Investigation Title: Analysis of Volatile Organic Compounds on Mir Station

Principal Investigator: Peter T. Palmer, Ph.D., San Francisco State University

Additional Investigator: Warren Belisle

INVESTIGATION OBJECTIVES

1. Characterization of volatile organic compounds (VOCs) in Mir air samples using both proven gas chromatography/mass spectrometry (GC/MS) and new direct sampling ion trap mass spectrometry (DSITMS) techniques.

PHASE 1 MISSIONS

Mir 19, Mir 21 - Mir 25

OPERATIONAL ACTIVITIES

Collection of air samples using both grab sample containers (GSCs) and solid sorbent air sampler (SSAS).

RESULTS

Documentation of VOC types and concentrations on Mir; development and validation of new technology for air quality monitoring.

CONCLUSIONS

Mir air quality meets NASA specifications; DSITMS technology shows promise as sensitive, selective means for real-time air quality monitoring for life support applications.

PUBLICATIONS

1. P.T. Palmer, C.M. Wong, R.A. Yost, N.A. Yates, and T.M. Griffin, "Advanced Automation for Ion Trap Mass Spectrometry - New Opportunities for Real-Time, Autonomous Analysis", in Artificial Intelligence Applications in Chemistry, S. Brown (Ed.), Wiley, 1996, pp. 25-60.
2. P.T. Palmer, X. Fan, C. Remigi, B. Nies, and L. Lee, “Direct Sampling Ion Trap Mass Spectrometry – A Growing Toolkit for Air Monitoring Applications”, SAE technical paper series 981743.
3. P.T. Palmer, D. Karr, and Carla Remigi, “Evaluation of Two Different Direct Sampling Ion Trap Mass Spectrometry Methods for Monitoring Volatile Organic Compounds in Air”, Journal of the Field Analytical Chemistry and Technology, manuscript submitted.

Investigation Title: Anticipatory Postural Activity (Posa)

Principal Investigator(s): Charles S. Layne, Ph.D., KRUG Life Sciences, Inc.; Inessa B. Koslovskaya, M.D.

Additional Investigators: Jacob J. Bloomberg, Ph.D., P. Vernon McDonald, Ph.D., and Andrei A. Voronov, Ph.D.

INVESTIGATION OBJECTIVES

1. Determine how long-duration space flight alters the anticipatory neuromuscular activity associated with arm movement.

2. Perform proof-of-concept research to determine whether foot sensory input modifies neuromuscular responses during space flight.

3. Determine the time course of adaptation during long-duration space flight to foot sensory input as measured by patterns of neuromuscular activation.

4. Determine whether long-duration space flight modifies anticipatory neuromuscular postural activity in the immediate postflight period.

5. Determine whether modifications in anticipatory neuromuscular postural activity associated with long-duration space flight are correlated with postural instability immediately after landing and during the recovery period.

PHASE 1 MISSIONS

Mir 21/NASA 2

OPERATIONAL ACTIVITIES

During all ground-based data collection, subjects wore shirts, T-shirts and stocking feet with electrodes and accelerometer leads attached to the body with adhesive tape (Belt Pack Amplification System (BPAS) vest assembly). An accelerometer was attached to a wrist splint worn by the subject. The subject stepped onto a force plate, assumed an upright position with feet shoulder-width apart and arms resting comfortably at the sides. With eyes closed, the subject performed 15 rapid, 90-degree shoulder flexions, keeping the arm and wrist locked throughout the movement. The movements were self-initiated and the subject regained stability before performing the next movement. The Flock of Birds motion analysis system was used during this testing to obtain measures of body segmental motion.

During inflight data collection, the BPAS vest assembly was used to collect EMG and acceleration data during a series of arm raises. Inflight testing involved four test conditions: 1) 15 arm raises while free-floating, 2) 15 arm raises while free-floating with the addition of foot pressure, 3) 15 arm raises while attached to the Mir support surface, 4) 15 arm raises while bunged to the Mir treadmill. The foot pressure boots were worn during test conditions 2 and 3. No force plate or motion analysis data was obtained in flight.

RESULTS

Inflight - The addition of foot pressure results in increased muscle co-contraction relative to movement conditions without the pressure boots. This measure is a further reflection of the increase in muscle activation caused by the addition of foot pressure. Free-floating arm movements performed without foot pressure resulted in the elimination or severe reduction of the lower limb muscle activation always observed prior to arm movements made while upright in unit gravity.

Free-floating arm movements performed with the addition of foot pressure (provided by the pressure boots) resulted in the lower limb muscle activation always observed prior to arm movements made while upright in unit gravity.

Ground-based - The crewmember demonstrated decrements in postural control associated with voluntary arm movements. The subject increased the magnitude of COP motion decreases in arm acceleration features. This increased COP motion brings the subject closer to the limits of the base of support, thus jeopardizing postural stability. Thus, the subject unable to optimally perform the arm raise task and demonstrated less postural control during the arm motion after space flight. The data indicates that the precise neuromuscular activation patterns necessary for optimal arm movement were not produced after space flight.

CONCLUSIONS

Evidence suggests that there are a wide range of individual responses of the movement control system to space flight and the ground-based Posa test can be utilized to characterize this response range. The ability to generate the same neuromuscular activation patterns that are used to perform the preflight movement is compromised after space flight. No preliminary conclusions concerning the inflight data can be drawn at this time. However, evidence from previous flights has consistently indicated that the addition of foot pressure results in enhanced neuromuscular activation.

PUBLICATIONS

1. Layne, C.S., Bloomberg, J.J., McDonald, P.V., Mulavara, A.P., and Pruett, C.J. The use of foot pressure to enhance neuromuscular activation during space flight. Annual Meeting of the American Institute of Aeronautics and Astronautics, Houston, TX, March, 1996.
2. Layne, C.S., McDonald, P.V., Mulavara, A.P., Kozlovskaya, I.B., and Bloomberg, J.J. Adapting neuromuscular synergies in microgravity. Bernstein's Traditions in Motor Control Conference, Pennsylvania State University, University Park, PA, August, 1996.
3. Layne, C.S., McDonald, P.V., Pruett, C.J., Mulavara, A., Kozlovskaya, I.B., Voronov, A.V., and Bloomberg, J.J. The impact of space flight on anticipatory muscle activation. Annual Meeting of the American Institute of Aeronautics and Astronautics, Houston, TX, March, 1996.
4. Layne, C.S., Mulavara, A.P., McDonald, P.V., Pruett, C.J., and Bloomberg, J.J. Somatosensory input enhances neuromuscular activation during movements performed while free-floating in microgravity. Society for Neuroscience Annual Meeting, Washington, D.C. November, 1996.
5. Mulavara, A.P., McDonald, P.V., Layne, C.S., Poliner, J., Pruett, C.J., and Bloomberg, J.J. Quantifying adaptive preparatory postural adjustments that occur following space flight. 14th Annual Houston Conference on Biomedical Engineering Research, Houston, TX, February, 1996.
6. Layne, C.S., Spooner, B.S. Microgravity effects on "postural" muscle activity patterns. Adv. in Space Res. 1994 (in press).
7. Layne, C.S., McDonald, P.V., Mulavara, A.P., and Bloomberg, J.J. "Adaptations in movement control after space flight.." Annual Meeting of the North American Society for Psychology of Sport and Physical Activity, St. Charles, IL, June, 1998.
8. Layne, C.S., Mulavara, A.P., McDonald, P.V., Pruett, C.J., Kozlovskaya, I.B., and Bloomberg, J.J. "The impact of long-duration space flight on upright postural stability during unilateral arm raises." Annual Meeting of the Society for Neuroscience, New Orleans, LA, October, 1997.
9. Layne, C.S., Mulavara, A.P., Pruett, C.J., McDonald, P.V., Kozlovskaya, I.B., and Bloomberg, J.J. "The use of inflight foot pressure as a countermeasure to neuromuscular degradation." Acta Astronautica, vol. 42, no. 1-8, 231-246 (1998).

Investigation Title: Assessment of Humoral Immune Function During Long-Duration Space Flight

Principal Investigator(s): Clarence F. Sams, Ph.D., NASA/Johnson Space Center; A.T. Lesnyak, Institute of Biomedical Problems

Additional Investigators: Irina Rykova, Richard Meehan, and Patricia Giclas

INVESTIGATION OBJECTIVES

1. Determine the effects of long-duration space flight on baseline levels of immunoglobulins in serum and assess the ability to produce appropriate antibodies in response to a specific antigenic challenge.
2. Assess secretory immune function by measuring salivary IgA and lysozyme levels.
3. Evaluate the responsiveness of B-cells to polyclonal activators immediately after space flight.

PHASE 1 MISSIONS

NASA 2 - NASA 4, NASA 6, NASA 7

OPERATIONAL ACTIVITIES

An inflight vaccination with specific antigens were used test the ability to mount an antibody response in vivo. Blood and saliva was collected from the test subjects before flight, before immunization during flight, 7 days, 11 days, 14 days, 17 days, 21 days, and 28 days after the immunization.

RESULTS

Status of Data Received/Analyzed: All samples have been collected. Initial measurements of the pre-immunization antibody titers for the preflight and inflight samples has been performed for the 4 common pneumococcal isotypes for the subjects from each mission. The remaining sample analysis is being performed in batch with the other NASA-Mir subjects and their age/sex matched ground control group.

CONCLUSIONS

No conclusions

PUBLICATIONS

No publications

Investigation Title: Bone Mineral Loss and Recovery after Shuttle-Mir Flights

Principal Investigator(s): Linda C. Shackelford, M.D., NASA/Johnson Space Center; Viktor Oganov, M.D., Ph.D.

Additional Investigators: Adrian LeBlanc, Ph.D., Helen Lane, Ph.D., Scott M. Smith, Ph.D., Steve Siconolfi, Ph.D., Boris Morukov, M.D., and Inessa B. Koslovskaya, M.D.

INVESTIGATION OBJECTIVES

1. Determine the regional losses in bone mineral density and lean body mass of the crewmembers of each of the Phase 1 Shuttle-Mir flights.
2. Determine the regional rate and extent of recovery of the bone mineral and lean tissue in the above crewmembers.
3. Determine the muscle strength of the lower extremities and back before and after flight. Relate muscle strength data to the bone loss during flight and to the degree and rate of bone recovery postflight.
4. Determine the levels of serum and urinary markers of bone metabolism before and after flight.

PHASE 1 MISSIONS

Mir 21/NASA 2, Mir 22/NASA 3, Mir 23/NASA 4, Mir 24/NASA 5, Mir 25/NASA 6, Mir 26/NASA 7

OPERATIONAL ACTIVITIES

Dual energy x-ray absorptiometry (DEXA) scans were obtained pre- and postflight using a Hologic QDR 2000 whole densitometer (U.S.) or QDR 1000W densitometer (Russia). Bone mineral density data were obtained from scans of the whole body, lumbar spine, proximal femur (hip) and calcaneous (heel). Whole body and regional measurements of lean tissue mass (LTM) were obtained from the whole body scans. Testing time points were: L-60 (60 days prior to launch), L-30, R+5 (5 days after landing), R+180, R+360, R+720 and R+1080 days.

Strength testing was performed pre- and postflight using a LIDO isokinetic dynamometer. Peak torque was measured for muscle groups in the legs and back. Testing time points were the same as for DEXA scans.

Serum and urinary markers of bone metabolism were measured pre- and postflight. Urine is collected over a 24-hour period; serum was collected by a fasting blood draw. Urine markers include total calcium, pyridium cross-links, n-telopeptide, hydroxyproline and creatinine. Serum markers included total and ionized calcium, pH, calcitonin, parathyroid hormone (PTH), osteocalcin, total and bone-specific alkaline phosphatase and vitamin D. Testing time points were: L-30, L-7, R+0 (landing day), R+7, R+14 and R+180 days.

Calcium kinetics testing was conducted pre-, in- and postflight during the NASA 6 and NASA 7 missions. The 22-day protocol included collection of urine, blood, saliva and fecal samples (fecal samples were not collected in flight, however) and the administration of stable calcium isotopes at the beginning of the 22-day test protocol. Testing time points (start of the 22-day protocol) are L-45 days, FD 28 (flight day 28), FD 96, R+3 days, R+6 months, and R+12 months. Samples will be analyzed to determine the levels of the stable isotopes administered for this protocol (^{44}Ca and ^{42}Ca).

RESULTS

All pre- and postflight U.S. DEXA data for the NASA 2 - NASA 7 missions have been analyzed. Russian cosmonaut DEXA data will be analyzed when all of the scan files have been received. Strength testing data analysis is approximately 50% complete. Serum and urinary markers of bone metabolism sample and data analysis is approximately 75% complete. Calcium kinetics sample analysis is complete for the NASA 6 samples collected and approximately 15% complete on the NASA 7 samples collected thus far. Completeness of data collected on the cosmonauts can not be verified at this time.

Preliminary DEXA findings on the crewmembers whose data have been analyzed to date indicate that the regional bone changes are similar to those documented in the 18 cosmonauts studied previously, both in terms of the variability in bone loss among individuals, as well as the site-specific variability in bone loss within a given individual. One NASA crewmember has shown complete bone density recovery at 6 months. All other NASA crewmembers still show significant losses with incomplete recovery. Muscle strength results will be correlated with bone density results during the 3-year recovery period and reported at a later date. Preliminary bone marker findings are not available at this time.

CONCLUSIONS

There are no conclusions to be drawn at the present time.

PUBLICATIONS

1. Shackelford, L., Feiveson, A., Spector, E., LeBlanc, A., and Oganov, V. "Prediction of femoral neck bone mineral density change in space." 12th Man in Space Symposium, Washington, DC (June, 1997).

Investigation Title: Cardiovascular Investigations - Adaptive Changes in Cardiovascular Control at μG (E712)

Principal Investigator: C. Gunnar Blomqvist, M.D., Ph.D., University of Texas Southwestern Medical Center

Additional Investigators: Benjamin D. Levine, M.D., Boyce Moon BSBE, James A. Pawelczyk, Ph.D., Julie Zuckerman R.N., Cole A. Giller, Ph.D., M.D., and Lynda Denton Lane, M.S., R.N.

INVESTIGATION OBJECTIVES

Adaptation to microgravity causes changes in the autonomic nervous system that have significant effects on the control of blood flow and blood pressure. These changes result in orthostatic intolerance, i.e. inability to provide sufficient blood flow to body tissues, particularly to the brain, in the upright body position upon return to Earth.

Our overall objective was to provide new physiological data that will improve our understanding of the function of the human heart and blood vessels in space and on return to Earth.

We conducted the current experiment as an integrated cardiovascular experiment based on sessions performed jointly with Dwain L. Eckberg, MD. and William Cooke, Ph.D. of the McGuire Research Institute, University of Virginia, Richmond, Virginia as well as Friedhelm Baisch, M.D., DLR, Cologne, Germany. Autonomic Mechanisms During Prolonged Weightlessness (E-709)

The primary hypothesis to be tested was that adaptation to the unique environment of microgravity causes alterations in the autonomic nervous system that interact with microgravity induced changes in body fluid distribution, and result in orthostatic intolerance upon return to Earth. We further hypothesized that this adaptation occurs rapidly and completely within the first few days-weeks of space flight and does not progress with long-term (months) exposure. We attempted to achieve the following specific objectives:

1. Establish whether efferent sympathetic nerve activity increase appropriately in response to baroreflex and non-baroreflex mediated stimuli before and after space flight. Our hypothesis was that adaptation to microgravity results in blunted reflex responsiveness with a relative decrease in efferent sympathetic nerve activity leading to inadequate vasoconstriction and orthostatic hypotension. This hypothesis could not be tested on Mir but data are now available from the studies we performed as members of the Neurolab Autonomic team. *

2. Detect functional abnormalities of the autonomic nervous system pre and postflight, and furthermore define the effects and time course of adaptation during space flight by applying integrated, clinical tests of autonomic function. Simple to perform, non-invasive tests such as the quantitative Valsalva maneuver, estimates of heart rate and blood pressure variability, cold pressor test, and static handgrip exercise can provide insights into the adequacy of afferent input, central processing of afferent signals, and sufficiency of neural and vasomotor responsiveness. Indirect, non-invasive measures of autonomic balance, including linear and non-linear variability of heart rate, blood pressure, and cerebral blood flow were obtained before, during and after flight. **

3. Determine if regulation of the cerebral circulation change in parallel with or independently of regulation of the systemic circulation before, during or after adaptation to microgravity. By measuring changes in cerebral blood flow velocity non-invasively using transcranial Doppler, we estimated changes in cerebral blood flow and resistance and related these to changes in systemic flow and resistance in response to metabolic (hypo- and hyperventilation) and hemodynamic (head-up tilt) provocative maneuvers. We hypothesized that in some individuals, autoregulatory failure may occur independent of systemic circulatory failure after space flight.

* We originally planned to measure carotid baroreflex responses; however, technical problems with the equipment required that we delete the measurement.

** Direct measurements of sympathetic nerve activity and norepinephrine Spillover were proposed; however, the crew declined participation.

PHASE 1 MISSIONS

Mir 23/Dara Mir 97E, Mir 24/NASA 6, Mir 25/NASA 7

OPERATIONAL ACTIVITIES

Operational activities involved baseline data collection setup, baseline data collection, crew training and familiarization, and procedure verification.

Our participation in the Mir 23/Dara Mir 97E Cardio experiments (which were closely coordinated with our present NASA7/Mir 25 experiments) required that we travel to DLR in Cologne Germany From August 18 - 27, 1996 for baseline data collection setup and again on September 21 - October 3, 1996 to conduct baseline data collection # 5. Mir 23/Dara Mir 97E later required our travel to Star City, Russia from November 8 - 20, 1996 for baseline data collection setup and again from November 30 - December 7, 1996 for baseline data collection # 6. From January 27 - February 4, 1997 we returned to Star City, Russia to conduct baseline data collection # 7. Our Mir 23 operational activities concluded with a trip to Star City, Russia to conduct baseline data collection # 8 during August 14 - 22, 1997.

NASA 6/Mir 24 experiments 712/709 required procedure verification; therefore, we traveled to Star City, Russia from March 14 - 22, 1997, to prepare. We traveled again to Star City from May 5 - 9, 1997 to setup for baseline data collection. Crew familiarization and training was achieved during our next trip to Star City from May 15 - 17, 1997. While still in Star City we conducted baseline data collection and crew training from May 18 - 22, 1997. On June 3, 1997 we traveled to NASA JSC, Houston, TX for preliminary examination of baseline data collection hardware and facilities. Crew training brought us back to Star City, Russia from June 6 - 22, 1997. From August 26 - 29, 1997 we traveled to NASA JSC, Houston, TX to setup for baseline data collection for both NASA 6/Mir 24 and NASA 7/Mir 25. We returned to NASA JSC from September 1 - 4, 1997 for additional setup and integrated team practice for NASA 6 preflight baseline data collection.

NASA 7/Mir 25 crew training and preflight baseline data collection required travel to NASA JSC from September 15 - 26, 1997. We concluded our NASA 7/Mir 25 activities with a return to Star City, Russia from August 20 - September 12, 1997 to conduct postflight data collection on the Mir 25 crew.

RESULTS

We are currently verifying collected data and writing supplemental software to complete the analysis of those data. The data analysis is performed jointly with Dr. Eckberg et al. of the University of Virginia.

CONCLUSIONS

Pending

PUBLICATIONS

Pending

Investigation Title: Cardiovascular Investigations - Autonomic Mechanisms During Prolonged Weightlessness (E709)

Principal Investigator: Dwain L. Eckberg, M.D., McGuire Research Institute

Additional investigators: William H. Cooke, Ph.D., Friedhelm J. Baisch, M.D., James F. Cox, Ph.D., and Kari U.O. Tahvanainen, M.S.

INVESTIGATION OBJECTIVES

1. To explore the probability that the disordered arterial baroreflex malfunction documented during weightlessness is part of, and a contributor to a broad range of autonomic abnormalities, and to understand the mechanisms and implications of such abnormalities during, and after long-duration space flights.

PHASE 1 MISSIONS

Mir 23, Mir 25

OPERATIONAL ACTIVITIES

We successfully recorded EKG, beat-to-beat arterial pressure, cerebral blood flow velocity, and whole-body fluid distribution during a battery of tests that activate different afferent fibers, evoking different patterns of neural and cardiovascular responses. Data were recorded L-14, MD18, and R+1 and 15 during Mir 23 for one cosmonaut. Data were recorded L-14, MD114, 148, 182, and R+1 and 15 for one, and L-12, MD120, 183, and R+15 for another cosmonaut during Mir 25.

RESULTS

Despite recording data on such a small sample of cosmonauts, our data suggest that prolonged weightlessness: 1) decreases vagal cardiac control; 2) decreases the buffering of arterial pressure by RR-interval variability at respiratory frequencies; 3) decreases arterial baroreflex gain despite indirect evidence of increased sympathetic traffic (this was assessed during Valsalva's maneuver, by spontaneous systolic pressure-to-RR-interval slopes, and by cross-spectral analysis of RR-interval and systolic pressure spectral power. Analysis of data is not complete.

CONCLUSIONS

Prolonged exposure to microgravity attenuates baroreflex regulation of arterial pressure, and alters neural cardiac control. Continuing in-depth analysis may reveal other, more telling results which may have clinical implications.

PUBLICATIONS

Manuscripts are in preparation, and are targeted for publication in Journal of Applied Physiology

Investigation Title: Collecting Mir Source and Reclaimed Water for Postflight Analysis

Principal Investigator(s): Richard L. Sauer, P.E., NASA/Johnson Space Center; Yuri Sinyak, Ph.D., Institute of Biomedical Problems

Additional Investigators: Lizanna Pierre, John Schultz, Ph.D., Leonid Bobe, Ph.D., Nikoli Protasov, Ph.D., and V. M. Skuratov, Ph.D.

INVESTIGATION OBJECTIVES

1. Characterize the chemical composition of Mir recycled water, Russian ground supplied water prior to launch and on orbit, and the Mir humidity condensate to support development and testing of the water recycling and monitoring systems for the ISS.

2. Determine and compare the chemical composition of Mir and Shuttle condensate.

3. Determine whether the potable water on board Mir meets the Joint U.S./Russian water quality specifications for ISS.

PHASE 1 MISSIONS

This experiment has flown under the Human Life Sciences Discipline during the Mir 18/NASA 1, Mir 19, Mir 20/STS-74, and Mir 21/NASA 2/STS-79 missions. In addition, this activity was performed under the Space Medicine Program during the Mir 22/NASA 3/STS-81, Mir 23/NASA 4/STS-84, Mir 23/NASA5/STS-86, Mir 24/NASA6/STS-89 and the Mir 25/NASA7/STS-91 missions.

OPERATIONAL ACTIVITIES

Recycled and stored water samples were collected periodically during each mission using U.S. developed water sampling hardware. In addition, raw unprocessed humidity condensate was collected using Russian supplied hardware, while partially processed condensate was collected using U.S. supplied hardware. The partially processed condensate samples were collected as a result of ethylene glycol leaks on board the Mir, to assess the ability of the water processor system to remove this contaminant.

RESULTS

In general, the recycled and stored water supplied to the Mir Space Station met NASA, Russian Space Agency (RSA), and/or U.S. Environmental Protection Agency (EPA) standards. Exceptions were found to include total organic carbon (TOC) and turbidity in the recycled water which routinely exceeded NASA standards. The TOC in some cases, exceeded Russian standards as well. Other parameters such as ethylene glycol, barium, nickel, chloroform, phenol, and dioctyl phthatate occasionally exceeded NASA, RSA or EPA standards. All but the TOC violations were transient.

The humidity condensate exhibited steadily increasing levels of ethylene glycol throughout Phase 1. This is believed to reflect the increased levels of ethylene glycol in the Mir atmosphere following coolant loop leaks and maintenance activities. In one case, the presence of ethylene glycol in a condensate sample alerted the ground and crew to the presence of a previously undetected coolant loop leak.

CONCLUSIONS

The chemical quality of the recycled and stored water, as determined through postflight analysis met performance and potability requirements. The analysis of samples has provided important data for assessing the potability of recycled water. In addition, these data will be instrumental in developing appropriate water quality monitoring standards for ISS.

PUBLICATIONS

1 .Pierre, L.M., Schultz, J.R., Johnson, S.M., Sauer, R.L., Sinyak, Y.E., Skuratov, V.M., and Protasov, N.N., Collection and Chemical Analysis of Reclaimed Water and Condensate from the Mir Space Station, SAE #961569, 26th International Conference on Environmental Systems, Monterey, California July 1996.

2. Pierre, L.M., Schultz, J.R., Sauer, R.L. Sinyak, Y.E., Skuratov, V.M., and Protasov, N.N., Chemical Analysis of Potable Water and Humidity Condensate Collected During the Mir 21 Mission, SAE #97ES-224, 27th International Conference on Environmental Systems, Lake Tahoe, Nevada July 1997

3. Sauer, R.L., Sinyak, Y.E, Pierson, D.L, Schultz, J.R., Straub, J.E., Pierre, L.M., Limardo, J.M., Koenig, D.W., Assessment of the Potable Water Supply on the Russian Mir Space Station, American Institute of Aeronautics and Astronautics Life Sciences and Space Medicine Conference, Houston, TX March 1996

Investigation Title: Crewmember and Crew-Ground Interactions During NASA-Mir

Principal Investigator: Nick A. Kanas, M.D., VA Medical Center at San Francisco

Additional Investigators: Vyacheslav Salnitskiy, Ph.D., Vadim Gushin, M.D., Olga Kozerenko, M.D., Charles R. Marmar, M.D., Alexander Sled, M.S., and Daniel S. Weiss, Ph.D.

INVESTIGATION OBJECTIVES

1. To measure and characterize crewmember and mission control personnel tension, cohesion, and leadership role during five Shuttle-Mir missions

PHASE 1 MISSIONS

NASA 3 - NASA 7

OPERATIONAL ACTIVITIES

None.

RESULTS

The data collection phase of this study ended in August 1998, although not all data have been received as of January 25, 1999. Five U.S. and four Russian space crews and their ground support personnel were studied during Shuttle-Mir missions that took place from 1995 to 1998. The number of subjects who participated included 6 astronauts, 11 cosmonauts, and 41 U.S. and 18 Russian mission control personnel. The overall compliance rate was 80%. To test hypotheses related to psychosocial issues affecting the 1st half versus the 2nd half of a typical mission, all of the subject responses were arrayed in terms of the midpoint of each subject's mission for each subscale of the Profile of Mood States (POMS), Group Environment Scale (GES), and Work Environment Scale (WES). Preliminary analyses of the GES data received to date showed that crewmembers reported significant declines in the 2nd half of the missions on measures of cohesion, leader support, and task orientation. Crew self-discovery dropped throughout the missions. There were significant overall differences between the Mir crews and personnel in mission control on five of the six POMS subscales, with astronauts and cosmonauts reporting less anxiety and dysphoria than mission control personnel. However, both subject groups obtained significantly lower scores than published adult norms on these measures. On the WES, Mir crewmembers scored significantly higher than did mission control personnel on measures of perceived managerial control and comfort with their physical environment. Managerial control scores for the crewmembers were significantly higher than published normative scores for ground-based work groups. Ground subjects scored significantly lower than the norms for physical comfort, indicating that they were less satisfied with their physical environment than other work groups. Evidence supporting the occurrence of displacement of tension and dysphoria to people outside the group was found among both crew and mission control subjects, with all measures of tension and dysphoria correlating in the predicted negative direction with supervisor support. There also was a positive relationship between leader support and cohesion for both crew and mission control subjects. U.S. and Russian subjects showed some variation in response, and these cultural differences will be analyzed in the future.

CONCLUSIONS

Preliminary analyses of the data received to date using a biphasic analysis supported 4 of the 6 study hypotheses regarding the effects of the phase of a space mission on tension, cohesion, and leadership role. As predicted, crew cohesion and perceived leader support declined significantly in the 2nd half of the missions, possibly indicating asthenic changes and disruptions in interpersonal relationships. The significant crew-ground differences in measures of dysphoria might be more reflective of the significantly low POMS scores reported from space than of a problem on the ground. The evidence for displacement suggests that it is important for crewmembers to learn strategies of openly dealing with on-board tension and dysphoria rather than displacing these negative affects to mission control personnel. The same can be said for the mission control group in relationship to displacing negative affects to agency management. In both subject groups, perceived leader support correlated with cohesion, illustrating the importance of the supportive role of the leader on the group’s ability to work together. The findings from this study suggest a number of important countermeasures that can be developed for use in future manned space missions in the areas of preflight selection and training; inflight support; and postflight readaptation to the social environment on Earth.

PUBLICATIONS

1. Kanas, N, Salnitskiy, V, Grund, E, Gushin, V, Kozerenko, O, Sled, A, Weiss, DS, and Marmar, CR: Crewmember and crew-ground interactions during Shuttle-Mir missions: Preliminary findings. Phase 1 Research Program Interim Results Symposium: Third Symposium Proceedings. Huntsville, AL; November 3-5, 1998.
2. Kanas, N, Salnitskiy, V, Grund, E, Gushin, V, Kozerenko, O, Sled, A, Weiss, DS, and Marmar, CR: Interactions of crewmembers and mission control personnel during Shuttle-Mir missions: Preliminary findings. Proceedings from the First Biennial Space Biomedical Investigators' Workshop of the Universities Space Research Association. NASA/JSC, January 11-13, 1999.

Investigation Title: The Effects of Long-Duration Space Flight on Eye, Head, and Trunk Coordination During Locomotion

Principal Investigator: Jacob J. Bloomberg, Ph.D., NASA/Johnson Space Center

INVESTIGATION OBJECTIVES

Determine if extended duration space flight modifies head-trunk coordination strategies that occur during terrestrial locomotion and determine if these changes are associated with disturbances in lower limb kinematics and muscle activity patterns of the leg during locomotion.

PHASE 1 MISSIONS

Mir 18, Mir 19, Mir 21, Mir 22, NASA 1, NASA 3, NASA 4

OPERATIONAL ACTIVITIES

Subjects were tested before and after 3-6 months aboard the Mir Space Station. Subjects performed two protocols: 1) walking on a motorized treadmill while performing different gaze fixation tasks; 2) overground locomotion on a 6.0 m walkway. Segmental kinematic data were collected with a video-based motion analysis system while muscle activity from the legs was measured using electromyographic methods.

RESULTS

Analysis of roll, pitch and yaw head and trunk movements during walking revealed postflight alterations in head and trunk movement control in all three planes of motion. Change in lower limb coordination was exemplified by modification in control of thigh, knee and ankle angular displacement, particularly during the heel-strike event of the gait cycle. Subjects also experienced decreased dynamic visual acuity during postflight walking.

CONCLUSIONS

Taken together these data indicate that exposure to long-duration space flight causes alteration in head and trunk movement control, lower limb coordination and dynamic visual acuity during locomotion. Thus, after long-duration space flight there is a loss of integration of the multiple full-body cascade of sensorimotor events required for efficient terrestrial locomotion.

PUBLICATIONS

Articles

1. Merkle, L.A., Layne, C.S., Bloomberg, J.J. and Zhang, J.J. Using factor analysis to identify neuromuscular synergies during treadmill walking. Journal of Neuroscience Methods, 82: 207-214, 1998.

2. Layne, C.S., Lange, G.W., Pruett, C.J., McDonald, P.V., Merkle, L.A., Smith, S.L., Kozlovskaya, I.B. and Bloomberg, J.J. Adaptation of neuromuscular activation patterns during locomotion after long-duration space flight. Acta Astronautica, 43: 107-119, 1998.

3. Reschke M.F., Bloomberg, J.J., Harm D.L., Paloski W.H., Layne, C.S., McDonald P.V. Posture, locomotion, spatial orientation, and motion sickness as a function of space flight. Brain Research Reviews, 28: 102-117, 1998.

Abstracts

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23. Mulavara, A.P., Verstraete, M.C., McDonald, P.V., Layne, C.S., Bloomberg, J.J. Coordination between the head and trunk during locomotion after long-duration exposure to weightlessness. Annual Houston Conference on Biomedical Engineering Research. February, 1999.

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Investigation Title: The Effects of Long-Duration Space Flight on Gaze and Voluntary Head Movements

Principal Investigator(s): Millard F. Reschke, Ph.D., NASA/Johnson Space Center; Inessa B. Kozlovskaya, M.D., Ph.D., D.Sc.

Additional Investigators: Jacob J. Bloomberg, Ph.D., Deborah L. Harm, Ph.D., William P. Huebner, Ph.D., Ludmilla Kornilova, M.D., and William H. Paloski, Ph.D.

INVESTIGATION OBJECTIVES

The primary objective of this study was to investigate the emergence or alteration of goal-oriented strategies required to maintain effective gaze when the interactive sensorimotor systems required for this function were modified following extended exposure to the stimulus rearrangement of space flight.

PHASE 1 MISSIONS

STS-60, STS-63, Mir 18, STS-71, Mir 19, Mir 21, NASA 2

OPERATIONAL ACTIVITIES

The design of the proposed experiment protocol was negotiated by the U.S. and Russian investigators through a series of meetings beginning in 1992 with meetings in both Moscow and Houston (Johnson Space Center). This effort was endorsed by NASA and Russian Life Sciences management as a joint effort to combine U.S. and Russian experimental procedures. In the experiment the subjects were asked to perform five major tasks. (1) Target Acquisition: The target acquisition task included acquiring targets in both the horizontal and vertical planes at preset angular distances, including targets that are beyond the EOM range. Two tests of target acquisition were performed. The first test used predictable targets (i.e., the targets are visible at all times, and acquired in a predetermined sequence known to and practiced by the subject). The second test required acquisition of unpredictable targets (i.e., fixation on a central target and a shift of gaze to a newly illuminated target in an unpredictable plane and to an unknown displacement). (2) Pursuit Tracking: Pursuit tracking, in both the horizontal and vertical planes, included pursuit of both predictable sinusoidal targets at frequencies where vision is expected to be dominate, and at higher frequencies that required visual-vestibular contributions for stable gaze. Unpredictable pursuit tracking used position ramps that vary in both maximal displacement and velocity. Pursuit was first done with the eyes only, head held stationary, then with both the head and eyes. (3) Sinusoidal Head Oscillations (head shakes): Voluntary head motions was done in both the horizontal and vertical planes at 0.2, 0.8, and 2.0 Hz with vision (maintaining a fixation point in the primary frontal plane) and with vision occluded (imagine the fix-ation point available with vision). (4) Memorized Head Rotations: Subjects used a head-fixed laser to quickly and accurately align the head with targets successively illuminated in a pseudorandom pattern. Vision was then occluded and the subject attempted to recreate a head rotation pattern matching the stimulus pattern with and without a delay between stimulus presentation and pattern matching. Head rotations were performed in both the horizontal and vertical planes. and (5) Test For Both Spontaneous and Gaze Nystagmus: Modified standard clinical test for both spontaneous and gaze nystagmus were conducted as part of an eye calibration sequence.

Tests for spontaneous nystagmus were done with the eyes open and shut, and gaze nystagmus was tested by having the subjects deviate the eyes to their maximum position in all planes, hold for 20 seconds, and then return to the center primary position. Pre-postflight eye movements were recorded with video and EOG. Head movements were recorded with a triaxial rate sensor assembly mounted on a head cap. The head cap also included a projection laser for calibration of the head.

RESULTS

Findings to date (not final) strongly suggest that the effects seen on short-duration missions (delayed target acquisition, reduced head velocity following flight, high gain in the visual vestibulo-ocular system, failure to suppress the VOR during head/eye target pursuit, etc.) are present following long-duration missions. Most importantly, the effects of long-duration flights relative to the short-duration Shuttle missions, is the duration of the modification in response parameters. That is, the long-duration flights produce long lasting effects. Recovery, particularly in the pursuit system was not observed in all crewmembers even 64 days following flight.

CONCLUSIONS

Final conclusions will follow with the completion of data analysis.

PUBLICATIONS

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2. Reschke, M.F., Huebner, W.P., Kozlovskaya, I.B., Berthoz, A., Paloski, W.H., and Bloomberg, J.J. "Modification of sensory-motor and gaze control as a function of space flight." Brain and Movement Symposium sponsored by Department of Physiology of Russian Academy of Sciences, Institute of Information Transmission Problems, and the Pavlov Institute of Physiology and Institute of Higher Nervous Activity and Neurophysiology, Moscow, Russia, July, 1997.
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Investigation Title: Evaluation of Skeletal Muscle Performance and Characteristics

Principal Investigator(s): Steven F. Siconolfi, Ph.D., Wayne State University; and Inessa B. Kozlovskaya, M.D.

Additional Investigators: Charles S. Layne, Ph.D., Yuri A. Koryak, Ph.D., Daniel L. Feeback, Ph.D., and Viktor J. Stepantsov, Ph.D.

INVESTIGATION OBJECTIVES

1. To evaluate how skeletal muscle performance and characteristics adapt to microgravity during long-duration space flight.
2. To determine the initial time course for readaptation to 1-g.
3. To evaluate the efficacy of the Russian Countermeasures.

PHASE 1 MISSIONS

Mir 22/NASA 3

OPERATIONAL ACTIVITIES

Preflight and postflight (1) muscle strength, endurance and tone, (2) neuromuscular efficiency, (3) voluntary and evoked contractions, and (4) preflight, inflight, and postflight graded cycle exercise.

RESULTS

Status of Data Analysis

Metabolic Gas Analysis System (MGAS) and muscle strength data is complete. EMG data analysis is 25% complete. Due to decreased funding, EMG analysis will be delayed.

Preliminary Research Findings

Initial muscle strengths were near preflight values and either improved or were maintained for all muscle groups except for knee extensors and flexors for two subjects. The other subject showed initial decreases but returned toward preflight values by the 3rd week of recovery.

CONCLUSIONS

1. Russian countermeasures were generally effective for maintaining gross muscle function.
2. Integrated muscle function was slightly compromised.
3. Russian countermeasure program provides excellent starting point to refine neuromuscular countermeasures for space flight.

PUBLICATIONS

Not provided by PI.

Investigation Title: Frames of Reference for Sensorimotor Transformations

Principal Investigator: Alain Berthoz, Ph.D., LPPA/CNRS-Collëge de France

Additional Investigators: Dr. Joseph McIntyre, Dr. Mark Lipshits, and Dr. Victor Gurfinkel

INVESTIGATION OBJECTIVES

1. To test the hypothesis that gravity can aide in coordinating visual and haptic sensory information and to measure how human subjects adapt eye-hand coordination to weightlessness.

PHASE 1 MISSIONS

NASA 4, NASA 5 (NASA 5 cancelled in flight due to failure of equipment)

OPERATIONAL ACTIVITIES

The NASA astronaut performed a battery of psychophysical tests in which he was required to coordinate visual and haptic (touch and movement) sensory information, using the French Cognilab workstation and Robotop force-actuated joystick.

RESULTS

On the ground, subjects demonstrate the so-called "oblique effect" for the sensation of visual and haptic information, identifying more quickly and precisely vertically and horizontally oriented stimuli. This effect is altered when the subject is tilted with respect to gravity, but remains when measured in the 0G environment.

CONCLUSIONS

These results indicate that the human nervous system uses both proprioceptive and graviceptive information for encoding stimulus orientations, but can substitute a purely proprioceptive reference frame when gravity is absent.

PUBLICATIONS

1. Lipshits, M. and McIntyre, J. (1999) Gravity affects the preferred vertical and horizontal in visual perception of orientation. NeuroReport, in press.

Investigation Title: Gas Analyzer System for Metabolic Analysis Physiology (GASMAP) Facility Operations

Principal Investigator(s): Floyd B. Booker, NASA/Johnson Space Center

Additional Investigators: N/A

INVESTIGATION OBJECTIVES

1. Record a subjects gas exchange with inspiration and expiration readings during exercise.
2. Analyze gas exchange.
3. Measure cardiovascular and cardiopulmonary parameters.
4. To assure the greatest possible analyzer accuracy and response time.

PHASE 1 MISSIONS

NASA 2 - NASA 5

OPERATIONAL ACTIVITIES

The Gas Analyzer System for Metabolic Analysis Physiology (GASMAP) is an instrument that analyzes the inspired and expired breath of subjects and performs metabolic calculations to aid in the health assessment of astronauts in microgravity. GASMAP can be used in conjunction with a bicycle ergometer, treadmill, EKG, blood pressure monitor, and rebreathing apparatus. GASMAP was delivered to the Mir Space Station during the NASA 2 mission. The GASMAP was powered up every 90 days for calibration purposes. The values measured by the GASMAP from calibration gases were recorded and downlinked for comparison with actual values of gases in the calibration tanks. Hardware checks were performed periodically during the NASA 3 mission to verify the operational status of the GASMAP unit. Two types of hardware checkouts were performed: partial checkouts and full checkouts. Partial checkouts were performed approximately every 30 days while full checkouts were performed every 90 days. The operational status of the GASMAP unit was also verified during the NASA 4 mission using partial and full checkouts. Operational status checks of the GASMAP unit continued on the NASA 5 mission until an accident occurred during the docking of a Russian Progress module. The Spektr module of the Mir Space Station was permanently closed after the accident. Consequently, the crew lost access to the GASMAP unit since it was housed in the Spektr module. Plans for GASMAP to support a cardiovascular experiment during the NASA 6 and NASA 7 missions were subsequently canceled.

RESULTS

The GASMAP was calibrated to measure N_2, O_2, CO_2, Ar, He, C_2H_2, and $C^{18}O$ during the calibration exercises and checkout procedures. GASMAP did not require calibration to measure calibration gases accurately. The analyzer measurements were within + 1.25% of full scale of analytical values, except for CO_2, and He; however, He and CO_2 readings were within + 3% of full scale analytical calibration gas values.

CONCLUSIONS

The first generation GASMAP analyzer on board Mir exhibited exceptional stability during the checkout procedures. We think the He and CO_2 measurements can be corrected by changing the analyzer warm-up period to include filament run time.

PUBLICATIONS

N/A

Investigation Title: Inflight Radiation Measurements

Principal Investigator: Gautam D. Badhwar, Ph.D., NASA/Johnson Space Center

Additional Investigators: Drs. V. Petrov, Inna Tchernych, and V. Shurshakov

INVESTIGATION OBJECTIVES

1. Measure crew radiation exposures.
2. Compare crew measurements using US and Russian techniques.
3. Map the radiation dose rate in all Mir compartments.
4. Obtain time resolved radiation data using a tissue equivalent proportional counter (TEPC) in various Mir modules to help in understanding the ISS radiation environment and gather data on radiation quality factor.

PHASE 1 MISSIONS

NASA 1 - NASA 7

OPERATIONAL ACTIVITIES

Crew read TEPC data every five days and relayed to the ground. The data were used to determine safe sleeping crew quarters. Data were periodically transfer to the disk and send then to ground on next Shuttle mission. Periodically the data were transferred electronically.

RESULTS

(1) Dose rates vary by about a factor of two each module. Kvant module had the highest rate, (2) TLDs do not measure the total dose rate, (3) In the Core module, the galactic cosmic ray (GCR) and trapped (SAA) dose rates were approximately equal, (4) GCR rates vary by ~ 15% within modules, and are well correlated with the deceleration potential, (5) Trapped dose rates vary considerably from module to module (~ 5) and with changing solar activity and altitude, (6) Trapped dose rate are well described by a power law relationship of atmospheric density computed 400 days prior to the observations, (7) Established the secular drift of the SAA with time to 0.29 degrees W longitude, and slight northerly component, (8) Particles with linear energy transfer (LET) > 10 keV/micron account for ~ 15% of dose but 65% of the dose equivalent, (9) Models of solar particles transmissions through the geomagnetic field are not in good agreement with the observations, and (10) The highest crew exposure rate was measured for the one of the Mir 23/24 crewmembers, with Russians measurements ~ 8% lower than US measurements.

CONCLUSIONS

(1) First direct measurements of SAA drift with help with EVA planning activity for the station, (2) GCR dose rate predicative model, good to ± 15% developed, and (3) The relationship of trapped dose rate with atmospheric density would help to develop time dependent model of SAA, and (4) helped the crew in selecting area of low dose rate and during November 6-7, 1998 solar particle event.

PUBLICATIONS

1. G.D. Badhwar, Drift rate of the South Atlantic Anomaly, *J. Geophys. Res.* 102, A2, 2343-2349 (1997)
2. G.D. Badhwar, W. Atwell, B. cash, V.M. Petrov, Yu. A. Akatov et al., Radiation Environment on the Mir Orbital Station During Solar Minimum, *Adv. Space Res.,*22, No.4, 501-510 (1998)
3. G.D. Badhwar, V.A. Shurshakov, and Tsetlin, Solar modulation of dose rate on board the *Mir* station, *IEE Trans of Nucl Sci.,* 44, 2529-2541 (1997).
4. G.D. Badhwar, A. Konradi, W. Atwell, et al., Measurements of the Linear Energy Transfer Spectra on the Mir Orbital Station …., *Rad. Meas.*, 26, No.2, 147-158 (1996).
5. G.D. Badhwar, Radiation Measurements on board the *Mir* orbital station, Phase 1 Symposium, November 1998, Huntsville, Al

Investigation Title: Magnetic Resonance Imaging (MRI) After Exposure to Microgravity

Principal Investigator: Adrian L. LeBlanc, Ph.D., Baylor College of Medicine

Additional Investigators: Inessa Kozlovvskaya, M.D., Ph.D., Valentine Sinitsyn, M.D., Daniel L. Feeback, Ph.D., Harlan Evans, Ph.D., Thomas Hedrick, M.D., Victor Oganov, M.D., Oleg Belichenko, M.D., Ph.D., Linda Shackelford, M.D., and Chen Lin, Ph.D.

INVESTIGATION OBJECTIVES

1. Measure the muscle volumes of the calf, thigh, back and neck using MRI before and after flight. These data will be compared with pre- and postflight muscle performance measurements.
2. Determine and compare the T2 and muscle volume changes on R+0 and R+4 days following space flight using MRI.
3. Determine the change in intervertebral disc size in the lumbar spine after flight and determine the rate of recovery after return to one G.
4. Determine the bone marrow T2 and cellularity of L3 before and after flight using MRI spectroscopy.
5. Document frequency, type, severity, and location of back pain during and after space flight.

PHASE 1 MISSIONS

NASA 1-7. Some data from NASA 6 and 7 still being analyzed.

OPERATIONAL ACTIVITIES

MRI Imaging:

- Muscle volume of the calf
- Muscle volume of the thigh
- Muscle volume of the lower back
- Muscle volume of the neck
- T2 of calf muscle
- lumbar spine disc size and lumbar spine length
- T2 of proton spectroscopy of L3

Fill out back pain questionnaire.

RESULTS

The change in muscle [gastrocnemius, soleus, anterior calf, quadriceps, hamstrings, intrinsic lower back (rotatores, multifidus, semispinalis, spinalis, longissimus, iliocostalis), psoas, neck muscles (splenius capitis, semispinalis capitis, semispinalis cervicus, multifidus)] volume as the percent change from baseline versus the length of flight has been determined in 15 astronauts and cosmonauts. The data include 14 male and one female representing 6 American astronauts and 9 Russian cosmonauts. The flight lengths varied from about 4 months to about 6 months. In spite of the considerable individual variation, it appears that the losses at around 4 months are similar to the 6 month data. This suggests that the amount of volume change has maximized by 4 months of flight. The changes were greatest in the calf and back and somewhat less in the thigh. The inter-individual variation may reflect in part the differences in the inflight exercise protocol followed by crewmembers. There were no measurable changes in the neck muscles measured. Comparison of the flight results with bed rest indicate that the changes in the leg muscles during flight were generally less than bed rest. This is likely a consequence of the exercise countermeasure employed during flight since the bed rest data did not include exercise. The back muscles, however, showed greater loss during flight compared to bed rest, which may be reasonable, considering that the back muscles are active to a substantial degree in bed rest. Postflight each of the flight crew were measured at multiple time points, generally 3-4. These results show that muscle volume recovers at variable rates depending on the region, but generally have returned to baseline by 30-60 days postflight.

Muscle T2 is available on 5 crewmembers, however, the analysis of this data is not complete (does not include NASA 5-7) and therefore conclusions are preliminary. The general pattern is that T2 tends to be increased relative to baseline at the first postflight measurement and almost always elevated at R+14 compared to the initial postflight measurement or baseline. By 30-70 days postflight the T2 has decreased toward baseline in all cases where these measurements were available. Muscle volume changes between R+0 and R+2-4 days after flight are complete on 5 crewmembers (not complete) on which this was available. This data demonstrates muscle swelling can occur during the early reambulation period; this is also usually seen after bed rest. The largest changes are in the calf, particularly the gastrocnemius.

The measurements of disc area and lumbar spine length indicate that there are only minor spine lengthening and disc expansion by the time measurements are obtained on landing day. Measurements are made within 2-4 hours after landing with some walking and sitting up on a stretcher by the crewmember before testing. By 2-4 days postflight there is some slight residual expansion remaining which by 2 weeks is back to baseline. Importantly, we do not see any long-term residual changes in disc size following these flights.

In only 4 individuals were the bone marrow spectroscopic data reasonably complete. In two of the individuals collection of preflight data was not possible and in two others postflight data collection was incomplete because of equipment problems. While the data a re preliminary and incomplete, comparison to the LMS, 17 day mission suggests that although the postflight T2 tens to increase as in the shorter LMS flight, there appears to be some significant differences. For example, three individuals demonstrated significantly reduced values postflight that gradually returned to baseline; this was not seen on LMS. Two other individuals appear to show a similar postflight pattern as LMS.

Out of 15 crewmembers (including one German guest cosmonaut, but not the data from NASA 6 and 7), 7 indicated that they experienced back pain or discomfort during the flight. Generally this occurred in the lower lumbar region during the first week of flight. The pain was typically described as “can be ignored,” lasted a few hours to several days in duration and was most noticeable during or after resting. Some crew indicated that bending or application of massage seem to relieve the pain. Postflight 6 of 15 crewmembers reported significant discomfort for some or all 10 days that monitoring was reported following flight. There were a number of cases where written reports were not available or were not filled out. Whenever possible the crew were asked about their experience during and after flight. When no information was available these were treated as being negative reports and therefore, the incidence rates above may underestimate actual rates.

CONCLUSIONS

There are measurable decreases in muscle volume during flight, which presumably, but not necessarily, represents muscle atrophy. These changes appear to be maximized within the first 4 months of flight. Compared to bed rest without exercise, the inflight muscle changes are less except in the back muscles. Recovery in all muscle groups is complete within 30-60 days after return to Earth, similar to recovery after bed rest. There are muscle volume and T2 changes during the first days and weeks after return from space flight compatible with muscle damage. We did observe small, but no long-term changes in disc size following these flights. There are postflight bone marrow changes with some significant differences compared to the shorter LMS flight. Although about 47% of the crewmembers reported some back pain during flight, the duration and magnitude of this problem seems not to be of major concern for long-duration flight. A more important consideration may be the potential for significant injury/pain after flight since about 40% reported significant postflight discomfort lasting for a number of days to weeks. This may be an important consideration for visits to planets with significant gravity after lengthy flights in microgravity.

PUBLICATIONS

A paper reporting the muscle results is in preparation.

Investigation Title: Microbial Interaction in the Mir Space Station Environment

Principal Investigators: George M. Weinstock, Ph.D., University of Texas Medical School

INVESTIGATION OBJECTIVES

1. Development of a DNA fingerprinting method for microorganisms suitable for space flight.
2. Application to tracking of microbes from NASA-Mir missions to determine the amount of microbial transfer between crew and from the Space Station, (3) Determination of the microorganisms that may transfer most often.

PHASE 1 MISSIONS

Mir18, Mir19, STS-71, Mir22/NASA3

OPERATIONAL ACTIVITIES

DNA fingerprinting technology development and application to microbial samples obtained from the Microbiology Laboratory at JSC.

RESULTS

A rapid and cost effective DNA fingerprinting method was developed for microbial samples. Application of this to isolates of Staphylococcus aureus demonstrated transfer of this bacterium between crewmembers, both during training and during flight. Analysis of a census of other microorganisms that were isolated during these missions showed several other candidates for DNA fingerprint analysis, based on their potential for transfer between crew or from the Space Station to the crew. The DNA fingerprinting method was shown to be applicable to these other types of bacteria.

CONCLUSIONS

Transactions involving microorganisms occur between crew and Space Station environment at a higher frequency that could previously be detected. Tracking of microbes by DNA fingerprinting is a reliable method for detecting and analyzing these movements.

PUBLICATIONS

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2. Comparison of rep-PCR and RFLP analysis by pulsed-field gel electrophoresis for DNA fingerprinting of Staphylococcus aureus. In preparation. C. K. Brauning, D. L. Pierson, G. M. Weinstock.
3. On the mechanism of rep-PCR DNA fingerprinting. In preparation. M. Chidambaram, E. J. Sodergren, D. L. Pierson, and G. M. Weinstock.
4. Transfer of Staphylococcus aureus between humans in a closed environment. In preparation. C. K. Brauning, D. L. Pierson, G. M. Weinstock.

Investigation Title: Microbiological Investigations of the Mir Station and Crew

Principal Investigators: Duane L. Pierson, Ph.D., NASA/Johnson Space Center; Dr. Aleksandr N. Viktorov

Additional Investigators: Theron Groves, Rebekah Bruce, Natalia Novikova, Vladimir Skuratov, and Nadezda Lizko

INVESTIGATION OBJECTIVES

1. Characterize the microbiota of crewmembers, air, surface, and water microbes before, during, and after a long-duration mission aboard the Mir Space Station.
2. Have operationally-ready hardware systems ready for ISS.

PHASE 1 MISSIONS

Mir 18, Mir 19, Mir 22, NASA 3, NASA 4, NASA 5, Mir 24, NASA 6, Mir 25, NASA 7

OPERATIONAL ACTIVITIES

*Crew Microbiology**

Preflight: Launch minus 6, 5, 4, 3, 2, and 1 month(s)

Inflight: Flight Days 15, 35, 55, 85, 115, and 135

Postflight: Return plus 0, 7, and 14 days

Analyses: Throat, nose, ear, hand, scapula, axilla, groin, urine, and feces cultures; Rapid Group A Streptococcus screen; Throat viral culture; Parasitology

*Environmental Microbiology**

Shuttle Air: Middeck, Flight Deck; Sampling at Rollout, launch minus 2 days, Flight Days 2 and 5

Mir Air: 4 sampling locations; Sampling during Shuttle docking and once per month in flight

Shuttle Surfaces: 3 sampling locations; Sampling at Rollout, Launch minus 2 days, Flight Days 2 and 5

Mir Surfaces: 5 sampling locations; Sampling during Shuttle docking and once per month in flight

Shuttle Water: Galley; Sampling at Launch minus 15 and 3 days, Return plus 1 day

Mir Water: 3 sampling locations; Sampling during Shuttle docking and once per month in flight

* Sampling frequency decreased upon implementation of the Space Medicine Program

RESULTS

Developed a surface sampling kit for culturing of microbes on a variety of spacecraft surfaces for inflight analysis.

Conducted microbial air sampling using a Burkard air sampler.

Developed a water microbiology kit for the inflight analysis of spacecraft water.

Conducted the first inflight microbial analysis of a spacecraft water supply.

CONCLUSIONS

Crew Microbiology

Aerobic microbiota of crewmembers were characteristic of healthy individuals.

Fecal anaerobic microbiota data indicated that a shift in intestinal microorganism ratios occurs in some crewmembers.

Dissemination of microorganisms between crewmembers was demonstrated by DNA fingerprinting.

Environmental Microbiology

The Mir environment is microbiologically similar to that of the Shuttle.

Microbial levels in air and on surfaces were generally within ISS acceptability limits; fungal levels tended to be higher on Mir than found on Shuttle.

Levels of microbes in hot water were within ISS acceptability limits; levels in ambient and ground-supplied water sources frequently exceeded US limits but were within Russian limits.

Analysis of surface condensation is important for environmental assessment (first inflight recovery of protozoa and dust mites).

Potential pathogens in a closed environment can increase the risk of infection in crewmembers.

Microorganisms play a key role in the biodestruction of materials and can contribute to equipment and hardware malfunctions.

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Investigation Title: Protein Metabolism During Long-Term Space Flights

Principal Investigator(s): T. Peter Stein, Ph.D., University of Medicine & Dentistry of New Jersey; Irina Larina

Additional Investigators: Not Applicable

INVESTIGATION OBJECTIVES

1. To determine the duration of the metabolic stress response associated with space flight.
2. To determine how long it takes for protein metabolism to return to its preflight state after a long-duration mission.

PHASE 1 MISSIONS

Mir 21/NASA 2, Mir 22/NASA 3

OPERATIONAL ACTIVITIES

The changes in protein metabolism caused by space flight were measured by using the 15N-glycine method. One gram of glycine, labeled with the stable 15N nitrogen isotope, was ingested four times during Mir 21/NASA2 and three times during NASA3/Mir22. Over the next 24 hours the protein metabolism was monitored by collecting urine and saliva samples, weight measurements and dietary monitoring. In addition, preflight measurements were used as a baseline and postflight measurements were performed to determine the recovery of the protein metabolism to preflight status.

RESULTS

Status of Data Received/Analyzed: Fewer whole body protein measurements were done during space flight than initially were planned for. There is a lack of early and middle inflight data for Mir 22/NASA3 missions.

CONCLUSIONS

1. After 4 plus months in space the whole body protein synthesis rate was reduced by an average of about 31% for Mir 21/NASA 2, and 53% for Mir 22/NASA 3 subjects. The decrease was greater than predicted from bed rest studies.
2. The cumulative data suggests that whole body protein synthesis declines with time in space.

PUBLICATIONS

Not provided by the Principal Investigator.

Investigation Title: Renal Stone Risk Assessment During Long-Duration Space Flight

Principal Investigators: Peggy A. Whitson, Ph.D., NASA/Johnson Space Center; German S. Arzamazov, M.D., Institue of Biomedical Problems

Additional Investigators: Robert A. Pietrzyk, M.S., C.Y.C. Pak, M.D., and Clarence F. Sams, Ph.D.

INVESTIGATION OBJECTIVES

1. Determine the effects of exposure to microgravity on the potential for renal stone formation.
2. Determine the effect of mission duration on the potential for renal stone formation.
3. Determine how long after flight the increased risks for renal stone formation.
4. Estimate the contribution of dietary and environmental factors to the risk of renal stone formation.

PHASE 1 MISSIONS

Mir 18, Mir 21, Mir 22, Mir 25, NASA 2, NASA 3, NASA 6, NASA 7

OPERATIONAL ACTIVITIES

- 24 hour urines were collected during the pre-, in- and postflight periods.
- Diet and fluid intake were logged for the 24 hr. period prior to urine collection and during the 24 hr. urine collection.

RESULTS

Thirteen astronauts and cosmonauts participated in this investigation. Two of these subjects performed a potential renal stone countermeasure during their flight by increasing fluid intake resulting in increased daily urine output. All crewmembers attempted to meet the requirements of this study. However, due to scheduling changes, it proved difficult to collect urine at the times requested and the effects of mission duration on renal stone formation may be difficult to assess. Instances of incomplete or missing urine collections and diet logging occurred throughout this investigation to various subjects. The study recently was completed following the landing of the Mir 25 crewmembers. Sample collection and data analysis from this mission has been completed. Construction of the database from all subjects who participated in this study is in progress.

During the NASA 6 and NASA 7 missions, a novel technique for preserving urine was evaluated. Urine samples were collected onto filter cards, the cards dried and the samples stored until return to Earth for analysis. Preservation of the urinary analytes was performed at room temperature without the uses of chemical preservation, refrigeration or freezing of samples.

CONCLUSIONS

Data from short-duration Shuttle missions have indicated that exposure to microgravity alters the urinary chemistry favoring the formation of renal stones. Preliminary conclusions from the long-duration Phase 1 investigations have supported this observation and have shown:

- Increased calcium excretion in most crewmembers despite decreased dietary calcium intake.
- Decreased inflight fluid intake resulting in lower daily urinary output.
- Decreased urinary citrate, an inhibitor of calcium-containing stone formation, during an immediately after flight.
- Individual subject response to microgravity appears to play a key role in changes observed in the urinary chemistry.
- The risk of renal stone formation increases early upon exposure to microgravity and continues throughout the flight.

The two crewmembers who performed a potential renal stone countermeasure by increasing their fluid intake to increase urine output effectively reduced the risk of renal stone formation by increasing the solubility limits of the stone forming salts. These crewmembers ingested greater than 3 liters of fluid per day. This may not be a practical alternative to all crewmembers due to individual needs or schedules and does not alter the changes observed in the urinary biochemistry. However, the knowledge gained from these two subjects and from Earth based observations of renal stone sufferers has been shared with astronauts and cosmonauts. Postflight Shuttle data have now shown an increased average urine output compared to earlier Shuttle missions. In light of the occurrence of two preflight renal stones and one postflight renal stone in the U.S Space Program and one inflight stone in the Russian Space Program, continued research and countermeasure assessment is warranted.

In a addition to the renal stone risk assessment, dried urine chemistry was evaluated during the NASA 6, Mir 25 and NASA 7 missions. Overall, this new technology proved itself successful. The urinary analytes of interest to this investigation were stable for an extended period of time. This technology may enhance the capability for medical science investigations on future space missions. This technology employs minimal power, requires no sample refrigeration or freezing and has the potential to preserve a large battery of biological compounds

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Investigation Title: Sleep Investigations - Human Circadian Rhythms and Sleep in Space (E639)

Principal Investigator: Timothy H. Monk, D.Sc., Ph.D., University of Pittsburgh

INVESTIGATION OBJECTIVES

1. To study sleep, daytime performance and mood, oral temperature and pre and post-sleep ratings from three 12-day measurement blocks in flight.

PHASE 1 MISSIONS

NASA 4, Mir 23, Mir 24

OPERATIONAL ACTIVITIES

In each day of the 12-day measurement blocks one astronaut was to:

1. Complete a pre-sleep diary (1/day).
2. Complete a post-sleep diary (1/day).
3. Perform a simple performance battery (1/day).
4. Rate mood and alertness and take oral temperatures (5/day).

RESULTS

NASA 4

Harvest rate for acceptable data (%) was as follows:

First Block: 100% for #1, 91.7% for #2, 91.7% for #3, 90% for #4

Second Block: 100% for #1, 100% for #2, 100% for #3, 100% for #4

Third Block: 91.7% for #1, 100% for #2, 100% for #3, 96.7% for #4

Mir 23

Harvest rate for acceptable data (%) was as follows:

First Block: 95.8% for #1, 95.8% for #2 , 91.7% for #3, 78.3% for #4

Second Block: 95.8% for #1, 100% for #2, 91.7% for #3, 87.5% for #4

Third Block: 45.8% for #1, 50% for #2, 45.8% for #3, 46.7% for #4

Mir 24

Harvest rate for acceptable data (%) was as follows:

First Block: 50% for #1, 41.7% for #2 , 20.8% for #3, 32.5% for #4

Second Block: 29.2% for #1, 16.7% for #2, 16.7% for #3, 3.4% for #4

Third Block: 0% for #1, 0% for #2, 0% for #3, 0% for #4

CONCLUSIONS

NASA 4

The data indicated that for various reasons some sleep episodes were of duration five hours or less. When the days following these sleeps were examined detrimental effects were observed in alertness, mood and perceived work performance

Mir 23

The data indicated that for various reasons some sleep episodes were of duration five hours or less. When the days following these sleeps were examined detrimental effects were observed in alertness, mood and perceived work performance

Mir 24

There were insufficient data for any meaningful scientific conclusions to be drawn

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Investigation Title: Sleep Investigations - Microgravity, Sleep/Wake Immune Functions (SWIF) in Humans (E710)

Principal Investigator: Harvey Moldofsky, M.D., University of Toronto, Canada

Additional Investigators: No additional investigators

INVESTIGATION OBJECTIVES

General research objectives were to determine the influence of gravity change on sleep and the immune system in crewmembers, especially as it related to well-being. Specifically, researchers expected that:

1. Space flight-related dysfunctions in health, sleep and circadian rhythms would result in a decrease in proportion of NK cells in peripheral circulation; alter plasma IL-1, IL-2, cortisol, and growth hormone (hGH); and impair NK cell cytotoxic activity.

2. Sleep, circadian rhythms, immune function, and well-being would normalize over time and become indistinguishable from sleep in normal gravity within 3 months.

PHASE 1 MISSIONS

Mir 23/NASA 4

OPERATIONAL ACTIVITIES

After the experiment was selected, it was merged at the request of NASA into a sleep experiment including scientific objectives from the University of Pittsburgh (Dr. Monk) and Harvard Medical School (Dr. Hobson.)

Pre-, in-, and postflight subjects answered questions on sleepiness, fatigue, pain and mood as well as performance that had been incorporated into a battery of questions prepared by colleagues at the University of Pittsburgh. Immunologic and endocrine assays were carried out on blood samples collected pre-, in-, and postflight. The relationship between delta or slow wave sleep activity to immune functions was examined.

RESULTS

The preflight BDC data from all crewmembers were compared to a group of healthy male volunteers to determine if sleep/wake age related immune and endocrine functions were present in middle-aged male (MAM) subjects during baseline conditions before flight on Mir vs. young healthy males (YM).

NK cytotoxicity declined during sleep versus wake in both groups, but the timing for such changes differed. There was no 24-hour mean NK difference between groups. MAM secreted less hGH over 24-hours than YM. Whereas both groups secreted their maximum hGH during sleep, there was only hGH during the daytime in YM. The cortisol level was higher in MAM, and the rise during sleep occurred later than in YM. Slow wave sleep showed minimum cortisol secretion in both groups.

Middle-aged crewmembers in preflight baseline conditions differed from young healthy males in the timing of the diurnal pattern of NK cytotoxicity, hGH, and cortisol. They also secreted less hGH and more cortisol over a 24-hour period. These hypothalamic-pituitary-adrenocortical (HPA) axis endocrine differences in healthy middle-aged men were similar to those seen in healthy older males. While the dynamic structure of NK cytotoxicity differed, there was no overall mean difference from young males.

CONCLUSIONS

Not provided by the PI.

PUBLICATIONS

No publications available.

Investigation Title: Sleep Investigations - Sleep and Vestibular Adaptation (E663)

Principal Investigator: J. Allan Hobson, M.D., Massachusetts Mental Health Center

Additional Investigators: Robert Stickgold, Ph.D., Irina Ponomareva, M.D., and Irina Larina, M.D.

INVESTIGATION OBJECTIVES

1. To design and test a portable, self applicable REM/nonREM/wake-state monitoring system with special reference to the constraints and conditions of prolonged space flight.

2. To obtain long-term data on the physiology and behavior of human sleep under prolonged microgravity conditions.

PHASE 1 MISSIONS

Mir 23/NASA 4, Mir 24/NASA 5

OPERATIONAL ACTIVITIES

One astronaut and four cosmonauts wore the Night Headband Monitor for a total of 317 nights of sleep data. Subjects recorded an average of 26 nights of sleep during the preflight period, 24 nights in flight, and 14 nights during the postflight recovery period. All told, 120 nights of sleep data were collected in flight, between the 24th and 171st day in orbit. Sixty of the 120 nights were recorded more than three months into the flight.

RESULTS

Preliminary analyses show that REM sleep was severely diminished during flight for all five subjects. Both REM time and REM % (of total sleep time) were significantly diminished (REM time, $F=20.5$, $p<0.001$; REM%, $F= 16.5$, $p<0.002$). On average, REM time was reduced by 53% and REM% by 35% in flight compared to preflight. All subjects showed at least a 40% reduction in REM time. In contrast, postflight rates were essentially the same as preflight, showing on average a 4% increase in both REM time and REM% compared to the preflight period.

There was also a decrease in total sleep time in flight ($F=7.1$, $p<0.02$). Inflight values were reduced by 27% on average, while postflight values were 0.3% higher. All subjects showed at least a 13% decrease in average nightly total sleep time. This did not result from a decrease in time in bed ($F=0.2$, $p=0.84$); subjects spent on average 4% longer in bed while in flight. Rather, it resulted from a decreased sleep efficiency ($F=24.1$, $p<0.0005$). Efficiency dropped from a mean of 89% in the preflight period to 63% in flight.

CONCLUSIONS

The Nightcap sleep monitoring system has permitted more extensive sleep recording during space flight than has been previously possible. The data collected over 6 months of flight indicate that extended space flight leads to a consistent and pronounced decrease in sleep efficiency, time spent in REM sleep, and the percent of total sleep time spent in REM sleep as measured by the Nightcap. Neither the causes nor the consequences of these alterations are clear. But the continued reduction in these values might well lead to diminished performance of crewmembers in space.

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