Gaze Stabilization During Locomotion Requires Full Body Coordination

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INTRODUCTION

Maintaining gaze stabilization during locomotion places substantial demands on multiple sensorimotor subsystems for precise coordination. Gaze stabilization during locomotion requires eye-head-trunk coordination (Bloomberg, et al., 1997) as well as the regulation of energy flow or shock-wave transmission through the body at high impact phases with the support surface (McDonald, et al., 1997). Allowing these excessive transmissions of energy to reach the head may compromise gaze stability. Impairments in these mechanisms may lead to the oscillopsia and decreased dynamic visual acuity seen in crewmembers returning from short and long duration spaceflight, as well as in patients with vestibular disorders (Hillman, et al., 1999). Thus, we hypothesize that stabilized gaze during locomotion results from full-body coordination of the eye-head-trunk system combined with the lower limb apparatus. The goal of this study was to determine how multiple, interdependent full- body sensorimotor subsystems aiding gaze stabilization during locomotion are functionally coordinated, and how they adaptively respond to spaceflight.

METHODS

Data were collected from six crewmembers who lived on the Mir Space Station for 3 to 6 months (mean ±1S.E, age 42.8 ±2.03 yrs, weight 80.48 ±1.70 kg, and height 1.73 ±0.013m). Data were collected 10 days prior to launch and on one, 3 to 6 and 7 to 9 days postflight. Body segment motions were measured using a six-camera motion measurement system (Motion Analysis Corp., Santa Rosa, CA) sampled at 60 Hz. Head and trunk segments were targeted with three markers for 3D analysis, while the right lower limb was targeted with two markers each affixed to the thigh, shank and foot segments for sagittal plane analysis. The shock transmitted to the head and shank was measured using triaxial accelerometers (Entran, Fairfield, NJ) and sampled at 1 kHz.

During each test session, the subjects performed two walking trials on a motorized treadmill (Quinton Series 90 Q55), each 20 sec in duration, at 1.79 m/sec while fixating their gaze on a centrally located earth-fixed target positioned 2m away from the eyes. Marker data were processed to derive 3-D position information relative to a coordinate frame coincident with the surface of the treadmill. The marker trajectories and accelerometer data were filtered using a zero-phase, 4th order, Butterworth filter with cut-off frequency at 5 Hz and 15 Hz, respectively. Foot-switches were used to determine heel-strike and toe- off.

Head re trunk angular motion was calculated. The power in the head re trunk motion in the flexion-extension plane was summed in the frequency range of 1.5-2.5 Hz reflecting the contributions of reflexive head stabilization mechanisms (Keshner, et al., 1995). The lower limb response to heel-strike was characterized by the total angular displacement of knee and ankle angles within the epoch from heel-strike to the first peak of knee flexion. The shock transmission characteristics of the body were assessed in the time and frequency domains (Lafortune, et al., 1996).

RESULTS AND DISCUSSION

The motion of the head re trunk during locomotion was significantly reduced ($p<0.05$) one day postflight in the flexion-extension plane compared to pre-flight (Figure 1). The knee and ankle total angular displacements were significantly increased ($p<0.05$) one day postflight indicating increased lower limb flexion subsequent to the heel-strike event (Figure 2). Evaluation of the shock wave transmission showed that the mean shock experienced by the shank and the head showed a significant decrease ($p<0.05$) of 40% and 20%, respectively, one day postflight compared to preflight levels.

We infer from these data that the subjects modulated their reflexive head stabilization mechanisms during locomotion after spaceflight to reduce the degrees of freedom to compensate for gaze instability. The increase in lower limb flexion may be an active gaze stablizing response designed to reduce the axial stiffness of the lower limb complex. This decreases the shock-wave to the head in response to the reduced dynamic visual acuity and oscillopsia experienced by returning crewmembers. Therefore, during normal terrestrial locomotion, dynamic modulation of head movement control coupled with the lower limb joint configuration may contribute to maintaining gaze stability. In this manner, we observed an emergent full-body coordination pattern produced to compensate for postflight gaze instability.

REFERENCES

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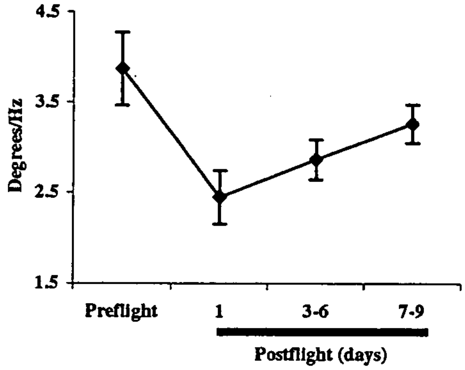

Figure 1: Comparison of the mean area (± 1 SE) in 1.5-2.5Hz for head re trunk flexion-extension movements.

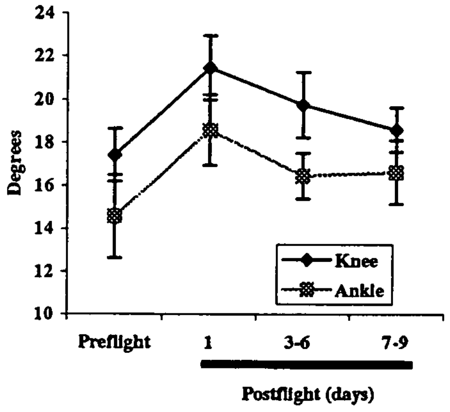

Figure 2: Comparison of the mean total angular displacement (± 1 SE) of the knee and ankle joints in the sagittal plane.