in the otolith organs. Therefore the VsEPs may serve as an electrophysiological tool for understanding vestibular function in different gravitoinertial environments.

QUANTITATIVE OBSERVATIONS ON THE STRUCTURE OF SELECTED PROPRIOCEPTIVE COMPONENTS IN ADULT RATS THAT UNDERWENT ABOUT HALF OF THEIR FETAL DEVELOPMENT IN SPACE

M. DeSantis^{1,2}, E. Eldred⁴, C. Helmick³, J. Hines¹, and A. Wong²

¹Department of Biological Sciences, ²Washington/Alaska/Montana/Idaho (WAMI) Medical Education Program, ³Electron Microscopy Center, University of Idaho, Moscow, Idaho, 83844, USA, and ⁴Department of Anatomy, UCLA School of Medicine, Los Angeles, California, 90024, USA

INTRODUCTION

Proprioceptive systems of vertebrates are important for control of posture and movement. On Earth those activities inherently encounter the influence of gravity, and, of course, proprioceptors have developed in the presence of Earth gravity. Yet, it has not been demonstrated what role, if any, gravity has in the "proximate" and "ultimate" causation - borrowing from concepts espoused by Ernst Mayr - for the existence of proprioceptors. We examined a proprioceptor in skeletal muscle - the muscle spindle - as well as the vestibular nuclei in the brains of rats that underwent part of their development in a near-zero gravity state. Thus, this is an initial analysis into whether gravity affects the ontogeny of these sensory systems.

METHODS

Female (F) and male (M) offspring of 10 pregnant rats that spent days 9 to 20 of gestation (where conception is day 1) in microgravity ($10^{-3}g$) were the experimental or Flight group. They were a payload (NIH.R1) aboard the space shuttle Atlantis launched November 3, 1994 (STS-66). This experimental group was compared with age-matched, ground-based offspring of Synchronous ($n=10$) and Vivarium ($n=25$) control dams. The rats reported on here were sacrificed when they were 100 days old; all were born and grew postnatally in Earth gravity ($1g$).

The animals were anesthetized and perfused with saline followed by 4% paraformaldehyde. The right soleus muscles were dissected from the hind limbs and immersed in either Bouin's fixative (light microscopy) or 4% paraformaldehyde (electron microscopy); brains were placed in aldehyde fixative.

Muscles examined by light microscopy were serially cross-sectioned in their entirety at $20\mu m$ thickness in a cryostat, picked up onto coverslips, stained with a modified van Gieson method, and permanently mounted onto slides. Those sections were examined for the presence of encapsulated muscle receptors. For each muscle spindle found, its position within the muscle was charted. Muscles examined by electron microscopy were embedded in epoxy resin. They were skip-serially cut in cross section. When a spindle was identified on $2\mu m$ thick sections stained with Stevenel's blue, then thin sections of it were cut, picked up on coated slot grids, contrasted with salts of heavy metals, and examined with a transmission electron microscope before continuing to section farther along the remaining muscle. Spindles were assessed ultrastructurally for the integrity of intrafusal muscle fibers and the presence of nerve endings.

Brain stems were cut in cross section at $50\mu m$ thickness from midbrain through medulla. Thionin stained, serial sections were examined by light microscopy to identify the vestibular nuclear complex (i.e. superior, lateral, medial, and inferior nuclei). The composite was traced from each section at constant magnification. The area bounded by that outline was measured using a digitizing tablet coupled to a computer running morphometry software. The volume of each vestibular nuclear complex in a rat was calculated separately by summing the individual section values ($\sum\{\text{area} \times \text{section thickness}\}$). Then values for the left and right sides were averaged for each animal. Comparisons of the overall average volume were made among groups and between sexes.

RESULTS

Muscle spindles were present in all Flight and control soleus muscles that have been examined. The average \pm standard deviation ($X \pm SD$) number of spindles per soleus muscle in Flight rats (4F, 1M) was 18.6 ± 0.9 . That was not significantly different from the values of 17.3 ± 2.0 for Synchronous controls (2F, 1M) and 18.0 ± 2.0 for Vivarium controls (4F, 2M). The distribution of spindles along the soleus muscle was also very similar among the groups. For example, Flight females ($n=4$) had 79% of their spindles distal to the nerve entry zone, while the combined control female rats ($n=6$) had 77% of that receptor type in the equivalent length of muscle. Nor were

there statistically significant differences between Flight and Synchronous control rats' soleus muscles embedded in plastic which were analyzed in even more detail (n=1 muscle each; both were F). In 80% of spindles for each of those muscles, four intrafusal fibers were present, and the remaining 20% had three fibers. Similarly, the average equivalent diameter of those intrafusal fibers was $12.3 \pm 2.1 \mu\text{m}$ for the Flight (n=15 spindles) versus $11.5 \pm 2.4 \mu\text{m}$ for the control (n=15 spindles). The average equivalent diameter bounded by the outer capsule of the spindle was also very close in the Flight and Synchronous control muscles, being $46.3 \pm 21.8 \mu\text{m}$ and $44.1 \pm 13.7 \mu\text{m}$, respectively. Finally, sensory and motor nerve terminals were identified abutting intrafusal fibers of spindles in the Flight as well as Synchronous control muscles. In summary, by every measure that we used for muscle spindles, there was no notable difference between the experimental and control adult rats.

The size of the vestibular nuclear complex was measured in six Flight (3F, 3M), six Synchronous control (3F, 3M) and four Vivarium control (2F, 2M) rats. There were no statistically significant differences when comparing the composite volume ($X \pm \text{SD}$) of Flight ($4.92 \pm 0.50 \text{mm}^3$) versus Synchronous control ($4.81 \pm 0.62 \text{mm}^3$) versus Vivarium control ($4.83 \pm 0.14 \text{mm}^3$) groups. In contrast, the volume of the vestibular nuclear complex was significantly smaller for the eight female rats ($4.56 \pm 0.31 \text{mm}^3$) as compared to the eight males ($5.15 \pm 0.41 \text{mm}^3$). Thus, the sex of the rat had more of a bearing on the size of the adult vestibular nuclear complex than did a limited prenatal experience in microgravity.

CONCLUSION

Exposure to a space flight environment through most of the latter half of gestation does not preclude the existence of normal proprioceptive structure when those rats subsequently grow to adulthood on Earth.

(Supported by NASA-Ames Cooperative Agreement No. NCC2-862 and Idaho Space Grant Consortium award FPK-934)

EFFECTS OF A NINE-DAY SHUTTLE MISSION ON THE DEVELOPMENT OF THE NEONATAL RAT NERVOUS SYSTEM: A BEHAVIORAL STUDY

D. Sulica, C. Heffernan, L. Benavides, D. Anshel, K. Walton

Dept. of Physiology & Neuroscience, N.Y.U. Medical Center, 550 First Ave, New York, N.Y. 10016

INTRODUCTION

We are interested in the adaptability of the developing nervous system to environmental influences and the mechanisms underlying this plasticity. Previous studies using the tail-suspension model of weightlessness identified a sensitive period, postnatal day (P)8-P13, during which hindlimb unloading leads to marked changes in motor performance. When tail suspension was continued until P31, the altered motor function was prolonged (Walton et al., *Neurosci.* 51: 763, 1992). We report here on the post-flight motor performance of the first neonatal rats flown in space. The animals were flown on the middeck of Endeavour (STS-72, NIH-R3) in January, 1996. Animals were launched at the ages proposed for the upcoming Neurolab mission. The flight animals (P7-16 and P15-24 during the mission) were housed in modified RAHF cages fitted within animal enclosure modules (AEM). Age-matched AEM-housed animals were used as ground controls for the behavioral studies.

METHODS

Righting reflexes, swimming and walking were videotaped at 60 fps (swimming and walking) or 200 fps (righting and walking) from landing day (R+0) through R+14. Free walking was also taped on R+52, R+67, R+215, R+234, R+279 and treadmill walking on R+80 and R+207. Surface righting was analyzed by measuring the speed with which the head, forelimbs (FL) and hindlimbs (HL) righted. Swimming stroke duration was measured using frame-by-frame analysis. The step cycle was analyzed using the Peak 5 Motion Measurement System (Peak Performance Technologies, Inc).

RESULTS

Differences between AEM and flight animals were seen in all three evaluations of motor function. Surface righting was significantly slower in flight compared to AEM control animals. On R+0 the righting reflex was slow in both groups of flight animals. The P7-16 flight animals righted their heads in 0.24 ± 0.01 sec compared to 0.17 ± 0.01 sec in the control animals. The values for the FL, were 0.27 ± 0.01 sec for flight and 0.21 ± 0.01 sec for controls. The values for the HL were 0.35 ± 0.01 sec for flight compared to 0.29 ± 0.01 sec for control animals. For the P15-24 animals the values were; head, flight 0.18 ± 0.01 sec, control 0.15 ± 0.004 sec; FL, flight 0.21 ± 0.01 sec, control 0.18 ± 0.004 sec; HL, flight 0.26 ± 0.01 sec, control 0.21 ± 0.004 sec. The differences were significant in both groups at the $p < 0.0001$ level. Righting reflexes recovered rapidly; the P15-24 animals recovered by R+1 and the younger animals recovered by R+3.

Nine days in microgravity did not seem to effect swimming speed. However, the flight and AEM animals could easily be distinguished on the basis of their swimming style. Most marked was a hyperextension of the hindlimbs as reported in the tail-suspended animals. This is being analyzed using the Peak system. We found that the P15-24 AEM control animals swam faster than the age-matched flight and other control animals.

Analysis of free walking showed differences in both hindlimb and forelimb joint angles during locomotion. The most marked effect was an extension of the hindlimbs that was seen during both the swing and stance phases of the step cycle. For example, in the P7-16 rats, the mean stance maximum angle for the ankle was $118.24 \pm 2.43^\circ$ in the flight compared to $94.86 \pm 2.01^\circ$ in the control animals ($p < 0.0001$). In the P15-24 group, the value was $124.33 \pm 2.50^\circ$ for the flight and $99.18 \pm 2.61^\circ$ for the control animals ($p < 0.0001$). The swing minimum angle was $42.19 \pm 2.50^\circ$ for the P7-16 flight animals compared to $27.37 \pm 1.13^\circ$ for the age-matched controls ($p < 0.0001$). No significant difference was seen in the swing minimum angle in the P15-24 animals. The animals recovered slowly, with some differences remaining after 6 months of re-adaptation to 1G.

CONCLUSIONS

These findings indicate that neonatal rats can nurse and survive 9 days of space flight. Further they show that development of the nervous system is altered for both weight-bearing (walking) and non-weight-bearing (swimming and surface righting) behaviors. However, the effect is more persistent for motor functions requiring the animals to bear their weight. Re-adaptation of righting reflexes to 1G was fast in both age groups, taking longer in the younger animals. The rapid recovery is probably due to the short flight duration. Persistent changes would be expected after longer flights such as Neurolab (16 days) when some of the animals will not return to 1G until after the end of their critical period of development. Due to the presence of sensitive and critical periods, neonatal rats offer a good model to study the effects of microgravity on the mammalian nervous system. Neonates are more sensitive to changes in the environment than adult animals, yet the cellular and molecular mechanisms underlying adaptation to microgravity and re-adaptation to 1G are likely to be the same in all mammalian species. Supported by NASA, the NINDS, and the NICHD.

MUSCLE ATROPHY ASSOCIATED TO MICROGRAVITY IN RAT: BASIC DATA FOR COUNTERMEASURES

M. Falempin and Y. Mounier

Laboratoire de Physiologie des Structures Contractiles, SN4, Université des Sciences et Technologies de Lille, F-59655 Villeneuve d'Ascq Cedex

Many reports have shown that real or simulated (using the hindlimb suspension HS model) microgravity led, especially in slow antigravitational muscles such as soleus, to pronounced structural atrophy, loss of force and changes in fibre typing and myofibrillar protein isoform expression. Mechanical measurements of contractile speed indicated that the slow-twitch soleus muscle acquires faster contractile properties after HS.

Among all the mechanisms suggested as a trigger for the muscular changes, a modification in the neuromuscular activity can be considered since i) EMG patterns were modified during real or simulated microgravity and ii) suppression of the nervous command during HS either by selective inhibition of the electrical impulse by TTX or by total denervation avoided the slow to fast changes in the fibre composition and kinetic properties of the soleus muscle. Therefore, we investigate the possibility to counteract the transformations of the unweighted rat soleus muscle using protocols which might regulate the nervous command.

Sustained low-frequency electrostimulation which resembled the firing pattern of normal slow motor units was imposed during HS. It prevented the kinetic and histochemical changes associated to HS; however, neither the loss of mass nor the decrease in force output were prevented.

The role of the afferent message was controlled in deafferented + suspended rats. Similar results as those described above were obtained. Moreover, stimulation of the Ia afferents by tendinous vibrations associated to passive stretching of the muscle led to a partial recovery of all properties.

Therefore, the whole results underlined the role of the pattern of discharge of the motoneuron and its regulation by the afferent message in the control of the muscle properties in unweighting conditions.

SIMULATED WEIGHTLESSNESS BY UNLOADING IN THE RAT. RESULTS OF A TIME COURSE STUDY OF BIOCHEMICAL EVENTS OCCURRING DURING UNLOADING AND LACK OF EFFECT OF A rhBMP-2 TREATMENT ON BONE FORMATION AND BONE MINERAL CONTENT IN UNLOADED RATS.

E. Zérath¹, X. Holy¹, A. Malouvier¹, B. Noël², M. Hott², C. André¹, S. Renault¹ and P. J. Marie²

¹ Department of Gravitational Physiology, Institut de Médecine Aérospatiale du Service de Santé des Armées, BP 73, 91223 Brétigny-sur-Orge, and ² Cell and Molecular Biology of Bone and Cartilage, INSERM U349, Lariboisière Hospital, 75475 Paris Cedex 10, France.

Mechanical function is known to be of crucial importance for the maintenance of bone tissue. Numerous experimental studies have shown that loss of total-body calcium, and marked skeletal changes occur in people who have flown in space. Infrequency and high financial cost of flights have created the need for ground models designed to mimic weightlessness effects. Anti-orthostatic suspension devices are now commonly used to obtain hindlimb unloading in rats, with skeletal effects similar to those observed after spaceflight. These effects have been demonstrated at the tissular level, by means of histomorphometric evaluations. They can be summarized in a decrease in bone volume and a reduction in bone formation activity beginning on the 5th day of unloading. But biochemical changes relative to bone and calcium homeostasis also affect blood during unloading. We have recently investigated this problem.

A time-course study of these bone and calcium biochemical events was performed during a 2-week unloading experiment in rats. We found significant changes in circulating levels of osteocalcin, total alkaline phosphatases (ALP), and parathyroid hormone (PTH). Indeed, as compared with values measured in age-matched control rats (i.e. normal loaded animals), we found higher levels of PTH on the 7th day of unloading, and lower circulating levels of osteocalcin at 2, 5, 7 and 14 days of unloading, and lower levels of total ALP on the 7th and the 14th day of unloading. These findings argue for a decrease in bone formation activity measurable as soon as the 2nd day of unloading.

In order to evaluate countermeasures against unloading bone loss, we used local factors, known to be important agents regulating differentiation and/or proliferation of bone forming cells. As part of these local growth factors, BMP-2 (bone morphogenetic protein 2) has been shown to be a potent inducer of bone formation when applied locally *in vivo*. We then investigated whether general administration of BMP-2 could counteract the effects of unloading on bone formation and on bone mass.

Recombinant human (rh) BMP-2 was continuously administrated at the dose of 2µg/kg bw/day to control and unloaded rats during a 14-day experiment. At the end of the 14-day period, animals were anesthetized, and tibiae and femurs were removed and processed for histomorphometric and bone mineral content analyses. Rat calvaria osteoblastic cells were used for cell-culture studies in order to verify rhBMP-2 activity. Cells were treated with rhBMP-2 for 24-120 h and cell proliferation and cell differentiation were tested by means of [³H]-Thymidine incorporation and alkaline phosphatase (ALP) activity-evaluations.

The time-course study in osteoblastic cell-culture showed that rhBMP-2 did not influence cell proliferation, but induced a dose-dependent increase in ALP-activity in cultured calvaria cells. However, treatment with rhBMP-2 in unloaded rats had no effect on parameters of skeletal growth and trabecular bone content. Moreover rh-BMP-2 treatment did not improve bone volume and static and dynamic bone formation parameters in the cancellous bone of tibial metaphyses in unloaded rats.

The present study shows that treatment with rh-BMP-2 has not been effective in promoting skeletal growth, stimulating bone formation, and maintaining the metaphyseal bone content in this rat model of osteopenia. However, rhBMP-2 was effective in promoting osteoblastic cell differentiation *in vitro*. These new data could indicate that, in contrast to the efficiency of stimulating osteoblastic cell proliferation in preventing unloading induced bone loss, stimulating cell differentiation fails to prevent bone loss induced by unloading in rats.

Acknowledgements : The authors wish to thank Ciba-Geigy (Basel, Switzerland) for the generous gift of rhBMP-2 and Centre National d'Etudes Spatiales (CNES, Paris, France) for the financial support of this study.

CYTOLOGICAL MECHANISM OF THE OSTEOGENESIS UNDER MICROGRAVITY CONDITIONS.

N.V Rodionova¹, Oganov V.S².

¹Institute of zoology NAS, Kiev, Ukraine; ²Institute of biomedical problems, Moscow, Russia.

INTRODUCTION

Decreasing of the bone growth rate and osteogenic processes, appearance of the osteoporosis and bone demineralization, diminution of the mechanical bone strength is characteristic alteration pattern for the weightlessness. The cytological mechanisms of microgravity-induced alteration and pattern of the adaptive and comprehensive reactions are needed in the further investigation. It is not clear the character of the osteogenic processes, the objective laws of the growth and differentiation pattern of the osteogenic and osteoclastic cells, peculiarities of their specific functions and of the cooperations during bone adaptive remodeling, the alterations of the bone matrix structure under microgravity conditions.

The aim of our work was to study the microgravity influence on the rat bone tissue cells during flight on the board of the american space laboratory SLS-2 during two weeks and to evaluate the readaptive processes in the bone after the space flight.

MATERIAL AND METHODS

As the material for the electron microscopy studying we used the fragments of the rat femoral epiphysis. Samples were fixed in the 2,5% glutaraldehyde with addition 1,5% paraformol in phosphate buffer, pH7,2 during 24h. After 3 veces washing the samples were transported in 70% alcohol to the Kiev, when they postfixed in 1% osmium acid, dehydrated in alcohol and embedded in araldit. Ultrathin sections were stained according Reinolds and examined in electron microscope Tesla BS-500.

RESULTS

We can judge about the intensity and characteristic features of the osteogenesis in the weightlessness only considering to ultrastructural study of the morphofunctional cell alterations in the osteogenic zones. It is known, that the collagen and protein components of the proteoglycans are synthesized in the rough endoplasmic reticulum (RER) polysomes. Synthesis of the alkaline phosphatase occurs there too. Goldgi complex participate in the sulphated glycosaminoglycans synthesis. It plays first fiddle in the accumulation and transportation of the proteins and polysaccharide substances, alkaline phosphatase, Ca and P compounds. The accumulation P and Ca ions took place on the RER membranes. The degree of the development and state of this organoids are the important markers of the differentiation and specific function intensity in the bone cells.

Our investigation demonstrates that the normal osteogenic cell population is not uniform. Osteoblasts are distinguished on the shape, ultrastructure, biosynthetic activity and topographic relation with the mineralization zone. We are distinguishing 4 morphofunctional types (or stages). In the zones of the active osteogenesis there are the young osteoblasts (1st type) with narrow RER channels and well developed Goldgi complex, the mature functional active osteoblasts with enlarged RER channels and cisterns (2nd type). Osteoblasts with hypertrophic RER are revealed too (3rd). They serve for the secret reserving. In the zones of the osteoplastic process fading (in the endost for example) osteoblasts turned into non-active state (4th type). This cells has narrow RER channels, many of the autofagolysosomes.

Using radionuclids we demonstrate, that proteoglycans and alkaline phosphatase biosynthesis, calcium compound accumulation and secretion are predominant in the 1st type osteoblasts. The synthesis of the collagen proteins predominant in the 2nd type osteoblasts. The 3rd type osteoblasts secretes proteins and glycosaminoglycans. These cells are characteristic for the intensive osteogenic zones.

In the rats from the flight group the metaphysis osteoblasts population is more uniform. It does not consist with the osteoblasts of the different functional stages, since such zones are characteristic for the normal osteogenesis in the control and synchronous control. Intensive osteogenesis take place in the some areas of the bone trabeculae only. It includes the agregations of the 1st type osteoblasts. They have low nuclei-to-cytoplasm ratio and well developed RER with the narrow (0,1-0,2 mkm) channels. The state of the endoplasmic reticulum suggested about relatively low level of the bone matrix biosynthesis. Mitochondria have the dense matrix and crystalline inclusions which demonstrate disturbance of the calcium metabolism. The nuclear chromatin is arranged on the perimeter and in the small agregations.

Osteoblasts like 4th type of the osteoblasts are predominant in the population. They have oval or elongated forms and lie parallel to the mineralization zone, beside the trabecula surface in the 1-2 layers or separately. The cytoplasm borderline which attached to the bone matrix has striated contours. The thin or slightly extended RER channels lie in compact. In the Golgi apparatus vesicles and vacuoles are predominant. There are many autophagolysosomes with membrane RER fragments. This ultrastructure picture suggests about low biosynthetic activity in comparison with the 2nd and 3rd type osteoblasts. In the 4th type osteoblasts collagen proteins are transferring from the RER polysomes to the Golgi complex where they coupled with glycosaminoglycans and transported in the intercellular space by vesicles. In all the types osteoblasts the alkaline phosphatase, phosphates and calcium compounds are excreted by exocytosis, by separation of the vesicles from the cytolemma, and by destruction of the surface cell zones. The vesicles are registered in the mineralization zone as the mineralization centres.

In the flight group mineralization zones are more narrow than in the control. Many of the osteoblasts are similar to the fibroblasts on their ultrastructure. Functional active 2nd type osteoblasts are rare (1 to the 5-10 of the 4th type). Osteoblasts of the 3rd type with hypertrophic endoplasmic reticulum are a single cells.

This morphological pattern of the osteogenic cells suggested about the lower level of the growth and synthetic processes. This effect is depended upon the disturbance of the optimal balance of the bone matrix compounds biosynthesis. The relatively small number of the 2nd and 3rd type osteoblasts in the osteogenic cells population among the 1st and 4th type prevalence reflects decreasing of the collagen synthesis and secretion intensity in comparison with the control. It seems that there are no asynchrony of the specific biosynthesis, a part it is no the disconnection of the collagen proteins synthesis and glycosaminoglycans synthesis, which is characteristic for the intensive osteogenic zones, such as metaphysis.

We obtained the similar data during our investigation microgravity influence on the osteogenesis, which was conducted on the rat metaphysis from biosatellite "Cosmos - 2044". During the studying of the biochemical peculiarities of the osteoporosis development under the microgravity action it is established alteration in the collagen and glycosaminoglycans metabolism: deceleration of the synthesis and intensification of the catabolism. The comparison of this alteration with the bone structure damages (such as reduction of the Ca and P content and increasing their excretion with the biological fluids) permits to do the conclusion about interrelation between breach of the glycosaminoglycans synthesis and the mineralization state.

In the some osteogenic zones around the osteoblasts the large areas with collagen fibrils are revealed in the rats from the flight group. It suggests about the destruction of the osteogenic function in the cells and demonstrates the tendency to cells conversion into the fibroblastic ones. We can propose, that disappearance of the gravitation overload provoke osteoblasts to synthesise the collagen proteins what are characteristic for the fibroblastic phenotype. In the some studies the possibility of the new forms of the collagen synthesis in the bone tissue and of the specific gene expression inhibition (for example of the osteocalcin-producing gene) are postulated under microgravity condition. It conducts to the disruption of the mineralization osteoid processes and to the appearance of fibrosis zones. The decreasing of the bone calcium content under microgravity condition is characteristic for the spongiosa bones. Intensification of the resorptive processes in the bone spongiosa occurs by increasing number of the "giant" osteoblastic forms with well developed fibrillar zona and ruffled border.

During the readaptation period the structure and the cell composition of the osteogenic zones in the metaphysis rebuild. They approximate to the control.

CONCLUSION

Under microgravity condition decreasing of the osteopoietic activity and increasing of the resorptive processes in the bone were established. The osteoblasts population of the flight rats group is represented by the relatively low active for the specific biosynthesis forms (1st and 4th types). Osteoblasts of the different functional state are characteristic for the active osteogenic zones in the normal bones and in the synchronous control, but in the flight group rat bone they are extremely rare. In the some areas osteoblasts demonstrate the fibroblastic phenotype features. In such areas we discover the extended zones with the collagen fibrills on the trabecula surface. During the readaptation period (14 days after the space flight) the cell composition of the osteoblast population restores. After this time population is represented by the typical forms. The alterations, which was described above, may be considered as the adaptive reactions of the bone tissue cells on the microgravity effect.

Thursday, June 12

529-51

074634

Session JP4

Room 4

11P.

2:30 - 5:30 p.m.

326988

**Biological Bases of Space Radiation
Risk**

Hematopoiesis Dynamics in Irradiated Mammals: Mathematical Modelling

O. A. Smirnova

*Research Center of Spacecraft Radiation Safety
Shchukinskaya st., 40, Moscow 123182, RUSSIA*

Mathematical models were developed which describe the dynamics of the bone-marrow hematopoiesis in mammals exposed to acute and chronic radiation. The blood-forming system is represented here as a combination of major hematopoietic lines: thrombocytopoiesis, lymphopoiesis, erythropoiesis, and granulocytopoiesis. The models are based on theories and facts well known in radiobiology and hematology. The models consist of the systems of nonlinear differential equations. Concentrations of cells of the above-indicated hematopoietic lines serve as variables and the dose of acute and the dose rate of chronic irradiation are variable parameters in them.

Analysis has shown that the models can quantitatively describe the effects of acute and chronic exposures on the hematopoietic system of mammals (mice and rats). The models simulate the dynamics of damage and recovery of pools of mature blood cells and their precursors in the bone marrow after acute irradiation, describe depletion of individual hematopoietic lines during chronic exposure at high dose rates, and reproduce the ability of the hematopoietic system to adapt itself to protracted irradiation at low and moderate dose rates. The models also describe the experimentally observed paradoxical effects of low level exposures. The most important of them are the stimulation of adaptive processes in the lymphopoiesis and granulocytopoiesis at low dose rates of chronic irradiation and the decreasing of radiosensitivity of thrombocytopoiesis and granulocytopoiesis systems in the result of prolonged exposure at low dose rates. The models can be useful for prediction of hematopoiesis system response on irradiation during long-time space mission.

The work was funded in part by DNA/AFRRI (USA).

ESTIMATING HEALTH RISKS IN SPACE FROM GALACTIC COSMIC RAYS

Francis A. Cucinotta¹, J.W. Wilson¹, J.F. Dicello², J. R. Williams², and Mack Mabry²

¹NASA, Langley Research Center, Hampton VA 23681-0001

²The Johns Hopkins Oncology Center, 600 Wolfe St., Baltimore MD 21287-5001

Long term space travelers to the moon or Mars will experience protracted exposures to galactic cosmic rays (GCR). The GCR consist of high energy hydrogen, helium, and heavy ions for which there are few epidemiological data on expected carcinogenic risk. Improvement in the understanding of the risk from the GCR will require better understanding of radiation physics, radiation shielding effectiveness, and basic studies in cancer biology. Radiation physics and shielding studies are currently hampered by the lack of fundamental understanding of the risks of cancer attributable to ions. These data are necessary to design cost effective shielding for space travelers. We present an overview of computational models that describe the passage of GCR through spacecraft shielding and tissue and highlight the importance of track structure effects. We discuss efforts to model molecular interactions of proto-oncogenes and tumor suppressor genes known to be important in human cancers and discuss critical experiments.

The HZETRN (high charge and energy ion transport) model describes the passage of the GCR through shielding and tissue. Methods to validate HZETRN include ground-based experiments of nuclear interaction and transport properties of neutrons, and light and heavy ions. Comparison of the HZETRN code to measurements on the Shuttle and the MIR space station provide further means for validation. However, the understanding of optimal shielding materials for lunar/Mars spacecraft relies on biological response models. We discuss shield evaluation using conventional risk assessment and track structure models that describe radiobiology experiments with ion beams for DNA strand breaks, HPRT mutations, and tumor prevalence in mice. The understanding of track structure effects is expected to be a determining factor in shielding selection, however existing studies are limited by their relevancy for estimating cancer risk in humans.

We are developing computational models in parallel with primary human cell lines that quantitatively describe relevant molecular pathways that are genetically or epigenetically altered in the progression towards human carcinogenesis. We have developed a non-linear kinetics description of cell cycle progression and inhibition by cyclins, cyclin dependent kinases (cdk), pRb, p107, E2Fs, and cdk inhibitors (cdki). The model is extended to consider ras and raf signal transduction and downstream effects on cdks and cdkis. Radiation exposure alters cellular functions through gene mutation and activation of signal transduction pathways. We discuss calculations of p53 signal transduction following DNA damage as a function of radiation type to study alterations in cellular proliferation. Calculations for photons and heavy ions are compared to limited existing measurements. Computer simulations of modifications of cellular proliferation by gene mutations induced by photons or heavy ions in relevant molecular pathways are discussed. These preliminary studies are being used to suggest critical experiments to evaluate the effectiveness of heavy ions and to establish the role of counter-measures such as radiation shielding in reducing cancer risks.

FAILURE OF HEAVY IONS TO AFFECT PHYSIOLOGICAL INTEGRITY OF THE CORNEAL ENDOTHELIAL MONOLAYER.

Jan P. Koniarek and Basil V. Worgul

Department of Ophthalmology, Eye Research Division, Columbia University, New York, NY 10032

INTRODUCTION

As planning for the space station and voyages to the planets is coming to an advanced stage, there is an increased interest in effects of heavy ion radiation on biological systems, especially on human health. Prolonged habitation in space will expose astronauts to this type of radiation from cosmic rays. Since it will not be possible to shield them from such highly energetic radiation, predicting their effects and designing appropriate therapeutic countermeasures is of great importance to mission planners.

It has long been recognized that heavy ions cause damage to living organisms at the molecular, cellular, and tissue levels. Furthermore, it has also been proposed, based on morphological observations, that they generate "microlesions" - discrete regions of focal cellular destruction (e.g., P. Todd. *Adv. Space Res.* 3:187-194, 1983). In membranes these microlesions would show up as holes. Several morphological studies conducted to test this hypothesis seem to suggest such an effect, but other studies cast doubt on this theory (Worgul et al., *Adv. Space Res.* 10: 315-323, 1989). A study investigating the effect of heavy ions on physiological parameters of tissues *in vitro* failed to show any effects (Koniarek and Worgul *Adv. Space Res.* 12: 417-420, 1992).

To determine if microlesions can form, and if they produce a prolonged physiological effect on cells, we investigated the effects of heavy ions on the electrical potential difference that is generated across the monolayer of cells of the corneal endothelium. The transendothelial electrical potential difference (TEPD) is generated by the endothelial fluid pump as it maintains the cornea at the level of hydration required for transparency. This fluid pump is driven by the transport of electrolytes across the endothelium. A perfectly intact endothelial cell layer is needed to maintain the TEPD at its normal level. Should holes in cell membranes develop, the ionic composition inside and outside would be rapidly altered and the TEPD would be abolished; hence this parameter is an excellent indicator of tissue integrity.

We also developed mathematical models related to formation and closure of holes in corneal endothelial cell membranes, taking into account parameters such as diffusion of phospholipids and attenuation of this diffusion by intercellular components and the extracellular matrix of these cells.

METHODS

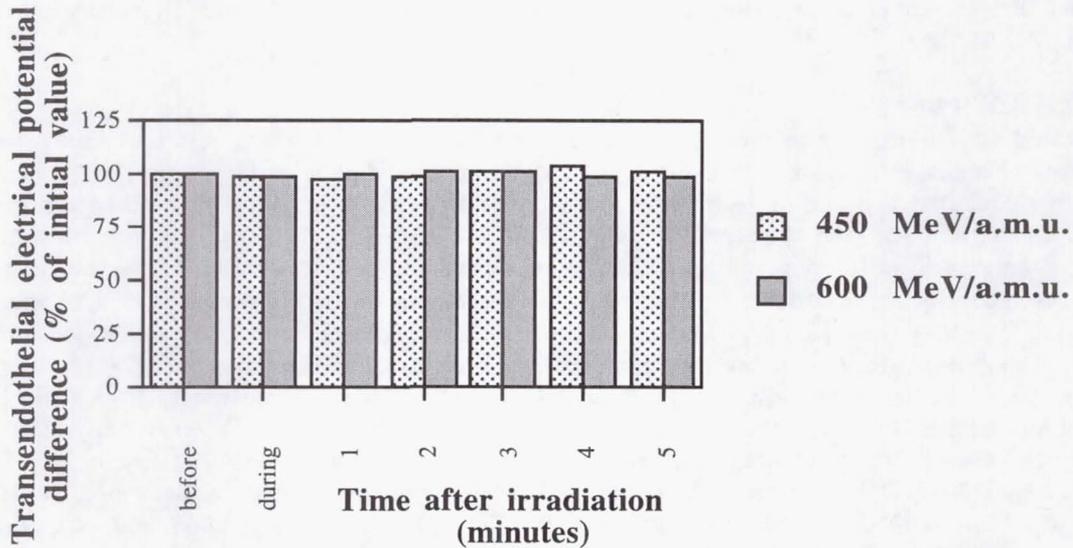
Corneas were dissected from RCS rats. Their epithelial layer was scrapped off (since this layer itself is also a source of a potential difference), and the stroma with its intact endothelial monolayer was mounted in an experimental chamber filled with a solution of basic salts and glucose, and which was temperature controlled at 37°C. The TEPD of about 600-800 μV was monitored with a pair of electrodes, one on each side of the preparation (Koniarek et al., *Invest. Ophthalmol. Vis. Sci.* 29: 657-660, 1988).

While the TEPD was monitored, the corneas were irradiated perpendicular to the beam path by one Gy doses of ^{56}Fe ions of 450 and 600 MeV/a.m.u. (LETs = 195 and 173 keV/ μm respectively). This ion is among the most prevalent in the zoo of particles in galactic cosmic rays, and it has been suggested that these particles could produce microlesions. The ions were delivered for 0.5 to several minutes at the rate of 10^3 particles/ mm^2/sec .; thus a typical endothelial cell (25 μm in diameter) was traversed by about 16-18 heavy ions per second. The experiments were conducted by the BEVALAC compound accelerator in Berkeley, California, before its decommissioning.

RESULTS

Before the irradiation the TEPD was monitored for about 30 minutes to ensure that it was steady. During irradiation the TEPD did not change significantly from pre-irradiation values, except for a transitory artifact resulting from the interaction of the ion beam and the recording electrodes, which ceased as soon as the beam was turned off. After irradiation the TEPD was monitored for 5 minutes (and in some cases longer, up to 15

minutes), and its values were not statistically significantly different from their pre-irradiation levels. The graph below summarizes our results.



CONCLUSION

Our results obtained with 450 and 600 MeV/a.m.u. ⁵⁶Fe ions failed to show any effects of this radiation on the TEPD. This observation suggests that no physiologically significant microlesions in form of overt, stable holes were produced in the cell membrane. It is also possible that membrane holes were in fact produced during irradiation, but that they were extremely transitory, and that they were quickly eliminated by the reforming cell membrane; our theoretical models indicate that such rapid repair is possible within a fraction of a second. In either case the several ion hits per second per cell are not enough to cause any long-lasting physiological effects on cell integrity and function of the corneal endothelium.

APPLICATION OF AN UNBIASED TWO-GEL cDNA LIBRARY SCREENING METHOD TO EXPRESSION MONITORING OF GENES IN IRRADIATED VERSUS CONTROL CELLS

E.K. Balcer-Kubiczek^{1,4,5}, S.J. Meltzer^{2,3,4,5}, L.-H. Han¹, X.-F. Zhang¹, M.-S. Zhong¹, G.H. Harrison^{1,5}, and J.M. Abraham^{2,4,5}

¹Department of Radiation Oncology (Radiation Research Division), ²Department of Medicine (Gastroenterology Division), School of Medicine, ³Veterans Affairs Hospital, ⁴Molecular and Cell Biology Program, Graduate School, and ⁵Program in Oncology, Marlene and Stewart Greenebaum Cancer Center, University of Maryland, Baltimore, MD 21201

INTRODUCTION

Rapid alterations in gene expression can occur after cellular exposure to injurious agents, including various types of ionizing radiation, ultraviolet light, 12-*O*-tetradecanoyl phorbol-13-acetate (TPA), heat shock, hydrogen peroxide and hypoxia. More than 50 genes responding to two or more of these agents have been described. Of these, fewer than 10 genes (for example, *gadd45*, *WAF-1/Cip1*, *mdm2*) respond more to DNA-damaging agents such as ionizing radiation than to non-damaging agents such as TPA. The discovery of radiation-responsive genes provides a starting point for elucidating the molecular processes associated with radiation pathology. A detailed understanding of the pleiotropic effects of ionizing radiation will require implementation of sophisticated methods for gene expression analysis and gene discovery.

In several studies, subtractive hybridization and differential display of messenger RNA (mRNA) have been employed to identify new genes activated by ionizing radiation. One of us (JMA) recently developed an improved nonbiased polymerase chain reaction (PCR)-based method for the identification of new genes or complementary DNA (cDNA) sequences by *random* differential library screening. In this paper, we describe a modification of this method, termed *the unbiased two-gel cDNA library screening method*, and its application to comparing transcriptional profiles in control *versus* irradiated cells, resulting in several important results.

METHODS

Our procedure involves PCR amplification of insert cDNAs pooled in a 12 x 16 matrix, using primers complementary to vector sequences flanking the cloning site followed by electrophoresis on exact duplicate agarose gels. The associated duplicate Southern blots were probed with cDNA synthesized from mRNAs isolated from control *versus* irradiated cells, and the autoradiographs compared for differential expression of the amplified cDNA sequences. Lanes that displayed differential expression patterns under given experimental conditions were further characterized using a second round of Southern blot analysis, followed by sequencing. Differential expression was confirmed by Northern blot analysis.

Two cDNA libraries constructed in the Lamba-ZAP-II vector, one from HL60 cells and another from MCF7 WT cells were used to prepare exact duplicate cDNA arrays for screening. Bacterial transformants were obtained by infecting *E.coli* strain XL1-Blue MRF⁺. Bacteriophage colonies were picked at random and propagated in 200- μ l aliquots, and inserts (0.3-2.0 kb) were amplified by PCR using appropriate primers. Investigated conditions, doses, radiation type and (post-irradiation time-points), for the initial identification of ionizing radiation-regulated genes were: 20 Gy X rays (3 h), 1.2 Gy fission neutrons (3 h or 1 week); 2 Gy 1 GeV/n Fe-ions (1 week; study currently in-progress). Our initial studies involving X-irradiation and short post-irradiation time of 3 h were performed with pre-leukemic HL60 cells; these cells are null for *p53*. All the other work was done using epithelial MCF7 WT cells; these cells are normal for *p53*. To explore a signalling pathway distinct from the radiation response, conventional Northern analysis was used to examine selected gene transcription after TPA and forskolin treatments. Chemical-treated or control cells were harvested, lysed, and used as a source of mRNA. Northern hybridization was done using the radioactively labeled cDNA corresponding to a the gene of interest.

RESULTS

The aim of this study is to identify genes involved in radiation response at the cellular level, including neoplastic transformation. By screening approximately 3000 cDNA clones, we isolated to date (January 1997)

13 independent clones differentially expressed in HL60 and MCF7 WT cells.

HL60 cells have been characterized as radiation-sensitive ($D_0 < 1$ Gy). Exposed to 20 Gy of X rays, they were viable for up to 12 h. Of 5 candidate radiation-responsive genes, the expression of one gene, *Csa-19*, was characterized in detail. The abundance of *Csa-19* mRNA decreased dramatically in HL60 cells 3 h after X-irradiation. The same transcription pattern was observed in MCF7 WT cells, and after exposure of HL60 or MCF7 WT cells to 1.2 Gy of fission neutron-irradiation. Our result that *Csa-19* is similarly repressed in *p53* normal and abnormal cells provides a new example of an immediate-early gene that is transcriptionally independent of *p53*, in contrast to other previously-discovered radiation-responsive genes (such as for example, *gadd45*, *WAF-1/Cip1*, *mdm2*).

Two of three known genes isolated in fission neutron-irradiated MCF7 WT cells, *L-23*, κ -*casein* and *TI-227* 1 week post-irradiation have been reported by other groups in association with tumorigenicity and metastatic potential. Accordingly, the *L-23* gene is implicated in *genomic imprinting* process and, thus, could be involved in multigene human diseases such as breast cancer. The postulated cellular function of *TI-227* is to regulate the expression of various genes as a transcription factor in the complex process of metastasis. All identified genes were nuclear, except oxidase II (mitochondrial). For remaining genes, no match has been found in the public data bases. Attempts to characterize both novel and known genes discovered in this laboratory is currently underway.

CONCLUSION

The present method offers several advantages over other approaches to expression analysis. The parallel format of the assay provides a *simultaneous differential expression* output for approximately 200 genes. This contrasts with sequencing-based methods, which require serial data collection for expression analysis. The availability of commercial cell-specific libraries provides a rich and readily accessible resource of human cDNA clones for this assay. Once the arrays have been constructed, they can be re-used for gene expression monitoring in different radiation conditions. As demonstrated, other practical advantages of this method are the ability to confirm differential expression by Northern blotting, the capability to detect low-copy-number transcripts, and the immediate availability of full-length cDNA clones for further analysis and sequencing. The identification of several known and possibly novel ionizing radiation-regulated genes in human pre-leukemic HL60 cells and in breast carcinoma MCF7 WT cells demonstrate sensitivity of an unbiased two-gel cDNA library screening method. Our current method provides a rapid and efficient means for large-scale discovery of human genes regulated by ionizing radiation.

Supported in part by the National Aeronautics and Space Administration (NASA) grant NAGW-4392.

DETECTION OF RADIATION-INDUCED DNA STRAND BREAKS IN MAMMALIAN CELLS BY ENZYMATIC POST-LABELING

Shunji Nagaoka¹, Yoshitaka Taniguchi², Sumiyo Endo², Takuo Onizuka², Masahiko Hirano², Kazunobu Fujitaka³, and Takeo Ohnishi⁴

1) National Space Development Agency of Japan, Tsukuba, Japan, 2) Toray Res. Center, Inc., Kamakura, Japan, 3) National Institute of Radiation Sciences, Chiba, Japan, 4) Nara Medical Univ., Kashihara, Japan

INTRODUCTION

An aim of this study is to develop a *in-situ* analytical method of DNA damage of human and animal cells caused by cosmic rays in space. It may be important to analyze DNA damages in cellular level to evaluate biological effects of cosmic radiation. In this study, we developed novel systems to detect DNA-strand breaks in mammalian cells by enzymatic post-labeling. In this system, we apply catalytic reactions of enzymes known as E.coli DNA polymerase I and terminal nucleotidyl transferase (TdT) which recognize 3' termini of DNA and introduce nucleotides to the sites.

METHOD

SV40-transformed human fibroblast cell line, WI38VA13, its non-transformed counterpart, WI38, and human glioblastoma cell line, T98G were used. Irradiated cells were chemically fixed, and then subjected to the post-labeling procedure. The reaction mixture contained enzyme (DNA polymerase I or TdT) and substrate (nucleotide). Tritiated nucleotide (³H]-dATP) was used to detect DNA strand breaks by autoradiography or using a liquid-scintillation counter. In the autoradiography, grains induced by ³H]-dATP molecules in individual cell could be detected visually under a light microscopy. Grain numbers per nucleus were counted subtracting the background grains with using non irradiated cells. In the liquid-scintillation counting method, the total ³H]-dATP uptake was measured under homogenate condition.

X-ray irradiation was carried out on ice using a MBR-1520 (Hitachi Medico) instrument operating at 150 kV and 20 mA. Carbon ion irradiation (290 MeV/n, LET around 100 KeV/μm) was carried out using Heavy Ion Medical Accelerator (HIMAC) at National Institute for Radiological Sciences at Chiba.

RESULTS

To optimize a detection sensitivity, conditions for chemical fixation and post-labeling were examined. Fixation with 1% formaldehyde followed by 70% ethanol did not cause non-specific DNA strand breaks. Cells were, however, mostly shrunk and changed morphologically. This changes reduced efficiency to detect grains in autoradiography. On the other hand, non-specific DNA strand breaks were caused with fixing by methanol. It may be due to endogenous endonuclease or radicals, but no cell morphology change was observed. Grains found in the nuclei were more clearly detected than fixed with formaldehyde.

In the post-labeling reaction, a combination of enzyme and substrate concentrations was found to be critical to attain sufficient sensitivity. We confirmed that ³H]-dATP uptake was increased depending on both enzyme and substrate concentrations and also their reaction time.

In the preliminary experiments with X-ray irradiation, the autoradiographic method developed with methanol as a fixative can detect DNA strand breaks of cells exposed 40 Gy and 100 Gy by DNA polymerase I and TdT, respectively.

We also applied the system with DNA polymerase I to cells irradiated by carbon ions. Cells exposed to 5 Gy showed significant increase in the grains than non-irradiated one. The grain number significantly increased in the dose dependent manner up to 40 Gy. Interestingly, the grain number per cells irradiated with 80 Gy was less than that irradiated with 40 Gy. Since DNA polymerase I can only recognize 3' termini in the presence of single-strand DNA templates, the result obtained at the high dose of heavy ions exposure suggested double-strand breaks or deletions of DNA rather than single-strand breaks.

EVALUATION OF BLEOMYCIN-INDUCED CHROMOSOME ABERRATIONS UNDER MICROGRAVITY CONDITIONS IN HUMAN LYMPHOCYTES, USING "FISH" TECHNIQUES

¹Mosesso P., ²Schuber M., ²Seibt D., Schatz A., ¹Fosci A., ¹Fonti E. and ¹Palitti F.

¹University of Tuscia, Dept. of Agrobiological and Agrochemistry, 01100 Viterbo, Italy.

²DLR Institut of Aerospace Medicine, MUSC, 51140 Köln, Germany.

ABSTRACT

One way to improve the estimation of radiation risks to human beings in future space mission and for establishing radiation standards for man in space is, in addition to physical dosimetry, to obtain quantitative information regarding the effectiveness of space radiations to induce chromosomal damage under microgravity conditions, which appear to influence in terms of potentiation the genetic effect.

Mosesso et al., 1996 reported that treatments with the radiomimetic agent bleomycin performed under simulated microgravity conditions in human lymphocytes using the cuvette clinostat as a tool to simulate weightless conditions induced significant increases of aberrant cells bearing dicentric chromosomes, as detected by conventional cytogenetic analysis, compared to the parallel treatments performed on the "ground".

In the present study we aim to extend the results obtained in the above mentioned investigation evaluating the induction of chromosomal damage with fluorescent *in situ* hybridisation (FISH) and chromosome-specific composite DNA probes (chromosome painting) to detect stable aberrations such as reciprocal translocations which can persist during several cell divisions and complex aberrations.

This approach will permit us to enhance the power of cytogenetic analysis and correlate phenomena of mis-repair of DNA with the eventual presence of complex aberrations which cannot be detected with conventional methods.

REFERENCES

Mosesso P., Schuber M., Seibt D., Fiore M., Fonti E., Gigliozzi S. and Palitti F. (1996) Effect of simulated microgravity conditions on radiation-induced chromosome aberrations and DNA-repair in normal human lymphocytes Proceedings of sixth European Symposium (European Space Agency ESA SP -390).

ACKNOWLEDGEMENTS

This investigation is sponsored by Italian Space Agency (ASI), Contract No. RS113.

TECHNICAL DESCRIPTION OF THE SPACE EXPOSURE BIOLOGY ASSEMBLY SEBA ON ISS

P. Hofmann¹, P. Rank¹, J.U. Schott², H. König³

¹Kayser-Threde GmbH, Wolfratshauer Str. 48, D-81379 München; ²DLR, Linder Höhe, D-51147 Köln;

³ESA/ESTEC, Keplerlaan 1, NL-2201 AZ Noordwijk

ABSTRACT

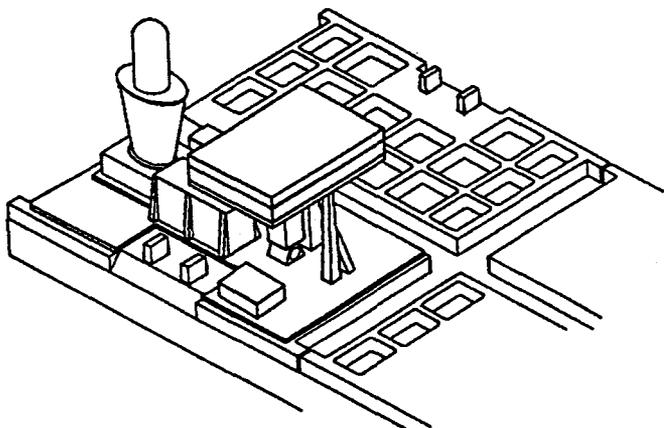
The "Space Exposure Biology Assembly" (SEBA) is a new multi-user facility for future space experiments in the fields of exobiology and radiation research. SEBA is scheduled for flight on the EXPRESS Pallet, an external platform of the International Space Station, in the year 2001.

The SEBA facility is dedicated to experiments in areas such as photobiology, photoprocessing and dose depth distribution measurements of space radiation. Most experiments require extended duration of space environment. The facility design of SEBA has been developed from concepts of already existing and successfully flown exposure facilities for microbiological research in space. New concepts for dosimetric measurements shall be realized.

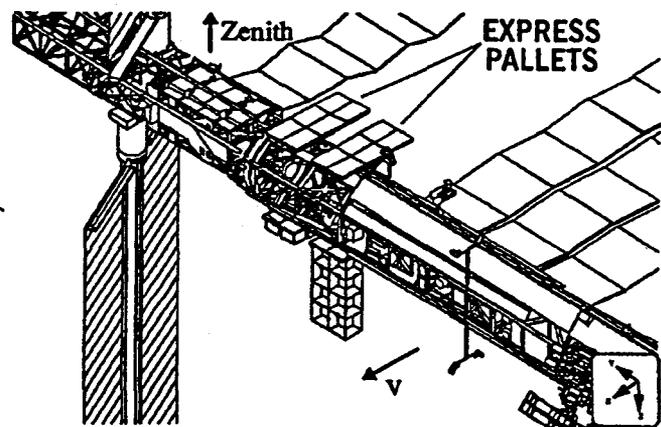
SEBA MECHANICAL CONFIGURATION ON EXPRESS PALLET

The configuration of SEBA on the EXPRESS Pallet is shown below. The SEBA facility is planned to be composed of two independent experiment units (EXPOSE used for photobiology, photoprocessing and Matroshka, used for dose depth distribution measurements of space radiation), a pointing device used in conjunction with EXPOSE, a central Control and Power Distribution Unit, a mechanical support structure as interface to the EXPRESS Pallet, an interconnecting harness, and thermal hardware. The remaining free areas on the carrier platform will be reserved for self-standing add-on experiments. The envelope of SEBA is defined by the footprint of a single EXPRESS Pallet Adapter (ca. 1.20 x 1.05 m²); the height will maximally be ca. 1.25 m.

The actual SEBA configuration as a result of the ongoing phase B study shall be presented in some detail, and its scientific capabilities shall be highlighted.



Preliminary configuration of SEBA



Section of the truss of the International Space Station with attached EXPRESS Pallets

Cytogenetic Research in Biological Dosimetry

V.Shevchenko¹, G.Snigiryova², V.Petrov³, B.Fedorenko³, S.Druzhinin³

¹ Institute of General Genetics, Russian Academy of Sciences

² Moscow Research Institute of Diagnostic and Surgery, Ministry of Health
and Medical Industry of the Russian Federation

³ State Scientific Center of RF - Institute for Biomedical Problems, Moscow

The possibility of using cytogenetic methods for biological dosimetry is explored on the basis of the materials from examinations of people affected as a result of the Chernobyl accident, nuclear explosions at the Semipalatinsk testing site, radioactive contamination of the Techa river (Chelyabinsk region) and the accident at the Three Miles Island nuclear plant (Pennsylvania, USA).

The level of lymphocytes with unstable chromosomal aberrations has been found to reduce in time. However, despite a relatively long time from the moment of irradiation (years, decades) in all examined groups of people this index significantly exceeds the control level.

The most promising for the purposes of biological dosimetry is the estimation of the frequency of stable chromosome aberrations (symmetric translocations) by the FISH method.

The preliminary data obtained from the cytogenetic examination of 23 astronauts were presented in this work too. Cytogenetic examinations included the analysis of unstable chromosome aberrations before and after a space flight. The investigations in the pre-flight period have been carried out with 14 of the astronauts. In this case the obtained results were assumed as the spontaneous level. The frequency and types chromosome aberrations were studied in 11 astronauts after the first space flight and in 11 astronauts - after repeated flights.

It is ascertained that within the pre-flight period the level of chromosome aberrations little differs from the assumed background values. The frequency of chromosome aberrations and aberrant cells raises after the flights. In particular, the frequency of dicentrics and centric rings was more than 6 times as high as the background level after the first space flights, and more than 15 times - after repeated flights.

The problems concerning the application of cytogenetic methods to estimate absorbed doses.

Friday, June 13

Session FA1
Room 1
8:30 - 11:30 a.m.

530-12
074635
54.
326989

**The Cooperative U.S./Ukrainian
Experiment: An Overview**

HISTORY OF THE COOPERATIVE U.S./UKRAINIAN EXPERIMENT (CUE)

J.A. Guikema¹, E.L. Kordyum², E. Hilaire³ and J.E. Leach³

¹Division of Biology and ³Department of Plant Pathology, Kansas State University, Manhattan, Kansas 66056, U.S.A.

²Department for Cell Biology and Anatomy, Institute of Botany, National Academy of Sciences of Ukraine, Tereschenkivska Str. 2, Kiev, Ukraine

INTRODUCTION

The Cooperative U.S./Ukrainian Experiment (CUE), a peer-reviewed middeck Shuttle flight experiment focused on plant cellular biology, has its history in the diplomatic relations between the United States and the member nations of the former Soviet Union. One goal of these diplomatic initiatives was to strengthen the ties between the U.S. and Ukraine, and early discussions at the State Department level identified cooperation in space science as an excellent beginning to an international dialogue. Thus, the initiation of discussions between the U.S. National Aeronautics and Space Administration (NASA) and the National Space Agency of Ukraine (NSAU) was a directive from each government. These discussions identified a suite of plant cellular biology experiments which had matured to the point where a spaceflight opportunity was appropriate and which focussed upon the mutual interests of U.S. and Ukrainian scientists.

HISTORY OF CUE

Signing of a Trilateral Statement between the U.S., Russia, and Ukraine in January, 1994, initiated the discussions between U.S. and Ukraine to collaborate in space research. NASA sent a delegation to Kiev in the spring of 1994 to explore collaborative options with NSAU scientists. In September, 1994, a discussion group of U.S. and Ukrainian space biologists was assembled in Washington, D.C. During this meeting, single-page collaborative preproposals, covering the range of space life sciences from human physiology to computational biology, were developed and submitted to NASA for consideration.

A "*Joint State of Future Aerospace Cooperation Between the United States and Ukraine*", dated November 22, 1994, directed NASA and NSAU to identify potential experiments and payloads which could qualify for flight and which could create an opportunity for a Ukrainian Payload Specialist to fly on Shuttle.

These early initiatives resulted in the construction of a multi-component proposal which was approved by the NSAU Coordinator for Space Biology in March of 1995 and selected by a NASA peer review panel in May, 1996. Authorization for payload development has resulted in a spaceflight experiment package which includes 5 middeck lockers, a vigorous bilateral collaboration between life scientists, and an educational overlay which will impact students in both nations.

THE COLLABORATIVE UKRAINIAN EXPERIMENT: SCIENCE OVERVIEW

Christopher S. Brown

Dynamac Corporation, Durham, NC 27713 and NASA Specialized Center of Research and Training, North Carolina State University, Raleigh, NC 27695

INTRODUCTION

Life on Earth originated in the relatively constant gravitational force we define as 1 g. Because of its constant nature and the difficulty in varying it in a reproducible manner (particularly downward), gravity has been relatively ignored in biological research. However, with the advent of manned spaceflight, opportunities for conducting significant biological experimentation in the microgravity environment of space are now available. This paper is an overview of the scientific rationale and objectives of one such opportunity involving multiple experiments proposed by investigators from Ukraine and the United States and is known as the Collaborative Ukrainian Experiment (CUE). CUE, manifested for flight on the Space Shuttle mission STS-87 in October 1997, and is scheduled for 16 days. The suite of experiments will utilize five mid-deck lockers and hardware including the Plant Growth Facility (PGF), Biological Research In Canisters (BRIC) chambers and BRIC chambers modified to include light emitting diodes. Four species will be flown, including *Brassica rapa* (rapeseed), *Glycine max* (soybean), *Ceratodon purpurea* (moss) and *Pottia intermedia* (moss). In the spaceflight environment, plants will be grown, observed, manipulated, fixed and frozen. Specimens will be returned to Earth for post-flight analysis.

RATIONALE AND OBJECTIVES

Plants respond to both the magnitude and direction of gravity. Plants which have been reoriented with respect to the gravity vector perceive the change, transduce the signal either inter- or intracellularly, and then respond via redirected growth and shifts in metabolism. Plants exposed to microgravity in the spaceflight environment exhibit changes in a number of growth, developmental and metabolic parameters. The mechanism(s) for these responses to gravity are not known with certainty at the present time and are the focus of the experiments of CUE.

Protonemata of the mosses *C. purpureus* and *P. intermedia* are tip growing cells which are negatively gravitropic in darkness. This is a unique model system since the perception of, and response to gravity purportedly occur within the same cell. Additionally, the protonemata are photo- as well as gravitropic. Vegetative fragments of the wild type and gravity mutant protonemata will be cultured in space and exposed to a number of light treatments. At various times during the mission, specimens will be fixed. Upon return to Earth, specimens will be measured and sectioned for light and electron microscopy to characterize plastid zonation, plastid morphology, subapical cell branching and degree of vacuolation. These experiments allow the study of the influence of gravity on cellular organization and offer an opportunity to resolve whether phototropism blocks gravitropism.

Plants grown in space exhibit a number of metabolic alterations in response to the stresses of spaceflight. In order to examine a number of these effects, both light-grown *B. rapa* and etiolated soybean seedlings will be germinated and grown in space. Tissue will be fixed and/or frozen on orbit and some will return to Earth. Post-flight analyses will focus on the influence of spaceflight on the photosynthetic apparatus of the leaves of *B. rapa* and measurement of compounds known to be altered under stress conditions. Etiolated soybean seeds will be germinated in space and used to determine the mechanism for spaceflight-induced altered carbohydrate and ethylene metabolism. A separate set of soybean seedlings will be challenged with a fungal pathogen, *Phytophthora sojae*, to determine if spaceflight results in altered plant/pathogen interactions. Tissue from both *B. rapa* and soybean will be used for the determination of the differential expression of stress-related genes and seedlings will be measured for growth to determine the impact of the spaceflight environment on biomass partitioning.

A particularly sensitive time in the life cycle of a plant seems to be the transition from the vegetative to the reproductive phase. Gravity may directly or indirectly influence reproductive events in plants. *B. rapa*, due to its compact size and short life cycle, will be used to examine the processes of pollination and fertilization. Plants will be launched at the pre-flowering stage of growth and as seeds which will germinate in space. Pollination will be performed on orbit on the older plants. Tissues from both populations of plants will be fixed in space and/or returned to Earth for extensive examination of parameters of reproductive success.

(This work is supported by the National Space Agency of the Ukraine and the National Aeronautics and Space Administration).

DOUBLE FERTILIZATION OF INQUIRING MINDS: TEACHERS AND STUDENTS
INVESTIGATING PLANTS IN SPACE FOR THE COLLABORATIVE UKRAINIAN
EXPERIMENT

Paul H. Williams, Dept. of Plant Pathology, University of Wisconsin, Madison, WI 53706 USA

Three ideas and situations came together in 1995 to create the Collaborative Ukrainian Experiment Education Project which is titled Teachers and Students Investigating Plants in Space. In May of 1995 the presidents of the United States and Ukraine issued a joint statement on cooperation in space via a joint Space Shuttle mission. Dr. Mary Musgrave of Louisiana State University became one of the plant scientists to be awarded space to run a controlled pollination and in-flight fixation of pollinated flowers of the special dwarf stock of rapid-cycling *Brassica rapa* known as "AstroPlants." The stock was developed by Paul Williams at the University of Wisconsin-Madison, where in the February of 1995 the Wisconsin Fast Plants Program had piloted an AstroPlants educational activity associated with the Astroculture experiments aboard Space Shuttle mission STS-63. Substantial educational benefit was experienced by 13 classrooms of students and teachers who shared this real time experiment with flight-based scientists. Dr. Musgrave had mentored one of those classrooms in Baton Rouge and she envisioned creating a similar educational project for STS-87. And thus CUE-TSIPS, with Paul Williams as Educational PI, was initiated. The STS-87 flight offers another real-time investigative opportunity to both United States and Ukrainian teachers and students.

An instructional manual for high school and advanced middle school levels has been written to include investigations on germination, orientation, growth and development, pollination, fertilization and embryogeny. The materials emphasize skills of observing, questioning, hypothesizing, experimenting, analyzing and communicating, and are alligned with the National Science Standards.

Plans for experimental classroom equipment have been designed using low cost, readily available materials that simulate the Shuttle's Plant Growth Chamber (PGC) and its environment. Students will grow their AstroPlants under 24 hour/day fluorescnet light, in 1g gravity.

Sixteen lead teachers in the U.S., four NASA Aerospace Specialists from various NASA centers and the Science Education Coordinator at KSC (sponsored by NASA and the Wisconsin Fast Plants Program) and 25 teachers and specialists in Ukraine (sponsored by the Ukrainian Junior Academy of Sciences), have been trained in the Fast Plants investigative exercises and techniques and are now training other colleagues. It is expected that CUE-TSIPS classrooms will generate a large set of experimental data that can serve as ground control information to be compared with information gathered from the flight experiments. Communication over the Internet will permit data sharing among classrooms and between the U.S. and Ukraine.

Some questions that teachers and students will be asking:

How responsive is the germinating seedling to Earth's gravity?

What would the orientation behavior of the seedlings be like in microgravity?

How is effective pollination carried out?

What are the indicators of normal fertilization and post-fertilization development that follow successful pollination?

Substantial interest from teachers and students to participate in this project has already been generated.

MISSION OPERATIONS FOR THE COLLABORATIVE UKRAINIAN EXPERIMENT

Cynthia Martin, NASA Payload Office, Mail Code BR, Kennedy Space Center, FL 32899 USA

The Collaborative Ukrainian Experiment (CUE) is a collection of plant space-biology experiments scheduled to fly on a 16-day space shuttle mission (STS-87) in October 1997. A Ukrainian Payload Specialist selected for the mission will conduct the manipulations and measurements required for the various experiments. The experiments will utilize the Plant Growth Facility (PGF) to grow *Brassica rapa* seedlings (a small mustard related to canola), while smaller sealed containers called Biological Research in Canisters (BRIC) will be used to grow soybean seedlings and moss plantlets. The CUE mission will be the first test of the newly developed Plant Growth Facility (PGF), a single suitcase-sized unit which contains six smaller plant chambers. Some of the environmental parameters controlled by the Plant Growth Facility include temperature (with the use of thermoelectric coolers), lighting (with fluorescent lamps), humidity (using Nafion membranes and introductions of dry cabin air), and carbon dioxide (using either LiOH scrubbing or additions of CO₂ -rich cabin air). The BRIC canisters will provide an enclosed, humid environment with passive ethylene scrubbing (potassium permanganate) for the soybean seedlings, and an enclosed environment with supplemental LED lighting for culturing the moss plants. In addition, specially developed hardware will be used for in-flight fixation of the plant tissue grown in the LED/BRICs and PGF.

Mission activities will include periodic pollination of flowers and watering of plants, harvesting, fixing, and freezing of plant tissue, gas sampling from the BRIC canisters, regular checks on system hardware performance, and several video downlinks to conduct educational sessions in support students and teachers following the mission. Science investigators and payload development staff will monitor progress of the experiments in the Experimental Monitoring Area of Hangar L, Kennedy Space Center, where mission activities and communications are monitored on a real time basis. In addition, science investigators and mission operations staff will conduct 48-h-delay ground controls in a second PGF unit and similar BRIC canisters maintained in the Orbital Environmental Simulator (OES) located in Hangar L. The OES can be programmed to provide environmental conditions similar to the Orbiter, except for gravity and atmospheric pressure. Landing for the mission is expected at Kennedy Space Center, after which the hardware and plant tissue will be returned to Hangar L for inspection and analysis.

Friday, June 13

531-52

074636

Session FA2

Room 2

8:30 - 11:30 a.m.

12p.

**Countermeasures for Maintenance of
Cardiovascular and Muscle Function
in Space Flight**

EFFECTS OF REPEATED LONG DURATION +2Gz LOAD ON MAN'S CARDIOVASCULAR FUNCTION

K. Iwasaki, K. Hirayanagi, T. Sasaki, T. Kinoue, M. Ito, A. Miyamoto, M. Igarashi and K. Yajima
Department of Hygiene and Space medicine, Nihon University School of Medicine, Tokyo JAPAN

INTRODUCTION

Usefulness of a short-radius human centrifuge is expected when it is used in space as a countermeasure against cardiovascular deconditioning, problem of bone-calcium metabolism, etc. However nothing is solidly established regarding the most desirable program for artificial G application. Moreover, we definitely need to understand more details about the effects of repeated long duration +Gz on human. Accordingly, this study was designed to analytically evaluate the effects of repeated long duration +2Gz load on human cardiovascular function.

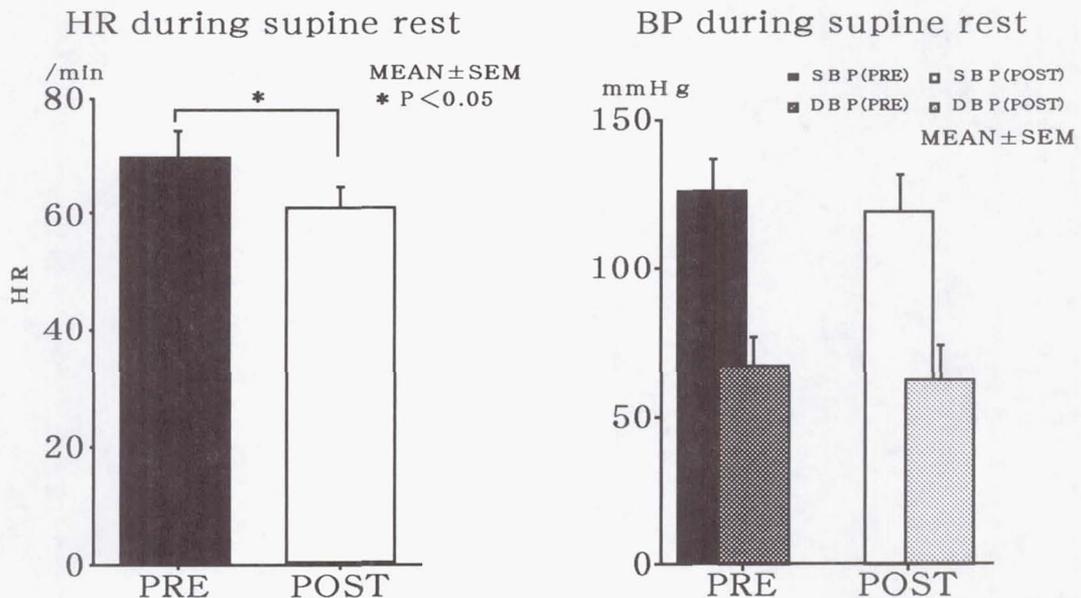
METHODS

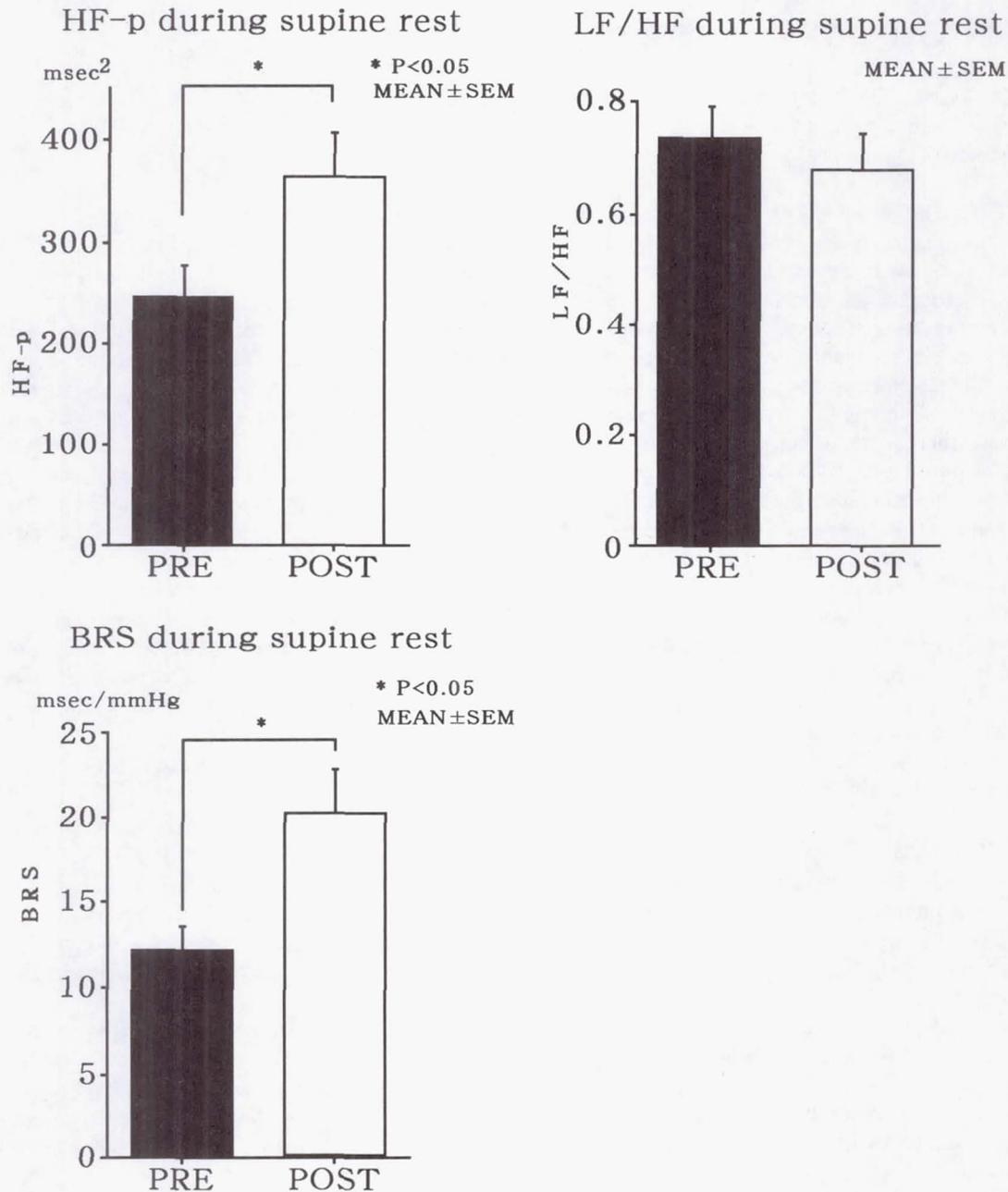
Nihon university's short-radius(1.8m)human centrifuge was used for this study. Experimental subjects were 9 healthy men. They were 22 to 23 years old. Written informed consents were obtained. They received 2G load along the body's +z axis, one hour daily for a periods of 7 days. The pre-load data were collected on supine position one day before that period. The post-load data were collected on supine position one day after that period. Electrocardiogram (ECG) was obtained from the third lead and continuous systolic blood pressure (SBP) and diastolic blood pressure (DBP) were obtained with Jentow® (Colin) from radial artery. Sympathetic and parasympathetic activities were evaluated with R-R interval spectral analysis. Arterial baroreceptor-cardiac reflex sensitivity was evaluated with Bertinieri's sequence method, from continuous blood pressure and R-R interval.

Data analysis: The R-R intervals (beat-to-beat mode) were changed to a time series data of 256 points every half second by the Spline interpolation method. Spectrum of R-R intervals were obtained by applying the fast Fourier transform (FFT) to the time series data and the Hanning window processing. Power of low frequency component(LF-p)(0.04~0.15Hz), power of the high frequency component (HF-p)(0.15~0.4Hz) and the ratio of these indexes(LF/HF) were obtained. Baroreceptor reflex sensitivity(BRS) calculated by Bertinieri's sequence method. The sequence method defined spontaneous baroreflex as the sequences of three or more consecutive beats in which SBP progressively rose and R-R interval progressively lengthened or SBP progressively fall and R-R interval progressively shortened. And the value of BRS was evaluated by application of linear regression to the sequences.

RESULTS

Data obtained pre and post G load period are shown in the figures.





When compared with the data of pre-G load period, post-G load period decrease of heart rate (HR), increases of spectral power of high-frequency component (HF-p) and baroreceptor reflex sensitivity (BRS) were statistically significant. Systolic blood pressure (SBP), diastolic blood pressure (DBP) and low-frequency component / high-frequency component ratio (LF/HF) tended to decrease. However, these changes were not statistically significant.

CONCLUSION

Heart rate spectral analysis is recognized as a useful tool for quantitatively evaluating parasympathetic and sympathetic activity. It is reported that HF-p is mediated selectively by parasympathetic activity. In this study post-G load period, the heart rate was decreased, HF-p and BRS were increased. This results indicate that repeated +2Gz load increases parasympathetic activity and arterial baroreceptor-cardiac reflex sensitivity. Many investigators suggested that space flight and head-down bedrest impaired baroreceptor-cardiac reflex responses and vagal control of sinus node. So our results suggest that repeated +2Gz load would be useful in preventing these changes.

CERTAIN APPROACHES TO THE DEVELOPMENT OF ON-BOARD AUTOMATED TRAINING SYSTEM

V.D. Sonkin¹, I.B. Kozlovskaya², V.V. Zaitseva¹, M.V. Bourchick¹, and V.I. Stepansov².

¹Space Biomedical Center for Training & research, Moscow, Russia;

²Institute of Biomedical Problems, Moscow, Russia

INTRODUCTION

Physical exercises are known to be among the most effective negative factor preventive aids during long-term space flight. System of physical training and controlling developed by IBMP members is successfully used by Russian cosmonauts in combination with other preventive measures.

Current technology of space flight physical training is based on regular connection of cosmonaut with on-earth specialists that is not rational during long-term orbital flights and in full unacceptable for future interplanet expeditions. Perspectives of long-term space programs make it necessary to develop autonomous computer system for crew-members' physical state controlling. The idea of such a biocybernetic system was given by Russian famous scientist V.V.Parin even in infant years of space era. Prototype of such a system can be seen in computer expert systems being used now in sports and health-caring physical culture for physical training reglamentation to for rich a desirable physical state.

In spite of the difference of goals and methods in health-caring and space training physical exercise, the main principles of expert system building are the same:

(a) accurate definition of training purposes and priorities at every stage of training process;

(b) choice of training aids and methods which could provide adequate solution of raised problems;

(c) objective and significant information on current organism state and feedback realization based on it.

While cases (a) and (b) have been investigated enough and their efficiency was proved in practice, (c) requires special working because at a terminal point it's necessary to replace the on-earth coach by on-board computer software.

The main aim of the work - to develop a set of objective formalizable indices which could provide required bio-feedback during crew-member physical training in long-term space flight.

METHODS

Investigations were performed in on-earth microgravity simulation (3- and 7-day dry immersion, 6 subjects; 2-month antiorthostatic hypokinesy, 10 subjects) with volunteers' participation as well with 34 members of MIR-station basic expeditions during long-term space flights. Moreover, model exercise test investigations were made with 20 young male volunteer subjects to evaluate informational validity of different physical state indices.

The model experiments directed on evaluation of subject physical state have used different forms of exercise tests (stepped graded load intensity, standard load, exercise up to exhaustion), different loading devices (cycle ergometer, treadmill, rowing ergometer). Heart function indices, gas change respiratory characteristics, blood lactate and others were registered. MIR-station crew-members performed compulsory treadmill tests before space flight and several times during it where ergometric indices and heart rate were measured.

Validity of all the physical state characteristics was evaluated by means of different mathematical statistics procedures.

RESULTS

A set of indices was found which, being simple enough for measuring, perform to get satisfactory adequate evaluations of current organism physical state of humans in long-term real or simulated microgravity. Model study of young healthy males proved that some ergometric indices could reflect real working ability even better than traditional characteristics of organism energy systems state. The best sensitivity to different influences was shown by indices characterizing heart rate recovery speed after physical load which reflect physiological cost of load performed. Among the indices got during cosmonaut compulsory testing the most valid were ergometric indices of performed work intensity and volume as well as pulse cost of a unit distance. Significant correlations were proved between physical state index dynamics and initial level of physical fitness as well the activity level of preventive physical exercise. It was proved that subjective

feeling of a human often are far from his physical state objectively registered characteristics. Possible kinds of mathematical interrelationships for working ability indices were analyzed to build solving rules and algorithms for physical state controlling during long-term space flight. Some recommendations were formed for compulsory test modernization to get more comprehensive and functionally-significant information about organism physical state.

CONCLUSION

The results permit to form a battery of indices necessary and sufficient for objective evaluation of organism physical state of crew-members performing long-term space flights. The same indices permit to determine the direction of physical training required for negative effect minimization of long-term space flight factors. Thus the scientific base was formulated to develop an algorithm for on-board automatic physical training controlling. Further investigations should be directed onto appropriate algorithms development and their adequacy checking during model experiments and real space flights.

CARDIAC, ARTERIAL and VENOUS ADAPTATION to 0g during 6 MONTH MIR-SPACEFLIGHTS WITH and WITHOUT "THIGH CUFFS" (93-95).

Ph.Arbeille¹, G.Fomina², I.Alferova², M.Porcher¹, J.Coulon¹, A.Kotovskaya², V.Poliakov². (1)Med Physio Spatiale, CHU-Trousseau, 37044 -Tours-France. (2) IMBP) Moscow- Russia.

INTRODUCTION: The program included the study of the cardiac and vascular adaptation to microgravity at rest or when using the so called "Bracelets" (thigh cuffs).

METHOD: The left ventricle as well as the main arteries and veins were investigated by ultrasound imaging and Doppler during 3 spaceflights of 6 months, on 7 cosmonauts. ECG and blood pressure were recorded at the same time. The following parameters were measured: Heart rate (HR), mean blood pressure (BP), left ventricle diastolic volume (LVDV), stroke volume (SV), cardiac output (CO), mean flow velocity in the middle cerebral artery (Qc), carotid (Qcc) and femoral (Qf) blood flow volume (Qcc), cerebral (Rc), carotid (Rcc), renal (Rr), and femoral (Rf) vascular resistance, cerebral to femoral flow ratio (Qc/Qf), jugular (Sj) and femoral (Sf) veins cross section area. Measurements were performed at rest at -30d, R+3 and R+7. Inflight measurements were performed at rest and 5 hours after wearing the bracelets (thigh cuffs).

RESULTS & DISCUSSION: Without bracelets LVDV and SV were moderately decreased until the end of the flight, which is in favor of a hypovolemia. HR was slightly increased, CO being slightly decreased due to the SV decrease, and BP remained stable (Fig:1). The Rr decrease was consistent with the existence of a hypovolemia (1). No significant increase in Rc was found at the beginning of the flight as previously in other cosmonauts during 2 week flights, but the first measurement was performed after 1 month in microgravity (Fig:2). Nevertheless Qc tended to decrease and Rc to increase in the second part of the flight and there was an important enlargement of the jugular vein (Sj) throughout the flight which confirms the venous stasis at the cervical level. The Qc/Qf ratio decreased inflight. (Fig:3;4). Such findings may lead to suspect a slight increase in intracranial pressure during the second half of the flight. Rf was decreased all during the flight, as already observed during flights and head down tilts on subjects not submitted to countermeasures (2). Rf remained lower than preflight more than one week postflight, and during this period cosmonauts showed hemodynamic signs of orthostatic intolerance. The assessment of the cardiovascular response to LBNP have demonstrated that Rf was one of the parameters the most disturbed in case of orthostatic intolerance (4). The lower limb vascular resistance as measured by Rf increase when active countermeasures like LBNP which improve orthostatic tolerance are applied (2). Sj and Sf remained enlarged throughout the flight. At the jugular level it confirms that the cephalic venous stasis exist all during the flight. Although the 0g induced fluid shift emptied the calf veins, the femoral vein remained enlarged which confirms also a venous stasis which may affect the vein wall properties and their ability to vasoconstrict. The Bracelets by reducing the venous return from the leg level reduced more or less LVDV, SV and BP, which simulates a moderate hypovolemia. By pooling blood into the legs they contributed to reduce the jugular vein distension and probably the venous stasis in the cephalic area which may explain the "sensation of comfort" mentioned by the cosmonauts. The Bracelets induced a significant increase of the vascular resistance in various areas in all the 7 astronauts as already observed during a 14 day flight (3). The Rc and Rr increase prevent any cerebral or renal flow increase, in case of CO increase as observed in ground studies (personal data). During the 6 month flights a significant CO increase was present at 5.5m only, but not enough cardiac measurements were available to conclude about the real CO changes at 1m and 3-4m. Rc and Rf became much higher than preflight, whereas Rr reached the preflight level. As a consequence of the Rc increase the cerebral flow (Qc) decreased, thus the flows distribution toward the cephalic area (Qc/Qf) reduced.

CONCLUSION: Finally at rest we found most of the cardiovascular patterns already described during short and medium term flights. BP, HR, cardiac and peripheral flow volume changes were not significant but LVDV and SV remained below the preflight level which is in favor of a hypovolemia. The vascular resistance were significantly decreased at the kidney and lower limb level, as already found, but not at the cerebral level. This confirms the interest of measuring the vascular resistance in various sites and not only the total peripheral resistances which mixes opposites changes from different areas. The Bracelets initially designed as a soft and passive measure to improve the comfort of the cosmonauts, induced significant hemodynamic changes. They reduced the volemia (slightly) and the jugular vein stasis (significantly), but enlarged the femoral vein and increased significantly the vascular resistance in most of the peripheral territories.

Nevertheless if it is clear that the Bracelets has a significant impact on the cardiovascular adaptative process to zero.g, it is not demonstrated that they may interfere with the development of orthostatic intolerance.

References:

- 1 - Arbeille Ph et al. Variation of the Renal flow, in relation with the volemia. The Physiologist .vol 33. n°.1. 175 - 176 . Suppl 1990.
- 2 - Arbeille Ph, Gauquelin.G, Gharib.C et al . Results of a 4 week Head down tilt, with and without countermeasure. Cardiac & peripheral hemodynamics - Comparison with a 25 day spaceflight. Aviat.space. Env.Med , 63. pp 9-13. 1992.
- 3 - Arbeille.Ph, Fomina.G, Pottier.J, et al. Influence of the thigh cuffs countermeasure on the cardiovascular adaptation to 0g (14 & 21 day Mir spaceflights). J. Gravitational Physiology; 2; 1; 9-10; 1995.
- 4 - Ph. Arbeille, Achaibou.F, G.Fomina, et al. Regional Blood Flow in Microgravity: Adaptation and Deconditioning. Medicine & Science in Sport & Exercise; vol 28; n°10; p 14-25. 1996.

Fig 1: Heart Rate (HR), Mean blood pressure (MAP), and Left ventricle diastolic volume (LVDV) with and without bracelets ("b" means with bracelets). Inflight differences in % of the preflight value are significant ($p < 0.05$) for HR at 3 & 5m, for MAP at 1 & 5m, for SV at 1, 3 & 5m.

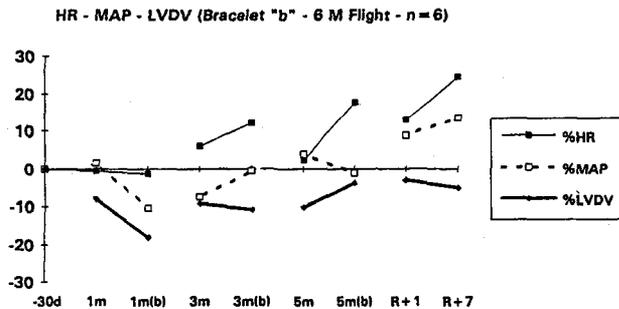


Fig 2: Mean flow velocity (Qc: cerebral; Qcc: carotid; Qf: femoral)with and without bracelets ("b" means with bracelets). Inflight differences in % of the preflight value are significant ($p < 0.05$) for Qc at 3 and 5 m and for Qf at 1, 3 and 5m.

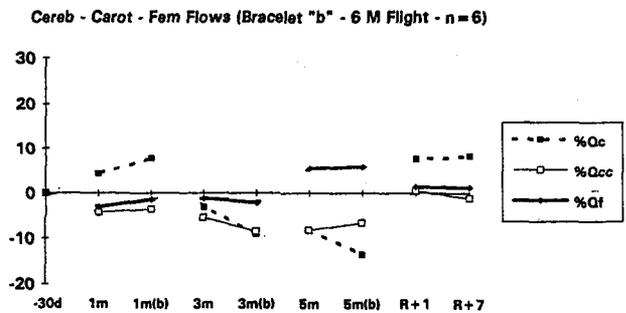


Fig 3: Vascular resistances (Rc: cerebral; Rcc: carotid; Rf: femoral; Rr: renal), and with and without bracelets ("b" means with bracelets). All inflight variations in % of the preflight value are significant ($p < 0.05$).

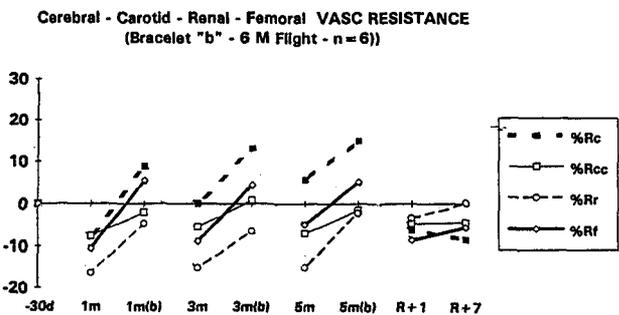
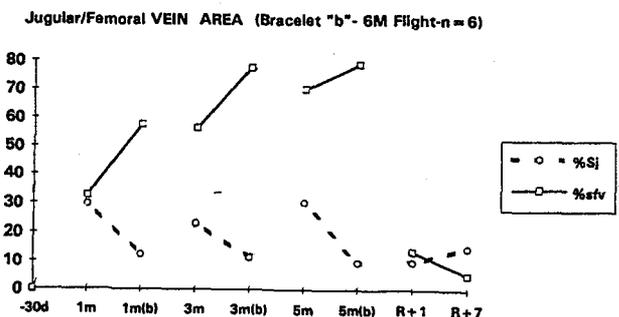


Fig 4: Jugular (Sj) and femoral (Sf) vein cross section with and without bracelets ("b" means with bracelets). All inflight differences expressed in % of the preflight value are significant ($p < 0.05$).



SPACE CYCLE™ INDUCED PHYSIOLOGIC RESPONSES

Arthur Kreitenberg, M.D., F.A.C.S.

Vincent J. Caiozzo, Ph.D.

Department of Orthopaedic Surgery
University of California, Irvine

The patented SPACE CYCLE™, has been proposed as a countermeasure on board the International Space Station. This unique device simultaneously provides exercise, gravity and impact loading to emulate conditions on earth. One or two crew members pedal themselves about a shaft located "above" their heads. The shaft is mounted to the space craft. This creates a short arm centrifuge with a head to toe force orientation. The potential advantages of the Space Cycle™ include 1) reversal of cephalad fluid shift, minimizing post flight orthostatic intolerance, 2) pedaling to maintain muscular and cardiovascular fitness, 3) maintenance of bone mass/density by impact loading with a pedal-crank mounted cam and frame mounted resistive device.

Studies in progress are attempting to quantify oxygen uptake, heart rate and blood pressure responses to a SPACE CYCLE™ session. Subject responses are being examined and compared among the following positions:

- a) upright rest
- b) lateral decubitus rest
- c) upright ergometer pedaling
- d) lateral decubitus ergometer pedaling
- e) lateral decubitus SPACE CYCLE™ passive riding
- f) lateral decubitus SPACE CYCLE™ active pedaling

If a lying down SPACE CYCLE™ workout can physiologically mimic an earth-based upright ergometer workout, there may be a protective cardiovascular effect in orbit.

Other anticipated advantages include generation of usable electricity, physiologic monitoring and a means of mass measurement. Motion sickness is controlled with restraints and virtual reality headsets. The SPACE CYCLE™ is compatible with International Space Station dimensional constraints.

MUSCULAR DECONDITIONING DURING LONG-TERM SPACEFLIGHT EXERCISE RECOMMENDATIONS TO OPTIMIZE CREW PERFORMANCE

N. Bachl¹, H. Tschan¹, R. Baron¹, I.B. Kozlovskaya², Yu. Koryak², M. Mossaheb³, R. Albrecht⁴

¹ Dept. Sport Physiology, Inst. Sports Science, University Vienna, Austria

² IMBP (Institute for Biomedical Problems, Moscow, Russia)

³ NOVA - Aerospace GmbH, Vienna, Austria

⁴ ST-ECF, Garching, Germany

INTRODUCTION

The insufficient loading of the muscle system in weightlessness has been shown to cause varying changes to the structure and function of the active and passive locomotor system. The loss of muscle mass, muscle strength and endurance is a medical concern for long-duration flights to the planets or extended stays aboard space stations. Knowledge of the extent and time course of the deterioration in muscle performance is important for the development of effective physical countermeasures for long-term manned space flights.

METHODS

A Constant Velocity Dynamo-Ergometer (Motomir) has been developed to investigate neuromuscular and physiological parameters during short and prolonged stays in microgravity. Beside the angle-specific diagnosis of neuromuscular reactions this device allows training of both extremities at various speeds using either concentric or eccentric mode of operation. In 5 different long-term missions that lasted from 126 - 439 days in the years 1991-1995 we examined 9 male cosmonauts several times in-flight on board Mir Space Station at comparable points of time as well as two times postflight to get information about the extent and temporal relationship of the decline in muscle strength, and fatigue resistance of skeletal muscles. Results about the average percent changes in maximal force production in muscle groups of the lower and upper extremities following various durations of exposure to real microgravity are presented.

RESULTS

Maximum voluntary isometric, concentric and eccentric capacity of knee extensor muscle group was reduced significantly ($p < 0.001$) during the whole mission. The data demonstrate that space flight also reduces static and dynamic strength of the ankle flexors significantly ($p < 0.01$ - $p < 0.001$). Decreases in strength were significantly greater in extensor than flexor muscle groups and in lower limbs than upper limbs. Two distinct phases in muscle contractile deterioration have become apparent: The first phase showed a 20-50% decrease in muscle strength during first days of flight when compared to preflight levels. The second phase started 3-4 weeks after the beginning of a flight, and the magnitude of muscle deterioration was highly dependent on the level of physical exercise on board. Findings of the research are discussed in detail for different neuromuscular parameters. Resistance and endurance exercise recommendations to maintain muscle strength during long-term manned space flight are proposed.

CONCLUSION

It does not appear that the countermeasures at the moment are completely effective in maintaining musculoskeletal, neuromuscular and cardiovascular functions. However for a flight duration of 439 days, the microgravity environment using common countermeasures for the crew has shown to be acceptable. Future in-flight exercise programs and devices will probably require: Countermeasure exercise programs which minimize the use of crew work time and life-support resources. A mix of dynamic and resistance exercise to maintain cardiovascular and musculoskeletal structure and functions and to preserve work capacity. New countermeasure devices that allow both fitness monitoring and training.

ACKNOWLEDGEMENTS

The authors are very obliged to the participating crewmembers for their exceptional motivation and co-operation. This work has been supported by funds of the Austrian Ministry for Science Traffic and Art and the Austrian Society for Aerospace Medicine.

STRUCTURE AND FUNCTION OF KNEE EXTENSORS AFTER LONG-DURATION SPACEFLIGHT IN MAN: EFFECTS OF COUNTERMEASURE EXERCISE TRAINING.

B.S.Shenkman¹, I.B.Kozlovskaya¹, S.Siconolfi², G.H.Gilbert², T.L.Nemirovskaya¹, I.A.Cheglova¹,
 V.I.Stepantsov¹, V.V.Stepantsov¹, Yu.A.Koryak¹.
 Neurophysiology Dpt, State Scientific Center-Institute of Biomedical Problems, Moscow, Russia¹; Neurosciences and Neuromuscular Laboratory, NASA Lyndon B. Johnson Space Center, Houston, TX, USA²

INTRODUCTION

This study evaluated the effects of long-duration spaceflight (76 days for cosmonauts A & B and 180 days for cosmonauts C & D) on skeletal muscle structure and function.

METHODS

Fiber cross-sectional area (CSA), capillary per fibre ratio (CF), capillary density (CD) and myofibrillar integrity were studied in samples obtained from m.vastus lateralis before and on the 3rd and 5th day after landing. Crewmembers A and B had quadriceps muscle strength (isometric and concentric isokinetic contraction at 30, 60, 120 and 180°/s) measured before and 6 days after flight. Most of crewmembers performed more than 80% of recommended exercise training loads in terms of volume and intensity. The training included high-intensity interval treadmill, aerobic-bicycle and resistive-bungee-cord exercises. Subject C performed lower intensity aerobic exercise during his treadmill sessions instead of the recommended protocol.

RESULTS

Almost no signs of myofibrillar damages were observed in muscle fibres of A and B subjects (according to electron microscopy).

Relative changes of structural and functional skeletal muscle characteristics(%)

Subj.	Days	CSA	CSA	CF	CD	Strength Nm				
		ST μm^2	FT μm^2			cap / mm^2	0°/s	30°/s	60°/s	120°/s
A	76	-7.7	-1.8	+19	-3.1	+12.3	+0.2	-7.4	-11.5	-16.2
B	76	-13.8	+6.7	-12	+7.9	+1.7	+0.9	-20.6	+15.4	-2.1
C	180	-19.7	-24.5	-18	+25	n.a.	n.a.	n.a.	n.a.	n.a.
D	180	-2.7	-3.4	-6.7	+46	n.a.	n.a.	n.a.	n.a.	n.a.

Very slight decreases were found in fibre CSA and in muscle capillary supply indices of A,B and D crewmembers. Cosmonaut C, "the jogger" had greater decreases in ST CSA and FT CSA than other crewmembers. The changes in isometric and concentric isokinetic strength in A & B crewmembers were smaller than reported for short-duration flights (Kozlovskaya et al,1983).

CONCLUSION

These results suggest that high-intensity, interval treadmill running was the main factor which maintained muscle structure and function in three cosmonauts.

Force and power characteristics of an exercise ergometer designed for use in space.

Hans E. Berg & Per A. Tesch, Department of Physiology & Pharmacology, Karolinska Institute, S-171 77 Stockholm, Sweden

NASA's Life Sciences Strategic Planning Study Committee identified physiological deconditioning as one of the primary obstacles to extended human space flight. Ground-based and space flight data, for example, suggest lower limb muscle force during voluntary effort to decrease at a rate of about 3-4% during the first weeks. Hence, exercise countermeasures to this effect is warranted. To combat such impairment in skeletal muscle function, exercise simulating weight-training on earth, appears to be an attractive approach. We have developed a non-gravity dependent mechanical device which provides resistance during the entire concentric and eccentric cycle of muscle action, through the inertia of a spinning fly-wheel (Fly-Wheel Ergometer; FWE). Our previous research, using a lower limb exercise configuration, showed that FWE exercise produced forces comparable to those typical for traditional weight-training using free weights. In addition, it was shown that FWE exercise could offer greater training stimuli during eccentric relative to concentric muscle actions, as evidenced by force and electromyographic (EMG) measurements. Here, we report muscle use of specific muscle groups during FWE and the barbell squat exercise, by studying the exercise-induced contrast shift of images using magnetic resonance tomography technique. In addition, force, power and EMG as well as fatigue characteristics measured over bouts consisting of consecutive repetitions for FWE, the leg press and one-joint knee extensions are described. For these studies subjects accustomed to physical exercise volunteered. The results of these studies show 1) muscle use is similar or greater for FWE compared to the barbell squat exercise 2) unlike free-weight exercise FWE exercise allows for maximal voluntary effort in each repetition 3) FWE, not unassisted free-weight exercise, produces eccentric "over-load". These results suggest that resistance exercise using FWE could be used as an effective exercise countermeasure in space. The results should be valid for any exercise configuration using the fly-wheel principle. In fact, a compact device using this principle has been designed. It allows for different exercises involving major muscle groups.

This research was funded by grants from the Swedish Board of Space Activities and NASA contract NAGW 3435.

THE SIMULATING OF OVERGRAVITY CONDITIONS FOR ASTRONAUTS' MOTOR APPARATUS AT THE CONDITIONS OF THE TRAINING FOR ORBITAL FLIGHTS

A. N. Laputin

Man's Institute of Ukrainian Cosmonautics Federation, Head of Kinesiology, University of Physical Education Sport, 252005 Kiev, Ukraine

Human motor function has been formed in the field of Earth gravity at the phylogenesis. The forces of Earth gravity stimulated the development of genotypical and phenotypical neuro-motor mechanisms of the control on the movements. Really the whole functional morphological complex of human organism that is included into the system of motor analyzer is tuned onto the perception, transformation and reflection of information about Earth gravitational field.

The hypothesis of this research is based on the supposition about that the perfecting of motor proficiency in the conditions of high gravity will allow to improve considerably the quality of astronauts' training before the flight at the expense of the increasing of force potential of their organism and the widening of their coordination abilities. The results about the tests of special training suit that is needed to simulate the conditions of overgravity for astronauts, who perfect their professional motor proficiency, are presented in the work. The methods of videocomputer analysis of movements and also the methods of myotonometry and tensodynamography were used as the methods for testing and forecasting about the acquisition process of models on motor tasks by astronauts.

The results of experiments showed that the astronauts' training before the flight in the conditions of artificial overgravity allowed to improve the biodynamic structure of their motor acquirements with considerable effect. It is set up the astronauts' force potentialities may be highly increased together with simultaneous successful perfecting onto those elements of biokinematic structure of those researching systems of movements that were programmed in motor tasks at the process of such gravitational training that was corrected by the using of methods of biomechanical control.

Friday, June 13

Session FA3
Room 3
8:30 - 11:30 a.m.

532-53
074637

326991

14A

Results from the Joint U.S./Russian
Sensory-Motor Investigations

THE EFFECT OF LONG DURATION SPACE FLIGHT ON THE ACQUISITION OF PREDICTABLE TARGETS IN THREE DIMENSIONAL SPACE

M.F. Reschke¹, I.B. Kozlovskaya², W.P. Huebner³, W.H. Paloski¹, J.M. Krnavek³, J.A. Krug³, J.J. Bloomberg¹, D.L. Harm¹, E.R. Eichelman³

¹Nasa Johnson Space Center, Medical Research Branch (SD3), Houston, TX 77058, ²Institute for Biomedical Problems, Moscow, Russia, ³KRUG Life Sciences, Houston, TX

INTRODUCTION

The ability to undertake goal-directed action is required for human survival. Self-orientation, self-motion, and the perception of that orientation and motion are required for and modified by goal-directed action. Specifically, given the documented disruptions that occur in spatial orientation during space flight and the putative sensory-motor information underlying eye and head spatial coding, the primary purpose of this paper is to examine components of the target acquisition system in subjects free to make head and eye movements in three dimensional space following adaptation to long duration space flight.

METHODS

Five male astronaut/cosmonaut subjects acquired spatially and temporally predictable targets located in the horizontal and vertical planes, both within and beyond the effective oculomotor (EOM) range, using a time-optimal strategy (move the head and eyes together as quickly and as accurately as possible to acquire the target) before and after two space flights aboard the Russian Mir station. Each flight had a duration of approximately three months. Horizontal and vertical eye movements were recorded with conventional DC electro-oculographic techniques, and three dimensional head movements were obtained with a triaxial rate sensor system mounted firmly to the head.

RESULTS

Typically an orienting gaze movement initiated to bring a selected part of the visual world onto the fovea consists of an eye movement saccade and a head movement followed by a reflexive compensatory eye movement driven by the VOR and visual fixation responses (VVOR). In the usual sequence, a saccade directs the eye either onto the target (for targets with a small angular displacement) or towards the target when the angular displacement is beyond the EOM. Unlike the majority of the preflight observations which used a normal sequence of head and eye movements to assist in acquisition of a target, and in spite of evidence for common driver signals to the head and eye, different strategies were used postflight to bring gaze onto a target. Figures 1a and 1b illustrate two different gaze-shift strategies that were used to obtain a target beyond the EOM. The response in Figure 1a was obtained preflight and shows a head movement synchronous with or beginning slightly before movement of the eye towards the target. The target acquisition response illustrated in Figure 1b was obtained postflight and shows an eye movement towards the target just prior to movement of the head. The primary difference between the preflight and postflight strategies is clearly seen in the velocity of the head, the final position of the head, and the number of saccades generated prior to gaze stability. In Figure 1a (preflight) the eye makes a major saccade toward the target and appears to be assisted by the movement of the head. A normal visual-vestibular ocular reflex (VVOR) is established with a gain just slightly greater than one. The postflight response on the other hand (Figure 1b) shows a delayed head movement, reduced velocity, less angular displacement, and multiple saccades (with gains up to 4.0) prior to final gaze position. The difference between these two responses can be clearly illustrated when gaze is plotted parametrically as a function of head position (Figures 2a and 2b). Total gaze error can be derived from integrating the area represented by the right 90° angle (head position 0° to maximum gaze displacement). This function is illustrated in Figures 2a and 2b. Please note that three major factors contribute to gaze error: response latency, time taken to achieve final gaze position and the number of saccadic eye movements generated. When gaze position is considered as a function of time, the preflight total gaze error is approximately 20°xsec and postflight it is 54°xsec. Perhaps one of the most important aspects of determining total gaze error as a function of time lies with its use as an index of performance. That is, when it is critically important to obtain a target in the shortest amount of time large gaze errors will result in less accurate target acquisition responses over time. Total gaze error can also be used to predict postflight (or in-flight) performance using preflight behavior. We tested this hypothesis by determining the absolute gaze error as a function of time from preflight trials (restricting ourselves to those targets beyond the EOM), and then relating the absolute gaze error to the head and eye velocity in the vertical plane for a specific trial obtained during target acquisition. In relating gaze error to head and eye velocity we categorized the error in terms of either a large or small gaze

error. When absolute gaze errors as a function of time were associated with postflight vertical head and eye velocities a clear trend was apparent. Large gaze errors were more likely to be associated with lower head and eye velocities, while small gaze errors were related to higher head and eye velocities. Among other things, this finding suggests that the neural strategies adopted during adaptation to microgravity may not be optimal for postflight performance. Those adopting a strategy of higher head and eye velocities may have less difficulty and reduced gaze error.

FIGURE 1a

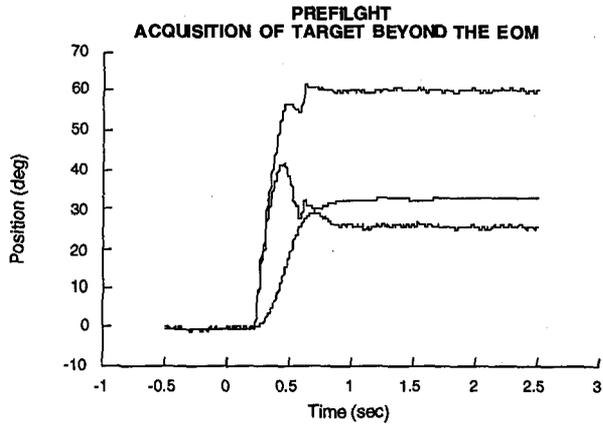


FIGURE 2a

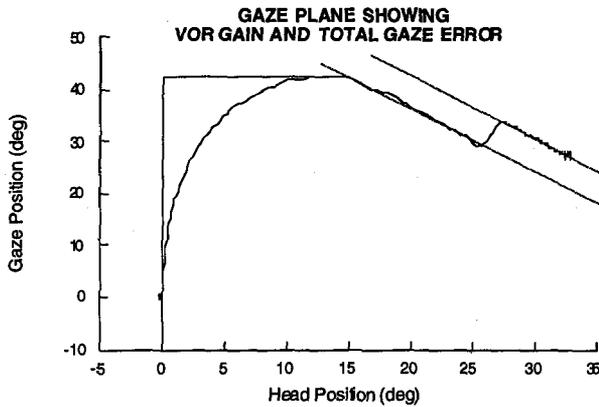


FIGURE 1b

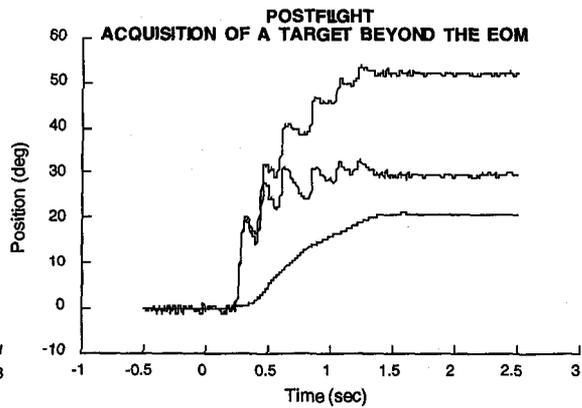
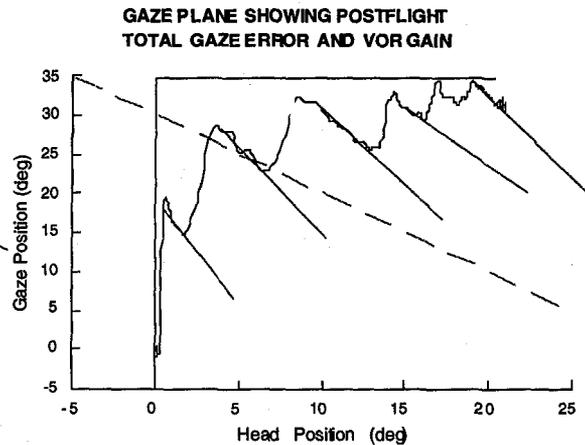


FIGURE 2b



CONCLUSION

Based preliminary on the data from a relatively small sample population (five subjects) the results appear to confirm the working hypothesis that eye/head movements will be modified during adaptation to microgravity. There is a degradation in the astronauts' ability to acquire targets with the head and eyes, even though the acquisition process has been practiced and rehearsed. Timing and accuracy is particularly degraded when the object to be acquired is outside of the central field of view (i.e., offset from center by more than 35°) and is located in the vertical plane thus requiring a pitch head movement for target acquisition. Processing and analysis of our remaining Mir data is necessary to confirm the preliminary results. It is interesting to note that the effects observed in the long duration crews appear to require more time following flight for a return to baseline values, and that specific individuals may require >70 days postflight for full recovery.

EFFECTS OF MICROGRAVITY ON SPINAL REFLEX MECHANISMS

I.B. Kozlovskaya, N.I. Burlachkova

Institute of Biomedical Problems, 76A Khoroshevskoye Shosse, 123007, Moscow, Russia

INTRODUCTION

Results of previous studies have shown that short and long-term exposures to real and simulated weightlessness are followed by clear signs of enhancement of excitability of stretch reflex mechanisms (Kakurin et al., 1971, I.B.Kozlovskaya et al, 1982, 1988, 1990). However the data, obtained in postflight observations or in the course of simulation experiments can not be directly interpolated to the weightlessness environment. Since alteration of activity of spinal reflex mechanisms can in its turn be

followed by movement control disturbances the series of experiments were performed that were directed to study characteristics of stretch knee tendon reflexes during long-term spaceflights. As a control tendon (T) Achilles reflexes and (H) Hoffmann ankle reflexes have been studied in long-term bedrest (BR).

METHODS

The characteristics of the recruitment curve namely, the threshold and the maximal amplitude of the tendon (T) (i) patellar and (ii) Achilles reflexes and of the H-reflexes has been studied in (i) 10 members in long duration (4-14 months) spaceflights and in (ii) 16 subjects - participants of long-term (from 4 to 12 months) bedrest studies. I) Parameters of electromyographic (EMG) responses of m. quadriceps femoris to standard impacts (small, moderate and submaximal ones) applied to the patella had been studied inflight. The standard position of the leg during testing was secured by special fixation device. ii) Under bedrest conditions the electromyographic responses of m. gastrocnemius lateralis to impacts applied to the Achilles tendon by the conventional neurological hammer that was supplied by the tensometric sensor have been studied.

RESULTS

The results of the studies revealed the clear cut signs of the reflex excitability enhancement. The amplitude of the EMG bursts responses that varied on-ground to stimuli of small, moderate and strong impacts from 1.5 mv to 2.8 mv reached during different phases of flight the range of 5.0 mv, 6.0 mv and even 8.5 mv. The same was true for the measurements made on the 2nd postflight day. The well-organized 2-wave response that was usually recorded under 1G conditions had been substituted inflight by polyphasic clonic activity. As a result the duration of the response had increased in space up to 500 ms to the small impact and even to 2000 ms to the strong one. During the first stage of flight that lasted up to 30 days, the amplitudes of T-reflexes were lowered though the clonic organization of the response pointed out to the enhancement of the reflex' excitability. Under the conditions of BR the maximal amplitudes of m.gastrocnemius lateralis' T-reflex was increased greatly (up to 4 mv vs 1 mv in average before BR) starting from the day 2 and reaching the peak values on the day 5 of BR. After that the reflex amplitude revealed the tendency to decrease under conditions of "pure" BR or to stabilize on the same high level when the physical exercises have been used. The very same time-course changes were revealed in BR in values of maximal amplitudes of the H-reflex and the M-response.

CONCLUSION

The results of studies allow to conclude that the primary effect of microgravity is the enhancement of the excitability of spinal stretch reflexes' mechanisms. However the values of the reflexes' amplitudes can be affected to a great extent by the processes which are developing in the muscle state.

REFERENCES

- Kakurin L.I., Cherepakhin M.A., Pervushin V.I. (1971). Effects of spaceflight factors on the human neuromuscular system. *Kosm.Biol. i Med.* 2:51-56
- Kozlovskaya I.B., Aslanova I.F., Kreidich Yu.V. (1982). Experimental analysis of motor effects of weightlessness. *The Physiologist* 25(6): 49-52
- Kozlovskaya I.B., Barmin V.A., Stepantsov V.I. (1990) Results of studies of motor functions in long-term spaceflights. *The Physiologist*, 33 (1 Suppl.) P.1-3

THREE DIMENSIONAL HEAD MOVEMENT CONTROL DURING LOCOMOTION AFTER LONG-DURATION SPACE FLIGHT

J. J. Bloomberg¹, A.P. Mulavara², P.O. Riley³, C. S. Layne², P. V. McDonald², S.L. Smith², I.B. Kozlovskaya⁴

¹Life Sciences Research Laboratories, NASA Johnson Space Center, Houston, TX, ²KRUG Life Sciences Inc., Houston, TX, ³Spaulding Rehabilitation Hospital, Boston, MA, ⁴Institute for Biomedical Problems, Moscow, Russia

INTRODUCTION

Research conducted in both U.S. and Russian space programs have revealed that exposure to the microgravity environment encountered during space flight induces adaptive alteration in sensorimotor function leading to post flight disturbances in locomotor control. We have recently characterized some of the underlying adaptive changes that contribute to these locomotion alterations following short-term space flight on the U.S. Space Shuttle (Bloomberg et al., 1997; Layne et al., 1997; McDonald et al., 1996). The purpose of the present study was to investigate the effects of long-duration space flight on segmental coordination during locomotion with particular emphasis on alterations in head movement control.

METHODS

Five astro/cosmonaut subjects were tested before and after 3-6 months stays aboard the Mir Space Station. As part of a larger protocol involving both overground and treadmill locomotion, subjects walked (6.4 km/hr) on a motorized treadmill while visually fixating on a FAR (2 m from the eyes) or a NEAR (30 cm from the eyes) visual target for trials of 20 s in duration. Kinematic data were collected with a video-based motion analysis system (Motion Analysis Corp., Santa Rosa, CA). Yaw, pitch and roll head position was calculated using three passive retro-reflective markers affixed to the vertex, occipital and right temporal positions of the head.

RESULTS

Analysis of the power spectra of yaw, pitch and roll head position during locomotion revealed individual post flight differences in all rotational planes. In addition, after space flight the dynamics of head movements during locomotion as defined by ensemble velocity and acceleration waveforms were markedly altered in yaw, pitch and roll planes. Recovery of head movement control was typically not complete in all rotational planes within the 9 day post landing testing period.

CONCLUSION

These results demonstrate that long-duration space flight induces adaptive changes in head movement control in all three rotational axes. We infer from these results that prolonged post flight impairment of head movement control following long duration space flight contributes to locomotor and postural dysfunction by disrupting descending vestibular control of body movement.

REFERENCES

Bloomberg, J.J., Peters, B.T., Huebner, W.P., Smith, S.L. and Reschke, M.F. Locomotor head-trunk coordination strategies following space flight. *Journal of Vestibular Research*. In press, 1997.

Layne, C.S., McDonald, P.V., Bloomberg, J.J., Jones, G., Pruett, C.J., and Merkle, L. Neuromuscular activation patterns during locomotion after space flight. *Experimental Brain Research*, 1997, 113:104-109

McDonald, P.V., Basdogan, C., Bloomberg, J.J., and Layne, C.S. Lower limb kinematics during treadmill walking after space flight: Implications for gaze stabilization. *Experimental Brain Research*, 1996, 112: 325-334.

HUMAN BODY SHOCK WAVE TRANSMISSION PROPERTIES AFTER LONG DURATION SPACE FLIGHT

P. V. McDonald¹, C. S. Layne¹, J. J. Bloomberg², I.B. Kozlovskaya³

¹KRUG Life Sciences Inc., Houston, TX, ²Life Sciences Research Laboratories, NASA Johnson Space Center, Houston, TX, ³Institute for Biomedical Problems, Moscow, Russia

INTRODUCTION

The purpose of the present investigation was to assess the effects of long duration space flight on the shock transmission characteristics of the human body while walking. Locomotor ground reaction forces (GRF) create shock waves that travel from the feet through the body to the head. Most frequency components of walking GRF are comprised between 0 and 50 Hz (Antonsson & Mann, 1985). Measurements of the shock at different sites along the musculo-skeletal system indicate similar frequency bandwidths. However, comparisons of power spectra indicate that the body alters the frequency composition of the input shock as it travels through the body (Lafortune et al, 1994; Shorten and Winslow, 1991). Moreover, a preliminary study of the effects of short duration flight indicated qualitative modifications of shock wave transmission while walking (Lafortune et al, 1997).

METHODS

Subjects flew on the Mir Space Station and data were collected twice pre-flight, with the sessions separated by at least one week, then again 1, 3, 7, and 180+ days after landing. Each data collection session consisted of at least 4 barefoot walking trials at a self selected velocity along a 6-8m walkway. GRF was measured with a Kistler 9286 force platform embedded in the walkway at about 4m. Head acceleration was measured with a triaxial Entran $\pm 5g$ accelerometer mounted onto a plexiglass bitebar which was held firmly in the molars. All channels were sampled at 1020 Hz and GRF was normalized to the subjects' own body weight. Data were sampled for eight seconds with the GRF signals being used to detect the contact of the right foot with the force platform. Using the initial 256 data points after ground contact, temporal and frequency domain measures of impact force and shockwave transmission were calculated for each subject for each test session.

RESULTS

Preliminary results from temporal domain analyses indicate some postflight changes in the magnitude of the initial ground reaction force peak. Similarly, one observes concomitant changes in the peak magnitude of head acceleration. Both these events occur within a few milliseconds of each other and are considered causally related. In the frequency domain, a ratio of the power spectra of the GRF and head acceleration, termed the gain-attenuation function, indicates selective changes in gain at certain frequencies.

CONCLUSION

These data indicate some postflight changes are occurring in shock wave transmission properties of the body. The potential sources for change will be discussed in reference to both physiological changes in the human body, as well as behavioral adaptations manifest postflight. However, the analyses are currently in their preliminary stages with more data required before firm conclusions can be drawn. Our intent is to evaluate these changes in light of challenges to head and gaze stability during walking following spaceflight (Bloomberg et al., 1996) and the possibility of changes in musculoskeletal impedance during space flight (McDonald et al, in press).

REFERENCES

- Antonsson, EK & Mann, RW (1985) The frequency content of gait. *J. Biomechanics* 18, 39-47.
- Bloomberg, JJ, Peters BT, Huebner WP, Smith SL, Reschke MF. (1997) Locomotor head-trunk coordination strategies following space flight. *Journal of Vestibular Research*.
- Lafortune, MA et al. (1994) Shock transmissibility of the human body. *Proc. Of the 8th Biennial Conference of the CSB, Calgary*, pp.168-169.
- Lafortune, M.A., McDonald, P.V., Layne, C.S., & Bloomberg, J.J. (1997). Space flight modifications of human impact loading and shock transmission during walking. Submitted for publication.
- McDonald, P.V., Bloomberg, J.J., & Layne, C.S. (In Press). A review of adaptative change in musculoskeletal impedance during space flight and associated implications for postflight head movement control. *Journal of Vestibular Research*.
- Shorten, MR & Winslow, DS (1992) Spectral analysis of impact shock during running. *Int. J. Sports Biomech.* 8, 288-304.

ADAPTATION OF NEUROMUSCULAR ACTIVATION PATTERNS DURING LOCOMOTION AFTER LONG-DURATION SPACE FLIGHT

C.S. Layne¹, G.W. Lange¹, C.J. Pruett¹, P.V. McDonald¹, L.A. Merkle¹, S.L. Smith¹, I.B. Kozlovskaya² and J.J. Bloomberg³.

¹KRUG Life Sciences Inc., Houston TX, ²Institute for Biomedical Problems, Moscow, Russia, ³Life Sciences Research Laboratories, NASA Johnson Space Center, Houston, TX

INTRODUCTION

Previous investigations in our laboratory identified that precise neuromuscular control necessary for optimal locomotion is compromised after short duration space flight, particularly around heel strike and toe off (Layne et al., 1997). Additionally, preliminary results indicate that locomoting subjects modify their neuromuscular activation patterns in response to changes in visual target distance. These neuromuscular modifications are consistent with documented changes in head motion and stride length in response to differences in visual target distance (Smith et al., 1996). In the present study, we hypothesized that extended exposure to microgravity will impact the sensory-motor control system's ability to generate adaptive neuromuscular activation patterns in response to changes in visual target distance during locomotion. Failure to adapt postflight neuromuscular responses in a manner similar to those observed preflight, may reflect a more generalized deficit in the ability to adaptively respond to changing environmental conditions after long-duration space flight.

METHODS

Four astro/cosmonauts walked (6.4 km/hr) on a motorized treadmill while fixating on either a NEAR (30 cm from the eyes) or FAR (2 m from the eyes) target. Testing occurred before and 1 day after 3-6 months aboard the Mir Space Station. Data from electronic foot switches were used to identify heel strike and toe off events of the gait cycle. In addition, surface electromyography (EMG) was collected from the tibialis anterior (TA), medial gastrocnemius (GA), biceps femoris (BF) and rectus femoris (RF) of the right lower limb. Activation waveforms for each muscle were obtained by first band pass filtering (30-300 Hz), full wave rectifying, smoothing (15 ms time constant) and then averaging the signals between consecutive right heel strikes. The activation waveforms were then reduced to 20 epochs with the value for each epoch representing the mean activity within the epoch. To determine if space flight modified the phasic features of neuromuscular activation Pearson *r* correlation coefficients were calculated between the pre- and postflight waveforms for each muscle. Activation waveforms normalized to the mean activity observed during the NEAR target condition for a particular test session were used to evaluate possible changes in relative amplitude between the pre- and postflight activity. The sum of activity associated with each burst, of each muscle was computed and comparisons between pre- and postflight activity levels were made. To determine the degree of neuromuscular flexibility in response to visual target distance, ratios between the sum of burst activity in the NEAR and FAR target conditions were developed for each muscle. An index of adaptability reflecting the degree to which space flight impacted the neuromuscular modifications associated with different target distance was also developed.

RESULTS

Pearson *r* correlation coefficients indicated a high degree of similarity between the pre- and postflight muscle activation waveforms (range 0.80-0.99). In general, relative activation amplitude was stable between the pre- and postflight testing with the exception of the activity of the tibialis anterior (TA) and rectus femoris (RF) around toe off. On average the postflight TA relative amplitude was 17% (SD=13%) different than preflight and the RF was modified by 16% (SD=10%) after flight. However, some subjects displayed increases while others displayed decreases in amplitude. The index of adaptability reflected a significant degree of change in how the subjects responded to the change in target distance. Again, the largest changes occurred in the TA and RF around toe off.

CONCLUSION

The results indicate that, while in general, the phasic properties of lower limb neuromuscular activation during locomotion can be reliably produced, the precise control observed preflight is disrupted after space flight. Additionally, the change in neuromuscular response flexibility due to different visual target distances after flight may reflect a non-optimal adaptive response to long-duration space flight.

REFERENCES

Layne, C.S., McDonald, P.V., Bloomberg, J.J., Jones, G., Pruett, C.J., and Merkle, L. (1997) Neuromuscular activation patterns during locomotion after space flight. *Experimental Brain Research* 113(1):104-109

Smith, S.L., Peters, B.T., Layne, C.S., McDonald, P.V., Bloomberg, J.J. (1996) Goal-directed Head Movement Control During Treadmill Locomotion. *Proceedings of the 20th annual meeting of the American Society of Biomechanics* 61

BALANCE CONTROL DEFICITS FOLLOWING LONG-DURATION SPACE FLIGHT

W. H. Paloski¹, I. B. Kozlovskaya², M. P. Shestakov², S. C. Nicholas³, A. M. Ivanov², and M. F. Reschke¹

¹Life Sciences Research Laboratories, Johnson Space Center, Houston, TX 77058 USA

²Institute for Biomedical Problems, Moscow, Russia

³Krug Life Sciences, Houston, TX, USA

INTRODUCTION

The sensory-motor systems of humans have evolved phylogenetically and ontogenetically to optimize body movements and posture control in the terrestrial gravitational field. The central nervous system (CNS) has developed neuro-sensory systems that monitor and process sensory inputs from visual, vestibular, somatosensory, and proprioceptive receptors to assess the biomechanical state of the body (spatial orientation), and neuro-motor systems that create, select, and employ motor command strategies and synergies to adjust the biomechanical state toward the desired equilibrium point. Adaptation to microgravity alters neuro-sensory systems by eliminating, reinterpreting, or modifying the weighting of sensory information used to assess spatial orientation in response to the sudden loss of tonic gravitational otolith stimulation (Paloski, et al., 1992, 1994, 1997). Adaptation to microgravity also alters neuro-motor systems by modifying the repertoire of motor command strategies and synergies used for movement control in response to the sudden redistribution of forces along the body, reductions in the biomechanical support reactions, and alteration of relationships between motor command and body movement (Kozlovskaya et al., 1981, 1987, 1995). These inflight sensory-motor adaptations disrupt postflight postural equilibrium control.

The objectives of this study were to determine the role of central adaptive mechanisms in reorganizing postural equilibrium control in humans subjected to long-duration space flight, and to compare these results with similar data obtained from short-duration missions. The specific hypotheses tested in this investigation were that the effectiveness of the closed loop control of quiet stance, which is known to be reduced after space flight, presumably because of inflight neuro-sensory adaptation, will be further reduced by concomitant neuro-motor adaptation, and the magnitude and recovery time course of this ataxia will increase with mission duration because of the increased time for sensory-motor adaptation to microgravity.

METHODS

Seven subjects from three separate long-duration (81-195 day) Mir Station space flight missions participated in this study. The subjects were tested on up to three occasions before flight and five occasions after flight. At each test session, the subject's posture control system was challenged by eliminating vision, decorrelating ankle proprioceptive inputs from earth-vertical, and/or decorrelating visual inputs from earth-vertical. These conditions altered the set of accurate sensory inputs available to the CNS for detection of sway errors and development of compensatory closed loop motor output adjustments.

The full set of six sensory organization tests was administered automatically using a modified clinical dynamic posturography system (Equitest, Neurocom International, Clackamas, OR, USA). To decorrelate the ankle proprioceptive and visual inputs from earth-vertical, the pitch orientations of the support surface and visual surround with respect to the subject's ankle joint were servo-controlled to follow the subject's center of mass sway. This process, which is referred to as sway-referencing, completely eliminated changes in ankle angle and visual flow during low frequency body sway. The six sensory organization test (SOT) conditions used were:

SOT 1: *eyes open* - control condition; all sensory feedback systems are available; tests the overall effectiveness of the closed loop posture control system;

SOT 2: *eyes closed* - tests the effectiveness of the closed loop posture control system without visual feedback;

SOT 3: *sway-referenced vision* - tests the effectiveness of the closed loop posture control system with an altered visual orientation reference; examines how well the system resolves visual-proprioreceptive and/or visual-vestibular conflicts;

SOT 4: *sway-referenced support surface* - tests the effectiveness of the closed loop posture control system with an altered proprioceptive orientation reference; examines how well the system resolves proprioceptive-visual and/or proprioceptive-vestibular conflicts;

SOT 5: *sway-referenced support surface with eyes closed* - tests the effectiveness of the closed loop posture control system with an altered proprioceptive orientation reference and absent visual feedback; only vestibular feedback is accurate; examines how well the system resolves proprioceptive-vestibular conflicts and/or how well the system controls posture with only vestibular feedback;

SOT 6: *sway-referenced support surface with sway-referenced vision* - tests the effectiveness of the closed loop posture control system with altered visual and proprioceptive orientation references; only vestibular feedback is accurate; examines how well the system resolves simultaneous visual-vestibular and proprioceptive-vestibular conflicts and/or how well the system controls posture with only vestibular feedback.

During each test session, three trials of each of the six sensory organization test conditions were presented to the subject. Each trial lasted for 20 seconds, and the order of presentation of the 18 trials was randomized.

The primary dependent measures in this experimental paradigm were derived from biomechanical measurements of segmental and center of mass body movements. In particular, peak-to-peak sway amplitudes, equilibrium scores, and center of pressure (COP) under each SOT condition were used to determine the degree to which the posture control system used visual, vestibular, and proprioceptive feedback to maintain closed loop control of postural equilibrium.

RESULTS

The earliest postflight data collection occurred within four hrs of landing (n=1); however, most subjects (n=4) could not be scheduled for initial testing until approximately 24 hrs after landing. Owing to the untoward effects of prolonged exposure to microgravity on multiple physiological systems early after return to earth, and to the competition among physiological investigators for the limited crew member availability during the first few days after flight, systematic timing of postflight test sessions was not possible. Nevertheless, by grouping data in time 'bins' it was possible to evaluate the postflight effects and compare them with the short-duration results.

Two of the three subjects scheduled for landing day testing were unable to participate that day because of profound postflight readaptation illness. Five subjects were tested at approximately 24 hrs after landing. All exhibited balance control deficits that were similar in character but more severe than those observed in short-duration subjects at the same postflight interval (Paloski, et al., 1997). The most substantial balance control deficits were observed under SOT 5 and SOT 6, those conditions in which only the vestibular system could provide accurate spatial orientation information. This finding is similar to previous findings after short-duration space flight; it suggests that altered vestibular information processing plays an important role in balance dyscontrol following long-duration space flight.

By 8-12 days after landing, general performance on the sensory organization test battery was similar to the performance observed before flight. However, in contrast to short-duration results, more subtle changes in balance control and intersegmental coordination, particularly in response to sudden postural perturbations (Shestakov, et al., 1997), persisted beyond this point, suggesting that new, long-lasting changes in neuro-motor coordination emerge following long-duration space flight.

CONCLUSIONS

The primary goal of these investigations was to extend our understanding of the central adaptive mechanisms responsible for the appearance and amelioration of postflight postural ataxia. We conclude that the neuro-sensory balance dyscontrol observed after long-duration space flight is similar in nature but far more profound than that observed following short-duration space flight. Furthermore, we conclude that neuro-motor coordination changes unobserved after short-duration flights begin to emerge after long-duration flights.

INFLUENCE OF WEIGHTLESSNESS ON POSTURAL MUSCULAR ACTIVITY COORDINATION

M. P. Shestakov¹, W. H. Paloski², I. B. Kozlovskaya¹, and A. M. Ivanov¹

¹Institute of Biomedical Problems, Moscow, Russia

²Life Sciences Research Laboratories, NASA/Johnson Space Center, Houston, TX, USA

INTRODUCTION

Prolonged exposure of humans to conditions of weightlessness causes important changes in the activity of the main proprioceptive inputs (bearing, muscular, vestibular), as well as in the condition of spinal reflex mechanisms and in the characteristics of the peripheral musculature (Berry, 1973; Mitarai et al., 1978; Kozlovskaya et al., 1981, 1987, 1995). These changes can, in turn, cause the development of the disturbances of the control mechanisms of voluntary movements, postural synergies, and locomotion (Homick et al., 1977; Kozlovskaya et al., 1981, 1987, 1995; Paloski et al., 1993). Studying the regularities of the genesis of coordination disturbances of the vertical posture after prolonged weightlessness is the subject of this paper.

METHODS

The experiment was performed by two Russian cosmonauts before and after the 193-day Mir-21 Mission. Stabilographic and electromyographic characteristics of correctional postural responses to disturbances causing the loss of equilibrium were studied using an "Equitest" postural platform system (NeuroCom, International, Clackamas, OR). The preflight tests were performed approximately 30 days before launch, and the postflight tests were performed approximately 24 hours after landing.

Two types postural disturbances were used. The first one consisted of an unexpected forward displacement (5.70 cm in 400 ms) of the support surface (force plate) in the horizontal plane. The second one consisted of graded pushes applied manually (with the help of a special tensometric device) to a rigid plastic plate (10x15 cm) fixed on the chest. All tests were executed with the subject standing erect on the stabilographic platform force plate with eyes closed.

While testing, the following indices were registered: EMG of leg, thigh, back and, abdominal muscles, oscillation of COG, and quantitative characteristics of the disturbances. The EMG was registered using pairs of silver-silver chloride surface electrodes, the inter-electrode distance being 20 mm. The value of the oscillation of COG was calculated from raw data obtained from four force transducers that were mounted in the support surface and independently sensed the ground reaction forces applied by the front and the rear parts of each. The tensometric device contained an integral force transducer to quantify the applied load and duration of each manual push.

All raw data were displayed in real-time for experiment monitoring and were digitized and stored on a personal computer for subsequent data reduction and analyses.

RESULTS

After the space flight both cosmonauts showed increased electro-myographic activity during posture correction: the amplitudes of electro-myographic responses of all the tested muscles were considerably increased. At the same time there were fixed changes in the amplitude and temporal characteristics of the stabilogram: both the amplitude and duration of oscillation of the COG were higher in the postflight tests than in the preflight tests.

Thus, the results of the experiment (as well as the earlier works of Kozlovskaya et al., 1983, 1988, 1989, 1993) show that after space flight vertical postural stability is decreased and the mechanisms of vertical posture correction are disturbed.

In further analyses of the data our main attention was focused on the strategies used in performing movements and in evaluating the work of different muscular groups participating in each experimental movement. The data were processed with the use of cross-correlation between the integrated values of EMG of a muscle and the changes of the COG position in the sagittal plane over segments beginning at the start of the disturbance and continuing through the second crossing of the initial level by the oscillation curve of the COG. Since the experiment used two types of tests with maximal disturbances (chest pushes and translation of the support surface), it was possible to analyze the peculiarities of the responses with different organization of muscular coordination.

Analysis of temporal characteristics of muscular responses showed a decreased latency and an increased duration of muscular activity returning COG to the initial position.

Also differences were revealed in the organization of the antagonist muscles work and in the temporal order of their engaging. There was an increased tendency toward coactivation of muscles-antagonists during the movements performed after both types of postural disturbances.

CONCLUSION

It is shown that in Earth conditions (1-g) when using two types of disturbances causing the loss of equilibrium, correctional muscular responses have coordinated schemes. Just after a prolonged stay in conditions of weightlessness (0-g) the schemes of responses acquire common features and can be characterized by a simultaneous co-activation of antagonist muscles of the whole body.

THE USE OF INFLIGHT FOOT PRESSURE AS A COUNTERMEASURE TO NEUROMUSCULAR DEGRADATION

C.S. Layne¹, A.P. Mulavara¹, C.J. Pruett¹, P.V. McDonald¹, I.B. Kozlovskaya² and J.J. Bloomberg³.

¹KRUG Life Sciences Inc., Houston TX, ²Institute for Biomedical Problems, Moscow, Russia, ³Life Sciences Research Laboratories, NASA Johnson Space Center, Houston, TX

INTRODUCTION

Maladapted sensory-motor function and loss of muscle strength contribute to the motor performance decrements displayed by crewmembers returning from space flight. During space flight, the lower limbs and trunk are no longer required to maintain the neuromuscular activation necessary for weight-bearing or locomotion. Thus, the trunk and lower limb musculature experience a significant loss of strength during long-duration space flight. Although existing exercise countermeasures (e.g. treadmill and bicycle ergometer) reduce the magnitude of potential strength loss, crewmembers are required to spend a substantial amount of time exercising each day. An inflight countermeasure which would increase neuromuscular activation and use as a complement to existing countermeasures would be useful in attenuating the loss of muscle strength during long-duration space flight. Preliminary evidence obtained during Space Shuttle flights (unpublished observations) suggest that foot pressure when applied to free floating subjects increases neuromuscular activation above the levels observed without foot pressure. This study was conducted to determine if foot pressure applied to free floating subjects experiencing long-duration space flight could be used to enhance neuromuscular activation during voluntary arm movements.

METHODS

Three cosmonauts and one astronaut who experienced 3-4 months of microgravity aboard the Mir space station served as subjects for this study. While free floating, subjects aligned their body segments in the sagittal plane and then performed rapid right shoulder flexions with and without foot pressure. Pressure was supplied to both feet using a boot modified with pneumatic bladders in the insole. Data were collected on Flight Day 101 for two subjects and on Flight Day 69 for the other two subjects. Surface electromyography was used to collect data from selected lower limb, trunk and shoulder muscles. Tangential arm accelerations were obtained with a uniaxial accelerometer attached to a wrist splint. All data were saved to cassette tape and digitized upon return to Earth. For each muscle and subject, the EMG was bandpassed filtered (30-300 Hz), full wave rectified and then averaged within a window 300 ms prior to arm raise onset to 50 ms after completion of the arm movement. The average waveforms were then reduced to three epochs comprised of: 1) a preparatory period (300 milliseconds before arm movement initiation); 2) arm acceleration and 3) arm deceleration. Each epoch consisted of the sum of neuromuscular activity within the designated epoch. Pearson *r* correlation coefficients were calculated to assess the degree of waveform similarity between the "with" and "without" foot pressure conditions. Potential differences in activation amplitude were evaluated by comparing the level of activity within each epoch between the "with" and "without" foot pressure conditions.

RESULTS

Pearson *r* correlation coefficients revealed that the phasic muscle activation characteristics were quite similar between conditions with and without foot pressure (mean $r = 0.78$ SD=0.15). Muscle activation in the without foot pressure condition was severely reduced compared to activity levels obtained during arm movements made preflight in 1g. Comparisons of the sum of activity in each epoch between the inflight with and without foot pressure conditions revealed that, in general, during the arm movement (acceleration and deceleration epochs) foot pressure served to increase neuromuscular activation.

CONCLUSIONS

The results of this investigation strongly indicates that the application of foot pressure can enhance neuromuscular activity above the level normally observed in free floating subjects during voluntary upper limb movements. Furthermore, the response to foot pressure remains present several months into flight. Thus, the evidence suggests that foot pressure resulting in increased neuromuscular activation may be useful as a countermeasure to neuromuscular degradation during long-duration space flight.

Friday, June 13

Session FA4
Room 4
8:30 - 11:30 a.m.

533-93
074638

81.

326992

**Operational Aspects of Space
Radiation**

Solar Particle Events and the International Space Station

John Baker, ANSER, Suite 800, 1215 Jefferson Davis Highway, Arlington, VA 22202

Ron Turner, ANSER, Suite 800, 1215 Jefferson Davis Highway, Arlington, VA 22202

The high inclination orbit for the International Space Station poses a risk to astronauts on EVA during occasional periods of enhanced high energy particle flux from the sun known as Solar Particle Events. We are currently unable to predict these events within the few-hour lead time required for evasive action. Compounding the threat is the fact that station construction occurs during increasing solar activity and through the peak of the solar cycle. In this paper we present an overview of the risk, the current methods to provide forecasts of SPEs, and potential risk mitigation options.

Radiation Environment on Mir and ISS Orbits During the Solar Cycle

M.V. Teltsov, M.I. Panasyuk and V.F. Bashkirov

The main components of the radiation environment in near Earth space are trapped radiation, galactic cosmic rays and Solar energetic particles. Now it is evident that all of these species undergo long-term variations associated with the solar activity cycle.

Since the 60's Skobeltsyn Institute of Nuclear Physics performed measurements of dose radiation onboard all Russian piloted missions.

The set of experimental data which was obtained during these missions gave unique information on long-term variations of radiation environment at the altitude of "Mir" station and is applicable to the future ISS "Alpha" mission.

The data analysis leads to the conclusion that the radiation hazard for the crew really exists, and due to variations of trapped radiation in the South Atlantic Anomaly.

During the long period of solar minimum radiation doses reach maximum values because of the cooling of upper layer of the atmosphere. The results of numerical simulation of these processes based on modern models of atmosphere, plasmasphere and geomagnetic fields are considered and compared in this paper.

New approach to Radiation Risk Assessment

E. E. Kovalev, O. A. Smirnova

*Research Center of Spacecraft Radiation Safety
Shchukinskaya st., 40, Moscow 123182, RUSSIA*

Mathematical models are developed which describe the radiation-induced mortality dynamics for homogeneous and inhomogeneous (in radiosensitivity) mammalian populations. These models relate statistical biometric functions with statistical and dynamic characteristics of critical systems in specimens belonging to these populations. The model of mortality for the inhomogeneous population involves two types of distributions, the normal and the log-normal, of its specimens with respect to the index of radiosensitivity for cells of the critical system.

The mortality model for the homogeneous population quantitatively reproduces the mortality rate of laboratory mice after exposure to very high doses of pulsed or continuous radiation when the small intestine is the critical system. This model also describes quantitatively the mortality of the same animals chronically irradiated at low dose rates when the hematopoietic system (specifically, the thrombocytopoiesis) is the critical one. The mortality model for the inhomogeneous population predicts a higher mortality rate and a lower survival than it could have been predicted proceeding from the averaged values of the radiosensitivity index of the critical system cells. The level of doses and dose rates of acute and chronic exposures presenting a hazard to inhomogeneous mammalian populations is the lower the greater the variance of the corresponding distributions. For mammals having hyperradiosensitive precursor cells, even low-level radiation can have fatal consequences. These model results have considerable theoretical and practical importance since they outline new pathways in the development of methods of radiation risk assessment for planning the long-time space mission.

The work was funded in part by DNA/AFRRI (USA).

A INDUSTRIAL METHOD TO PREDICT MAJOR SOLAR FLARES FOR A BETTER PROTECTION OF HUMAN BEINGS IN SPACE

M.C.CALVET (Aerospatiale), J.BOURRIEU (ONERA/DERTS),
P.LANTOS (Observatoire de Meudon)

Taking into account the solar flare occurrences begin to be a real problem for manufacturers of on-board electronic equipments.

Aerospatiale encountered the problem during the development of Ariane 5 launchers, and was lead to propose an empirical method to predict, with a good accuracy, the occurrence of a solar flare, before deciding a launch, and more precisely the particle flares which are the most dangerous for human beings.

This method could be used for the future manned flights of the CRV program, in order to define more precisely the periods during which the passengers have must be protected from radiation.

In the present communication, we first recall general information on the star « SUN », its structure, what is defined as « solar cycle », and the description of the areas on the SUN surface as called « actives zones ».

We define next what are the mechanisms which signal the occurrence of a solar flare, and the electromagnetic waves which can be detected just before the event.

We then go through the specific case of particle flares (rich in protons and heavy ions), which are the most dangerous ones for human beings.

We examine the particle flares from the last three solar cycles, essentially through GOES information given by Boulder's prediction centre. We then propose criteria which could have announced the solar events; those a posteriori criteria are summerized, in order to define the most important ones.

We finally define procedures to de followed in order to predict solar particle flares, from an industrial point of view; i.e. by using directly the « Today's Space Weather », service proposed by the Space Environment Centre of Boulder(US).

The most important procedure is to follow the « Space Weather Outlook » and the « X-rays flux » figures. The indications for a major event leading to the emission of particles would be the occurrence of a special output on the X-ray flux.

This observation has been correlated to almost all the major events for the last three cycles.

This work has been supported by the French Space Agency, with the collaboration of such specialized scientific laboratories as ONERA/CERT and the French Solar Flare Prediction Centre of Meudon.

The validity of the identified criteria will be tested during the next solar cycle, for which maximum activity period will take place after 1997.

Description of the Space Radiation Control System for the Russian Segment of ISS

M.Panasyuk¹, A.Biryukov¹, A.Myasnikov¹, A.Akulin¹, S.Filipuchev¹, S.Svertilov¹, M.Teltsov¹,
V.Bashkirov¹,
A.Lobakov², V.Lyugushin²,
Ts. Dachev³, J. Semkova³, B. Tomov³, Yu. Matviichuk³, Pl. Dimitrov³,
V. Petrov⁴, R. Beaujean⁵, G. Reitz⁶

¹ *Institute of Nuclear Physics, 119899 Moscow Russia*

² *NPO «Energy» 141070 Korolev Russia*

³ *Solar-Terrestrial Influences Laboratory, 1113 Sofia, Bulgaria*

⁴ *Institute of Biomedical Problems, 123007 Moscow, Russia*

⁵ *Institute fuer Kernphysik des Universitaet Kiel, Olshausenstr. 40/60, d-24118 Kiel, Germany*

⁶ *DLR, Institute fuer Luft-und Raumfahrtmedizin, Linder Hohe, 51140, Cologne, Germany*

The Space Radiation Control System will be developed to be placed at large inhabited space objects with a long living time. System will consist of:

- 1. Radiation Environment Modeling Unit** accepts the ballistic parameters from the board systems (once per circuit) and object orientation information (continuously). Basing on the implemented Earth Magnetosphere Counting Model, the Unit calculate the estimated profile of the radiation intensity per 24 hours forward, and passes it by cosmonauts request to the board indication units, in a graphics form. The Unit uses the solar activity data, received from Earth in the counting process;
- 2. Stationary Dosimeter (DOSTEL)** is used for radiation dose measurements in the internal volume of the object with high sensitivity. Detector part consists of two silicon detectors (600 mm² each) with thickness of 0.3 mm, placed one under another in 15 mm distance;
- 3. Penetrating Radiation Spectrometer** is placed outside of the object. It measures the flux and the spectrums of electrons with energies of 0.1 - 10 MeV, protons and nucleuses with energiies of 1 - 200 MeV/nucleon, an x-rays with energies of 10 - 100 keV. Dynamic range of the counting rate is from 10⁻² to 10⁵ particles per second. The purpose of unit is the monitoring of the magnetosphere particle population. Detector part of the unit is based on a CsI(Tl) crystal and CsI(Na) crystal. Passive and active shield from the plastic and Pb glass, so as the method of front-based pulse division, allows to register the different types of particles separately.
- 4. Mobile Radiation Exposure Control Subsystem (MRECS)** main purpose is to be monitored simultaneously the doses and fluxes at four independent places of the segment. In case of special study the subsystem can be used for personal monitoring of the doses and fluxes obtained in 5 days by 4 selected cosmonauts. The subsystem consists of 4 Mobile Dosimetry Units (MDU), 4 Stationary Dosimetry Units (SDU) and one Control and Interface Unit (CIU). Further developments of the subsystem will allow extending of the number of MDUs, SDUs and ICUs up to 64.

All units of the Radiation Control System are connected with board systems by the Ethernet network. Information from dosimeters and spectrometers of the System, and the results of modeling, are passed to the Earth, to define the model correctness. The model coefficients can be corrected from Earth.

Orbit Selection and Its Impact on Radiation Warning Architecture for a Human Mission to Mars

Joshua Levine, Representing Thomas Jefferson High School for Science and Technology and ANSER, Suite 800, 1215 Jefferson Davis Highway, Arlington, VA 22202

Ron Turner, ANSER, Suite 800, 1215 Jefferson Davis Highway, Arlington, VA 22202

With the recent announcement of the discovery of the possibility of life on Mars, there is renewed interest in Mars missions, perhaps eventually in manned missions. Astronauts on such missions are at risk to occasional periods of enhanced high energy particle flux from the sun known as Solar Particle Events. These events can pose a substantial risk to the health of the astronauts and to the on-board electronics. Effective forecast and warning of these events could provide time to take steps to minimize the risk (retreating to a safe haven, shutting down sensitive equipment, etc.) Providing that forecast capability will require additional monitoring capability. The extent of this architecture is sensitive to the orbit selected for the transfer to and from Mars. This paper looks at the major classes of Mars missions (Conjunction and Opposition) and sub-categories of these classes and draws conclusions on the number of monitoring satellites needed for each, with a goal to reducing total system cost through optimum orbit selection.

**Space Nuclear Power:
Technology, Policy and Risk Considerations
in Human Missions to Mars**

*Victoria P. Friedensen
Aeronautics and Space Engineering Board
National Research Council, HA 292
2101 Constitution Ave., NW
Washington, DC 20418*

This paper discusses the disconnect between the stated requirement for nuclear propulsion and power systems for human exploration of Mars and the current status of R&D funding for these technologies. Mission planners and spacecraft designers, energized by the recent claims of possible discovery of life on Mars and responding to increased public interest in the crewed exploration of Mars, frequently propose nuclear reactors for interplanetary spacecraft propulsion and for power supply on the surface of Mars. These plans and designs typically assume the reactors will be available “on-the-shelf,” and do not take the extensive research and development costs required to develop such reactors into consideration. Current U.S. policies, if unchanged, will prohibit the launch of nuclear reactors.

Recent work by the National Academy of Sciences on space nuclear reactors is reviewed and recent Congressional action canceling the last U.S. research program supporting this technology is addressed. Radiation risk to humans from nuclear powered spacecraft and nuclear power systems on the surface of Mars is considered. The current state of nuclear space technology is discussed and possible necessary changes in the policies of the United States to allow the development and launch of crewed nuclear powered spacecraft are proposed.

Wednesday, June 11

Blue Room
2:30 - 5:30 p.m.

Poster Session

534-52 ✓

074 639
CLOSE

326993

181.

J. F. DeFrance, J. Degioanni, C. Hymel, F.C. Schweitzer, S. Estes, R. Calkins, F. Kutyna, and I. Tarkka. **Development of correlative measures for the assessment of attention and memory.**

This project¹ developed a collection of performance paradigms to detect subtle changes in attentional and memory processing, and established baseline profiles with more than 50 normal volunteer subjects. The tasks were specifically designed to be provocative of frontal and temporal lobe pathways, and the initial emphasis was upon establishing task *sensitivity*, *validity*, and *reliability*. The central concept is that prolonged stress can induce physiologic changes along the prefrontal-temporal lobe axis - which can be manifested as changes in a person's mood, ability to sustain attention, ability to suppress unwanted behaviors, alertness to the environment, and ability to handle interfering information. Since isolation, confinement, and circadian rhythm changes are stressors, the implication is that astronauts are likely to exhibit psychological changes will appear as cognitive difficulties, such as attentional and memory lapses. The tasks and procedures were designed to have ecological validity for monitoring human performance in a variety of remote and isolated conditions - including *space* by combining behavioral (e.g., performance) measures with simultaneously acquired EEG/ERP components. The performance battery provides important information related to response accuracy and reaction time. The EEG analyses focuses on the spectral content, while the ERP studies focused upon both *automatic* (e.g., N150, P200) and *controlled* (e.g., P300, N400) components.

There is a confluence of research suggesting that stress due to isolation, or lack of normal circadian timing cues, can lead to a decline in the ability to perform complex tasks - most often within the domains of attention/concentration and memory. Thus, the end product was essentially a specific set of protocols, with enhanced diagnostic capability, ideal for continuously monitoring for the onset of difficulties with attention/concentration and memory. This will be extremely useful in isolated environments as expected in habitats such as a space station or a lunar base, and would be capable of being developed into an ambulatory, non-invasive diagnostic aid to understand psychological mechanisms for coping with environmental stressors.

Attention and memory functions are the result of a complex interaction of discrete brain systems, so their study is optimally addressed through a multifaceted approach. The final performance battery consisted of seven basic performance tasks, plus alternate forms suitable for repeated testing. They were designed to determine an individual's capacity for sustaining attention (i.e., vigilance), consistency of performance, effectiveness of meaningful stimuli, freedom from distractibility, willingness to exert effort, sensitivity to interference, and learning curves. Both *implicit* and *explicit* memory functions are sampled. Finally, a model of attentional processing was also developed, as well as exploration of ERP dipoles with BESA.

A continued search for the physiological boundaries of the various forms of attention and memory disorders is needed because of symptom overlap with certain affective disorders, such as anxiety and depression. Also, the capacity for accurate performance monitoring is vital for ensuring NASA personnel safety and successful missions, and has great health care implications for the general population.

¹ Supported by NASA #NAG9-413

Biodynamical Responses of the Crewmember Head / Neck System During Emergence Ejection

T. He, Ronald L. Huston, Dajun Zhang
IAIR, University of Cincinnati, Cincinnati, Ohio 45221

Abstract

An efficient method for gross motion simulation of a crewmember in aeronautical force environment is presented. The method is a modification of SUPERCRAASH victim simulation code. It is designed for study and analysis of the dynamical responses of a crewmember on ejection propeller shock and windblast during emergence ejections. Using the method, together with experimental data, we obtained the relative trajectories, relative velocities and relative accelerations of crewmember head mass center, angular velocities and angular accelerations of crewmember head and neck, and joint reaction forces acting on each body at the moment out canopy in different Mach Number and different constraint configurations. These response parameters are then applied to analyzing Head Injury Criterion(HIC) values and comparing with nontraditional measures of head injury as affected by combinations of rotational and translational motion. Some conclusions and recommendations about this approach to studying crewmember dynamics in aeronautical force environment are presented.

FECUNDATION IN THE SKY : A TEN YEARS OLD EXPERIMENT IN MICROGRAVITY .

Luc Henriët , Université de Louvain , Belgium .

INTRODUCTION.

To throw male and female gametes in the space could seem to be a strange idea as well as to make mustard in weightlessness , few reasons suggesting that the results should differ from terrestrial accomplishments . The fecundation indeed , occurred on the earth and endures since millenaries . Precisely , because such a performance , fecundation experiments in microgravity will seem less strange when one is thinking that the whole world life is entirely sustained by the fecundation ; the fate of all the living beings of all the species , the human species included , is closely linked with their reproduction capacity . Likewise , this ability holds in his power the solution for the heavy world hunger problem .

Moreover , for the scientists , the penetration of one cell in an other cell appears as an exceptional fact ; this fact results of a long serie of chemical and physical reactions , some of these are clearly explained , some are not well definite , many remains unknown .

The monospermy , excluding all he spermatozoa except one , illustrates a recently open field of researches for the medical and zoological sciences : the factors of attachment and of non-attachment .

On another hand , considering the efficiency of the fecundation , it must be said that , in the mammals , the success rate is not admirable : the survival rate reaches a little 50 % . All increasing method should be welcome .

Considering gravity and microgravity , it may be said that spermatozoa and oocytes are little , microscopic beings , but they have a weight and they undergo uncaesingly , throughout the genital tracts , the law of gravitation ; this fact increases in importance since the probability of an extraterrestrial life increases the preoccupations of the astronomers . If the probability becomes a certitude , the gravity should be considered as a variable parameter for the fecundation .

Finally , opposite to microgravity experiments , centrifugations of sperms samples revealed that an increased gravity is injurious for the spermatozoa , the tails agglutinate in an inextricable network imprisoning all the cells .

Experiments of fecundation in microgravity don't appears so as a vain and luxurious amusement but as offering a large field for intersting investigations .

MATERIAL & METHODS .

1. The Species and the Gametes .

Gametes issued out bulls and cows of the breed "Blanc Bleue Belge" were selected because this material is easy obtainable and also because of the precise fertility controls performed in the artificial insemination centers . Highest fertile sperm samples were stored in liquid nitrogen until the ultimate moment before the flight . Oocytes were carefully picked out ovaries and cultured in an " artificial heart-lung-kidney system (5) ; the morning after , they were transfered with culture medium in a test tube maintained at 38,5° C. in a thermos .

The reunion of the gametes happened , the same morning , at the aerodrome , the semen being added to the test tube after thawing , all togheter was confided to the aviator and embarked in a Fouga Magister

2. The Flights.

The aviator described 15 parabolas during 25 -30 seconds each . After landing , the test tube was immediately cooled and transfered to te laboratory for a first examination under a Normanski phase contrast microscope , and later the gametes were fixed for an examination under electron microscope .

THE RESULTS .

The first experimental flight happened at 4 March 1987 . 23 oocytes were recovered after landing , numerous spermatozoa were found surviving without agglutination , 4 oocytes showed signs of degeneration , 3 oocytes showed the first stages of fecundation (cytoplasmic retraction , expelling of polar body .)

These numbers are considered as normal .

The flights were repeated three times with comparable results , no special disturbance was detected to.

CONCLUSION .

The in vitro fecundation don't seem suffering of short and repeated microgravity periods . That is to be compared with the effects of the increased g during the centrifugation . That can be also compared wit the results on the Earth and can be used as a comparative experimental field .

From a practical point of view , the price of a minuscule flap-seat in a space vessel hinders many original experiences ;this parabolic flight demonstrates that some could be performed at lower cost ; fortunately the gametes seems to be an ideal material :easy obtainable , cheap , extremely little , .(about 20.000 can be lodged into the volume of a ring bezel) ,that all together involves a lighten embarkment material . Moreover , the spermatozoa shows instantaneously that the life conditions are favorable or not and that ,without any hard or long manipulations .

All the here above mentioned problems were of course not solved or elucidated , these immense task asks more and more parabolas . But unwanted researches join the same field as for instance , the experiments carried out by the laboratories Helena Rubinstein (beauty products) , in microgravity with as purpose the study of the factors of attachment and non-attachment at the level of the membranes (4.)

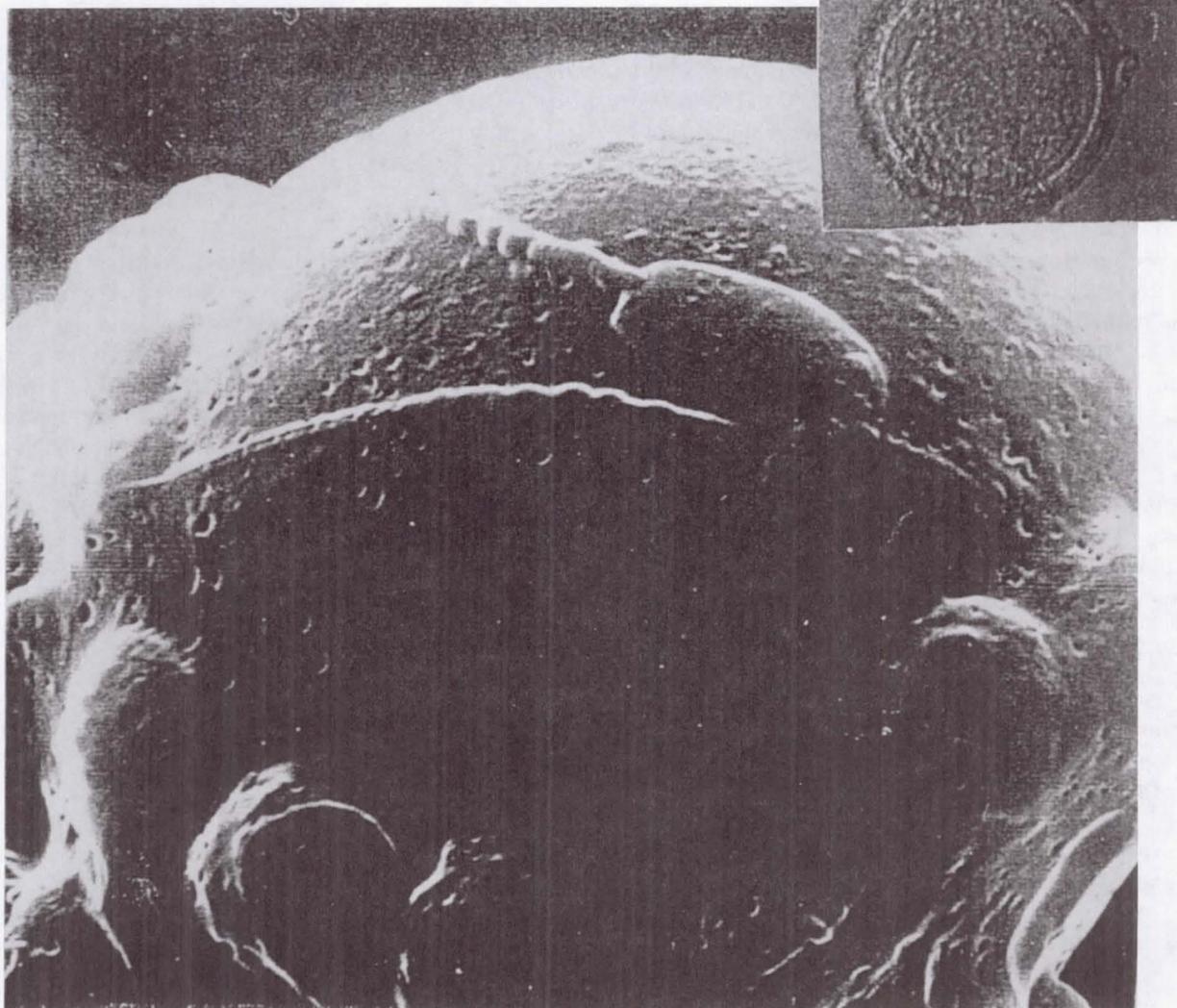
BIBLIOGRAPHY .

1. **Bloc Notes** :Première belge en microgravité, 1987 p.24 .
2. **Space Daily** :Biospace technology announces 1st successfull test flight ,Brussel ,Thursday 9 April 1987 .
3. **Henriet L** ,Athena , La fécondation dans l' espace ,n° 32 June 1987 , p.45-50.
4. **Trends Tendances** , 6 Octob. 1988 .
5. **Henriet L, Hulhoven D , Seynaeve V , Maion J-H** ,10 th Internat. congress on animal reproduction and artificial insemination , Urbana Chmpaign ,14-6-84 ,p.227-229 .

FIGURES : Oocytes fertilized in the space(phase contrast) and penetration figure (electron microscopy)

MAILING : stadsvest , 57--3012 Wilsele

Belgium .



A MODIFIED BOTEX INCUBATOR AS A TRANSPORT SYSTEM FOR DEVELOPING CRICKETS INTO SPACE

E. Horn¹, S. Pfalzer¹, P. Riewe¹, C. Sebastian¹, G. Kämper², U. Friedrich³ and P. Junk⁴

¹Department of Neurology, Gravitational Physiology, University of Ulm, D-89081 Ulm, Germany; ²Department of Neurobiology, University of Ulm, D-89081 Ulm, Germany; ³DARA German Space Agency, D-53227 Bonn, Germany; ⁴OHB System, D-28359 Bremen, Germany

INTRODUCTION

Specific scientific problems demand suitable animal models for their solution. In gravitational physiology research, however, also suitable transport systems are necessary, which enables the scientist to expose his samples to micro- or hypergravity for many days or weeks. With crickets as the animal model and the modified incubator BOTEX as the necessary transport system, a suitable combination is available which allows to investigate questions on development and regeneration of gravity sensitive sensory systems and the underlying neuronal network. - Why crickets are useful animals? Their gravity sense organs and related responses are well defined; they possess two roll sensitive interneurons which can be identified by neurophysiological recordings; the gravity sensory system is able to regenerate under earth- and hypergravity conditions. - What is the advantage of the BOTEX incubator so that modifications were useful? BOTEX (Botany Experiments), originally developed for investigations in the field of botany, offers a large space to transport many subjects; it is also equipped with a 1g-reference centrifuge. Here, we describe some modifications of this incubator and present test experiments with crickets to demonstrate the usefulness of this system.

METHODS

BOTEX modifications included the development of survival conditions in closed mini-containers (CRIC1 to CRIC4) and a proper temperature range control. The system was tested several times in experiment verification tests (EVT) performed in the course of the preparation of the experiment CRISP (Crickets in Space) which will be flown on NEUROLAB. Eggs, 1st, 4th and 6th instar larvae were brought into the closed BOTEX incubator for 20 days at a temperature of 27 ± 1 °C. The usefulness of the system was demonstrated (i) by animals' survival rates, and (ii) their moult numbers during the 20-days period.

RESULTS

It was found that cricket larvae up to the 5th instar which were supplied only with autoclavated rat food pellets, 2 ml water and a piece of filter paper can be reared in tightly closed Petriperm dishes with an internal volume of 25 ml for at least 20 days. At least 50% of the larvae survive in these mini-containers. The highest survival rates were seen if the number of individuals were between 6 and 10 per Petriperm dish. The optimal number depended on the age at the beginning of the development in the closed system. Hatching from eggs occurred at a similar percentage. Larvae performed a mean number of 3 moults. Gravity related responses, recorded after these rearing procedure, were similar to that observed in the instars which developed under standard laboratory conditions. The survival rate and number of moults recorded from crickets after the 20 days lasting 3g-condition was at the same level as that in the 1g-reared controls. The modified BOTEX incubator allows the transport of 80 Petriperm dishes used for the μ g- or hg-samples. Under space conditions, 30 dishes for the inflight 1g-control, 20 for a 0.7g- and 10 for a 0.3g-condition are also available. There is additional space for 8 larger containers of 415 to 625 ml volume for the transport of stage 6 and older instars under μ g-conditions. Tests with these containers demonstrated similar survival and moulting rates.

CONCLUSION

The transport of insects, used as experimental models to study basic phenomena of developmental biology, under hypergravity conditions can be performed in an extremely reduced ecological environment for at least 20 days. The developed procedure will be used to transport eggs and larvae of crickets into space on NEUROLAB in 1998. The aim of the project CRISP is to study the effect of gravity deprivation (i) on the morphological and functional development of neurons with well-developed gravity sensitivity and (ii) on the morphological and functional regeneration of a gravity sensory system. The principles of the CRIC containers and the feeding strategies can be applied even to other animals as well as to other space-tested transport systems.

Supported by the German Space Agency (DARA), grant no. 50WB9543 to E. Horn

CHROMOSOMAL ABERRATIONS IN PERIPHERAL LYMPHOCYTES OF COSMONAUTS AND ASTRONAUTS AFTER SPACE FLIGHTS

G. Obe, I. Johannes, N. Heckeley, K. Hallman
Department of Genetics, University of Essen, 45117 Essen, Germany.

INTRODUCTION

The analysis of chromosomal aberrations in peripheral lymphocytes of exposed persons is the only feasible method so far to assess mutagenic activities of environmental agents *in vivo* in man. Many of the radiation types occurring in space can only approximately be simulated on earth (e.g. heavy ions, protons, HZE particles). Therefore the relative biological effectiveness (RBE) for many radiation types in space are not well determined and some of them could have been underestimated.

METHODS

The normally used method to determine radiation exposure and to assess the received dose is scoring of chromosomal aberrations in phytohemagglutinin stimulated peripheral lymphocytes from venous blood. Chromosomal aberrations can be classified as so called "unstable chromosome aberrations", namely dicentric and ring chromosomes and the "stable chromosome aberrations" such as insertions and translocations. The latter type of chromosome aberrations normally allows the affected cells to proliferate and eventually to form cell clones. Stable aberrations can be analyzed by the method of fluorescence *in situ* hybridization (FISH) of selected chromosomes. We performed our investigations with the peripheral lymphocytes of astronauts and cosmonauts before launch and directly after return.

RESULTS

Significant elevations of the frequencies of chromosomal aberrations (dicentric and ring chromosomes) were found in the peripheral lymphocytes of astronauts from MIR missions '94-'95. Using FISH stable aberrations were found, but the data do not allow statistical analyses up to now.

CONCLUSION

Radiation in space leads to chromosomal aberrations in the peripheral lymphocytes of astronauts and cosmonauts. Our data indicate a mutagenic risk of space flights.

METHOD FOR ESTABLISHING LONG TERM BONE MARROW CULTURES UNDER MICROGRAVITY CONDITIONS

N.N. Khan, S.O. Fadulu

The Department of Biology, Texas Southern University, Houston, Texas 77004

INTRODUCTION

Exposure to microgravity leads to physiological abnormalities. The exact cause of these conditions has yet to be determined. In order to simulate spaceflight conditions here on earth, we have established long term bone marrow cultures under microgravity. These cultures are compared with a control containing bone marrow grown under normal tissue culture conditions.

METHODS

Using a hemocytometer, cells from 1 ml of normal human bone marrow are quantified. Trypan blue is used to check for cell viability by dye exclusion. Bone marrow is now resuspended into 9 mls of media (IMDM with 10% fetal calf serum and 10% fetal horse serum) and placed into the 10 ml HARV vessel of the *Synthecon* bioreactor. The speed of the bioreactor is maintained at a rate in which cells are visibly suspended. They are maintained in a 5% CO₂ tissue culture incubator at 37°C and 99% humidity. A control is set up in a 75 cm³ flask, containing 1ml of normal bone marrow and 9 mls of media. After six days culture is measured. Small aliquots are removed to test for changes within culture. Culture should be established in one to two weeks within control flask.

RESULTS

Initially, 2.08×10^6 /ml cells are placed under microgravity conditions as well as into control flask. After six days, the microgravity induced tissue culture yielded 3.0×10^5 /ml cells, this being an 86% decrease. The control flask contained 2.9×10^6 /ml cells, a 39% increase.

CONCLUSION

Spaceflight conditions appear to decrease cell growth potential, and infer that the necessary biological processes for normal cell proliferation are gravity dependent. Further testing in which time period for testing is increased should substantiate these results.

Acknowledgments:

This research is funded by a National Aeronautics and Space Administration grant "Microgravity and Sickle Cell Anemia" Grant Number: NAG 9-682. Special thanks to Astronaut Ellen Baker, MD, the technical advisor for this project.

References:

Chang J, Morgenstern G, Deakin D, Testa N, Coutinho L, Scarffe J, Harrison C, and Dexter T. "Reconstitution of Haemopoietic Systems with Autologous Marrow taken During Relapse of Acute Myeloblastic Leukemia and Grown in Long -Term Culture"(1986): *Lancet*. 1: 294-5.

Davis TA, Wiesmann W, Kidwell W, Cannon T, Kerns I, Serke C, Delaplaine T, Pranger A, and Lee KP. "Effect of Spaceflight on Human Stem Cell Hematopoiesis: Suppression of Erythropoiesis and Myelopoiesis"(1996): *J. of Leukocyte Biology*. 60: 69-76.

Fadulu SO. "Composition and Method for Treatment of Hemoglobinopathies"(1995) United States Patent: 5,447,720 September 5, 1995.

REPRODUCTION UNDER SIMULATED WEIGHTLESSNESS ---MAMMALIAN *in vivo* EXPERIMENTS UNDER SUSPENSION---

T. Kinoue¹, M. Ito^{1,2}, S. Kita², Y. Ohira³, R. Hashizume², H. Katoh⁴, N. Yamaguchi¹, R. Maru¹,
and K. Yajima¹

¹Department of Hygiene/Space Medicine, Nihon University School of Medicine, 30-1 Ohyaguchikamimachi, Itabashi-ku, Tokyo 173 JAPAN, ²Department of Bioproduction, Faculty of Bioindustry, Tokyo University of Agriculture, ³Department of Physiology and Biomechanics, National Institute of Fitness and Sports,

⁴Department of Pathology, The Jikei University School of Medicine

INTRODUCTION

A tail-suspension model to simulate weightlessness has been widely used for studies of physiological changes not only of the musculoskeletal system, but also of the cardiovascular system. In this study, we applied this model in order to investigate whether it is possible or not for male spermatogenesis to occur, and for female rats to maintain pregnancy on this model.

METHODS (Table)

Experiment 1

Adult Sprague-Dawley rats (2 male, 30 female) were utilized in the study. Male rats were suspended with the right inguinal canal ligated loosely for 14 days, and female rats were suspended after copulation (the day when spermatozoa were identified on a smear from a female rat referred to as Day 0 for her in this paper). Duration of suspension of female rats was chosen dependent upon events to be confirmed in the course of pregnancy. To demonstrate the effect of suspension on implantation, the first and second groups consisted of non-suspended rats penetrated at the base of the tail in the same way as suspended rats, and the rats suspended during the former half of pregnancy. The third and the final groups consisted of rats suspended during the latter half and throughout the pregnancy, respectively.

Experiment 2

To confirm our hypothesis, female rats were suspended throughout the pregnancy again but for this time they had been suspended for a week beforehand. A week after presuspension ended, the rats were copulated and suspended again. Morphological analysis of young was performed in search of teratism.

Experiment 3

Eggs were collected by flushing the oviducts and the uteri of female rats after they were mated and suspended as described in Experiment 1 until around Day 4. Then the eggs were observed under a stereo microscope and the stages of embryo development were determined.

RESULTS (Table)

Histological analysis of male rat testes showed that the testes on the ligated side were scarcely impaired, while the others were degenerated presenting similar appearances of cryptorchidism. Levels of serum testosterone were lower than control values. Although these findings were seen in literature, in the present study we treated the one side of testes and left the other of the same animal unligated, of which the results mean the testis was degenerated mainly by local high temperature rather than by humoral factors. As for female rats, implantation occurred in Experiment 1, and from Experiment 3 we knew that the preimplantation embryos developed to the morula/blastocyst stage without delay even if the mother was suspended. In Experiment 1 the third group rats failed to deliver, but if the rat was suspended throughout the pregnancy, it succeeded in parturition. To corroborate this result that the longer the suspension period, the easier the delivery would be, we carried out Experiment 2, which resulted in accordance with our hypothesis. Macroscopically, newborn young seemed normal. Details of morphological analysis will be presented at the conference.

CONCLUSION

Several models to suspend animals were known and they were said to bring about stress to the animal to some extent. However, in this study it was indicated that a tail-suspended rat, if it was acclimatized to its environment, could succeed in parturition. By employing this model, we can certainly elucidate some new aspects of mammalian reproduction in space.

Table. Experiments and Results (female rats)

Experiment (n)	presuspension	suspension	results
Experiment 1 (20)	-	-	control
	-	Days 0-12~	implantation occurred
	-	Days 10-20~	parturition unsuccessful
	-	Days 0~22	parturition successful
Experiment 2 (5)	7 days	Days 0~22	parturition successful (easily)
Experiment 3 (10)	-	Days 0~4 1/2	Early development of embryos was normal.

TOWARDS HUMAN MOVEMENT ANALYSIS WITHOUT THE USE OF MARKERS

F. Marzani¹, T. Pozzo², L. Legrand¹ and M. Venet³¹Laboratoire d'Informatique Medicale, UFR Medecine, Universite de Bourgogne, 7 Bd J. d'Arc, F21033 Dijon cedex, France²Groupe d'Analyse du Mouvement, UFR STAPS, Universite de Bourgogne, B.P. 138, F21004 Dijon cedex, France³CNES, Agence Française de l'Espace, 18 Ave E. Belin, F31055 Toulouse cedex, France

INTRODUCTION

Among the different applications of human motion analysis, the study of humans in weightlessness conditions leads for example to the understanding of the role of the gravity in the control and the coordination of movements by the nervous system.

A few years ago, the quantitative analysis of human motion was done by chronographic techniques. Nowadays, the systems of motion analysis give a description of the kinetic and the dynamic parameters of tri-dimensional human motions in time. Unfortunately, available systems are based on the tracking of markers located on the human body. This is the case of the 'Kinelite' system based on the real time recognition of reflective passive markers : a set of few cinecameras acquires digital sequences of binary images ; the tracking of these sequences allows a tri-dimensional reconstruction of the motion of the markers. Consequently, the human motion analysis is limited to the study of the kinetic and the dynamic parameters of the markers.

The aim of this work is the analysis of human motion in the tri-dimensional space without using markers. The method we propose uses gray level image processing techniques. It maps a tri-dimensional model on the images of the body in motion acquired by three cinecameras ; this volumetric model, which can be seen as a mathematical description of the movement of the human body during the time, allows the extraction of the right parameters of human motion. In order to facilitate the understanding of this method, we first describe it in the bi-dimensional case at the beginning of the following paragraph ; the tri-dimensional extension is then briefly approached.

METHODS

We have a sequence of digital images which represents a human body (or a part of it) in motion.

First of all, we apply an optical flow technique for determining an estimation of the displacement of each picture element (pixel) between each pair of successive images. We obtain a sequence of displacement vectors field by this process with differential methods based on the spatio-temporal changes of the gray levels. The largest displacements are obtained along the boundaries in motion.

Then, a segmentation stage is processed on the displacement fields. This segmentation consists in the extraction of pixels having a large estimate displacement compared to their neighbors. By seeing each point of a displacement vectors field as a geographic point with an altitude proportional to its displacement magnitude, the sets of extracted points are the crest lines of this virtual tri-dimensional map. So, we obtain a sequence of sets of points which represents roughly the boundaries of the objects in motion in our scene at any moment.

The next stage is the matching between each cloud of points with a model. With this end in view, we use a volumetric model and each member of the human body is described by an object. In the case of the study of a leg, three objects are necessary to describe the thigh, the calf and the foot. We notice that this decomposition can be made finer in accordance with the study. We chose the superquadric curves, the equation of which is recalled below, as the model of a member.

$$F(x, y) = \left(\left(\left(\frac{x}{a_1} \right)^{2/\varepsilon} + \left(\frac{y}{a_2} \right)^{2/\varepsilon} \right)^\varepsilon \right) = 1.$$

By making vary the coefficient ε , we obtain a rectangle when ε is close to 0 and a diamond-shape when ε is equal to 2. We can remark that $\varepsilon=1$ gives an ellipse with a_1 and a_2 the values of the radii.

Finally, we solve the matching between each cloud of points and the superquadric-based model by using a fuzzy clustering technique. It consists in the minimization of the following equation :

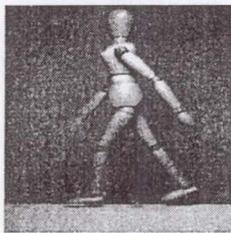
$$\sum_{c=1}^{nb_clusters} \sum_{p=1}^{nb_points} \mu_{cp}^m \cdot D_{cp}^2,$$

with $\mu_{cp} \in [0, 1]$ being the fuzzy membership of the point p to the superquadric c and with D_{cp} being the distance between this point and the superquadric curve. The solution of this non-linear system gives the parameters of the superquadrics which fit at best with the set of points. This system of equations is iteratively solved and is initialized at each step with the results obtained at the previous step. This method does not require any operator's action since the computer knows the model and its rough initial position.

The tri-dimensional procedure consists in matching at any moment the three bi-dimensional contours computed from three different calibrated cinecameras with different points of view in order to build a tri-dimensional volumetric model based on tri-dimensional superquadric objects. Let us notice that this reconstruction procedure requires some tests of coherence : first, a spatial coherence test in order to respect the geometry of the human parts, each part being taken independently and then considered with its interactions with the other parts ; secondly, a temporal coherence test in order to ensure the dynamic laws of the human body. Finally, this tri-dimensional model takes into account each of the bi-dimensional contours issued from the calibrated cinecameras, while respecting the geometric and the dynamic spatio-temporal laws of the human body motion. Such a tri-dimensional model may be animated and allows the relevant searched parameters to be calculated.

RESULTS

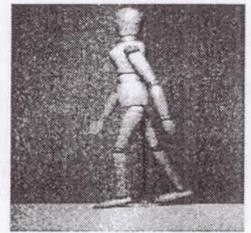
We complete now the tri-dimensional reconstruction. The images presented below represent the movement of the bi-dimensional models obtained with and without markers, applied to the motion of a mannequin's left leg. The left stick figures are built by linking the markers located at the joints. In the case of our approach at the right side, we obtain a decomposition of the leg in three volumetric objects. So, this model allows a more precise extraction of dynamic parameters compared to the markers-based technique.



time 0

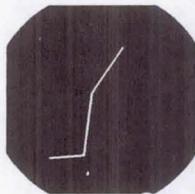


time t

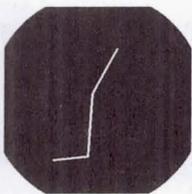


time N

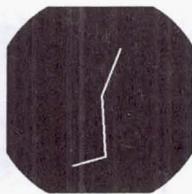
initial sequence



time 0

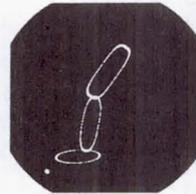


time t

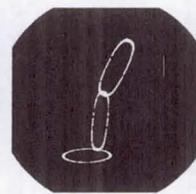


time N

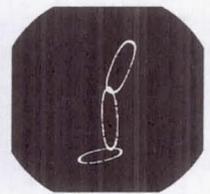
markers-based model



time 0



time t



time N

superquadrics-based model

CONCLUSION

We have presented in this paper a new approach for analyzing human motion in space without the use of markers. Unlike the present systems of motion analysis with markers which require a preliminary step in order to stick markers accurately, the proposed approach first does not require this delicate stage, secondly ensures a repeatability between operators and thirdly, is less sensitive to the changes of the illumination of the scene.

The presentation of this new approach is followed by some bi-dimensional results. They are encouraging but perfectible : however, in a near future, a further development of the reconstruction procedure will allow a presentation of tri-dimensional results with the respect of the geometric and the dynamic laws of the human body in motion (previously called tests of coherence) which are done during this reconstruction procedure.

The first results of the comparison between the parameters obtained with the markers-based method and those obtained with this method allow us to be optimistic as for the future of this study of feasibility as a new generation of kinesigraph.

HABITABILITY REQUIREMENTS FOR A COGENT MARS MISSION

Susmita Mohanty

Industrial Designer, International Space University, Strasbourg Central Campus, Parc d' Innovation, Boulevard Gonthier d' Andernach, 67400 Illkirch-Graffenstaden, France

ABSTRACT

New goals set for the U.S. Space Program focus on re-establishing the human presence on the Moon and sending the first manned mission to Mars in the 21st century. The necessary first step in supporting these goals is identifying habitability requirements that drive the development of new technologies.

This paper reviews long duration Space stay experiences of the American astronauts of the Shuttle-Mir missions and even some Russian cosmonauts who have been in Space for extended periods of time. It critically analyses the habitability requirements planned for International Space Station Alpha.

It takes a look at the Martian landing sites, climate, surface chemistry, radiation, temperature, water and volcanism. It then goes on to analyse and synthesise key habitability requirements for a Mars mission given the current planning, transit times, communication constraints, crew compliment etc. Key habitability issues include environmental factors, architectural/design issues, medical/health concerns, psychological issues, life-support mechanisms, sociological and cross-cultural issues.

It also proposes "testable" habitability principles for the BIOPLEX (a 90-day confinement experiment to be conducted by NASA later this year) and the International Space Station Alpha.

THE SAUCER CONCEPT FOR SPACE HABITATS

Susmita Mohanty

Industrial Designer, Student-Master of Space Studies Program 96-97, International Space University, Strasbourg Central Campus, Parc d' Innovation, Boulevard Gonthier d' Andernach, 67400 Illkirch-Graffenstaden, France

ABSTRACT

After more than 30 years of manned Space flights, when the idea of colonising beyond the earth seems only an extension of the present, it is time we went beyond the pure purpose of technology to *humanise the design of our Space habitats*. Both existing (Mir) and planned (Alpha) enclosures are tubelike, cramped and present a hostile environment for long duration stays.

This paper proposes a *change in paradigm*--from the *capsule to the saucer*. These two shapes are compared and analysed for environment perception, comfort and movement, work and living space, human ecology and safety. Piecemeal construction of the saucer has been detailed out. Floor plans for the habitation deck have been proposed and two sample designs for interiors included. It is envisaged that the astronaut be a key member of the design process. The ways in which spaciousness will enhance the quality of life aboard our Space habitats, have been discussed.

NEW WAY IN MODELING THE GROWTH OF THE ORGANISM

L. Novák, emeritus professor of physiology, Medical Faculty, Masaryk University Brno, Srbská 15a, 612 00 BRNO, Czech Republic

INTRODUCTION

Modeling the body mass growth, in relation to the nourishment, motor activity and the influence of various stressing factors, represents a very important question so far the body mass development of a man and animals are concerned. The classical growth functions of Gompertz, Robertson, Bertalanfy, Richards, and also the methods of the linear or non-linear regression analysis, often used to the construction of the growth curves, describe the body mass growth of the organism formally, as a pure mathematical function of time. The common denominator of all above mentioned growth functions is that the coefficients forming the course of the growth curves, have none direct relations to the mechanisms taking part in the transformation of the feed ingested, to the mass of the product formed. These coefficients must be calculated only from the experimental growth values and therefore their validity is limited.

New methodical approach named selfregulating growth model (SGM), (Novák 1996), generates the growth curve independent on the growth of the control group of individuals belonging to the defined species under investigation. The calculation of the growth values occurs from the input data characterizing the organism, its nourishment, its basic biophysical parameters and the cooling power of the environment.

METHODS

Selfregulating growth model, generates the growth curve from the differential of the body mass (dG), and its specific amount of the gross energy (SGEG). From the mathematical point of view, the equation of the body mass differentials (1), represents the application of the basic physical law of the mass and energy conservation, to the conversion of the foodstuff's mass and energy to the organism's body mass and energy. The body mass increase (dG) in general named the product, with the gross energy content (SGEG) denotes, not only the body mass change or the fetus growth in the pregnant mammals, but also the milk produced in mammals, or the egg's laying in birds. The products formation however could be performed only from that part of the mass and metabolizable feed energy ingested, which was not transformed to the thermostatic heat (THF), neither to the heat produced under the influence of the various stressors (THX). Among these stressors (X) we consider for instance the influence of heat or cold, the motor activity, changes in the gravitational field, psychic stress and many others. The increase of body mass (of the product) in kilograms per individual per day ($\text{kg}/\text{i}/\text{d}$), is than expressed by the equation:

$$dG = [(IMEF - (THF+THX))/SGEG] \cdot QGL \quad [\text{kg}/\text{i}/\text{d}] \quad (1)$$

The quotient QGL expresses the biological quality, the degree of the left potency for the body mass growth. This quotient QGL is generated automatically as the function of the actual body mass. The selfregulating model calculates the value of the body mass increase from the input parameters describing the modelled organism by: the initial body mass (G_0), the body mass of the adult individuals and species under investigation (G_L), the body core temperature (T_i), the thermal insulation of the body core against the environment (I_{si}), further the input data about the daily feeding dose (DFD) and the value of specific amount of the metabolizable energy in the eaten food (SMEF). The resulting daily amount of metabolizable energy taken in the food (IMEF) is than given by the equation:

$$IMEF = DFD \cdot SMEF \quad [\text{MJ}/\text{kg}/\text{d}] \quad (2)$$

In the real time, expressed as the age of the modelled organism, the mass differential (dG) is calculated for the environmental temperature of the optimal product generation (T_{op}), in a defined time interval (t). Calculated body mass changes e.g. increases, or in the case that the feeding is insufficient also decreases, are integrated to the actual body mass [$G(t)$]. The development of the body mass in the desired age points, $G(t)$ values, are defined by the equation:

$$G(t) = G_0 + \int_0^t dG \cdot dt \quad [\text{kg}/\text{i}] \quad (3)$$

RESULTS

For illustration, the results of modeling the body mass growth of female rats of the Wistar strain (BFU Brno) are presented in the Tab. 1. Two groups of animals, each of ten individuals in the equal age, were bred in the same time in the room tempered to $24 \pm 1^{\circ} \text{C}$. The animals were housed in the standard unmaplex cages, five individuals in each. The pelleted feed, with the specific amount of metabolizable energy $\text{SMEF} = 12 \text{ MJ/kg}$, was supplied regularly once a day. In the group A the feed was supplied in the limited DFD of 6 g, 12 g and 18 g as indicated in the Tab. 1. The group C, during the whole experimental period, was supplied with the uniform DFD of 24 g. In drinking bottles water was to all animals accessible the whole day (Novák, Pipalová 1996).

From the experimental results presented in the tab.1. follows, that the DFD of 6 g was sufficient only for the maintenance of the body mass, and the body mass did not increase. In the age interval 42 - 52 days the DFD was increased twofold to the value of 12 g. The increase in the feed intake, was immediately followed by the steep increase of the body mass. However this body mass increase levelled up to the 60th day of age, despite the fact that the growth maturity, expressed by the QGL coefficient was not yet reached. The new body mass increase started again, after the DFD was increased to 18 g. The animals in the group C exhibited from the beginning a steep increase of the body mass. At the end of the experiment (on 85th day) they had at disposal the left potency for growth only 0,11. In comparison, the animals in the group A, have reached in average only 0,89 fraction of the average body mass of the group C, because of the limited feeding, at the end of the experiment however they had at disposal the twofold value of the left potency for growth e.g. 0,26 so that they were still able to increase the body mass further and would probably equalize the average of the body mass of the group C later under the appropriate DFD intake.

Tab. 1. Experimental values of female rats growth and their comparison with the growth values calculated by means of the selfregulating growth model. Input data: $\text{GLi} = 0,300 \text{ kg/l}$, $\text{Ti} = 37,0^{\circ} \text{C}$, $\text{Ist} = 0,155 \text{ m}^2 \cdot \text{K/W}$, $\text{SMEF} = 12 \text{ MJ/kg}$.

Group A, (N=10)								Group C, (N=10)							
Experimental values								Experimental values							
Age, days	25	32	42	50	60	75	85	25	32	42	50	60	75	85	
$\phi\text{G g/h}$	90,0	94,3	92,2	151	171	195	229	91,3	126	169	201	220	251	257	
+SE l	1,07	0,97	1,42	1,34	1,39	2,39	2,82	1,26	1,28	2,32	2,81	2,58	2,94	2,39	
DFD g/h/d	6	6	12	12	12	18	18	24	24	24	24	24	24	24	
Calculations of SGM for the group A								Calculations of SGM for the group C							
$\phi\text{G g/h}$	90,0	92,0	90,0	149	168	200	223	91	131	165	204	230	253	261	
MOBEG MJ/kg	3,5	3,5	3,5	3,5	6,0	7,0		5,0	5,0	9,0	9,0	9,0	15,0	15,0	
QGL	0,68	0,69	0,70	0,51	0,44	0,34	0,26	0,69	0,57	0,45	0,32	0,23	0,15	0,11	

CONCLUSION

The comparison of the experimental values of body mass growth, with the values calculated by the selfregulating model of growth, clearly demonstrates that the calculated values sensibly follow the influence of the DFD on the body mass growth as it does the average value of body mass of the real experimental organisms. Moreover, from the figures of QGL it is evident how much of the potency for growth remains left, and also the values of SGFG indicate that the composition of the body mass increase depends on the value of DFD. From this point of view it is possible to consider the calculation of the selfregulating growth model as the reaction of a clearly defined "ideal control organism" which in general reacts on the DFD in a similar way as the real individuals in the described experimental conditions.

L. Novák. 1996: Selfregulating growth model in homoiotherms (SGM). Acta Vet. Brno, 65:107-114.

L. Novák, I. Pipalová. 1996: The modelling of the body mass development in the female Wistar strain rats, grown on regulated daily doses of the standardized feeding. Scripta Medica (Brno) 69:179-190.

THE FRACTIONATION OF HYDROGEN AND OXYGEN STABLE ISOTOPES BY LIFE SUPPORT SYSTEMS OF SPACE STATION "MIR"

I. E. Siniak¹, V. B. Gaidadimov¹, B. G. Pokrovskii¹, and R. L. Sauer²

¹Institute for Biomedical Problems, ²NASA Johnson Space Center

INTRODUCTION

The stable isotopes of chemical elements have distinctive chemical, biochemical and biophysical properties in spite of identical electron orbits. These distinctive properties are particularly evident in light elements. Compounds containing heavy isotopes have different biological influences than the similar compounds containing normal isotopic elements. For example, heavy water containing high concentrations (>80%) deuterium has toxic properties: plants, mice, rats, dogs, have died after being exposed to heavy water. The life support systems must generate and support optimal isotope composition in the habitable environment. The first stage of this research was the investigation of the hydrogen and oxygen stable isotope fractionation by water and atmosphere regeneration systems in ground-based mock-ups and systems which are on "MIR" station.

METHODS

In this research we studied the fractionation of the hydrogen isotopes (protium and deuterium) and oxygen isotopes (O-16, O-18) by the regeneration systems ("SRW-C", "SRW-U" and "Electron") on space station "MIR". The isotopic composition of the regenerated water and atmospheric condensate was determined by the mass-spectrometric method.

RESULTS

It was shown that each regeneration system changed the isotopic composition of the water and atmosphere. This effect will influence the isotope composition of habitable environment of the space station during long missions. It was established that fractionation of hydrogen and oxygen isotopes takes place during the first stages ("SRW-C") of the regeneration system. The water obtained from "SRW-U" was found to be enriched by light hydrogen and oxygen isotopes. The fractionation coefficients of hydrogen and oxygen isotopes in water, regenerated from urine by "SRW-U" are less than 1 and increase in accordance with degree of the water extraction from urine. The concentration remaining after urine evaporation is enriched with the heavy isotopes of hydrogen and oxygen. Removal of the concentrate from the regeneration system "SRW-U" leads to removing heavy isotopes from the ecological system. The generated oxygen from mock-up system of "Electron" is enriched by heavy isotope O-18. This finding may be explained by the long-duration utilization of electrolyte in this system. Analysis of stored water, atmospheric condensate, and regenerated water from the system, "SRW-C", were conducted for the presence of protium, deuterium, O-16 and O-18 in samples delivered from the long-duration orbital station "MIR" during MIR 20 and MIR 21 expeditions. It was found that these samples were slightly enriched with the light isotopes of oxygen and hydrogen with respect to the stored water. The potable water which is delivered to MIR by the STS "Shuttle" is enriched with the light isotope of hydrogen by 0.05 to 0.1% and the heavy isotope of oxygen by .02 to .03%.

CONCLUSIONS

In order to predict the isotope composition of a habitable environment during the long-time space missions, it is necessary to investigate fractionation coefficients of the isotopes in all parts of ecological system including the man.

EFFECT OF SPACE FLIGHT ON NEUTROPHIL FUNCTION

R. P. Stowe¹, S. K. Mehta², I. Kaur², M.L. Jones³, D. L. Feedback², A. D. T. Barrett¹, and D. L. Pierson²

¹Department of Pathology, University of Texas Medical Branch, Galveston, Texas 77555, ²Life Sciences Research Laboratories, NASA/Johnson Space Center, Houston, Texas 77058, and ³Department of Pathology, University of Michigan Medical School, Ann Arbor, Michigan 48109

INTRODUCTION

Alterations in immune capabilities, as a function of space flight (microgravity), have been suggested by a number of recent studies. Recruitment and sequestration of polymorphonuclear (PMN) and monocytic leukocytes are fundamental responses to injury. The current data available indicates deficiencies in several aspects of humoral and lymphocyte-mediated response capabilities. In this study we sought to explore the effects of spaceflight on neutrophil chemotaxis, adhesion, and adhesion molecule expression.

METHODS

Peripheral blood neutrophils were purified from crew members of Space Shuttle missions at 10 days before lift-off (L-10), 3 days (L-3), recovery day (R+0), and 3 days after recovery (R+3). The neutrophils were labeled with a fluorescent dye (2', 7'-bis-(2-carboxyethyl)-5-(and -6)-carboxyfluorescein (BCECF/AM)), and quantitatively tested for their ability to directionally migrate in response to several doses of formyl-Methionyl-Leucyl-Phenylalanine (fMLP). The ability of BCECF/AM-labeled neutrophils to adhere to tumor necrosis factor-stimulated human umbilical vein endothelial cells (HUVECs) was also quantitatively tested. Adhesion molecule expression was analyzed by flow cytometry.

RESULTS

At landing, in some cases there was approximately a 2-fold increase in the number of peripheral blood neutrophils as compared to mean preflight levels. Band neutrophils were observed at L-10 and R+0 on some missions. The chemotactic results show a 10-fold decrease in the optimal dose response to fMLP at R+0 or R+3. This suggested an alteration in the neutrophils ability to respond to fMLP and not in cell number. The expression of L-selectin was significantly increased at landing; CD11b (Mac-1), a member of the integrin family of adhesion molecules, was significantly decreased. Neutrophil adhesion to HUVECs was also significantly increased at R+0.

CONCLUSION

The results of this study indicate that the chemotactic response of neutrophils is altered post-flight. The increase in chemotactic activity may reflect an increased or hypermetabolic state of the neutrophils, possibly due to the combined stress hormones released during reentry and landing. To further define the role of the effects of space flight on phagocytic cell function, future experiments are planned to address oxidative burst and phagocytosis of microorganisms.