Tuesday, June 10

S8-53
072382

Session TA3
Room 3
8:30 - 11:30 a.m.

Visuo-Vestibular Interactions

VESTIBULO-OCULOMOTOR INTERACTION IN LONG-TERM MICROGRAVITY.

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INTRODACTION

The nature of interaction between vestibular and ocular systems is known to be directly related to tracking a visual object which is one of the key components of professional operator's activity. In this connection, of particular interest is a study of oculomotor reactions in long-term microgravity reflecting peculiarities and nature of vesibulo-ocular interactions.

METHODS

Vestibulo-oculomotor interaction was examined in 18 cosmonauts by the electrooculographic (EOG) method (one cosmonaut was examined by additional video-oculographic method) during long-term spaceflights (146-438 days). Spontaneous oculomotor activity, torsion ocular counterrolling during active, voluntary head-to-trunk roll tilt, pursuit function, gaze fixation ability and optokinetic function was investigated.

RESULTS

In the initial stage of adaptation to microgravity the changes in the operation of the vestibulo-oculomotor system are commonly observed in spaceflight (spontaneous nystagmus, disorders of tracking of vertical and diagonal movements of the stimulus, absence static torsional eye movement component during static head roll tilt). Changes in spontaneous and visually induced oculomotor reaction occur in a high proportion of persons exposed to such conditions, although there are individual differences with regard to severity, nature, time and duration of occurrence, and the dynamics of the process. After completion of initial stage of adaptation to microgravity the studied parameters improved, however anomalous spontaneous and evoked eye movement responses often observed after 50 days of exposure to microgravity. The adaptation process in during long-term spaceflight had an undulating course, in which a period of adaptation was followed by a period of de-adaptation.

CONCLUSION

Adaptation to microgravity, even if there is no subjective discomfort and no abnormal autonomic responsiveness, is associated with a resetting of the relation among sensory systems.

EFFECTS OF WEIGHTLESSNESS ON THE SPATIAL ORIENTATION OF VISUALLY INDUCED EYE MOVEMENTS

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INTRODUCTION

The purpose of this study was to examine changes in the spatial reference frame used for optokinetic nystagmus (OKN) and after-nystagmus (OKAN) as a function of spaceflight. Previous experiments have demonstrated components of eye movements out of the plane of the visual stimulus during tilted conditions on Earth in both monkeys and humans. Changes in the direction of OKN and OKAN have been interpreted as reflecting a function of central vestibular processing (known as velocity storage) in orienting gaze toward alignment with the gravitational frame of reference. For example, during roll-tilt with a horizontal optokinetic stimulus, vertical eye movements will cause a reorientation of the resultant eye velocity axis toward closer alignment with gravity. Previous spaceflight experiments have characterized OKN primarily on the basis of gain and beating field relative to the plane of stimulus. However, the effects of exposure to weightlessness on the spatial orientation of the eye movement in response to an optokinetic stimulation have never been investigated. The hypothesis of the present experiment was that the orientation of the OKN would move from an exocentrical, gravitational frame of reference to an egocentrical, body frame of reference. This hypothesis was tested during pre- and postflight testing by providing optokinetic nystagmus during roll-tilt, thereby disassociating the gravitational and body frames of reference.

METHODS

Horizontal and vertical optokinetic stimulation was provided by head-fixed stimulators during different static roll-tilt positions. This experiment was conducted in two parts during separate Shuttle missions. The first part was performed during the First International Microgravity Laboratory (IML-1) space mission as part of the Microgravity Vestibular Investigations. During this mission, three subjects were tested while seated upright and while lying on their left side (90 deg roll-tilt). The second part was conducted before, during, and after the Life and Microgravity Spacelab (LMS) mission. During this mission, four subjects were tested in both upright and ±30 deg roll-tilt positions. Horizontal OKN with a 30 deg head tilt relative to the long body axis, and oblique OKN (45 deg stimulus orientation) with head upright were also evaluated as part of the LMS ground and flight testing. Eye position was recorded by an eye video system (during IML-1) and by electro-oculography (during LMS). Horizontal and vertical eye velocities were estimated using a two-point differentiation of the corresponding eye positions. The magnitude and orientation of the resultant eye velocity vector computed from horizontal and vertical components were then computed to evaluate the spatial orientation of the OKN responses.

RESULTS

During all phases of testing, the optokinetic nystagmus remained primarily aligned with the direction of the visual stimulus, with only small deviations toward alignment with gravity during the ground-based tests. For horizontal OKN during preflight testing, the resultant eye velocity was systematically reduced during roll-tilt. During early postflight testing; however, there was no difference in magnitude of horizontal OKN responses between upright and tilted body positions. For vertical OKN, only slight differences were observed between the upright and tilted body orientations during either pre or postflight testing. OKAN was sporadic, with no consistent changes observed as a function of flight phase.

CONCLUSION

This study and other recent ground-based studies in our laboratory have failed to duplicate the results of other investigators suggesting that OKN responses would reorient toward a gravitational frame of reference during roll-tilt on Earth. Since a reorientation of the OKN responses to align with gravity would not be compensatory for the visual stimulus, there may be individual differences in the degree to which subjects are able to maintain alignment of eye movement response with the visual stimulus axis. The lack of OKAN, which has been difficult to elicit in humans, may also suggest that the velocity storage elicited during our testing was weak and therefore was not sufficient to drive a reorientation in the response axis. However, the reduction in the magnitude of the horizontal OKN during roll-tilt may reflect the same spatial orientation function. We interpret this as follows. During natural horizontal head movements, the axis of head rotation and therefore optokinetic stimulation is normally aligned with gravity. During roll-tilt on Earth, the horizontal OKN is suppressed when the response axis is not aligned with gravity. Following adaptation to weightlessness, however, the horizontal OKN responses are no longer suppressed when the visual stimulus axis is not aligned with gravity. This change is therefore consistent with the hypothesis that the processing of low frequency graviceptor tilt information is altered as a function of spaceflight.

ADAPTIVE MODIFICATION OF THE THREE-DIMENSIONAL VESTIBULO-OCULAR REFLEX DURING PROLONGED MICROGRAVITY

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INTRODUCTION

The flux of otolith-mediated, gravitoinertial information is radically altered in microgravity. Based on the results from a number of experiments onboard the MIR station, the influence of this adaptive modification on the three-dimensional vestibulo-ocular reflex (3D-VOR) is demonstrated.

METHODS

Eye and head movements were recorded by three-dimensional video-oculography (VOG) during active roll, pitch and yaw oscillations of the head, both in space and on earth. In the first experiment the oscillatory head movements were performed during visual fixation of space-fixed and imaginary targets. Analysis of the three-dimensional vestibulo-ocular response (3D-VOR) by way of 3x3 velocity gain matrices and estimation of minimal gain vectors yielded a compact representation of the orientation of the VOR coordinate system.

RESULTS

Distinct changes in the 3D-VOR were observed during the inflight and postflight phases of the mission. This was observable in the reduction in the vertical and horizontal components under microgravity conditions and their regeneration during the days after landing. These changes were reflected in the vector representaion of the VOR coordinate system. This was particularly the case during the imaginary target condition, where the vestibular afferences play a greater role than during testing with visual control of gaze direction.

CONCLUSION

The results demonstrate that the co-ordinate system of the 3D-VOR is re-oriented during the inflight period, and again after return to the one-g environment. This is interpreted as evidence that - under one-g conditions - the otolith-mediated gravitational reference is used to stabilise the internal spatial co-ordinate system in the vestibular and oculomotor systems. . During prolonged microgravity, it appears that a body co-ordinate system, presumably mediated by distributed proprioception, is used as frame-of-reference. It is suggested that the loss of the unequivocal one-g, otolith-mediated reference, which corresponds closely to the visual frame, results in a "de-calibration" in the central vestibular system. The subsequent individual recalibration under microgravity conditions is dependent on proprioceptive and visual input and is less stable than on earth.

THE DYNAMIC CHANGE OF BRAIN POTENTIAL RELATED TO SELECTIVE ATTENTION TO VISUAL SIGNALS FROM LEFT AND RIGHT VISUAL FIELDS

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INTRODUCTION

As it was found that the event-related potential(ERP), which was considered as the 2nd window to observe brain's activity, changed during simulated weightlessness, to study further the effect of HDT on ERP, the dynamic features of visual ERP changes during 2 hour HDT(-10^0) were compared with that during HUT($+20^0$).

METHODS

20 normal subjects aged 19 to 27 participated the experiments. The stimuli were consisted of two color LED flashes appeared randomly in left or right visual field(LVF or RVF) with same probability. The subjects were asked to make switch response to target signals(T): switching left to T in LVF and right to T in RVF, and ignore non-target signals(NT). Five sets of tests were made at 10, 35, 55, 95 and 110 min after the subject was switched to HUT or HDT from supine position. Each subject completed two experiments on different days for HUT or HDT, respectively, of which the order was cross-balanced among subjects. ERPs were obtained from 9 locations on scalp, i.e., F5, F6, C5, C6, P5, P6, Fz, Cz, and Pz.

RESULTS

The main results were as follows. 1) Prominent slow positive potential(SPP) appeared at all locations recorded during signal selection both for T and NT; 2) The amplitudes of SPP were decreased both during HUT and HDT from the 1st to 5th set of tests; 3) While the amplitude of SPP during HDT were lower than that during HUT compared for each set of tests, the most prominent differences appeared at the 4th and 5th sets; 4) The effect of HDT on ERP revealed some dependency upon brain location and brain process.

CONCLUSION

As that the SPP probably reflects some active inhibition activity in brain's non-specific system during attention process, these data provide further evidence for the effect of simulated weightlessness on higher brain function which should be concerned during space fight.

LOCOMOTOR ERRORS CAUSED BY VESTIBULAR SUPPRESSION

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INTRODUCTION

Since the vestibular otolith organs function as linear accelerometers, sensing inertial acceleration and gravity, it has long been assumed that reflexes from these organs must be altered by the prolonged weightlessness of space flight. It is also known that postural and locomotor control are abnormal in returning astronauts. Unfortunately, it is still not clear if the former causes the latter. Indeed, the normal role of vestibulospinal reflexes in general is still a matter of some debate.

We have been studying the effects of "torso rotation" (TR), a natural way of temporarily and reversibly changing human vestibular function. (Watt et al, 1992) In summary, TR consists of continuously sweeping one's gaze back and forth, usually for 30 minutes. This abnormally high "duty cycle" of vestibular suppression causes changes in central processing that persist for some minutes after TR is ended. During that time, subjects experience gaze and postural instability, altered perception of self-movement and sometimes motion sickness.

While it has been relatively easy to document changes in oculomotor control after TR, it has been more difficult to measure objective changes in posture and locomotion. Furthermore, most experiments have concentrated on changes in reflexes originating in the semicircular canals rather than the otolith organs. The present experiment addresses both of these issues by forcing standing subjects to use an otolith organ reference to maintain the position of their head in space.

METHODS

Ten normal individuals were tested in this study. Each was asked to stand facing forward on a treadmill with the fore-aft position of the head and feet carefully standardized, and to close the eyes before motion began. A dental bite and system of linear bearings allowed only fore-aft and vertical linear motion of the head and a potentiometer measured fore-aft displacement. At an unexpected moment, the treadmill was started and allowed to run for 4 sec at 29 cm/sec. The subject's task was to keep the head in an imaginary, earth-fixed box by means of rapid, short steps. The latter were used to minimize the use of natural walking cadences as velocity references.

Each test series consisted of 60 treadmill starts over a period of 12.75 minutes, with the time between starts varied randomly. A complete experiment consisted of one series of 60 starts, a 30 minute break during which the subject continued normal activity, a second series of 60 starts, 30 minutes of torso rotation and a final series of 60 treadmill starts. During TR, the subjects were instructed to sweep their gaze back and forth between two visual targets located 135° to either side of straight ahead. The frequency of this rhythmical motion was set at 0.7 Hz by a sound cue.

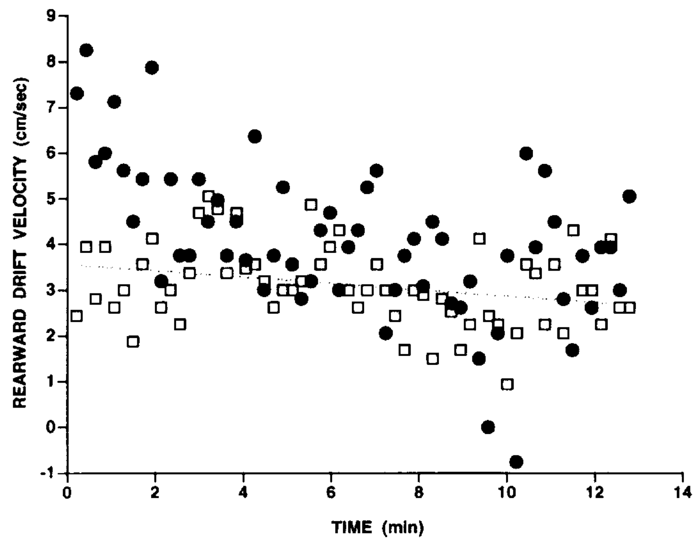
RESULTS

On average, subjects were able to maintain their position quite well during treadmill start-up, although most developed a slow, constant velocity, rearward drift. Every subject made occasional, significant errors at start-up, however, and in those cases no recovery was possible until contacting the limits of the linear bearing system. Presumably, this reflected the inability of the otolith organs to sense steady velocities and a lack of interpretable position cues that could be substituted.

More detailed data analysis began by averaging head position across the 10 subjects for each of the 180 treadmill starts. A linear regression line was then fitted to each of these average curves to determine drift velocity between 1 and 2 seconds after treadmill start. Data recorded before this period were complicated by treadmill acceleration and initial postural transients. Results recorded later than 2 sec were occasionally contaminated by the subject reaching the end stops, which provided an absolute position reference. However, if a drift was established in the time gate under study, it usually continued until the treadmill stopped.

Subjects demonstrated a small learning effect, as evidenced by a progressive reduction of rearward drift velocity during both series of control tests, and by a small decrease of average drift velocity between these two series. Statistical analysis showed these changes to be marginal, however.

While most subjects developed a slow, rearward drift even before TR, it was significantly increased afterward, especially during the first 5 minutes. This is illustrated in the following figure, in which all pre-TR control results have been combined and shown as boxes and the post-TR responses have been shown as filled circles. Time is measured relative to the start of each test series. A linear regression line has been fitted to the combined control data.



The magnitude of the increased drift seen for the first few minutes after TR was considerably greater than any previous tests, and the identical 30 minute delay between the two series of control tests had little if any effect on drift velocity. This rules out lack of practice as a cause of the degraded performance.

Finally, head displacement measured in the initial second of treadmill start-up was compared before and after TR. These results were surprisingly consistent from test to test and seemed unaltered by the manoeuvre. This demonstrates the importance of passive, biomechanical factors and suggests that measuring initial postural reactions to support perturbations may be a relatively insensitive way of testing for changes in vestibular function.

CONCLUSION

Under the conditions of this experiment, the presence of a slow, rearwards drift even in normal subjects suggests that the measurement of linear acceleration by the otolith organs, or conversion of that signal to position by double integration, is a less than perfect process. It can be compromised further by the simple application of excessive vestibular suppression, even that occurring during purely angular movement. The extra error disappears along a roughly exponential time course, with near-complete recovery in 10 minutes, similar to previous studies of the effect of TR on the angular vestibulo-ocular reflex (VOR). Interestingly, the method had little if any effect on short-term postural control. This suggests that relatively small changes in otolith sensitivity lead more to inertial navigational errors, i.e. problems in controlling locomotor trajectory , and less to problems in maintaining the upright position. This is consistent with the results of Glasauer et al (1994), who tested patients with bilateral vestibular deficits.

Astronauts have produced many anecdotal reports of bumping into walls, missing turns in hallways and other evidence of locomotor errors encountered soon after returning from prolonged space flight. If the central processing of otolith signals is modified by exposure to weightlessness, many of these phenomena could be explained by the incorrect perception of self-movement that would result. The errors would appear suddenly and apparently randomly when the individual happened to ignore visual cues because of distractions or other reasons and could occur in the absence of deficits in rapid postural control.

A NOVEL, IMAGE-BASED TECHNIQUE FOR THREE-DIMENSIONAL EYE MEASUREMENT

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State-of-the-art image-processing technology facilitates the accurate measurement of all three components of eye rotation. The non-invasive character of such video-oculographic techniques render them particularly suitable for applications in difficult environments. However, the adherence of the system components employed (CCD cameras, framegrabbers) to standard video conventions has critically restricted spatio-temporal sampling performances. Essentially, sampling rates higher than 25/30 Hz can only be obtained at the cost of reducing spatial resolution.

A novel approach using non-standard imaging methods is introduced here, which yields sampling rates of 300 Hz and beyond. This is based on smart sensor devices which eliminate the bottleneck of the classical framegrabber concept.

The present technique draws from the principle of reducing image redundancy by means of coding, noise suppression, thresholding and selective pixel acquisition – all performed on the sensor/processor chip. This eliminates the extremely high data rate required for repetitious digitisation of full frames from a high resolution CCD sensor. Essential to this technique has been the recent development of CMOS imaging devices, which incorporate programmable sensor and data processing elements.

Currently, this smart sensor approach permits sampling rates of upwards of two hundred per second when measuring all three orthogonal components of eye rotation; for those applications requiring only horizontal and vertical components of eye movement, sampling rates of typically six hundred per second have been attained. These eye position data are processed and output in realtime. The image data stream, containing only the non-redundant pixel information from each image can also be stored on digital mass storage for subsequent re-evaluation.

A lightweight head-mounted assembly is currently being designed to facilitate realtime measurement of head and binocular eye movement, where it is foreseen that device slippage will be detected and compensated by additional processing of the corneal reflection. The smart-sensor approach provides the technical performance and non-invasiveness for accurate and comprehensive eye movement measurement of smooth pursuit, nystagmus, vergence and saccade behavior without the restrictions of many other current techniques.