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Following Spaceflight, Human Ocular Counter-Rolling Control

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ABSTRACT

After spaceflight, ocular counter-rolling (OCR), caused by whole body tilt in roll, has been investigated as a sign of otolith function adaptation to microgravity. It has been asserted that the overall pattern of OCR responses during static body tilt following spaceflight is suggestive of a diminished role for the otolith function, but the outcomes of these studies have not been consistent, primarily because of the significant individual and interindividual variability in the OCR. Off-vertical axis rotation (OVAR), in contrast to static head tilt, offers the benefit of producing a sinusoidal modulation of OCR, enabling averaged measurements across multiple cycles, boosting measuring accuracy. According to studies, there was no discernible difference between the OCR during the OVAR shortly before landing and the preflight. Although it was noticeably bigger right after the flight, the amplitude of the felt roll tilt during OVAR quickly reverted to control levels over the next few days. The lack of change in OCR postflight indicates that the peripheral otolith organs continue to operate correctly during short-term spaceflight since the OCR response is mostly related to the shearing strain applied on the utricular macula. A re-weighting of the internal representation of gravitational vertical as a result of adaptation to microgravity is likely to be the cause of the enhanced perception of roll tilt, which implies a change in the central processing of gravitational information.

KEYWORDS: Microgravity, Human Spaceflight, ocular torsion, adaptation, Neuroscience.

HUMAN OCULAR COUNTER-ROLLING AND SPACEFLIGHT

Ocular counter-rolling (OCR), which is produced during head roll tilt in terrestrial circumstances, is an orienting eye movement caused by the otolith. This reflex, which is presumably triggered by the shear force of gravity acting along the maculae of the otolith utricular organs, tends to keep the retinal meridian oriented vertically. A tiny, torsional conjugate eye movement in the opposite direction of the static head roll constitutes the ocular reaction. With significant inter-individual variations [35], OCR only adequately corrects 10–20% of static head roll tilt in humans [3, 4,28] and seldom reaches 8–10 [11]. In those lacking functional otolith organs, it is virtually nonexistent [29]. The gain of OCR is either reduced during head roll to the side ipsilateral or contralateral to the lesion [34], or it remains unaltered [50] in individuals with long-standing unilateral vestibular deafferentation. A significant ipsilateral decrease of the OCR gain was seen in individuals who underwent testing soon after unilateral deafferentation, with compensation to normal values occurring over the course of many years [15,40]. Many of the postural, locomotor, and gaze control issues observed by returning astronauts have been attributed to deconditioning of otolith-mediated ocular reflexes after adaptation to microgravity. In microgravity, static head tilt does not stimulate the otoliths, and static head rolling on the neck does not result in OCR [6]. The effect of microgravity exposure on otolith function has thus been assessed using this reflex in several postflight investigations [16,23,32,38,45,52]. Studies utilising a static full body tilt have had mixed results, nevertheless. While some studies indicate post-flight gains in OCR or no changes at all, others show declines in astronauts' OCR compared to pre-flight (Fig. 1). These results may be inconsistent because of the many experimental techniques used, such as flash afterimages, flash photography of the eyes, or video-oculography. Overall, it should be highlighted that for body tilt angles spanning from 15 to 45 degrees, the difference between pre- and postflight OCR values was found to be less than 0.6 degrees. The sense of the body tilt in relation to the gravitational vertical is another otolith-driven reaction. The perceived postural vertical has been demonstrated to represent the processing of graviceptive information in higher brain areas, namely in the thalamus and vestibular cortex, when vision is absent (see [13,24]). Contrary to OCR, which appears to be largely generated by stimulation of the otoliths (utricles), the internal representation of body vertical incorporates both vestibular and somesthetic information. It is widely known that estimations of tilt in persons with vestibular dysfunction show more variation than those in subjects with normal vestibular function [5, 17]. However, tilt estimations are further hampered by the loss of somesthetic cues caused by submersion in water, particularly in persons with vestibular disorders [2,19,33]. Therefore, a somatic estimate of tilt may be enough on its own, but'reliable' vestibular information boosts sensitivity. The investigations carried out in astronauts during and just after spaceflight reveal that the sense of self-orientation in relation to the environment is changed [7,18]. As anticipated, free-floating astronauts are unable to reliably describe the orientation of the local (spacecraft) vertical in the absence of optical and graviceptive signals, i.e., the inaccuracy in their estimate of tilt varies between 0 and 180 [44]. Additionally, Merfeld [26] discovered that the manual control of roll tilt in the dark by numbing pseudorandom motion disturbance was greatly reduced on landing day in an experiment assessing astronauts' capacity to perceive roll tilt after travel. Seven astronauts who were regularly forced to vocally estimate the tilt of their body with respect to the gravitational vertical were used in a prior set of studies in which we were able to compare roll tilt perception between pre- and postflight static body tilt in darkness [10]. Significant deviations from the gravitational vertical were seen shortly after flight (Fig. 2), which are in line with the other research stated above and show that the body tilt was overestimated. It has been suggested that the presence of an internal estimate of the gravitational vertical might explain the disorientation phenomena that occur during and after spaceflight [18]. This estimate would gradually be revised downward in microgravity. The perceived impression of roll tilt during low frequency stimulation of the graviceptors would be enhanced as a result of this reduction in the estimation of gravitational vertical carrying over to the postflight period [10]. The semicircular canals of the vestibular system will initially sense rotation when subjects are rotated in yaw about a rotation axis that is tilted with respect to the direction of gravity, a stimulation known as off-vertical axis rotation (OVAR) [21]. However, after an exponential decay, the semicircular canals' activity will cease. However, a spinning gravity component will continuously activate the otolith organs by producing a sinusoidally fluctuating linear stimulus along the utricular macula. These sinusoidal fluctuations in shearing force have a frequency related to rotational speed and an amplitude proportional to tilt angle. Thus, OVAR offers the benefit of providing a continuous sinusoidal modulation of OCR in comparison to static head roll tilt, enabling a more reliable estimate of mean response across a number of cycles. Additionally, it has been demonstrated that OVAR at constant velocity and low angle of tilt causes a perception of head sway around a cone, leading to a sensation of roll tilt, which lasts for the duration of rotation [14,22,49]. Therefore, the goal of this experiment1 was to ascertain if human OVAR's OCR and roll tilt perception were affected by spaceflight.

CONCLUSION

There is a separation between otolith-driven eye movement and perception during passive vestibular stimulation during space flight, according to studies [25]. This confirms the hypothesis that orientation perception and ocular torsion are controlled by brain systems that function in qualitatively separate ways [53]. While perception of tilt is primarily determined by the integration of graviceptive cues, including somesthetic, pre- sumably centrally processed through neural models of the physical laws of motion, OCR is primarily a response to otolith activation by low-frequency linear acceleration along the interaural axis. Short-duration spaceflight would not significantly alter the peripheral vestibular organ, but it is likely to have an impact on the central processing of gravitoceptor inputs and the outputs of internal models for spatial orientation. This separation would account for why otolith-driven eye movements seem to be generally unaffected by microgravity (for a review, see [9,25]), whereas perceptual and oculomotor responses dependent on central vestibular processing can be severely compromised.

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