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SUMMARY PAGE

THE PROBLEM

To measure changes in amount of ocular counterrolling as a function of duration of body tilt in the frontal plane.

FINDINGS

Four normal individuals and three persons with severe bilateral loss of labyrinthine function served as test and control subjects, respectively. Each subject was held in a lateral tilt position, 60 degrees from upright, for a period of 8 hours. During this period the roll position of his right eye was measured eighteen times immediately upon reaching the terminal tilt position and in like number at 30-minute intervals thereafter. The recorded eye roll position varied to an expected small extent within each test session; this variation about a given mean roll position was similar among the test sessions for all subjects. The mean roll position, on the other hand, changed from session to session in substantial amounts, but these changes appeared to be random with respect to time and among subjects. Furthermore, the intersessional variation in the mean torsional eye position of the normal subjects was equivalent to that of the labyrinthine-defective subjects who displayed little or no counterrolling. These results suggest that the human counterrolling response is maintained either by essentially nonadapting macular receptors or by extremely fine movements of the head in the gravitational field, such as may have been allowed by the biteboard/headrest restraint system used in this study, which served as an everchanging accelerative stimulus.

INTRODUCTION

Maintenance of equilibrium without a visual framework while the head (body) is held in a given position must rely upon nonvisual stimulus-response mechanisms that provide continuous valid information on the relative direction of gravity. It is well known that the cilio-otolith system as a specialized gravireceptor mechanism acts as a major influence in man's nonvisual perception of the upright, at least in those measurements made during a typically brief course of an experiment, and a physiological basis for this system's possible role in sustained static orientation has been indicated by the recordings of vestibular neural signals in animals. The frequency of these signals was found by several investigators to be significantly different in a tilted animal position compared to an upright reference level and showed little accommodation over periods up to several minutes' duration (1, 2, 4, 5, 8). Man's ability to orient himself to a gravito-inertial frame of reference without empirical visual cues over much longer periods of time was well demonstrated by the relative constancy of the oculogravic illusion as observed by four experienced subjects throughout a 4-hour period of exposure to constant lateral centripetal acceleration (3). The cilio-otolith system under these conditions probably acted as the primary sensory mechanism, but nonotolithic systems, including touch, pressure, and kinesthesis, responding to the resultant acceleration vector could have played a part in these observations (7). In order to monitor more directly the effect of sustained gravitational stimulation upon man's otolithic activity with relative freedom from nonotolithic gravireceptor influences, the ocular counterrolling reflex was selected as the test parameter for the present study (11). This choice, however, did not necessarily rule out all extraneous factors such as spontaneous changes in extraocular muscle tonus which would affect eye roll position during the 8-hour recording period. For this reason, bilateral labyrinthine-defective individuals who were apparently normal in all other respects were included in this study as our control subjects.

PROCEDURE

SUBJECTS

Four healthy Navy enlisted men, 19 or 20 years of age, served as the normal subjects, and tests revealed normal hearing, as well as normal nonacoustic labyrinthine function; their counterrolling response was in the high normal range (Counterrolling Index = 383 to 456) (9-11). The control group comprised three deaf persons with severe loss of vestibular function as detailed in Table I.

METHOD

The counterrolling test device, described elsewhere (11, 12) and portrayed in Figure 1, was used for positioning the subject with respect to gravity. The subject was first stationed erect in the carrier portion of the device in a semistanding position, with

Table I

Clinical Findings in Three Deaf Subjects with Bilateral Labyrinthine Defects

		Deafness		Hearing		Caloric Response*		
Subject	Age	Etiology	Age of Onset	R	L	R	L	Counterrolling Index†
HR	30	Meningitis	13	Nil	Nil	Negl.	Negl.	43
LR	24	Meningitis	6	>110 dB	>110 dB	Negl.	Negl.	51
MY	26	Meningitis	8	Nil	Nil	Negl.	Negl.	99

*Negligible or no observable nystagmus when tympanum irrigated with ice water.

†Calculated as one-half the sum of the eye roll measured in minutes of arc at the 50° rightward and leftward tilt positions.

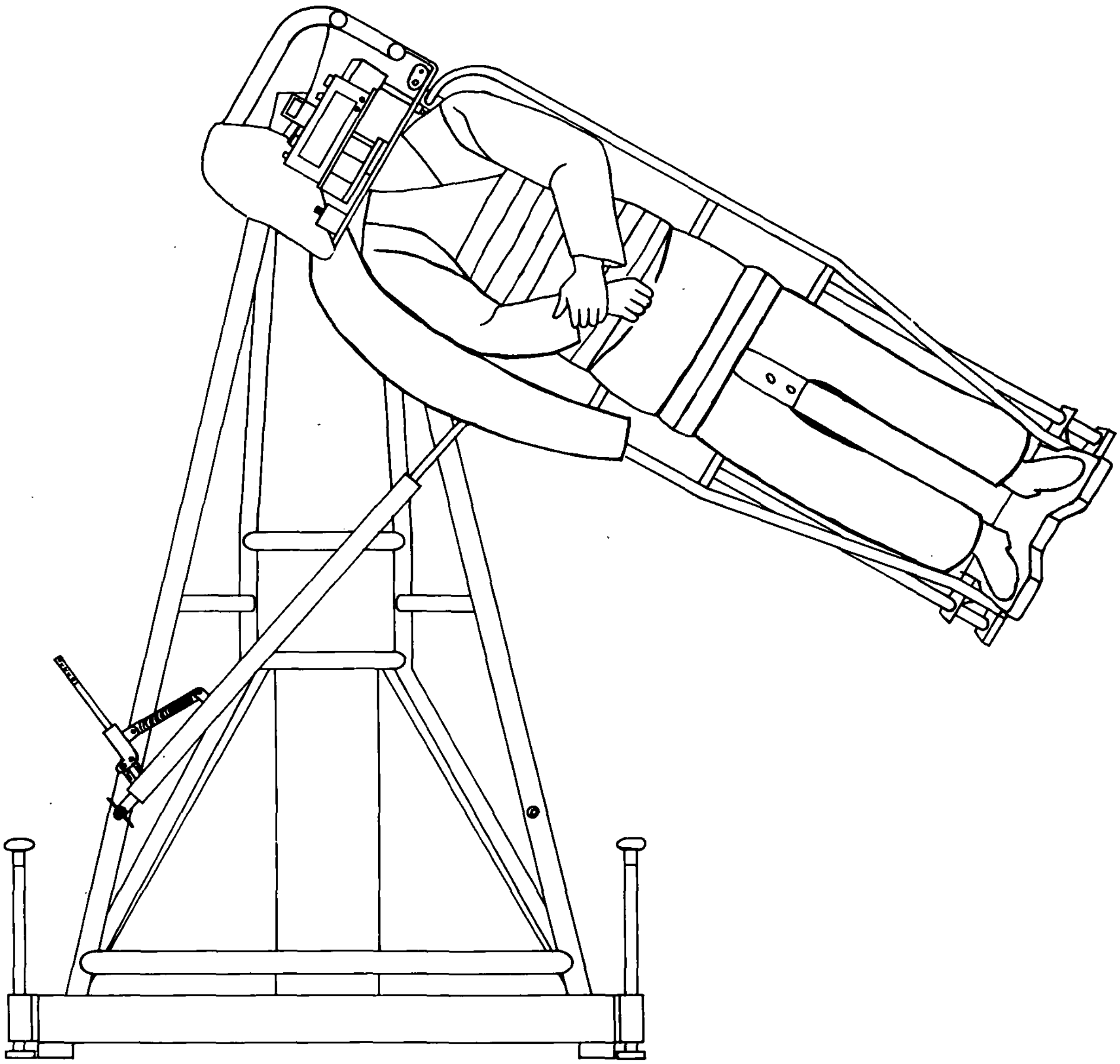

Figure 1

Diagram Showing Subject Positioned in the Counterrolling Test Device and Tilted at 60 Degrees from Upright. Camera Recording System Shown on Platform in Front of Subject's Face .

his weight distributed between a saddle-type seat arrangement and an adjustable footrest platform. A locked headrest and biteboard assembly kept the subject's head precisely, yet comfortably in this position. The platform was raised or lowered by a hydraulic mechanism, and the subject was shifted sidewise until the center of the pupil of his right eye, during proper fixation of a ring target supplied for this purpose, fell on the optic axis of the camera system. Coincidence was determined when the pupillary image was concentric with specific circular markings on the camera's ground-glass viewing screen. In this position several straps and a tight-fitting vest constructed of velcro material secured the subject's body to the device. Foam-rubber padding was used in this particular study to cushion the right side and arm of the subject when held in the tilted position.

One or two drops of 1 per cent pilocarpine hydrochloride was instilled approximately 15 minutes prior to the initial testing and subsequently as required to reduce the overall size and physiological oscillations of the pupil, which aided the subsequent analysis of eye position based upon natural iris landmarks. The analytical procedure has been described elsewhere (10).

Thirty-six photographic recordings of the subject's right eye were made when he was upright; then the subject was slowly tilted 60 degrees in the rightward direction. Sixty seconds after reaching this tilt position, the first of 18 photographs was taken; an identical number was recorded every 30 minutes during the 8-hour period of sustained tilt. After 8 hours the subject was slowly returned to the upright, and his iris photographed 36 more times over a period of approximately 5 minutes. The average roll positions of his eye as recorded in the initial and terminal upright positions were averaged and used as the baseline (zero) position to which all other measurements were related. During the several minutes that separated the test sessions, the subject remained fixed in his tilted position, but his biteboard was removed for comfort.

RESULTS

Figures 2 and 3 summarize the changes in ocular counterrolling of the normal and labyrinthine-defective (L-D) subjects as a function of time within and among the various test sessions, respectively. Figure 2 portrays the extremely small intrasessional torsional variations (average deviations) of the eyeball about the mean position measured for each session; the variability found for subjects of both groups throughout the 8-hour test period was relatively small, but somewhat greater deviations were recorded within the normal group. Figure 3 presents the mean ocular roll position of each subject as recorded during each of the several test sessions. As expected from the preliminary calibration tests, the L-D subjects clearly manifested less ocular counterrolling than the normals, but their individual data tended to complement those of the normal subjects in forming a continuum of response over a range from essentially none to greater than 10 degrees of arc. Within the 8-hour test period each normal and L-D subject manifested substantial intersessional changes (up to approximately ± 2 degrees) in mean eye roll position, but this appeared to be independent of the duration of sustained tilt. A measure of the randomness of the intersessional changes was provided by averaging

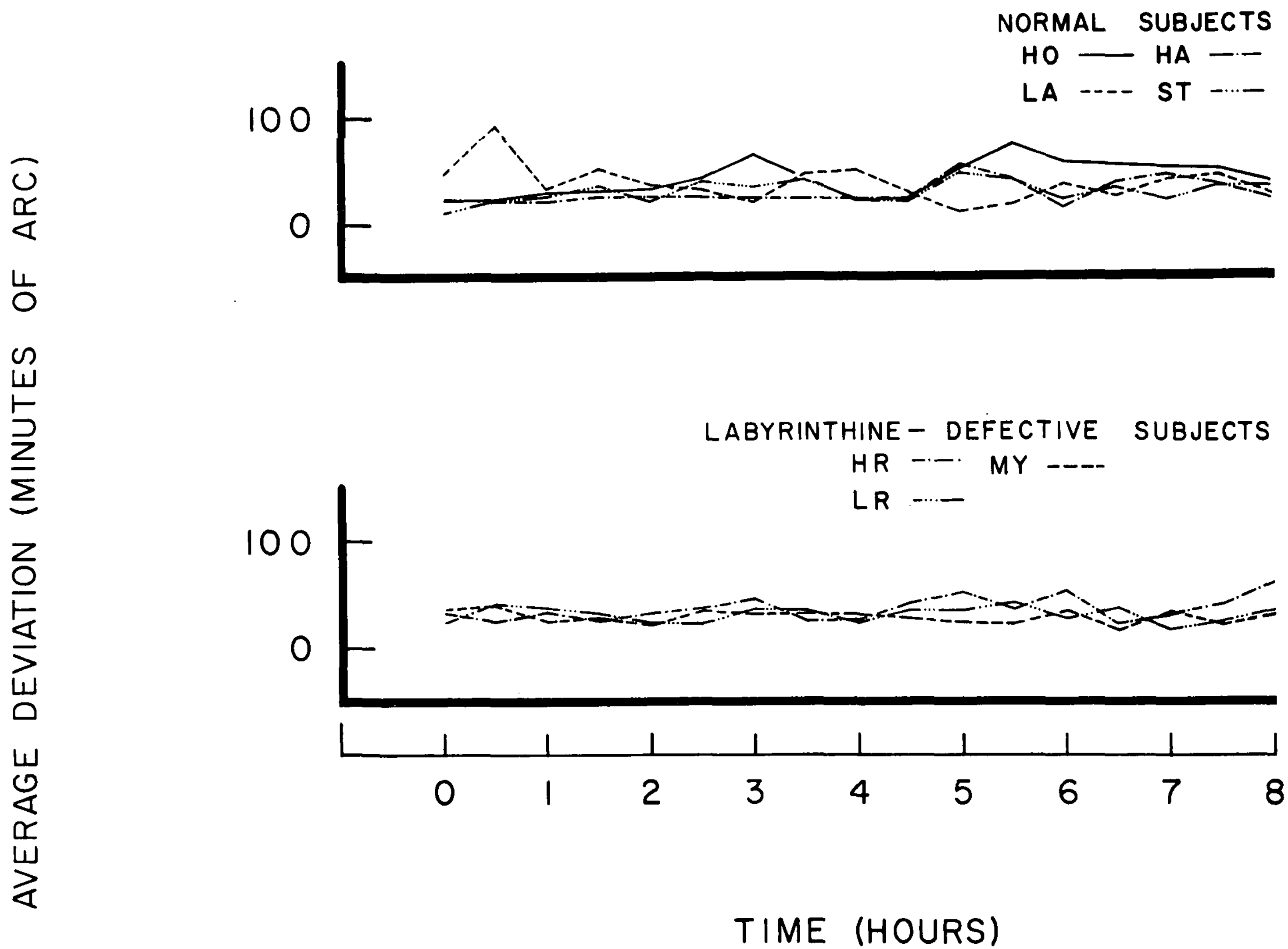

Figure 2

Ocular Counterrolling Intrasessional Variability (Average Deviation of Eighteen Eye Roll Recordings Per Test Session) in the Normal and Labyrinthine-Defective Subjects as a Function of Time Held in a 60-Degree Body Tilt Position.

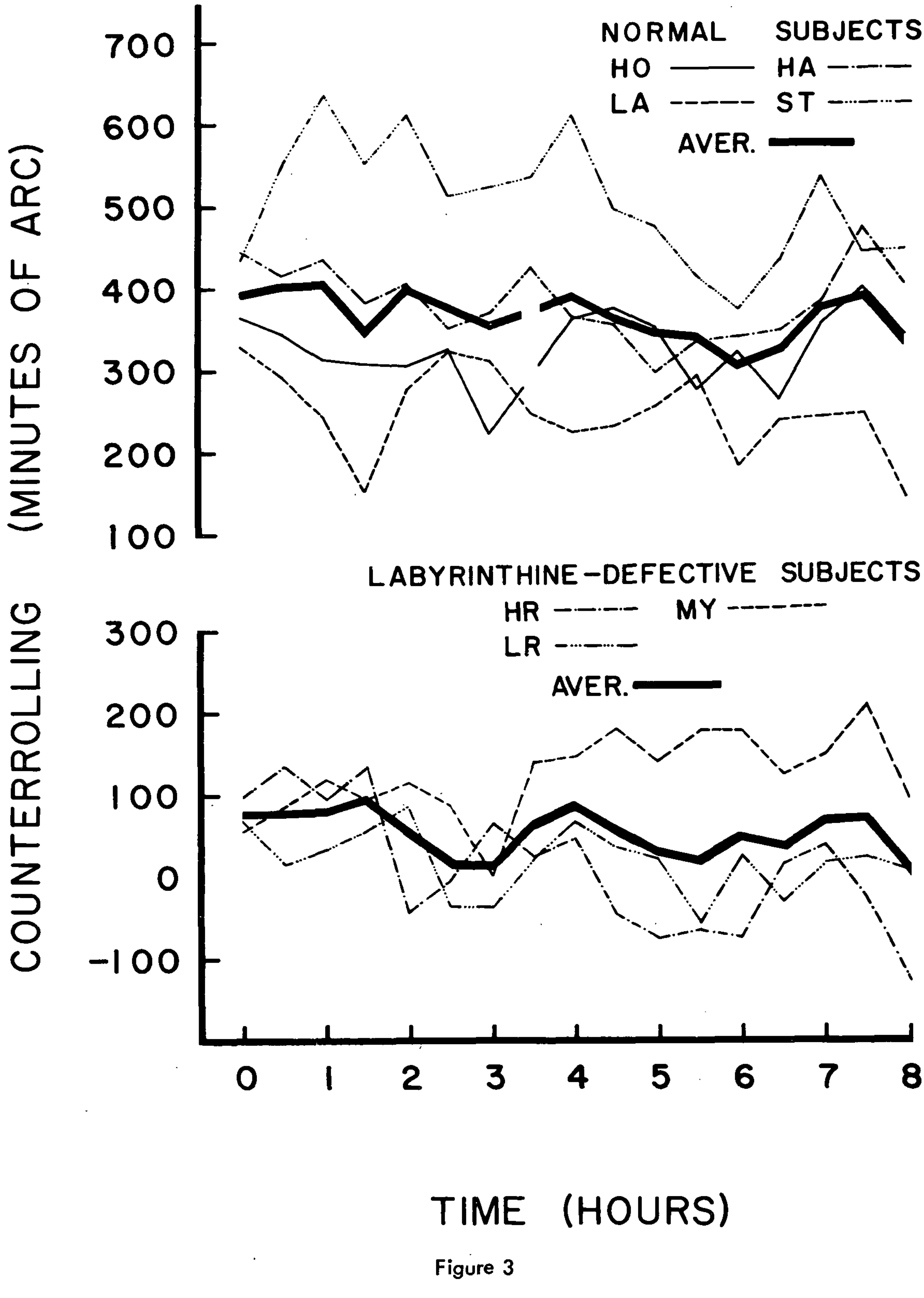

Figure 3

Average Ocular Counterrolling Values of the Normal and Labyrinthine-Defective Subjects Plotted Individually and as Groups as a Function of Time Held in the 60-Degree Body Tilt Position. Each of the Individual Data Points Represents an Average of Eighteen Eye Roll Recordings.

individual data according to subject group. The resultant average curves of the normal and L-D subjects are relatively smooth and appear to follow essentially horizontal and therefore time-independent courses. The break in the curves of the normal group (Figure 3) marks the session in which the data of HO were lost for technical reasons.

DISCUSSION

Although constant error changes in the eye roll position were recorded for the normal and labyrinthine-defective subjects, the amount was relatively small and inconsistent throughout the 8-hour test period. On the basis of these data and the previously found evidence that this response closely reflects otolith activity (12, 14, 15), it would appear that the macular source of tonic innervation to the extraocular muscles was effectively undiminished by time. These results can be explained either by the existence of nonadapting macular receptors in man or by some artifact in the test procedure. In the present experiment, for example, the subject's head was stabilized by the simplest and most practical method available: a biteboard/headrest system. This restraint method assured a high degree of head rigidity (otolith organ stabilization), but it is conceivable that extremely fine movements might have occurred, particularly when the biteboard was removed between test sessions, which could have served as an ever-changing accelerative stimulus to the otolith organs. The extreme precision in the measuring techniques, on the other hand, precluded any significant error being introduced by this factor.

The different sources of tonic innervation that influenced the measurements in this study can be differentiated to some extent by comparisons of the results of the normal and the L-D subjects who manifested little or no counterrolling. The latter subjects provided data on extraocular muscle tonus under the prolonged test conditions which was primarily dependent upon nonotolithic neurochemical processes. The intrasessional variations in eye roll position among these L-D subjects was extremely small, which tends to confirm the evidence that the basic tonic equilibrium of the extraocular muscles is more persistently maintained than that of other skeletal muscles (2) and indicates that this activity can be independent of normal otolithic inputs. In fact, the slightly greater general intrasessional variability in the recordings of normal subjects would suggest that otolithic activity acts to decrease ocular stability.

Some support of this possibility is offered by the recordings of spontaneous irregular firing activity of the otolith organs in animals. Fujita et al. reported, for example, that the neuronal signal recorded from cells of the lateral vestibular nucleus in cats held in a specific tilt position was marked by a wide scatter of interspike interval values which they judged would require a probabilistic approach to identifying head position (5). These spontaneous variations in otolith signals with a given body position may also offer partial explanation for the perceptual phenomenon of rotary autokinesis (13). However, it is unknown whether the eyes fluctuate in their torsional position in simple accord with this perceptual illusion; more likely, the illusion is based upon the complex neural activity resulting from an interplay of nonotolithic and otolithic gravireceptor inputs that have undergone central processing. This hypothesis is supported by the finding that prolonged lifting of the g-load tends to reduce variability in the judgment of horizontality (6).

The slower rates of change in the eye roll position that were recorded among sessions, separated by approximately 30 minutes, would appear to be nonotolithic in origin since the L-D subjects, and in particular subject HR with essentially complete functional loss of his otolith organs, revealed variations in mean ocular roll position that were indistinguishable from those of the normals.

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13. ABSTRACT
Adaptation of otolith organ activity was investigated by monitoring the ocular counterrolling response of four normal individuals and three persons with severe bilateral loss of labyrinthine function. Several eye photographs were recorded every 30 minutes during a period of 8 hours in which the subject was held in a lateral tilt (60°) position. The recorded eye roll position varied to an expected small extent within each test session; this variation about a given mean roll position was similar among the test sessions for all subjects. The mean roll position, on the other hand, changed from session to session in substantial amounts, but these changes appeared to be random with respect to time and among subjects. Furthermore, the intersessional variation in the mean torsional eye position of the normal subjects was equivalent to that of the labyrinthine-defective subjects who displayed little or no counterrolling. These results suggest that the human counterrolling response is maintained either by essentially nonadapting macular receptors or by extremely fine movements of the head in the gravitational field, such as may have been allowed by the biteboard/headrest restraint system used in this study, which served as an everchanging accelerative stimulus.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Ocular counterrolling						
Otolith organs						
Labyrinthine defects						
Tonic reflex						