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Understanding the effects of spaceflight on head–trunk coordination during walking and obstacle avoidance

S. Madansingh [a,*], J.J. Bloomberg [b]

[a] University of Houston, Department of Health and Human Performance, Houston, Texas, USA
[b] NASA Johnson Space Center, Neuroscience Laboratory, Houston, Texas, USA

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ABSTRACT

Prolonged exposure to spaceflight conditions results in a battery of physiological changes, some of which contribute to sensorimotor and neurovestibular deficits. Upon return to Earth, functional performance changes are tested using the Functional Task Test (FTT), which includes an obstacle course to observe post-flight balance and postural stability, specifically during turning. The goal of this study was to quantify changes in movement strategies during turning events by observing the latency between head-and-trunk coordinated movements. It was hypothesized that subjects experiencing neurovestibular adaptations would exhibit head-to-trunk locking ('en bloc' movement) during turning, exhibited by a decrease in latency between head and trunk movement. FTT data samples were collected from 13 ISS astronauts and 26 male 70-day head down tilt bed rest subjects, including bed rest controls (10 BRC) and bed rest exercisers (16 BRE). Samples were analyzed three times pre-exposure, immediately post-exposure (0 or 1-day post) and 2–3 times during recovery from the unloading environment. Two 3D inertial measurements units (XSens MTx) were attached to subjects, one on the head and one on the upper back. This study focused primarily on the yaw movements about the subject's center of rotation. Time differences (latency) between head and trunk movement were averaged across a slalom obstacle portion, consisting of three turns (approximately three 60° turns). All participants were grouped as 'decreaser' or 'increaser', relating to their change in head-to-trunk movement latency between pre- and post-environmental adaptation measures. Spaceflight unloading (ISS) showed a bimodal response between the 'increaser' and 'decreaser' group, while both bed rest control (BRC) and bed rest exercise (BRE) populations showed increased preference towards a 'decreaser' categorization, displaying greater head–trunk locking. It is clear that changes in movement strategies are adopted during exposure to an unloading environment. These results further the understanding of vestibular–somatosensory convergence and support the use of bed rest as an exclusionary model to better understand sensorimotor changes in spaceflight.

1. Introduction

Adaptation to the microgravity environment experienced by astronauts during long-duration spaceflight (6-month missions aboard the International Space Station) has a number of deleterious effects on the body, affecting mainly those physiological systems reliant on Earth's

* Corresponding author. Tel.: +713 743 9840.
E-mail addresses: simadansingh@uh.edu (S. Madansingh), jacob.j.bloomberg@nasa.gov (J.J. Bloomberg).

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constant 1 g acceleration for normal functioning. These changes include musculoskeletal deconditioning [1–3], decreased cardiovascular function [4,5], often characterized by orthostatic intolerance [6,7], and adaptive modification of sensorimotor systems leading to postural and locomotor disturbances [8–12]. Gravity is sensed by the vestibular organs, particularly the otoliths, and is detected by proprioceptive and somatosensory systems due to gravitational forces [10]. Visual information, specifically the orientation of our environment and affordances [13] from objects in the environment, provide directional cues associated with gravity, enhancing one's perception of internal orientation and defining their position in space [8]. Previous studies have shown that sensorimotor adaptation and afferent signal reweighting during spaceflight manifests itself as changes to static balance stability [12] and dynamic stability during locomotion [10,14,15]. Gaze stabilization and dynamic visual acuity changes are also observed, and have been associated with vestibular changes in the vestibular–ocular reflex (VOR) [16] and locomotor head–trunk coordination [14,15,17] upon return to Earth.

The Functional Task Test (FTT) is a set of seven functional activities used to assess astronaut performance that is coupled to a set of interdisciplinary physiological measurements to identify factors which contribute to functional decrements, for use in countermeasure design. Some of these FTT activities and their focuses include: seat egress and walk (coordinated movement time), recovery from fall-to-stand (postural stability, orthostatic intolerance), open/close a hatch (torque generation) and the ladder climb. The seat egress and walk task, the focus of this study, requires musculoskeletal strength and balance, as well as coordinated head-and-trunk movement to successfully navigate an obstacle course, and is measured in time to complete the course. During the slalom portion of the obstacle course, participants are required to make three turns (approximately 60° each) around upright pillars as quickly as possible, without running or colliding with the obstacles. Classical quantification of whole body turns while walking around corners (changing direction by 90°) show the systemic movement of the head and eyes towards the new trajectory, followed by the torso and feet during steering locomotion [18,19]. Hollands et al. [20] extended this research isolating the relationship between head and trunk turning in increments of 30° and 60° during normal steering and trajectory planning, as well as an experimentally controlled head-to-trunk locked body posture. These authors found that when natural head-to-trunk movement was compromised, both control of trunk reorientation and control of body center of mass (COM) translation were significantly affected.

Head-to-trunk locking, or ‘en bloc’ movement of the head and trunk during locomotion, has been shown to relate in adulthood to ambulation in an increasingly difficult environment (unfamiliar or unstable) [21], or to systemic impairments as a result of pathology, such as vestibular impairment [15] or Parkinson's disease [22,23]. Individuals experiencing chronic vestibular loss (bilateral labyrinth deficiencies) have also been shown to reduce their head pitch amplitude and adopt a head–trunk locking strategy when compared to normal subjects [15]. Various mechanisms have been described to contribute to changes in head trunk coordination strategies, such as a gaze focused feed-forward system [24], a feed-back systems grounded in the vestibular–ocular reflex (VOR) and vestribulo-collic reflex (VCO) [25], or simply a vestibular input mediated response to provide head stabilization in space [26]. Parkinsonians, specifically, show the appropriate control strategy, however demonstrate decreased head-to-trunk movement latencies as well as decreased head and trunk movement velocity during walking turns. Akram et al. [27] also showed increased ‘en bloc’ movement in elderly populations during walking 90° turns when visual information was limited, such as an eyes-closed condition. Evidence of the influence of microgravity on head–trunk coordination has been shown as an increase in head-pitch-to-trunk locking while treadmill walking during a gaze stabilization task, upon return to Earth [14,15,17].

To better understand how microgravity impacts physiology and performance, six-degree head down tilt (HDT) bed rest campaigns have been used as a ground based analog to spaceflight, and have been shown to successfully reproduce muscular and cardiovascular deconditioning [28,29]. In a corresponding study, participants were tested using the FTT protocol before and after 70 days of 6° head-down bed-rest as an analog for spaceflight. Bed-rest provides the opportunity to investigate the role of prolonged axial body unloading in isolation from the other physiological effects produced by exposure to the microgravity environment of spaceflight. The bed rest analog allowed us to isolate the impact of body unloading without other spaceflight environmental factors on both functional tasks and on the underlying physiological factors that lead to decrements in performance, and compare those results with results obtained during our spaceflight study.

The purpose of this study was to investigate the effects of microgravity exposure and 70-day HDT bed rest unloading on the head–trunk coordination of participants during over-ground locomotion through an obstacle course. We hypothesized that, given the potential influence of the vestibular system in such a control strategy, long duration exposure to microgravity would result in a profound neuro-vestibular adaptation exhibited by head-to-trunk locking during walking turns and obstacle avoidance. This ‘en bloc’ movement would be characterized by a decrease in the latency between head and trunk movements. Long duration bed-rest participants, however, would not experience a shift in their head-to-trunk locking strategy, due to their consistent exposure to Earth's gravitational vector. Acute decrements to head–trunk coordination during ambulation in astronauts returning to a gravity environment represents a deviation from the nominal movement strategy and pose a risk to astronaut safety, especially in an unfamiliar, low visibility or unstable environment.

2. Methods

2.1. Subjects

Data collected from 13 astronauts (46.6 ± 4.5 years), who participated in long-duration missions (6 months) aboard the International Space Station (ISS) are presented