INFLIGHT CENTRIFUGATION AS A COUNTERMEASURE FOR DECONDITIONING OF OTOLITH-BASED REFLEXES

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INTRODUCTION

The human balance system comprises of the semi-circular canals, which sense rotation of the head, and the otoliths, which act as linear accelerometers. On Earth, the otoliths sense the constant linear acceleration of gravity, and this information is used by the brain to determine the spatial vertical, and the orientation of the head with respect to the vertical. This information is critical in controlling our posture and eye movements during everyday activities such as walking and driving an automobile. In addition, recent studies have suggested that the otoliths play a role in the activation of sympathetic outflow in response to changes in posture, triggering a vestibulo-sympathetic reflex which produces changes in heart rate and vascular tone that contributes to maintain blood flow to the brain during orthostatic stress.

During our 1998 Neurolab (STS-90) experiment, four payload crewmembers were exposed to artificial gravity (a 1-g or 0.5-g centripetal acceleration) generated by in-flight centrifugation. In contrast to previous post-flight studies, both in-flight and post-flight measures of otolith-ocular function were unimpaired. Post-flight tests also indicated no symptoms of orthostatic intolerance (an inability to maintain blood flow to the brain) in all four payload crew. This is an unlikely occurrence if the finding that 64% of astronauts experience profound symptoms of post-flight orthostatic intolerance (Buckey et al. J Appl Physiol 1996; Fritsch Yelle et al. J Appl Physiol 1996) is a general phenomenon. In addition, preliminary data suggests that sympathetically-mediated vasoconstriction was better maintained in the payload crew compared to two other crewmembers not exposed to in-flight centrifugation. A possible explanation for these results is that intermittent exposure to artificial gravity during the 16-day mission had prevented deconditioning of otolith-ocular and vestibulo-sympathetic reflexes in the microgravity environment.

The aim of the current proposal is to obtain control measures of otolith and orthostatic function following short duration missions, utilizing techniques developed for the Neurolab flight, from astronauts who have not been exposed to in-flight centrifugation. This will enable a direct comparison with data obtained from the Neurolab crew. Deficits in otolith-mediated responses, specifically ocular counter-rolling and spatial orientation of the angular vestibulo-ocular reflex, would support the hypothesis that intermittent exposure to in-flight centripetal acceleration is a countermeasure for otolith deconditioning. Furthermore, a correlation between post-flight otolith deconditioning and orthostatic intolerance would establish an otolithic basis for this condition.

CURRENT STATUS OF RESEARCH

Methods

We plan to perform pre- and post-flight testing on astronauts after short duration shuttle missions. The techniques used to assess vestibular function and orthostatic tolerance are similar to those developed for the Neurolab mission, and are summarized below.

Vestibular Testing

Subjects will be tested pre- and post-flight during off-axis centrifugation. Subjects will be oriented tangentially and face the direction of motion, and we will measure the resultant three-dimensional (3D) eye movements as well as tilt perception (the somatogravic illusion). At constant angular velocity, a 1-g interaural centripetal acceleration will be generated at the otoliths, which when added to the 1-g dorsoventral gravity component, tilts the gravito-inertial acceleration (GIA) vector 45° relative to head vertical. This will induce rotation of the eyes towards the GIA (ocular counter-rolling or OCR), an otolith-mediated reflex (Fig. 1). Off-axis rotation also activates the angular vestibulo-ocular reflex (aVOR) during angular acceleration and onset of constant velocity rotation, which generates a horizontal eye velocity. An otolith-dependent vertical eye velocity component also develops that tends to align the eye velocity axis with the tilted GIA (we term this ‘spatial orientation of the aVOR’). Subjects will also be presented with horizontal and vertical optokinetic stimuli during constant velocity centrifugation. Optokinetic nystagmus (OKN) also exhibits spatial orientation. That is, a vertical component appears during yaw optokinetic stimulation that tends to orient the axis of eye velocity towards the tilted GIA. The gain of OCR, and spatial orientation of the aVOR and OKN toward a tilted GIA, allows us to assess the effect of microgravity exposure on otolith-ocular reflexes.

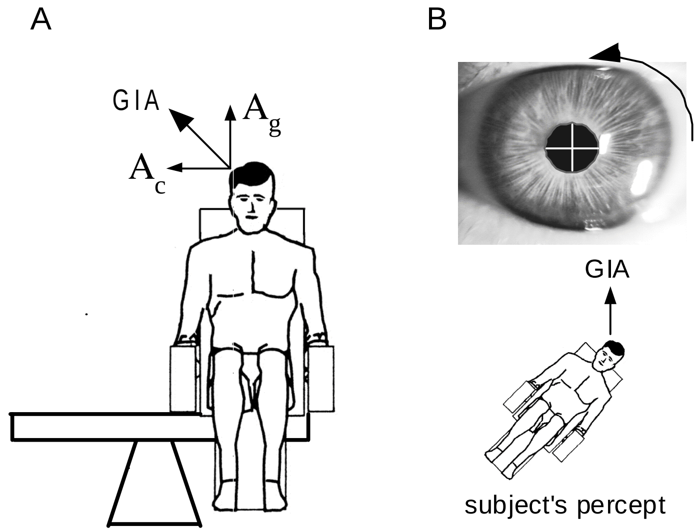

Fig. 1. Short-arm centrifugation as a means to assess otolith function. A. The subject is shown in the left-ear-out orientation. Constant rotation at 254 °/s generates a centripetal linear acceleration, A_c, of 1-g, which adds with the 1-g of gravity, A_g, to tilt the GIA vector 45° with respect to the head. B. Subjects perceive the GIA as the spatial vertical, and feel a strong sense of tilt in the opposite direction, termed the somato-gravic illusion. The eyes tend to rotate about the line of sight towards the GIA, which is an otolith-mediated reflex (ocular counter-rolling or OCR). Thus, post-flight changes in OCR gain would suggest deconditioning of otolith-based reflexes.

Orthostatic Tolerance

Astronauts will be tested pre- and post-flight. Orthostatic tolerance will be ascertained by monitoring heart rate and blood pressure during a standardized tilt test as previously used for the Neurolab mission. Segmental impedance will be used to estimate fluid shifts and stroke volume, from which vascular resistance can be calculated and used as an estimate of sympathetic activation. We will also use spectral analysis of heart rate and blood pressure as an additional parameter to estimate autonomic responses. Any changes in these parameters produced by post-flight head-up full body tilt will be correlated with measures of post-flight otolith-ocular function obtained during centrifugation.

FUTURE PLANS

This project is currently in the flight definition phase. We plan to test approximately 12 astronaut subjects both prior to and upon return from short-duration missions during the assembly stage of the International Space Station. We will compare the post-flight function of otolith-ocular reflexes with pre-flight data to gauge the effect of microgravity exposure on otolith function. Any deficits in these otolith-mediated eye movements would support the hypothesis that centrifugation during the Neurolab flight helped to maintain otolith function. We will also attempt to correlate any deficits in sympathetically-mediated vasoconstriction during head-up tilt with otolith-ocular function. This may provide an otolithic basis for post-flight orthostatic intolerance.

INDEX TERMS

artificial gravity, centrifugation, countermeasure, eye movements, vestibulo-ocular reflex, orthostatic intolerance