
Thursday, June 12

522-54

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Session JA1
Room 1
8:30 - 11:30 a.m.

Studies Relating to EVA

**THE STAGED DECOMPRESSION TO THE HYPOBARIC ATMOSPHERE AS A
PROPHYLACTIC MEASURE AGAINST DECOMPRESSION SICKNESS DURING
REPETITIVE EVA**

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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)

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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.

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METABOLIC ASSESSMENTS DURING EXTRA-VEHICULAR ACTIVITY

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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

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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 cosmoaunts 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 rigidness, 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

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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

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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

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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 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, exertable 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.

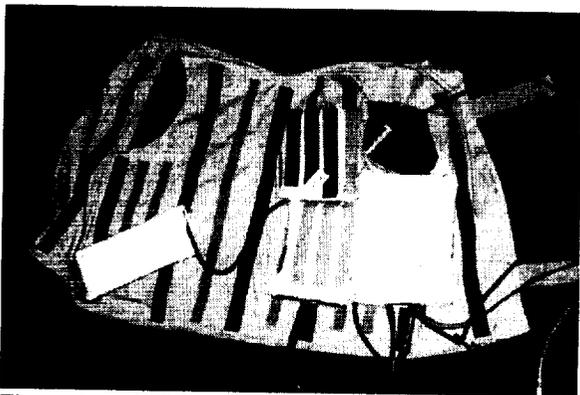


Figure 1: JAMS System Hardware and Vest

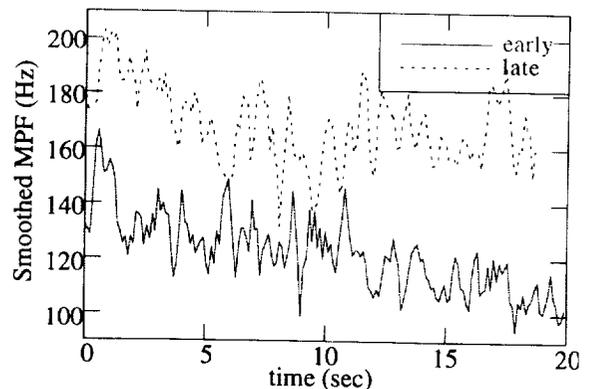


Figure 2: Mean Power Frequency during isometric handgrip in early and late taskboard cycles

EXPERIMENTAL INVESTIGATION OF COOPERATIVE HUMAN-ROBOTIC ROLES IN AN EVA WORK SITE

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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.

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

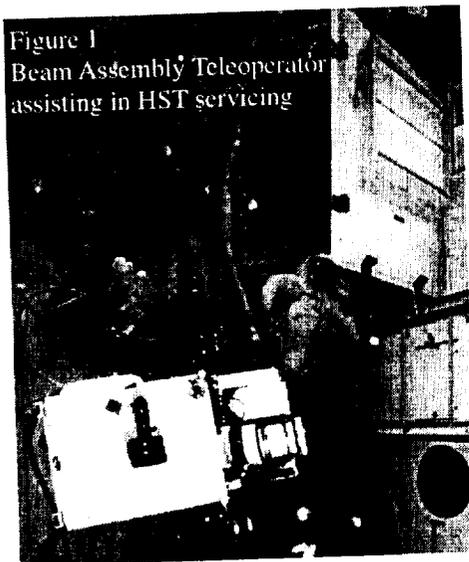




Figure 2
SCAMP monitoring EVA
training for STS-80

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.

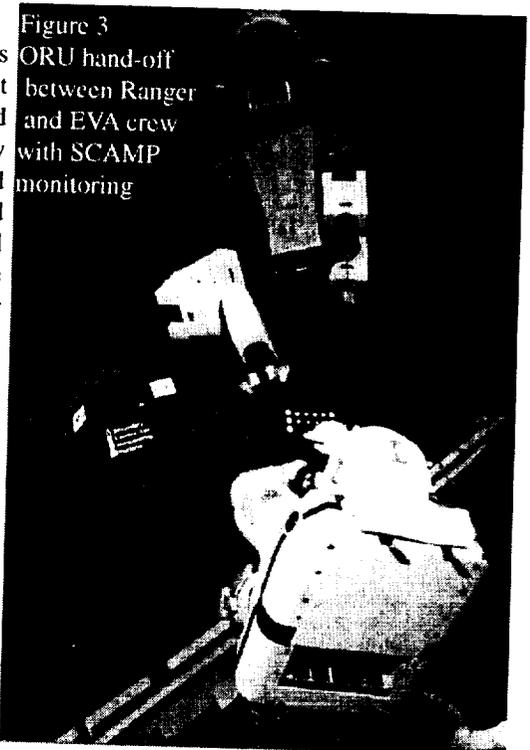


Figure 3
ORU hand-off
between Ranger
and EVA crew
with SCAMP
monitoring

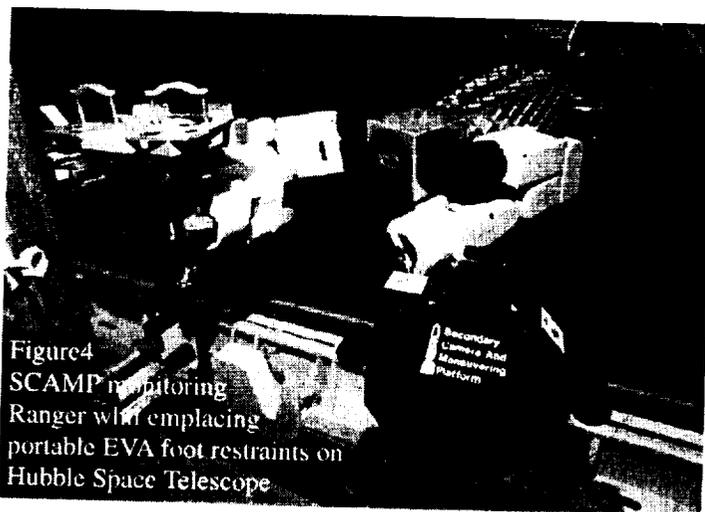


Figure 4
SCAMP monitoring
Ranger with emplacing
portable EVA foot restraints on
Hubble Space Telescope

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.