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Key Personnel Changes/Previous PI:			
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Task Description:

Following their return to Earth, astronauts experience disturbances in their ability to walk and maintain postural stability due to neural adaptation to the microgravity conditions of space flight. These changes can impact mission objectives during planetary EVAs and may impair emergency vehicle egress capability. At present, no operational countermeasure is available to mitigate these risks by facilitating rapid sensorimotor re-adaptation to gravitational environments. Therefore, the goal of this project is to develop a balance and gait training program that will facilitate recovery of functional mobility after space flight.
There is strong evidence in both the motor learning and clinical rehabilitation literature, that training with task variability along with exposure to repeated sensorimotor adaptive challenges leads to faster adaptation to new environments and readaptation to the normal environment. During this type of training the subject gains experience producing the appropriate adaptive behavior under a variety of sensory conditions and balance challenges. As a result of this training a subject learns to solve a class of balance and walking problems, rather than producing a single solution to one problem. Therefore, the subject gains the ability to "learn to learn" under a variety of conditions that challenge the balance and walking control systems. This study will develop an in-flight countermeasure built around the ISS treadmill exercise activities. By manipulating the sensory conditions of exercise (by varying visual flow patterns during walking) and modifying the task constraints (reading, head movements) this training regimen will systematically and repeatedly promote adaptive change in walking performance improving the ability of the astronaut to adapt to a novel gravity environment. It is anticipated that this training regimen will facilitate neural adaptation to planetary gravitational environments after space flight. Adaptability training may be one of the most comprehensive and cost effective sensorimotor countermeasures as the training can be embedded into nominal exercise programs without incurring a significant increase in crew time commitment.

The Mobility protocol is performed by two sets of ISS subjects comprising Control and Experimental groups. All participating subjects (Control and Experimental) perform two tests of locomotor performance both pre and postflight: the Integrated Treadmill Locomotion Test and the Functional Mobility Test. The Experimental Group will also perform the in-flight training protocol throughout the increment and an inflight test of Dynamic Visual Acuity. Comparisons will then be made between recovery rates in the Control vs. Experimental groups.

Operational Protocols

Gait Adaptability Training Protocol

Locomotion is controlled through the integration of multiple sensory inputs, including vision. Visual inputs provide us with important cues for orientation and self-movement perception during locomotion. The patterned visual motion seen during self-movement constitutes the optic flow field that provides perceptual cues about self-movement and environmental structure. Exposure to visual flow variation is an effective way to challenge the balance and gait control system. For this study a visual display system (Mobility Graphics Display, MGD) was developed to provide variation in visual flow during regular treadmill exercise. The MGD is mounted at eye level over the ISS treadmill (TVIS, Treadmill with Vibration and Isolation System). Crewmembers will see a visual representation of a virtual scene varying in yaw, pitch and roll motions. Subjects will be exposed to this stimulus during the 10 minute warm up and cool down periods of their regular inflight treadmill exercise session.

The virtual visual scenes presented on the MGD were created using graphic modeling software (3ds max 4; Discreet, Montreal, Quebec, Canada) and rendered using virtual environment software (VRUT Version 2.5, Python Version 2.0) on a PC computer (2.2 GHz, Intel Pentium 4 processor, nVIDIA Quadro2 EX graphics card). Scenes are rotated or oscillated or moved linearly to depict motion in all six degrees of freedom relative to space. The scenes consist of a cubical room or an outdoor scene of a park with simulated dimensions rich in polarizing visual content. The cubical room includes distinctive markings on the floor and ceiling and realistic texture-mapped objects such as trees, desks, chairs, and gravity-cued pictures. The subject’s simulated eye point is placed such that it seems as if the subject is walking down a hallway or through a walkway in the park at a fixed rate. Simulated scene dimensions were chosen to maximize desired perceptual effects as determined from pilot studies. These multiple scenes were categorized depending on perceived degree of difficulty as determined by ground-based studies ranging from low to high and would be presented to the user in various combinations by an apriori determined training schedule. These scenes were part of a software package that was developed to interact with the subjects with a graphical user interface that was intuitive and easy to use.

Pre and Postflight Testing

Locomotor function in both Control and Experimental groups are assessed before and after space flight using two tests of gait function. The Integrated Treadmill Locomotion Test characterizes alterations in the integrated function of multiple sensorimotor sub-systems. This test calls for subjects to walk on a motorized treadmill while we assess changes in dynamic postural stability, head-trunk coordination, visual acuity and lower limb coordination strategies. The Functional Mobility Test provides a corresponding assessment of the functional and operational changes in locomotor function by testing subject’s ability to negotiate an obstacle course placed over a medium-density foam floor.

Test 1: Integrated Treadmill Locomotion Test

Subjects walk at 6.4 km/h on a motorized treadmill while performing a visual task consisting of identifying the position of the gap in the letter “C” that is presented centrally on a laptop computer positioned 4 meters in front at eye level. Each trial lasts approximately 30 seconds and is repeated four times.

Subjects also walk at 6.4 km/h on the treadmill while performing the same visual task described above but in this case with the letter “C” is presented centrally on a micro-display positioned 50 centimeters in front at eye level. Each of these trials last approximately 30 seconds and are repeated four times.

While subjects are walking on the treadmill and performing the visual task 3-dimensional full-body motion data are acquired using a video-based motion analysis system; gait cycle timing is measured using foot switches placed in the shoes and dynamic visual acuity is assessed by the visual task described above.

Test 2: Functional Mobility Test

To determine if a behavior like locomotion is altered by space flight it is important to define metrics of performance that relate to functional activities. The Functional Mobility Test (FMT) serves as a global test of locomotor performance that when implemented along with other physiological tests can be used to link changes in underlying sensorimotor systems with operational performance relevant to returning astronauts. To perform the FMT crewmembers walked at a preferred pace through an obstacle course set up on a base of 10 cm thick medium density foam (Sunmate Foam, Dynamic Systems, Inc., Leicester, NC). The 6.0m X 4.0m course consisted of several pylons made of foam; a Styrofoam barrier 46.0cm high that crewmembers stepped over; and a portal constructed of two Styrofoam blocks, each 31cm high, with a horizontal bar covered by foam and suspended from the ceiling which was adjusted to the height of the crewmember's shoulder. The portal required crewmembers to bend at the waist and step over a barrier simultaneously. All obstacles were lightweight, soft and easily knocked over. Crewmembers were instructed to walk through the course as quickly and as safely as possible without touching any of the objects on the course. This task was performed three times in the clockwise direction and three times in the counterclockwise direction that was randomly chosen. The dependent measures for each trial were: time to complete the course (seconds) and the number of obstacles touched or knocked down.

Rationale for HRP Directed Research:

Research Impact/Earth Benefits:

As people age on Earth, they sometimes experience instabilities in standing and walking. The development of unique walking and balance training procedures like the ones proposed in this study can be used to help prevent falling and injury in the elderly population. An associated study being conducted at the University of Texas Medical Branch, funded by the NASA Graduate Student Research Program, is currently investigating this issue.

Task Progress:

Summary of Results to Date
As part of the effort to evaluate the gait adaptability-training regimen, we have collected pre and post flight locomotion data from International Space Station Expeditions 5-12 (n =18) who will serve as the Control group.

Functional Mobility Test (FMT)

The time to complete (TCC) the FMT course data from all 18 subjects for each post flight day were averaged and collated for further analysis. A logarithmic curve using a least squares procedure was fit through these points and its intersection with the average ± 95% confidence interval of the mean preflight TCC across all subjects was calculated to determine the duration of time taken to recover functional locomotor performance. Results from FMT of the 18 subjects indicate that the adaptation to space flight led to a significant increase in time to traverse the obstacle course and recovery of function took an average of 2 weeks after their return.

Evaluation of TCC for each individual subject over the days of re-adaptation revealed the presence of two distinct postflight recovery patterns: 1) a rapid learning curve over the first six FMT trials conducted on R+1 and 2) a slower recovery pattern across days (R+1 - R+25). We infer that the learning curve shown within each test day represent strategic learning while the longer recovery period represent adaptive remodeling in sensorimotor function. Subjects were then classified into two groups, the Slow Recovery Group (SRG) and the Fast Recovery Group (FRG), based on the significance of the curve fit results for the data obtained on one day after landing. Comparing the average recovery rates for one day after landing (R+1) and the overall rate (R+1 - R+25) across the subjects in the two groups we see that subjects who demonstrate a fast initial strategic learning effect on R+1 also show a faster overall recovery during the R+1 - R+25 recovery period.

Integrated Treadmill Locomotion Test

The movement of head and torso body segments was measured using a video-based motion measurement system. Six time synchronized CCD cameras, sampling at 60 Hz, were used to obtain the three dimensional positions of light weight retro-reflective markers placed on these body segments. The 3D positions of these markers were used to calculate the head and torso angular orientations. Each 30-second trial period for each of these movement parameters was subjected to Fourier analysis. The amplitude of the predominant frequency in the signals was measured to estimate the contributions of vestibular reflexive mechanisms to head movement control. The temporal variations of the head and trunk roll, pitch and yaw angular orientations were time normalized over the entire gait cycle - heel strike (0%) to the following heel strike (100%) of the right foot - at one percent gait cycle intervals. These time normalized waveforms were used to determine the cross correlation functions between the head and trunk movements about the roll (HRTR), pitch (HPTP) and the yaw (HYTY) planes. The maximum values closest to the zero phase lag were quantified as the estimate of coordination between the head and trunk movements. Each measurement was averaged and its 95% confidence interval (CI) was determined across the six trials pre and post flight. Subjects were then classified into three groups based on the overlap of the Pre and Post flight confidence limits: A) significantly increased, B) no change, and C) significantly decreased, relative to pre-flight. Analyzing the each subject's amplitude of the predominant frequency for the head angular roll, pitch and yaw orientations with respect to space (deg) we found that after space flight, subjects showed a significant change in the head roll and pitch orientations, respectively, during walking. In contrast, only smaller percentage of subjects showed a significant change in head movement magnitudes in the yaw orientation, during walking. Analyzing each subjects maximum cross correlation values for the HRTR, HPTP and the HYTY functions we found similar results in that after space flight, subjects showed a significant change in coordination between the head and torso in the roll and pitch planes, respectively, with minimal changes in the yaw plane, during walking.

Dynamic visual acuity (DVA) data collected following their long-duration (~6 months) stays in space showed a decrement in walking acuity. For some subjects the decrement was greater than the mean acuity decrement seen in a population of vestibularly impaired patients collected using a similar protocol. In summary, head movements during locomotion showed postflight changes predominantly in the pitch and roll planes presumably due to the central reinterpretation of otolith information. Dynamic visual acuity was decreased followed by an improvement in performance during the post flight recovery period. Adaptation to space flight led to a 50% increase in time to traverse the obstacle course on R+1, and recovery of function took an average of 2 weeks after return. Importantly, alterations in kinematics and dynamic visual acuity were accompanied by commensurate changes in functional mobility.

CONCLUSIONS

Recovery of functional mobility after long-duration space flight is composed of two distinct processes: a rapid on-line strategic change characterized by immediate onset after landing and a slower adaptive change requiring days to complete after landing. Therefore the composition and timing of sensory challenges experienced during gait training sessions need to be optimized to facilitate the acquisition of rapid on-line strategic changes. Further, training that facilitates rapid reorganization of sensorimotor function will allow improved functional performance during the early

	phase of readaptation to a planetary g-environment.
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