Friday, June 13

S31-52
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Session FA2
Room 2
8:30 - 11:30 a.m.

Countermeasures for Maintenance of Cardiovascular and Muscle Function in Space Flight

EFFECTS OF REPEATED LONG DURATION +2Gz LOAD ON MAN'S CARDIOVASCULAR FUNCTION

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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.

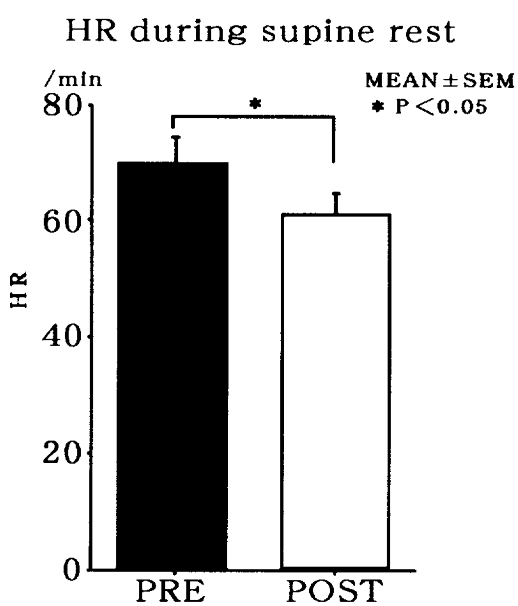
METHODS

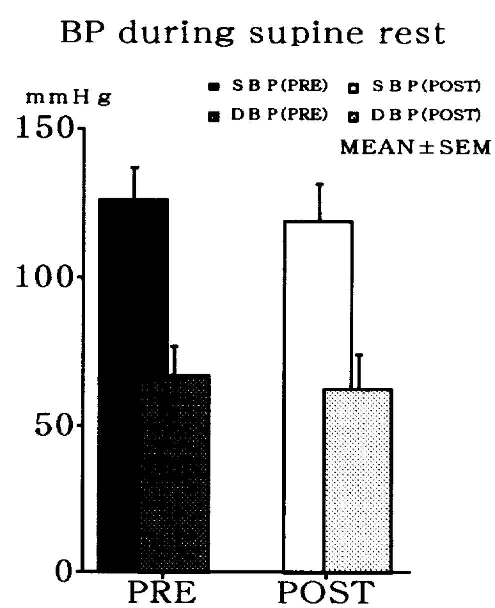
Nihon university's short-radius(1.8m)human centrifuge was used for this study. Experimental subjects were 9 healthy men. They were 22 to 23 years old. Written informed consents were obtained. They received 2G load along the body's +z axis, one hour daily for a periods of 7 days. The pre-load data were 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.

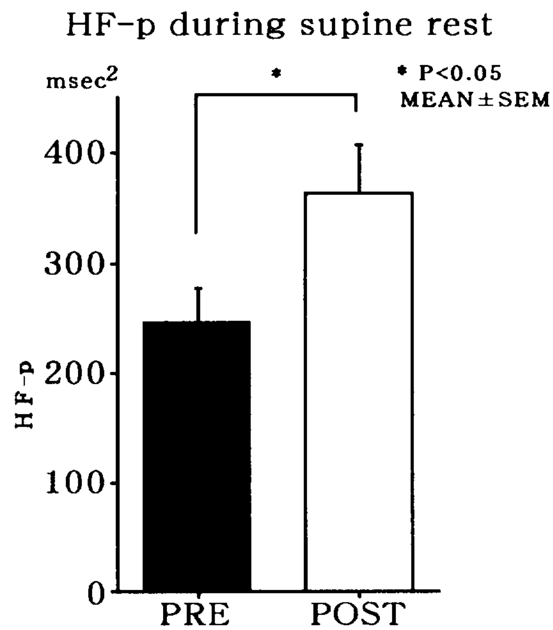
Data analysis : The R-R intervals (beat-to-beat mode) were changed to a time series data of 256 points every half second by the Spline interpolation method. Spectrum of R-R intervals were obtained by applying the fast Fourier transform (FFT) to the time series data and the Hanning window processing. 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.

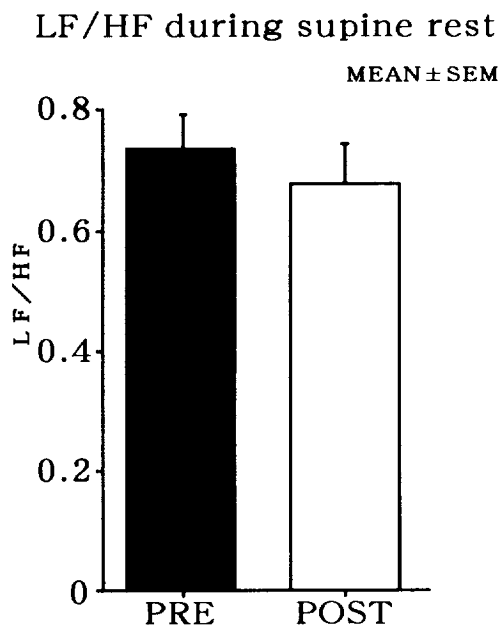
RESULTS

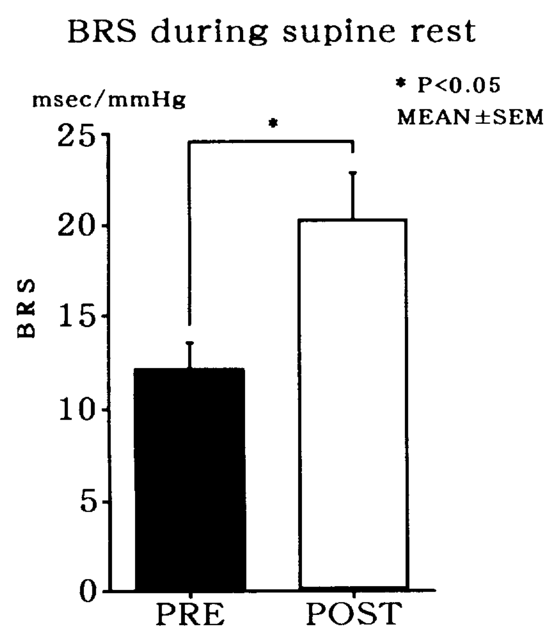
Data obtained pre and post G load period are shown in the figures.











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

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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-tern 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).

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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 moderatly decreased until the end of the flight, which is in favor of a hyovolemia. HR was slightly increased, CO being slightly decreased due to the SV decrease, and BP remained stable (**Fig:1**). The Rr decrease was consistant with the existence of a hypovemia (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 submited 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 assessement 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" mentionned by the cosmonautes. 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 (personnal 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 interfer with the development of orthostatic intolerance.

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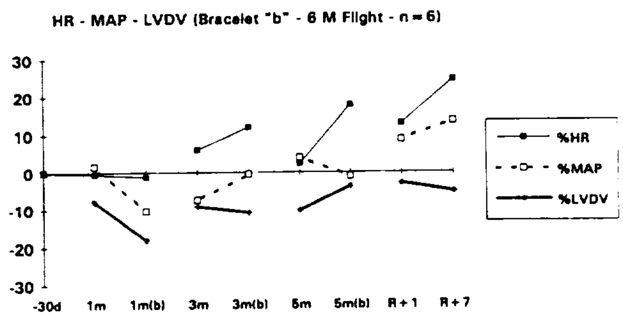

Fig: 1: Heart Rate (HR), Mean blood pressure (MAP), and Left ventricle diastolic volume (LVDV) with and without bracelets ("b" means with bracelets). Inflight differences in % of the preflight value are significant ($p<0.05$) for HR at 3 & 5m, for MAP at 1 & 5m, for SV at 1, 3 & 5m.

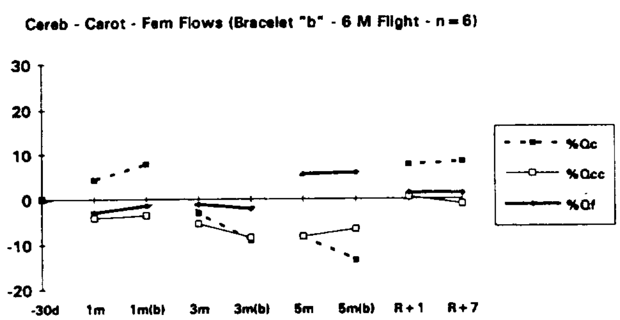

Fig 2: Mean flow velocity (Qc: cerebral; Qcc: carotid; Qf: femoral)with and without bracelets ("b" means with bracelets). Inflight differences in % of the preflight value are significant ($p<0.05$) for Qc at 3 and 5 m and for Qf at 1, 3 and 5m.

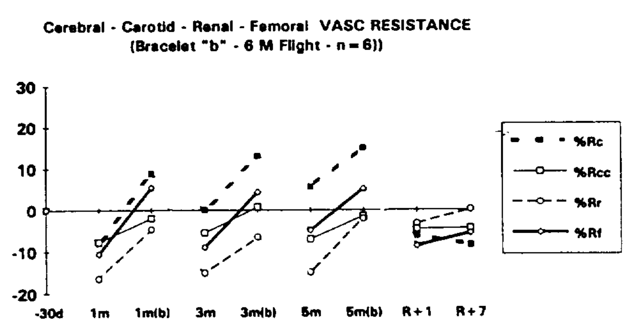

Fig 3: Vascular resistances (Rc: cerebral; Rcc: carotid; Rf: femoral; Rr: renal), and with and without bracelets ("b" means with bracelets). All inflight variations in % of the preflight value are significant ($p<0.05$).

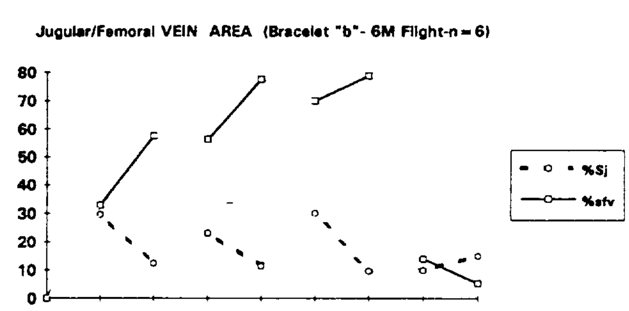

Fig 4: Jugular (Sj) and femoral (Sf) vein cross section with and without bracelets ("b" means with bracelets). All inflight differences expressed in % of the preflight value are significant ($p< 0.05$).

(Work supported by CNES grants)

SPACE CYCLE^{TM} INDUCED PHYSIOLOGIC RESPONSES

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The patented SPACE CYCLE^{TM}, 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^{TM} 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^{TM} 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^{TM} passive riding
f) lateral decubitus SPACE CYCLE^{TM} active pedaling

If a lying down SPACE CYCLE^{TM} 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^{TM} is compatible with International Space Station dimensional constraints.

MUSCULAR DECONDITIONING DURING LONG-TERM SPACEFLIGHT EXERCISE RECOMMENDATIONS TO OPTIMIZE CREW PERFORMANCE

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INTRODUCTION

The insufficient loading of the muscle system in weightlessness has been shown to cause varying changes to the structur 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 extend 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 allowes 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 extend and temporal relationship of the decline in muscle strength, and fatique 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 significant greater in extensor than flexor muscle groups and in lower limbs than upper limbs. Two distinct phases in muscle contractile deterioration have become apperent: 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 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 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 minimise the use of crew work time and 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 Ministary 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.

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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 ST μm^2	CSA FT μm^2	CF	CD cap / mm^2	Strength Nm 0°/s	30°/s	60°/s	120°/s	180°/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.

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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

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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.