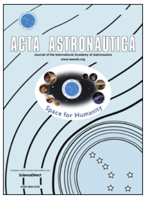
Acta Astronautica 121 (2016) 110–115

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro



Acute effects of Dry Immersion on kinematic characteristics of postural corrective responses

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ARTICLE INFO

Article history:
Received 22 July 2015
Received in revised form
30 October 2015
Accepted 30 December 2015
Available online 8 January 2016

Keywords:
Human
Balance
Postural corrective responses
Microgravity
Dry Immersion
Weight-bearing

ABSTRACT

Impairments in balance control are inevitable following exposure to microgravity. However, the role of particular sensory system in postural disorders at different stages of the exposure to microgravity still remains unknown. We used a method called Dry Immersion (DI), as a ground-based model of microgravity, to elucidate the effects of 6-h of load-related afferent inputs on kinematic characteristics of postural corrective responses evoked by pushes to the chest of different intensities during upright standing. The structure of postural corrective responses was altered following exposure to DI, which was manifested by: (1) an increase of the ankle and knee flexion during perturbations of medium intensity, (2) the lack of the compensatory hip extension, as well as diminished knee and ankle flexion with a further increase of the perturbation intensity to submaximal level. We suggest that the lack of weight-bearing increases the reactivity of the balance control system, whereas the ability to scale the responses proportionally to the perturbation intensity decreases. Disrupted neuromuscular coordination of postural corrective responses following DI can be attributed to adaptive neural modifications on the spinal and cortical levels. The present study provides evidence that even a short-term lack of load-related afferent inputs alters kinematic patterns of postural corrective responses, and can result in decreased balance control. Because vestibular input is not primarily affected during the DI exposure, our results indicate that activity and the state of the load-related afferents play critical roles in balance control following real or simulated microgravity.

1. Introduction

Postural disorders have been reported to be an inevitable consequence of space flights. The microgravity-induced lack of somatosensory information, decrease in descending drive, and lower body muscular unloading can all affect the balance control [1–6]. However, the contribution of particular sensory systems in postural impairments at different stages of the exposure to microgravity still remains unknown. It was suggested that the

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Abbreviations: DI, Dry Immersion; COP, Center of pressure; SD, Standard deviation; ANOVA, Analysis of variance

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http://dx.doi.org/10.1016/j.actaastro.2015.12.054

leading cause of the decline in balance control following space flights can be alterations in vestibular function [3,7–9]. Our work, however, indicates that a reduction of weight-bearing and consequently – the deficit of load-related afferent inputs, can at least contribute, if not be a primary cause, of the decline in posture and locomotion control [1,2,5,10–13].

Although it may be difficult to distinguish the contribution of specific sensory systems leading to impaired balance control following space flights using traditional studies,, it is possible to employ ground-based models in order to reproduce particular physiological effects on the somatosensory-spinal system that are found in 0 G. In this context, a method called "Dry Immersion" (DI) can serve as an exclusionary analog, allowing differentiation of changes that are unique to induced somatosensory deficits from those that are mediated primarily through the vestibulospinal system [14–16]. During horizontal DI, the gravity load is distributed equally across the body, only the head and neck are not fully supported by the water. Thus, the absence of mechanical support of specific areas of the body, as well as the lack of weight-bearing, result in physiological effects akin to weightlessness. This is in contrast to the usual standing and supine positions, in which limited areas of the body carry the weight (feet or back). Given that load on the foot sole induced by standing has been suggested as a fundamental parameter determining the motor output during upright stance [10,17–19], we hypothesized that even a short-term lack of weight-bearing will affect balance control. The purpose of the present study was to use 6-h DI to simulate microgravity, leaving vestibular functions primarily intact to answer the question: to what extent does a short-term lack of load-related afferent inputs affect balance control during postural corrective responses?

2. Methods

Experimental procedures were approved by the Russian Institute for Biomedical Problems ethics committee in accordance with the declaration of Helsinki on the use of human subjects in experiments. Six individuals, all males (mean ± SD: age 25.8 ± 5.6 yrs, height 176.2 ± 10.9 cm, body mass 67.7 ± 6.8 kg), volunteered to participate in this study, and after all procedures and risks associated with the experiment were explained, informed consent was obtained from each participant. Tests were performed before and after 6 h of DI (Fig. 1) [14]. During DI, the participant was "floating" in the supine position in a specially designed tub of $200 \times 100 \times 100$ cm^3 filled with water of a constant temperature of 33 °C. The participants were dressed in a cotton T-shirt and shorts and were separated from the water by free floating waterproof fabric attached to a metal rim around the external margin of the bath. The fabric was thin and elastic and of sufficient area to allow the participant to appear to be "freely suspended" in the water, providing an almost complete lack of mechanical support. In order to maximize the effects of weight-bearing deficits, only the participant's head and neck were not fully covered by the water.

Fig. 1. Dry Immersion (DI) experimental setup. The participant is "floating" in the supine position in a tub filled with water. The participant is separated from the water by free floating waterproof fabric attached to a metal rim around the external margin of the bath. In order to maximize the effects of supportlessness, only the participant's head and neck are not fully covered by the water.

The DI and balance tests were administered at the same day and time for all participants in order to avoid any impact of circadian rhythms [20]. The data collection was performed with the force plate analysis system "Stabilan-01" (Rhythm, Russia). Postural perturbations were evoked by providing pushes at the chest using a calibrated force transducer. A video motion analysis system was used to track the postural corrective responses, and included video camera and recorder, TV monitor, computer, and video frame digitizer. Only movements in the sagittal plane were recorded. Reflective markers (10 mm in diameter) were attached to the subject's skin in the area of the left *processus zygomaticus*, *acromion*, *trochanter major*, *epicondylus lateralis*, *malleolus lateralis*, *phalanx distalis V* of the foot, and the posterior part of the *calcaneus* (Fig. 2). Signals from the force plate and force transducer were sampled at a rate of 100 Hz, while the motion tracking information was sampled at a rate of 25 Hz.

During the test, the participants stood in an upright position on the force plate, barefoot and with eyes closed. The participants were asked to maintain their normal standing posture, with straight knees and arms folded across the chest. A safety overhead system was used in combination with a harness to prevent falls during postural perturbations. Prior to the test participants were familiarized with the perturbation probes to reduce the effects of adaptation [21,22]. Pushes of various intensities, ranging from threshold to maximum, were targeted at a plastic plate of 10×15 cm^2 that was affixed to the participants' chest. The time between two successive perturbations was randomized between 8 and 12 s. During each test session, 10–15 pushes were delivered.

The peak-to-peak amplitude of the maximal anterior–posterior deflection of the center of pressure (COP), as well as the changes of the neck, hip, knee, and ankle joint angles, following the perturbation were calculated. To normalize the results, postural perturbations were grouped as threshold, medium and submaximal, by the intensity of applied stimulus. The dependent variables were submitted to a 2 (conditions: pre- and post-DI) by 3 (perturbation