Locomotor Dysfunction after Long-duration Space Flight and Development of Countermeasures to Facilitate Faster Recovery

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Exposure to the microgravity conditions of space flight induces adaptive modification in sensorimotor function allowing astronauts to operate in this unique environment. This adaptive state, however, is inappropriate for a 1-g environment. Consequently astronauts must spend time readapting to Earth's gravity following their return to Earth. During this readaptation period, alterations in sensorimotor function cause various disturbances in astronaut gait during postflight walking. They often rely more on vision for postural and gait stability and many report the need for greater cognitive supervision of motor actions that previous to space flight were fully automated. Over the last several years our laboratory has investigated postflight astronaut locomotion with the aim of better understanding how adaptive changes in underlying sensorimotor mechanisms contribute to postflight gait dysfunction. Exposure to the microgravity conditions of space flight induces adaptive modification in the control of vestibularly-mediated reflexive head movement during locomotion after space flight. Furthermore, during motor learning, adaptive transitions are composed of two main mechanisms: strategic and plastic. Strategic mechanisms represent immediate and transitory modifications in control to deal with changes in the prevailing environment that, if prolonged, induce plastic mechanisms designed to automate new behavioral responses. The goal of the present study was to examine the contributions of sensorimotor subsystems such as the vestibular and body load sensing (BLS) somatosensory influences on head movement control during locomotion after long-duration space flight. Further we present data on the two motor learning processes during readaptation of locomotor function after long-duration space flight.

Eighteen astronauts performed two tests of locomotion before and after 6 months of space flight: a treadmill walking test to examine vestibular reflexive mechanisms controlling head movement control and a functional mobility test to investigate overall functional locomotor ability. Postflight sessions were given on days 1, 2, 4, 7 after their return. Subjects walked on a treadmill driven at 1.8 m/s while performing a visual task. Motion data from head and trunk segmental motion data were obtained to calculate the angular head pitch (HP) movements during walking trials while subjects performed the visual task, to estimate the contributions of vestibular reflexive mechanisms in HP movements. Astronauts showed a heterogeneous response pattern of both increases and decreases in the amplitude of HP movement. We investigated the underlying mechanisms of this heterogeneity in postflight responses in head movement control by examining data obtained using the same experimental test paradigm on a vestibular clinical population (VC) and in normal subjects undergoing adaptation to acute body load support unloading. Results showed that exposure to unloaded locomotion caused a significant increase in HP movements, whereas in the VC patients the HP movements were significantly decreased. We infer that BLS-mediated somatosensory input centrally modulates vestibular input and can adaptively modify head-movement control during locomotion. Thus, space flight may cause a central adaptation of the converging vestibular and body load-sensing somatosensory systems.

To investigate changes in functional mobility astronaut subjects walked at their preferred pace around an obstacle course consisting of several pylons and obstacles set up on a foam floor, which provided an unstable walking surface. Subjects were instructed to walk around the course as fast as possible without touching any of the objects on the course for a total of six individual trials per test session. One of the dependent measures was time to complete the course (TCC, sec). The learning rate over the six trials performed on preflight and the first day after landing (micro curve) was used to characterize the immediate compensatory strategic response. The learning rate over the six trials of the postflight test days (macro curve) was used to characterize the longer-term plastic response. Adaptation to space flight led to a 52% increase in TCC one day after landing. Recovery to preflight scores took an average of two weeks after landing. Subjects showed both strategic and plastic recovery patterns based on the slopes obtained from the micro and macro curves compared to preflight. A regression analysis revealed a significant correlation between the slope values of the macro and micro curves indicating a relationship between strategic and plastic recovery processes. Results showed that both strategic and plastic motor learning processes play a role in postflight restoration of functional mobility and showed a dynamic interplay between these two mechanisms during postflight recovery. These results suggest that gait adaptability training programs which are being developed to facilitate adaptive transition to planetary environments, coupled with low levels of electrical stimulation of the vestibular system, can be optimized to engage both strategic and plastic processes to facilitate rapid restoration of postflight functional mobility.