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Session FA3
Room 3
8:30 - 11:30 a.m.

Results from the Joint U.S./Russian Sensory-Motor Investigations

THE EFFECT OF LONG DURATION SPACE FLIGHT ON THE ACQUISITION OF PREDICTABLE TARGETS IN THREE DIMENSIONAL SPACE

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INTRODUCTION

The ability to undertake goal-directed action is required for human survival. Self-orientation, self-motion, and the perception of that orientation and motion are required for and modified by goal-directed action. Specifically, given the documented disruptions that occur in spatial orientation during space flight and the putative sensory-motor information underlying eye and head spatial coding, the primary purpose of this paper is to examine components of the target acquisition system in subjects free to make head and eye movements in three dimensional space following adaptation to long duration space flight.

METHODS

Five male astronaut/cosmonaut subjects acquired spatially and temporally predictable targets located in the horizontal and vertical planes, both within and beyond the effective oculomotor (EOM) range, using a time-optimal strategy (move the head and eyes together as quickly and as accurately as possible to acquire the target) before and after two space flights aboard the Russian Mir station. Each flight had a duration of approximately three months. Horizontal and vertical eye movements were recorded with conventional DC electro-oculographic techniques, and three dimensional head movements were obtained with a triaxial rate sensor system mounted firmly to the head.

RESULTS

Typically an orienting gaze movement initiated to bring a selected part of the visual world onto the fovea consists of an eye movement saccade and a head movement followed by a reflexive compensatory eye movement driven by the VOR and visual fixation responses (VVOR). In the usual sequence, a saccade directs the eye either onto the target (for targets with a small angular displacement) or towards the target when the angular displacement is beyond the EOM. Unlike the majority of the preflight observations which used a normal sequence of head and eye movements to assist in acquisition of a target, and in spite of evidence for common driver signals to the head and eye, different strategies were used postflight to bring gaze onto a target. Figures 1a and 1b illustrate two different gaze-shift strategies that were used to obtain a target beyond the EOM. The response in Figure 1a was obtained preflight and shows a head movement synchronous with or beginning slightly before movement of the eye towards the target. The target acquisition response illustrated in Figure 1b was obtained postflight and shows an eye movement towards the target just prior to movement of the head. The primary difference between the preflight and postflight strategies is clearly seen in the velocity of the head, the final position of the head, and the number of saccades generated prior to gaze stability. In Figure 1a (preflight) the eye makes a major saccade toward the target and appears to be assisted by the movement of the head. A normal visual-vestibular ocular reflex (VVOR) is established with a gain just slightly greater than one. The postflight response on the other hand (Figure 1b) shows a delayed head movement, reduced velocity, less angular displacement, and multiple saccades (with gains up to 4.0) prior to final gaze position. The difference between these two responses can be clearly illustrated when gaze is plotted parametrically as a function of head position (Figures 2a and 2b). Total gaze error can be derived from integrating the area represented by the right 90° angle (head position 0° to maximum gaze displacement). This function is illustrated in Figures 2a and 2b. Please note that three major factors contribute to gaze error: response latency, time taken to achieve final gaze position and the number of saccadic eye movements generated. When gaze position is considered as a function of time, the preflight total gaze error is approximately 20°xsec and postflight it is 54°xsec. Perhaps one of the most important aspects of determining total gaze error as a function of time lies with its use as an index of performance. That is, when it is critically important to obtain a target in the shortest amount of time large gaze errors will result in less accurate target acquisition responses over time. Total gaze error can also be used to predict postflight (or inflight) performance using preflight behavior. We tested this hypothesis by determining the absolute gaze error as a function of time from preflight trials (restricting ourselves to those targets beyond the EOM), and then relating the absolute gaze error to the head and eye velocity in the vertical plane for a specific trial obtained during target acquisition. In relating gaze error to head and eye velocity we categorized the error in terms of either a large or small gaze error. When absolute gaze errors as a function of time were associated with postflight vertical head and eye velocities a clear trend was apparent. Large gaze errors were more likely to be associated with lower head and eye velocities, while small gaze errors were related to higher head and eye velocities. Among other things, this finding suggests that the neural strategies adopted during adaptation to micrograyity may not be optimal for postflight performance. Those adopting a strategy of higher head and eye velocities may have less difficulty and reduced gaze error.

FIGURE 1a

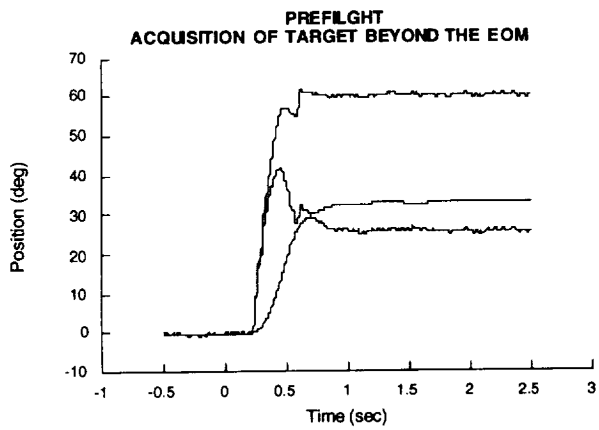


FIGURE 1b

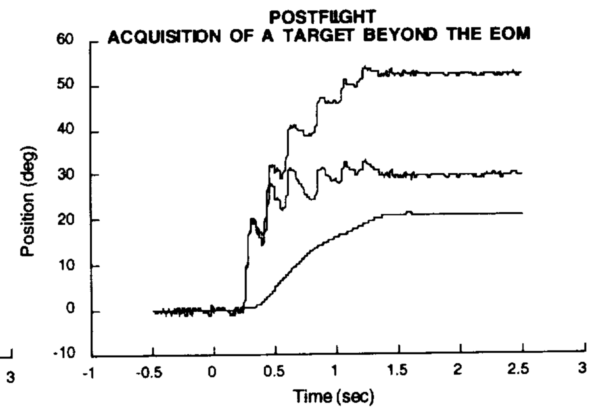


FIGURE 2a

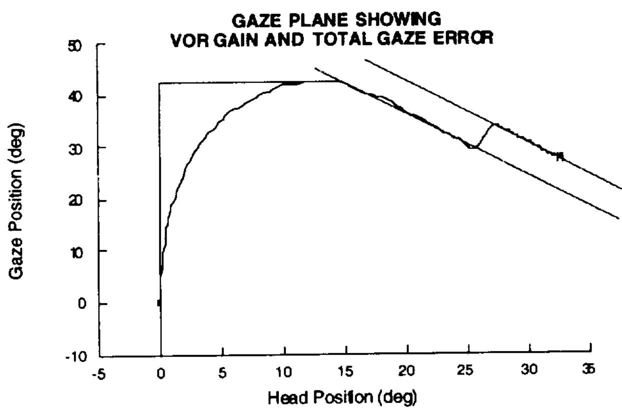
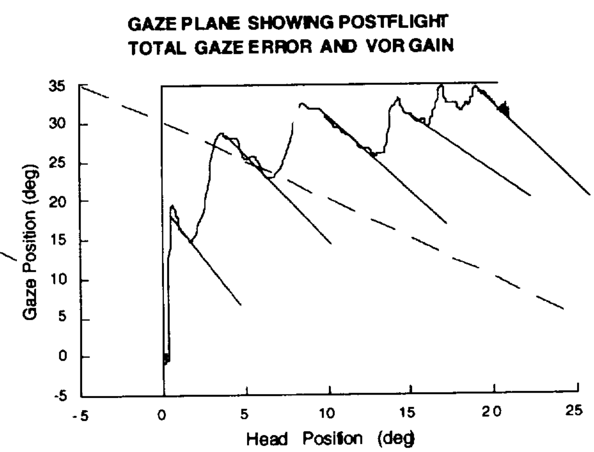


FIGURE 2b



CONCLUSION

Based preliminary on the data from a relatively small sample population (five subjects) the results appear to confirm the working hypothesis that eye/head movements will be modified during adaptation to microgravity. There is a degradation in the astronauts' ability to acquire targets with the head and eyes, even though the acquisition process has been practiced and rehearsed. Timing and accuracy is particularly degraded when the object to be acquired is outside of the central field of view (i.e., offset from center by more than 35°) and is located in the vertical plane thus requiring a pitch head movement for target acquisition. Processing and analysis of our remaining Mir data is necessary to confirm the preliminary results. It is interesting to note that the effects observed in the long duration crews appear to require more time following flight for a return to baseline values, and that specific individuals may require >70 days postflight for full recovery.

EFFECTS OF MICROGRAVITY ON SPINAL REFLEX MECHANISMS

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INTRODUCTION

Results of previous studies have shown that short and long-term exposures to real and simulated weightlessness are followed by clear signs of enhancement of excitability of stretch reflex mechanisms (Kakurin et al., 1971, I.B.Kozlovskaya et al, 1982, 1988, 1990). However the data, obtained in postflight observations or in the course of simulation experiments can not be directly interpolated to the weightlessness environment. Since alteration of activity of spinal reflex mechanisms can in its turn be
followed by movement control disturbances the series of experiments were performed that were directed to study characteristics of stretch knee tendon reflexes during long-term spaceflights. As a control tendon (T) Achilles reflexes and (H) Hoffmann ankle reflexes have been studied in long-term bedrest (BR).

METHODS

The characteristics of the recruitment curve namely, the threshold and the maximal amplitude of the tendon (T) (I) patellar and (ii) Achilles reflexes and of the H-reflexes has been studied in (I) 10 members in long duration (4-14 months) spaceflights and in (ii) 16 subjects - participants of long-term (from 4 to 12 months) bedrest studies. I) Parameters of electromyographic (EMG) responses of m. quadriceps femoris to standard impacts (small, moderate and submaximal ones) applied to the patella had been studied inflight. The standard position of the leg during testing was secured by special fixation device. ii) Under bedrest conditions the electromyographic responses of m. gastrocnemius lateralis to impacts applied to the Achilles tendon by the conventional neurological hammer that was supplied by the tensometric sensor have been studied.

RESULTS

The results of the studies revealed the clear cut signs of the reflex excitability enhancement. The amplitude of the EMG bursts responses that varied on-ground to stimuli of small, moderate and strong impacts from 1.5 mv to 2.8 mv reached during different phases of flight the range of 5.0 mv, 6.0 mv and even 8.5 mv. The same was true for the measurements made on the 2nd postflight day. The well-organized 2-wave response that was usually recorded under 1G conditions had been substituted inflight by polyphasic clonic activity. As a result the duration of the response had increased in space up to 500 ms to the small impact and even to 2000 ms to the strong one. During the first stage of flight that was lasted up to 30 days, the amplitudes of T-reflexes were lowered though the clonic organization of the response pointed out to the enhancement of the reflex' excitability. Under the conditions of BR the maximal amplitudes of m.gastrocnemius lateralis' T-reflex was increased greatly (up to 4 mv vs 1 mv in average before BR) starting from the day 2 and reaching the peak values on the day 5 of BR. After that the reflex amplitude revealed the tendency to decrease under conditions of "pure" BR or to stabilize on the same high level when the physical exercises have been used. The very same time-course changes were revealed in BR in values of maximal amplitudes of the H-reflex and the M-response.

CONCLUSION

The results of studies allow to conclude that the primary effect of microgravity is the enhancement of the excitability of spinal stretch reflexes' mechanisms. However the values of the reflexes' amplitudes can be affected to a great extent by the processes which are developing in the muscle state.

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THREE DIMENSIONAL HEAD MOVEMENT CONTROL DURING LOCOMOTION AFTER LONG-DURATION SPACE FLIGHT

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INTRODUCTION

Research conducted in both U.S. and Russian space programs have revealed that exposure to the microgravity environment encountered during space flight induces adaptive alteration in sensorimotor function leading to post flight disturbances in locomotor control. We have recently characterized some of the underlying adaptive changes that contribute to these locomotion alterations following short-term space flight on the U.S. Space Shuttle (Bloomberg et al., 1997; Layne et al., 1997; McDonald et al., 1996). The purpose of the present study was to investigate the effects of long-duration space flight on segmental coordination during locomotion with particular emphasis on alterations in head movement control.

METHODS

Five astro/cosmonaut subjects were tested before and after 3-6 months stays aboard the Mir Space Station. As part of a larger protocol involving both overground and treadmill locomotion, subjects walked (6.4 km/hr) on a motorized treadmill while visually fixating on a FAR (2 m from the eyes) or a NEAR (30 cm from the eyes) visual target for trials of 20 s in duration. Kinematic data were collected with a video-based motion analysis system (Motion Analysis Corp., Santa Rosa, CA). Yaw, pitch and roll head position was calculated using three passive retro-reflective markers affixed to the vertex, occipital and right temporal positions of the head.

RESULTS

Analysis of the power spectra of yaw, pitch and roll head position during locomotion revealed individual post flight differences in all rotational planes. In addition, after space flight the dynamics of head movements during locomotion as defined by ensemble velocity and acceleration waveforms were markedly altered in yaw, pitch and roll planes. Recovery of head movement control was typically not complete in all rotational planes within the 9 day post landing testing period.

CONCLUSION

These results demonstrate that long-duration space flight induces adaptive changes in head movement control in all three rotational axes. We infer from these results that prolonged post flight impairment of head movement control following long duration space flight contributes to locomotor and postural dysfunction by disrupting descending vestibular control of body movement.

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HUMAN BODY SHOCK WAVE TRANSMISSION PROPERTIES AFTER LONG DURATION SPACE FLIGHT

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INTRODUCTION

The purpose of the present investigation was to assess the effects of long duration space flight on the shock transmission characteristics of the human body while walking. Locomotor ground reaction forces (GRF) create shock waves that travel from the feet through the body to the head. Most frequency components of walking GRF are comprised between 0 and 50 Hz (Antonsson & Mann, 1985). Measurements of the shock at different sites along the musculo-skeletal system indicate similar frequency bandwidths. However, comparisons of power spectra indicate that the body alters the frequency composition of the input shock as it travels through the body (Lafortune et al, 1994; Shorten and Winslow, 1991). Moreover, a preliminary study of the effects of short duration flight indicated qualitative modifications of shock wave transmission while walking (Lafortune et al, 1997).

METHODS

Subjects flew on the Mir Space Station and data were collected twice pre-flight, with the sessions separated by at least one week, then again 1, 3, 7, and 180+ days after landing. Each data collection session consisted of at least 4 barefoot walking trials at a self selected velocity along a 6-8m walkway. GRF was measured with a Kistler 9286 force platform embedded in the walkway at about 4m. Head acceleration was measured with a triaxial Entran ±5g accelerometer mounted onto a plexiglass bitebar which was held firmly in the molars. All channels were sampled at 1020 Hz and GRF was normalized to the subjects' own body weight. Data were sampled for eight seconds with the GRF signals being used to detect the contact of the right foot with the force platform. Using the initial 256 data points after ground contact, temporal and frequency domain measures of impact force and shockwave transmission were calculated for each subject for each test session.

RESULTS

Preliminary results from temporal domain analyses indicate some postflight changes in the magnitude of the initial ground reaction force peak. Similarly, one observes concomitant changes in the peak magnitude of head acceleration. Both these events occur within a few milliseconds of each other and are considered causally related. In the frequency domain, a ratio of the power spectra of the GRF and head acceleration, termed the gain-attenuation function, indicates selective changes in gain at certain frequencies.

CONCLUSION

These data indicate some postflight changes are occurring in shock wave transmission properties of the body. The potential sources for change will be discussed in reference to both physiological changes in the human body, as well as behavioral adaptations manifest postflight. However, the analyses are currently in their preliminary stages with more data required before firm conclusions can be drawn. Our intent is to evaluate these changes in light of challenges to head and gaze stability during walking following spaceflight (Bloomberg et al., 1996) and the possibility of changes in musculoskeletal impedance during space flight (McDonald et al, in press).

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ADAPTATION OF NEUROMUSCULAR ACTIVATION PATTERNS DURING LOCOMOTION AFTER LONG-DURATION SPACE FLIGHT

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INTRODUCTION

Previous investigations in our laboratory identified that precise neuromuscular control necessary for optimal locomotion is compromised after short duration space flight, particularly around heel strike and toe off (Layne et al., 1997). Additionally, preliminary results indicate that locomoting subjects modify their neuromuscular activation patterns in response to changes in visual target distance. These neuromuscular modifications are consistent with documented changes in head motion and stride length in response to differences in visual target distance (Smith et al., 1996). In the present study, we hypothesized that extended exposure to microgravity will impact the sensory-motor control system's ability to generate adaptive neuromuscular activation patterns in response to changes in visual target distance during locomotion. Failure to adapt postflight neuromuscular responses in a manner similar to those observed preflight, may reflect a more generalized deficit in the ability to adaptively respond to changing environmental conditions after long-duration space flight.

METHODS

Four astro/cosmonauts walked (6.4 km/hr) on a motorized treadmill while fixating on either a NEAR (30 cm from the eyes) or FAR (2 m from the eyes) target. Testing occurred before and 1 day after 3-6 months aboard the Mir Space Station. Data from electronic foot switches were used to identify heel strike and toe off events of the gait cycle. In addition, surface electromyography (EMG) was collected from the tibialis anterior (TA), medial gastrocnemius (GA), biceps femoris (BF) and rectus femoris (RF) of the right lower limb. Activation waveforms for each muscle were obtained by first band pass filtering (30-300 Hz), full wave rectifying, smoothing (15 ms time constant) and then averaging the signals between consecutive right heel strikes. The activation waveforms were then reduced to 20 epochs with the value for each epoch representing the mean activity within the epoch. To determine if space flight modified the phasic features of neuromuscular activation Pearson *r* correlation coefficients were calculated between the pre- and postflight waveforms for each muscle. Activation waveforms normalized to the mean activity observed during the NEAR target condition for a particular test session were used to evaluate possible changes in relative amplitude between the pre- and postflight activity. The sum of activity associated with each burst, of each muscle was computed and comparisons between pre- and postflight activity levels were made. To determine the degree of neuromuscular flexibility in response to visual target distance, ratios between the sum of burst activity in the NEAR and FAR target conditions were developed for each muscle. An index of adaptability reflecting the degree to which space flight impacted the neuromuscular modifications associated with different target distance was also developed.

RESULTS

Pearson *r* correlation coefficients indicated a high degree of similarity between the pre- and postflight muscle activation waveforms (range 0.80-0.99). In general, relative activation amplitude was stable between the pre- and postflight testing with the exception of the activity of the tibialis anterior (TA) and rectus femoris (RF) around toe off. On average the postflight TA relative amplitude was 17% (SD=13%) different than preflight and the RF was modified by 16% (SD=10%) after flight. However, some subjects displayed increases while others displayed decreases in amplitude. The index of adaptability reflected a significant degree of change in how the subjects responded to the change in target distance. Again, the largest changes occurred in the TA and RF around toe off.

CONCLUSION

The results indicate that, while in general, the phasic properties of lower limb neuromuscular activation during locomotion can be reliably produced, the precise control observed preflight is disrupted after space flight. Additionally, the change in neuromuscular response flexibility due to different visual target distances after flight may reflect a non-optimal adaptive response to long-duration space flight.

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BALANCE CONTROL DEFICITS FOLLOWING LONG-DURATION SPACE FLIGHT

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INTRODUCTION

The sensory-motor systems of humans have evolved phylogenetically and ontogenetically to optimize body movements and posture control in the terrestrial gravitational field. The central nervous system (CNS) has developed neuro-sensory systems that monitor and process sensory inputs from visual, vestibular, somatosensory, and proprioceptive receptors to assess the biomechanical state of the body (spatial orientation), and neuro-motor systems that create, select, and employ motor command strategies and synergies to adjust the biomechanical state toward the desired equilibrium point. Adaptation to microgravity alters neuro-sensory systems by eliminating, reinterpreting, or modifying the weighting of sensory information used to assess spatial orientation in response to the sudden loss of tonic gravitational otolith stimulation (Paloski, et al., 1992, 1994, 1997). Adaptation to microgravity also alters neuro-motor systems by modifying the repertoire of motor command strategies and synergies used for movement control in response to the sudden redistribution of forces along the body, reductions in the biomechanical support reactions, and alteration of relationships between motor command and body movement (Kozlovskaya et al., 1981, 1987, 1995). These inflight sensory-motor adaptations disrupt postflight postural equilibrium control.

The objectives of this study were to determine the role of central adaptive mechanisms in reorganizing postural equilibrium control in humans subjected to long-duration space flight, and to compare these results with similar data obtained from short-duration missions. The specific hypotheses tested in this investigation were that the effectiveness of the closed loop control of quiet stance, which is known to be reduced after space flight, presumably because of inflight neuro-sensory adaptation, will be further reduced by concomitant neuro-motor adaptation, and the magnitude and recovery time course of this ataxia will increase with mission duration because of the increased time for sensory-motor adaptation to microgravity.

METHODS

Seven subjects from three separate long-duration (81-195 day) Mir Station space flight missions participated in this study. The subjects were tested on up to three occasions before flight and five occasions after flight. At each test session, the subject's posture control system was challenged by eliminating vision, decorrelating ankle proprioceptive inputs from earth-vertical, and/or decorrelating visual inputs from earth-vertical. These conditions altered the set of accurate sensory inputs available to the CNS for detection of sway errors and development of compensatory closed loop motor output adjustments.

The full set of six sensory organization tests was administered automatically using a modified clinical dynamic posturography system (Equitest, Neurocom International, Clackamas, OR, USA). To decorrelate the ankle proprioceptive and visual inputs from earth-vertical, the pitch orientations of the support surface and visual surround with respect to the subject's ankle joint were servo-controlled to follow the subject's center of mass sway. This process, which is referred to as sway-referencing, completely eliminated changes in ankle angle and visual flow during low frequency body sway. The six sensory organization test (SOT) conditions used were:

<u>SOT 1</u>: *eyes open* - control condition; all sensory feedback systems are available; tests the overall effectiveness of the closed loop posture control system;

<u>SOT 2</u>: *eyes closed* - tests the effectiveness of the closed loop posture control system without visual feedback;

<u>SOT 3</u>: *sway-referenced vision* - tests the effectiveness of the closed loop posture control system with an altered visual orientation reference; examines how well the system resolves visual-proprioceptive and/or visual-vestibular conflicts;

SOT 4: *sway-referenced support surface* - tests the effectiveness of the closed loop posture control system with an altered proprioceptive orientation reference; examines how well the system resolves proprioceptive-visual and/or proprioceptive-vestibular conflicts;

SOT 5: *sway-referenced support surface with eyes closed* - tests the effectiveness of the closed loop posture control system with an altered proprioceptive orientation reference and absent visual feedback; only vestibular feedback is accurate; examines how well the system resolves proprioceptive-vestibular conflicts and/or how well the system controls posture with only vestibular feedback;

SOT 6: *sway-referenced support surface with sway-referenced vision* - tests the effectiveness of the closed loop posture control system with altered visual and proprioceptive orientation references; only vestibular feedback is accurate; examines how well the system resolves simultaneous visual-vestibular and proprioceptive-vestibular conflicts and/or how well the system controls posture with only vestibular feedback.

During each test session, three trials of each of the six sensory organization test conditions were presented to the subject. Each trial lasted for 20 seconds, and the order of presentation of the 18 trials was randomized.

The primary dependent measures in this experimental paradigm were derived from biomechanical measurements of segmental and center of mass body movements. In particular, peak-to-peak sway amplitudes, equilibrium scores, and center of pressure (COP) under each SOT condition were used to determine the degree to which the posture control system used visual, vestibular, and proprioceptive feedback to maintain closed loop control of postural equilibrium.

RESULTS

The earliest postflight data collection occurred within four hrs of landing (n=1); however, most subjects (n=4) could not be scheduled for initial testing until approximately 24 hrs after landing. Owing to the untoward effects of prolonged exposure to microgravity on multiple physiological systems early after return to earth, and to the competition among physiological investigators for the limited crew member availability during the first few days after flight, systematic timing of postflight test sessions was not possible. Nevertheless, by grouping data in time 'bins' it was possible to evaluate the postflight effects and compare them with the short-duration results.

Two of the three subjects scheduled for landing day testing were unable to participate that day because of profound postflight readaptation illness. Five subjects were tested at approximately 24 hrs after landing. All exhibited balance control deficits that were similar in character but more severe than those observed in short-duration subjects at the same postflight interval (Paloski, et al., 1997). The most substantial balance control deficits were observed under SOT 5 and SOT 6, those conditions in which only the vestibular system could provide accurate spatial orientation information. This finding is similar to previous findings after short-duration space flight; it suggests that altered vestibular information processing plays an important role in balance dyscontrol following long-duration space flight.

By 8-12 days after landing, general performance on the sensory organization test battery was similar to the performance observed before flight. However, in contrast to short-duration results, more subtle changes in balance control and intersegmental coordination, particularly in response to sudden postural perturbations (Shestakov, et al., 1997), persisted beyond this point, suggesting that new, long-lasting changes in neuro-motor coordination emerge following long-duration space flight.

CONCLUSIONS

The primary goal of these investigations was to extend our understanding of the central adaptive mechanisms responsible for the appearance and amelioration of postflight postural ataxia. We conclude that the neuro-sensory balance dyscontrol observed after long-duration space flight is similar in nature but far more profound than that observed following short-duration space flight. Furthermore, we conclude that neuro-motor coordination changes unobserved after short-duration flights begin to emerge after long-duration flights.

INFLUENCE OF WEIGHTLESSNESS ON POSTURAL MUSCULAR ACTIVITY COORDINATION

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INTRODUCTION

Prolonged exposure of humans to conditions of weightlessness causes important changes in the activity of the main proprioceptive inputs (bearing, muscular, vestibular), as well as in the condition of spinal reflex mechanisms and in the characteristics of the peripheral musculature (Berry, 1973; Mitarai et al., 1978; Kozlovskaya et al., 1981, 1987, 1995). These changes can, in turn, cause the development of the disturbances of the control mechanisms of voluntary movements, postural synergies, and locomotion (Homick et al., 1977; Kozlovskaya et al., 1981, 1987, 1995; Paloski et al., 1993). Studying the regularities of the genesis of coordination disturbances of the vertical posture after prolonged weightlessness is the subject of this paper.

METHODS

The experiment was performed by two Russian cosmonauts before and after the 193-day Mir-21 Mission. Stabilographic and electromyographic characteristics of correctional postural responses to disturbances causing the loss of equilibrium were studied using an "Equitest" postural platform system (NeuroCom, International, Clackamas, OR). The preflight tests were performed approximately 30 days before launch, and the postflight tests were performed approximately 24 hours after landing.

Two types postural disturbances were used. The first one consisted of an unexpected forward displacement (5.70 cm in 400 ms) of the support surface (force plate) in the horizontal plane. The second one consisted of graded pushes applied manually (with the help of a special tensometric device) to a rigid plastic plate (10x15 cm) fixed on the chest. All tests were executed with the subject standing erect on the stabilographic platform force plate with eyes closed.

While testing, the following indices were registered: EMG of leg, thigh, back and, abdominal muscles, oscillation of COG, and quantitative characteristics of the disturbances. The EMG was registered using pairs of silver-silver chloride surface electrodes, the inter-electrode distance being 20 mm. The value of the oscillation of COG was calculated from raw data obtained from four force transducers that were mounted in the support surface and independently sensed the ground reaction forces applied by the front and the rear parts of each. The tensometric device contained an integral force transducer to quantify the applied load and duration of each manual push.

All raw data were displayed in real-time for experiment monitoring and were digitized and stored on a personal computer for subsequent data reduction and analyses.

RESULTS

After the space flight both cosmonauts showed increased electro-myographic activity during posture correction: the amplitudes of electro-myographic responses of all the tested muscles were considerably increased. At the same time there were fixed changes in the amplitude and temporal characteristics of the stabilogram: both the amplitude and duration of oscillation of the COG were higher in the postflight tests than in the preflight tests.

Thus, the results of the experiment (as well as the earlier works of Kozlovskaya et al., 1983, 1988, 1989, 1993) show that after space flight vertical postural stability is decreased and the mechanisms of vertical posture correction are disturbed.

In further analyses of the data our main attention was focused on the strategies used in performing movements and in evaluating the work of different muscular groups participating in each experimental movement. The data were processed with the use of cross-correlation between the integrated values of EMG of a muscle and the changes of the COG position in the sagittal plane over segments beginning at the start of the disturbance and continuing through the second crossing of the initial level by the oscillation curve of the COG. Since the experiment used two types of tests with maximal disturbances (chest pushes and translation of the support surface), it was possible to analyze the peculiarities of the responses with different organization of muscular coordination.

Analysis of temporal characteristics of muscular responses showed a decreased latency and an increased duration of muscular activity returning COG to the initial position.

Also differences were revealed in the organization of the antagonist muscles work and in the temporal order of their engaging. There was an increased tendency toward coactivation of muscles-antagonists during the movements performed after both types of postural disturbances.

CONCLUSION

It is shown that in Earth conditions (1-g) when using two types of disturbances causing the loss of equilibrium, correctional muscular responses have coordinated schemes. Just after a prolonged stay in conditions of weightlessness (0-g) the schemes of responses acquire common features and can be characterized by a simultaneous co-activation of antagonist muscles of the whole body.

THE USE OF INFLIGHT FOOT PRESSURE AS A COUNTERMEASURE TO NEUROMUSCULAR DEGRADATION

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INTRODUCTION

Maladapted sensory-motor function and loss of muscle strength contribute to the motor performance decrements displayed by crewmembers returning from space fight. During space flight, the lower limbs and trunk are no longer required to maintain the neuromuscular activation necessary for weight-bearing or locomotion. Thus, the trunk and lower limb musculature experience a significant loss of strength during long-duration space flight. Although existing exercise countermeasures (e.g. treadmill and bicycle ergometer) reduce the magnitude of potential strength loss, crewmembers are required to spend a substantial amount of time exercising each day. An inflight countermeasure which would increase neuromuscular activation and use as a compliment to existing countermeasures would be useful in attenuating the loss of muscle strength during long-duration space flight. Preliminary evidence obtained during Space Shuttle flights (unpublished observations) suggest that foot pressure when applied to free floating subjects increases neuromuscular activation above the levels observed without foot pressure. This study was conducted to determine if foot pressure applied to free floating subjects experiencing long-duration space flight could be used to enhance neuromuscular activation during voluntary arm movements.

METHODS

Three cosmonauts and one astronaut who experienced 3-4 months of microgravity aboard the Mir space station served as subjects for this study. While free floating, subjects aligned their body segments in the sagittal plane and then performed rapid right shoulder flexions with and without foot pressure. Pressure was supplied to both feet using a boot modified with pneumatic bladders in the insole. Data were collected on Flight Day 101 for two subjects and on Flight Day 69 for the other two subjects. Surface electromyography was used to collect data from selected lower limb, trunk and shoulder muscles. Tangential arm accelerations were obtained with a unixial accelerometer attached to a wrist splint. All data were saved to cassette tape and digitized upon return to Earth. For each muscle and subject, the EMG was bandpassed filtered (30-300 Hz), full wave rectified and then averaged within a window 300 ms prior to arm raise onset to 50 ms after completion of the arm movement. The average waveforms were then reduced to three epochs comprised of: 1) a preparatory period (300 milliseconds before arm movement initiation); 2) arm acceleration and 3) arm deceleration. Each epoch consisted of the sum of neuromuscular activity within the designated epoch. Pearson *r* correlation coefficients were calculated to assess the degree of waveform similarity between the "with" and "without" foot pressure conditions. Potential differences in activation amplitude were evaluated by comparing the level of activity within each epoch between the "with" and "without" foot pressure conditions.

RESULTS

Pearson *r* correlation coefficients revealed that the phasic muscle activation characteristics were quite similar between conditions with and without foot pressure (mean $r = 0.78$ SD=0.15). Muscle activation in the without foot pressure condition was severely reduced compared to activity levels obtained during arm movements made preflight in 1*g*. Comparisons of the sum of activity in each epoch between the inflight with and without foot pressure conditions revealed that, in general, during the arm movement (acceleration and deceleration epochs) foot pressure served to increase neuromuscular activation.

CONCLUSIONS

The results of this investigation strongly indicates that the application of foot pressure can enhance neuromuscular activity above the level normally observed in free floating subjects during voluntary upper limb movements. Furthermore, the response to foot pressure remains present several months into flight. Thus, the evidence suggests that foot pressure resulting in increased neuromuscular activation may be useful as a countermeasure to neuromuscular degradation during long-duration space flight.