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**EFFECTS OF HIGH ACCELERATION ON VESTIBULO-OCULAR RESPONSES**

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## FOREWORD

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This report has been reviewed and is approved.



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## ABSTRACT

Preliminary investigations into the effects of high linear accelerations on the vestibulo-ocular responses to both caloric and Coriolis stimulations were made. Pilots were subjected to short-duration accelerations on the USAF School of Aerospace Medicine centrifuge. A spontaneous slow-phase downward nystagmus was observed in some pilots in post-centrifuge tests. Some peripheral and central-neural modification resulting from centrifugation was observed.

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## EFFECTS OF HIGH ACCELERATION ON VESTIBULO-OCULAR RESPONSES

### I. INTRODUCTION

Past experiments and relative literature reveal that centrifugal force resulting in positive G produces important physiologic effects. Positive G force acts upon man from head to foot. The effects produced by high positive G force are loss of vision (grey-out to black-out) and failure of consciousness. At present, very little experimentation has been done on the levels and duration of acceleration which produce temporary or permanent damage to the vestibular receptors and possibly to the central nervous system.

This report is concerned with preliminary investigations into the effects of high linear acceleration on the vestibulo-ocular responses to both caloric and Coriolis stimulations.

### II. PROCEDURE

The subjects in this study were pilots assigned to special flight programs and candidates for space pilot programs. Every subject was exposed to short-duration positive-G acceleration on the USAF School of Aerospace Medicine centrifuge. The profile was 1 G each 5 seconds to grey-out or black-out and 1 G each 15 seconds to black-out. All accelerations were counterclockwise.

Coriolis stimulations were given to 36 experienced flyers under controlled laboratory conditions before and after centrifugation. Of these subjects, 19 demonstrated a spontaneous downward slow-phase nystagmus during Coriolis stimulation after centrifugation (group B). The remaining 17 pilots demonstrated no spontaneous nystagmus after centrifugation (group A).

Of the 19 pilots in group B, 15 were given caloric stimulation before and after centrifugation. The test schedule permitted post-centrifuge caloric testing for only 15 pilots of group B.

The Coriolis test has been described elsewhere by Dowd (3), and the method of analyzing electronystagmograms to Coriolis stimuli was also described by Dowd (5), Moore (13), and Cramer et al. (2). The caloric test utilized the Fitzgerald-Hallpike technic (7), in which the slow-phase velocity of the electronystagmograms was measured and analyzed. The caloric test apparatus consisted of two Sargent water baths equipped with controlled temperature for 30° C. in one bath and 44° C. in the other. Horizontal nystagmic responses to caloric stimuli were recorded through a Grass (model P5) 2-channel polygraph using Grass low-level d.c. preamplifiers. Vertical eye movements induced by the Coriolis stimuli were preamplified by a Grass low-level d.c. preamplifier filtered at 1/2 amplitude at 15 cps, and connected to a Heiland 906B galvanometer recorder. The time constant for the recorders for both caloric and Coriolis tests was 1.8 seconds. A tilt signal was also recorded and electronystagmograms of a subject after pre- and post-centrifuge tests were made.

In recording horizontal eye movements silver-disc EEG electrodes were taped at the outer canthi with the indifferent electrode on the forehead. For vertical nystagmus, electrodes were taped at the upper and lower orbital ridges using the same indifferent electrode as for horizontal nystagmus. All recordings were accomplished with eyes open in the dark.

Vertical electronystagmograms were recorded for all Coriolis stimuli. The dynamic

characteristics of nystagmic responses were measured for the rate of decay or recovery of nystagmus to a Coriolis acceleration ( $\beta$ ). The sensitivity coefficient ( $\alpha S$ ) of the system was also determined (4, 13).

The following method was used in measuring the horizontal electronystagmograms recorded with caloric stimulations. The amplitude of nystagmus was measured in 10-second intervals by averaging the distances from the peak of the fast phase of each eye beat to the baseline of the slow phase of that beat in centimeters. This measurement was then converted to degrees of eye turning speed per second from the calibration calculations made at the beginning of the test. The mean turning speed was plotted by averaging the means of

left beats for both 30° C. right ear and 44° C. left ear irrigations, and similarly for right beats to 30° C. left ear and 44° C. right ear irrigations.

### III. RESULTS

Spontaneous downward slow-phase nystagmus was observed in the post-centrifuge Coriolis test in 19 pilots. Test schedules permitted observations of spontaneous downward slow-phase nystagmus lasting up to 10 days for 2 subjects and for 4 or 5 days for the remaining 17 subjects.

Examples of the recorded vertical nystagmic responses are illustrated in figures 1A and 1B. Pre- and post-centrifuge Coriolis stimuli

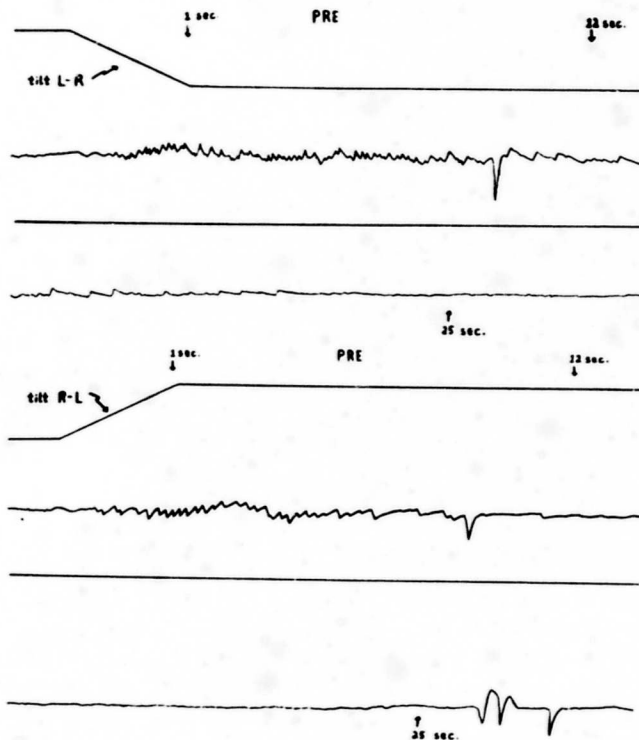


FIGURE 1A

*Induced vertical nystagmus of subject XR to Coriolis stimulation (pre-centrifuge test, left-to-right and right-to-left tilts).*

of both left-to-right tilts (L-R) and right-to-left tilts (R-L) of subject XR are shown. Note the difference between the pre- and post-centrifuge L-R tilt. This variation illustrates the effect of the spontaneous downward slow-phase nystagmus on the induced upward slow-phase nystagmus in the post-centrifuge test. In the pre-centrifuge L-R tilt, there is no spontaneous downward slow-phase nystagmus and the induced upward slow-phase nystagmus ceases before 25 seconds after the tilt. In the post-centrifuge L-R tilt the induced upward slow-phase nystagmus shifts as a result of the spontaneous downward slow-phase nystagmus approximately 7 seconds after the tilt. In the pre-centrifuge R-L tilt the induced downward slow-phase nystagmus ceases approximately 14 seconds after the tilt, while in the post-centrifuge R-L tilt there is no cessation of this downward slow-phase nystagmus

since it is continuing as a spontaneous nystagmus.

Table I presents the means of the exponential decay function ( $\beta$ ) and the sensitivity coefficient ( $\alpha S$ ) for both pre- and post-centrifuge responses to Coriolis acceleration tilts for group A, in which no spontaneous nystagmus was observed, and group B, in which a spontaneous downward slow-phase nystagmus was observed.

In group B, spontaneous nystagmus was subtracted from the nystagmic responses to Coriolis stimulation in determining both  $\beta$  and  $\alpha S$ . The differences for group B in the exponential decay function ( $\beta$ ) and the sensitivity coefficient ( $\alpha S$ ) are obvious from post- to pre-centrifuge trials.

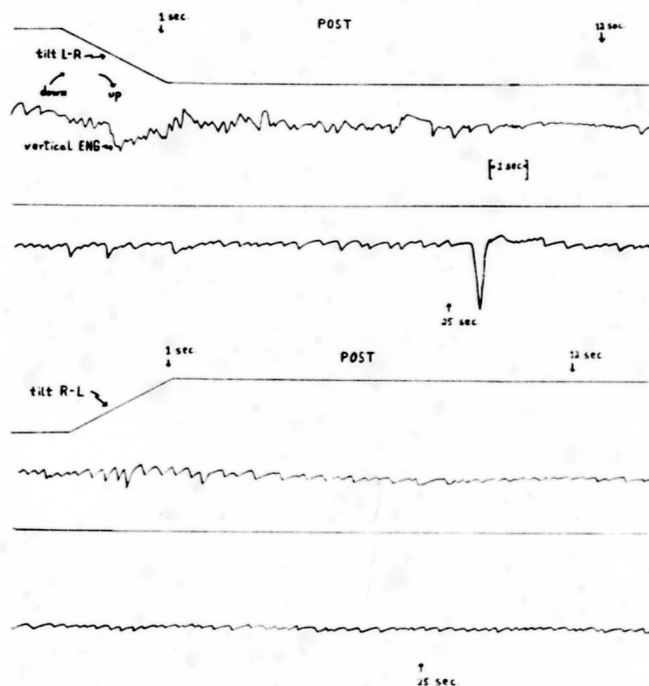


FIGURE 1B

*Induced vertical nystagmus of subject XR to Coriolis stimulation (post-centrifuge test, left-to-right and right-to-left tilts).*

TABLE I

Exponential decay functions( $\beta$ ) and sensitivity coefficients( $\alpha S$ ) of responses to Coriolis acceleration

	L-R tilt		R-L tilt	
	Pre-centrifuge	Post-centrifuge	Pre-centrifuge	Post-centrifuge
( $\beta$ )	(Mean)			
Group A	0.137	0.126	0.188	0.186
Group B	0.150	0.085	0.161	0.203
( $\alpha S$ )				
Group A	7.5	5.9	8.8	5.6
Group B	6.6	11.2	7.0	4.6

Group A -- No spontaneous nystagmus observed (N = 17).

Group B -- A spontaneous (slow phase downward) nystagmus observed in post-centrifuge tests (N = 19).

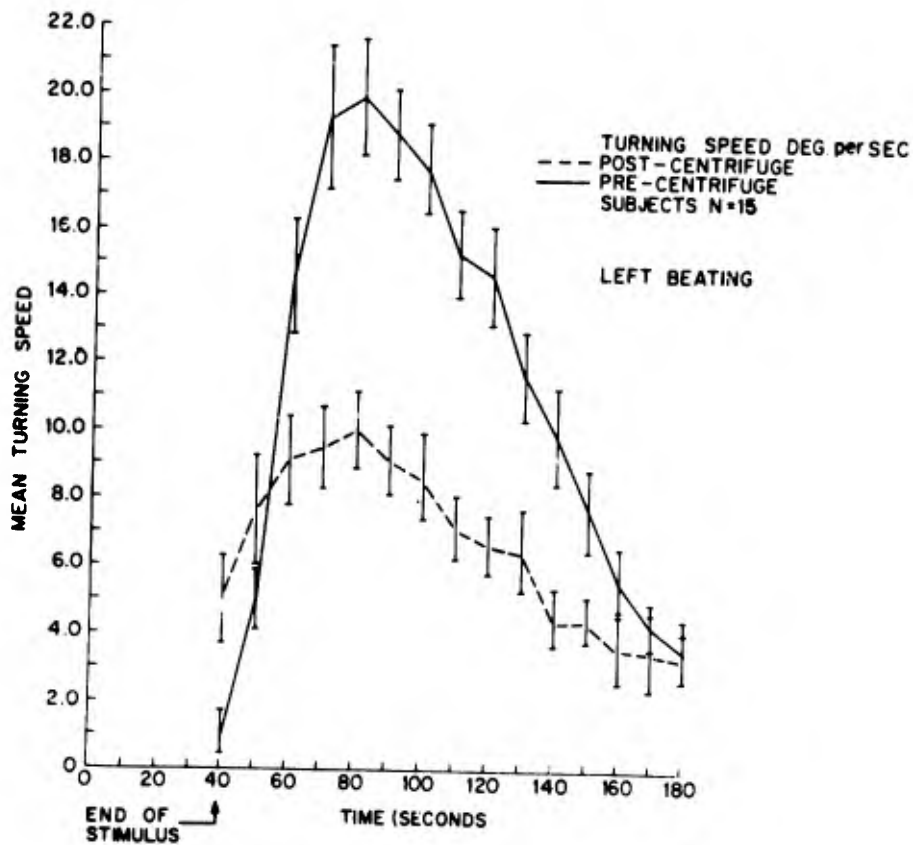


FIGURE 2A

Pre- and post-centrifuge left beating nystagmus to caloric stimulation (Fitzgerald-Hallpike technic, 30° C. right ear, 44° C. left ear).

The mean age for group A was 32.4 years, and for group B 33.0 years, with a range for both groups of 28 to 36 years. Thus, age was not a contributing factor in the results.

The results of the caloric pre- and post-centrifuge tests are illustrated in the graphs in figure 2 for 15 pilots who demonstrated vertical spontaneous nystagmus after centrifugation. There is a considerable reduction in the turning velocities of both left beating and right beating nystagmus in the post-centrifuge group.

All subjects reported that their sensations and general autonomic reactions during both Coriolis and caloric tests were considerably less intense post-centrifuge than during the pre-centrifuge tests. Some of the post-centrifuge pilots also reported nausea, emesis, and dizziness for 4 to 5 days after centrifugation.

Some pilots complained of headaches and vertigo after quick head movements for 4 or 5 days after centrifugation. Two pilots had difficulty in sleeping for a few days after centrifugation in that they experienced sensations of their bed spinning or moving in space.

#### IV. DISCUSSION

Our findings show definite modifications in responses to stimulation of the lateral canals in caloric tests and of the vertical canals to Coriolis stimulation after centrifugation. The difference between pre- and post-centrifuge Coriolis tests for group B demonstrates the effect of centrifugation on the induced vestibular responses to both post-centrifuge tilts. The pre- and post-centrifuge Coriolis test results for group A are similar to those

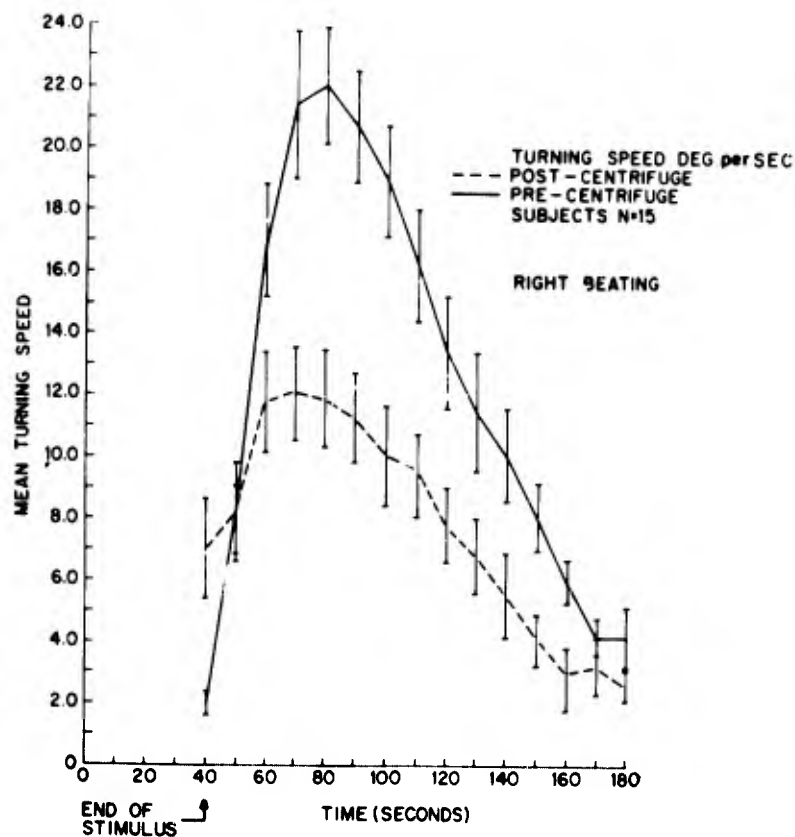


FIGURE 2B

*Pre- and post-centrifuge right beating nystagmus to caloric stimulation (Fitzgerald-Hallpike technic, 30° C. right ear, 44° C. left ear).*

found in studies by Dowd (6) and Moore (13) on decay and sensitivity coefficients.

The considerable reduction in turning speeds of both left beating and right beating nystagmus in the post-centrifuge group cannot be attributed to habituation when compared with other studies by Lidvall (11, 12), Fluor and Mendel (8, 9), and Capps and Collins (1). Rather, this reduction appears to be a result of the post-centrifuge spontaneous downward slow-phase nystagmus observed in the 15 pilots tested.

At present we cannot specify the levels and durations of acceleration which will produce permanent damage to the vestibular apparatus. This report is concerned with our preliminary investigations into the effects of short-duration high acceleration (+G). Some investigators claim that the otoliths are primarily affected, i.e., that the otoconia are missing over areas of the macula. Gillingham (10) ventures to state that such "disturbances are the result of utricular otoliths or loosened fragments of otolithic membranes being centrifuged onto the cupulae of various semicircular canals with the effect that the semicircular canals suddenly respond to linear acceleration and gravity in addition to the angular accelerations to which they ordinarily respond." The apparent recovery from the symptoms which takes place over a period of several days to weeks is a manifestation, he believes, of compensation by the central nervous system. Parker's work with high acceleration in guinea pigs reveals vestibular damage as a result of loss of otoconia in the maculae sacculi and of the utricle plus a "distortion of the cupula of a crista as shrinkage with fixation" (14). It is impossible to attribute the modifications in our studies to such peripheral organic changes since Parker's findings are not thoroughly defined histologically and Gillingham's statement has yet to be

experimentally demonstrated. Others look to the central nervous system for such temporary modifications. As a result of vascular changes such as acute hyperemia of the central nervous system, the possibility of cell damage due to hypoxia may result in such vestibulo-ocular modifications. Differences have been found in the reflex mechanisms of circulatory regulation as a result of changing conditions in the vasomotor centers (15).

Symptoms of nausea, emesis, and dizziness as reported by some post-centrifuge pilots over periods of 4 or 5 days and more, and the persistence of post-centrifuge spontaneous nystagmus may well indicate some central nervous system modifications which would necessitate periods of compensation of 2 weeks or more.

To date, very little is known on the effects of high linear acceleration on the vestibular system as measured by nystagmic responses, sensations, and general autonomic reactions to Coriolis and caloric stimulations. Speculation as to which part of the nervous system (central or peripheral) is most responsible for the vestibular modifications reported here is fruitless until more data have been obtained.

It is reasonable to assume that similar acute modifications may have occurred and will occur in some space crews following launch or re-entry. The lack of evidence of such acute modifications in the vestibulo-ocular systems of space crews may have resulted from their failure to report such information or from inadequate postflight testing.

Future research, hopefully, will enable us to define our pathology and the effects of controlled high accelerations on the vestibular system.

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