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Research article

Selective weighting of cutaneous receptor feedback and associated balance impairments following short duration space flight

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HIGHLIGHTS

- Short duration space flight increases low frequency (3 Hz) perception threshold.
- Balance impairments are observed following short duration space flight.
- There is no correlation between a change in 3 Hz perception and balance measures.
- The most sensitive astronauts have the largest sway velocity and COP path length.
- An exploratory balance strategy may be used when sensory feedback is available.

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ABSTRACT

The present study investigated the perception of low frequency (3 Hz) vibration on the foot sole and its relationship to standing balance following short duration space flight in nine astronauts. Both 3 Hz vibration perception threshold (VPT) and standing balance measures increased on landing day compared to pre-flight. Contrary to our hypothesis, a positive linear relationship between these measures was not observed; however astronauts with the most sensitive skin (lowest 3 Hz VPT) were found to have the largest sway on landing day. While the change in foot sole sensitivity does not appear to directly relate to standing balance control, an exploratory strategy may be employed by astronauts whose threshold to pressure information is lower. Understanding sensory adaptations and balance control has implications to improve balance control strategies following space flight and in sensory impaired populations on earth.

1. Introduction

In a gravitational environment, sensory feedback from the vestibular system and cutaneous input from the soles of the feet is integrated to control standing balance [1]. Short duration space flight exposes astronauts to a unique microgravity environment, which leads to a variety of sensorimotor and postural adaptations [2,3]. These changes have been attributed to altered vestibular function and associated somatosensory and visual system compensations [4,5]. Sensorimotor changes pose challenges for astronauts as they return to earth and readapt to a gravitational environment. Consequently, short duration space flight provides a unique opportunity to investigate the relationship between sensory reweighting and standing balance.

Standing balance is commonly quantified by the oscillations of the center of pressure (COP) within the base of support (BOS). Increased COP variability, movement and velocity are traditionally linked to impaired postural control [1,6]. An alternative hypothesis suggests that in quiet stance, COP movement represents a natural exploratory mechanism, necessary to provide dynamic sensory feedback to the central nervous system (CNS) [6,7]. In this view, COP

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movements may in fact facilitate standing balance in certain situations by enhancing somatosensory feedback. This makes it difficult to tease out whether increases in COP movements are indicative of a decrease in balance control or the attempt to increase sensory feedback, or both.

Individual balance strategies are influenced by the quality and weighting of sensory feedback by the CNS; which can change depending on the situation. Previous studies have shown standing balance to be impaired immediately following space flight evidenced by increased sway parameters [2,4,5,8]. However, it remains unclear how somatosensory adaptations across participants, specifically within the different tactile channels, influence the observed changes in COP excursions.

When cutaneous feedback is reduced experimentally through cooling [9] anesthetic [10] or via normal aging [11], COP variables have been shown to increase; however little is known about the contributions of the different tactile channels. Slow adapting (SA) skin afferents from the soles of the feet signal information about pressure, verticality and the boundaries of the BOS [12], and are suggested to be important in the maintenance of upright stance [13]. In contrast, fast adapting (FA) afferents are sensitive to dynamic stimuli, such as slips and high frequency vibration. FA afferents are thought to be critical in dynamic balance control [14] but may play a relatively minor role compared to SA afferents in controlling COP position [13]. How cutaneous feedback from the different afferent classes interacts and is weighted within the CNS for the control of standing balance is not known. A better understanding of the perceptual reweighting of foot sole cutaneous feedback following short duration space flight, and the associated balance control strategies used, may have implications for balance control screening and interventions back on earth; specifically with an aging population with an observed decline in skin sensitivity.

Anecdotal reports suggest that skin sensitivity may change following space flight. In our previous work, we hypothesized that we would observe an increase in skin sensitivity [15]. Indeed, hypersensitivity to high frequency vibration (250 Hz) was observed for a subset of participants. However, unexpectedly, we also found a decrease in sensitivity to lower frequencies (primarily 3 Hz) in most participants (9 of 11). As responses to low frequencies are mediated by SA afferents, we wanted to more closely investigate specific parameters of postural control to evaluate the influence of reduced sensitivity within the SA afferent channel. The purpose of the present study was to explore specific COP measures of postural control (90% confidence ellipse area, path length, velocity) that are not reflected in the previously reported computerized dynamic posturography (CDP) equilibrium quotient (EQ) scores [15]. These additional measures may be more sensitive to subtle change in balance control strategies while providing a comparison to changes in foot sole sensitivity. It was hypothesized that participants with high 3 Hz VPT on landing day (less sensitive) would exhibit reduced postural control, compared to participants with increased sensitivity, evidenced by increased COP 95% confidence ellipse area, path length and mean velocity.

2. Methods

The present study is a continuation of the work published by Lowrey et al. [15]. Foot sole sensitivity ($n = 11$) and standing balance measures ($n = 9$) were collected from space shuttle astronauts on three test days: Baseline, which was 30 days prior to launch (L-30), on landing day ($R + 0$) following spaceflight (12–16 days in space) and two or four days after return ($R + 2/4$). Two astronauts were excluded from correlation analyses due to missing data on $R + 0$, giving an n of 9. All procedures were approved by the University of Guelph Research Ethics Board, NASA Johnson Space Center Committee for Protection of Human Subjects (CPHS) and the Human Research Multilateral Review Board (HRMRB).

2.1. Vibration perception thresholds

Foot sole skin sensitivity was evaluated through vibration perception threshold (VPT) testing at three foot sole sites (great toe, 5th metatarsal and heel) and at four frequencies (3 Hz, 25 Hz, 60 Hz and 250 Hz). The current investigation focused on 3 Hz VPT. Two second vibration pulses were applied through a 2 mm diameter probe, attached to a mini-shaker (4810, Bruel and Kjaer, Denmark) and preloaded to 2N (confirmed with a force transducer, Honeywell International Inc., NJ, USA). An accelerometer (4507 B 002, Bruel and Kjaer) attached to the probe recorded the vibration profiles, which were used to calculate probe displacement (μm). VPT was established through step decreases/increases in the probe amplitude, separated by 3–5 s intervals, controlled by custom software (Visual Basic). Trials consisted of 11 separate bursts of stimulation, over which participants (eyes closed), indicated if they perceived a burst by depressing a trigger. The amplitude of the burst was reduced (when perceived by participant) or increased (when not perceived). The lowest perceived amplitudes over three trials were averaged to give a VPT. Smaller VPT amplitude indicated higher sensitivity.

2.2. Standing balance measures

Computerized dynamic posturography (CDP; EquiTest, NeuroCom International, Clackamas, OR) was used to obtain EQ and COP data using a force plate under the feet. The current investigation focused on sensory organization test-2 (SOT-2) trials; standing balance with eyes closed. Three, 20-s trials were performed on each test day (L-30, $R + 0$, $R + 2/4$), and the average EQ score, 95% confidence ellipse area (CEA), total path length (PL) and mean velocity (VEL) measurements were calculated. EQ scores are a well established measure of postural control performance [16]. They were calculated as a percentage of peak-to-peak anterior–posterior sway relative to the theoretical limits of stability where values toward 100% indicate a high level of stability and lower values indicate instability or fall (0). The 95% confidence ellipse area is the area of an ellipse, which encompasses ± two standard deviations of the COP path. Path length is the total length of the COP path over the 20-second trial and is approximated by summing consecutive positions along the path. Mean velocity is the average velocity of the COP throughout the trial. Detailed analysis of these COP parameters have been published elsewhere [17].

2.3. Analysis

Foot sole sensitivity and postural stability measures were examined across test days using a one-way, repeated measures analysis of variance (ANOVA). The data were tested for normality (Shapiro-Wilkes) and homogeneity of variance (Levene's) and were found to meet these assumptions. Two subjects were removed from analysis due to missing standing balance data on $R + 0$, giving an n of 9 for correlation analysis. To examine the relationship between 3 Hz VPT and postural control, the change from L-30 to $R + 0$ was calculated for VPT and COP parameters (indicated by Δ symbol preceding parameter name). Pearson's correlation coefficients were calculated for ΔVPT and the COP balance parameters (ΔCEA, ΔPL, ΔVEL). To examine within group relationships, participants were ranked on both their 3 Hz VPT (1 low threshold – 10 high threshold) and balance parameters (1 low/small measure – 10 high/large measure) on each test day, and Spearman's correlation coefficients were calculated to compare ranked 3 Hz VPT with postural stability measures. Ranked data provides a normalized group