NAMI-953

ELICITATION OF HORIZONTAL NYSTAGMUS BY PERIODIC LINEAR ACCELERATION

Jorma I. Niven, W. Carroll Hixson, and Manning J. Correia

JOINT REPORT

UNITED STATES NAVAL AEROSPACE MEDICAL INSTITUTE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

December 1965

Distribution of this document is unlimited.

Distribution of this document is unlimited.

ELICITATION OF HORIZONTAL NYSTAGMUS BY PERIODIC LINEAR ACCELERATION*

Jorma I. Niven, W. Carroll Hixson, and Manning J. Correia

Bureau of Medicine and Surgery
Project MR005.13-6001
Subtask 1 Report No. 128

NASA Order No. R-93

Approved by

Captain Ashton Graybiel, MC USN
Director of Research

Released by

Captain H. C. Hunley, MC USN
Commanding Officer

17 December 1965

* This study was supported in part by the Office of Advanced Research and Technology, National Aeronautics and Space Administration.

U. S. NAVAL AEROSPACE MEDICAL INSTITUTE
U. S. NAVAL AVIATION MEDICAL CENTER
PENSACOLA, FLORIDA

SUMMARY PAGE

THE PROBLEM

This study was designed to determine whether systematic nystagmus could be elicited in man by a periodic linear acceleration stimulus.

FINDINGS

A highly systematic horizontal nystagmus was observed in response to dynamic translatory linear accelerations of sinusoidal form and to linear accelerations generated by a counterrotation-type rotating vector stimulus. Vertical nystagmus could not be demonstrated in response to similar stimuli. The magnitude of the slow component of nystagmic eye velocity and its phase lag behind the linear acceleration stimulus were found to differ markedly from those associated with periodic angular acceleration stimulation of the semicircular canals in a comparable frequency range. Regardless of the stimulus form, the effective stimulus element for elicitation of the horizontal nystagmus appeared to be the dynamic change in the linear acceleration component directed along the y (left-right) head axis.

ACKNOWLEDGMENTS

The authors wish to express appreciation to A. N. Dennis and C. A. Lowery for the instrumentation, C. L. Browning for fabrication of the D-C electrodes, D. Russell for operation of the device, and the Overhaul and Repair Department of the Naval Air Station for manufacture of the subject-cab.

INTRODUCTION

In general, it has been accepted that the semicircular canals serve as the primary biological transducer for angular motions, while the otolith mechanisms are considered to be the equivalent sensor for linear acceleration stimuli. Experimentation in the vestibular field has been such, however, that a great deal more data are available to describe the response behavior of the semicircular canals than are available to quantify the stimulus-response characteristics of the otolith mechanism. It has been shown (3) how frequency response analysis techniques making use of sinusoidal angular accelerations of varying frequency and magnitude as stimuli and ocular nystagmus as a physiologically objective response may be applied to the quantification of the performance characteristics of the semicircular canals.

The presentation of dynamic or time-variant linear acceleration stimuli fully independent of potential angular acceleration effects is more difficult, and fewer such studies have been performed. McCabe (7) presented sinusoidal linear acceleration stimuli to cats, chinchillas, and human subjects in the form of vertical oscillations along the cephalocaudal axis and reported vertical eye movements with occasional, marked, slow-fast components of nystagmic form. Nystagmic beats were observed by Jongkees and Philipszoon (5) in eye movement records obtained from rabbits when placed in a lateral position on a cart and accelerated sideways and also when swung side to side on a parallel swing. They also elicited nystagmic beats in a human subject lying in normal and lateral positions on a parallel swing but only when he looked in the direction of the fast component of the expected nystagmus. In both of these studies, the nystagmus was of a continuous nature, i.e., nonreversing, and not keyed to the cyclic changes in direction of the acceleration stimulus.

Nystagmus, the generally accepted ocular response of the semicircular canals to angular acceleration, would seem to be a promising indicator, but a survey of the experimental literature showed that it has not been accepted as a response to linear acceleration. Many experiments, e.g., Woellner and Graybiel (9), have demonstrated the occurrence of ocular displacement but not of nystagmus as a function of the magnitude and direction of time-invariant (static or constant) linear acceleration. Other experimenters, e.g., Lansberg, Guedry, and Graybiel (6), have reported the modification of an existing nystagmus initiated by angular acceleration through the introduction of linear acceleration acting simultaneously. Several studies (1,2) have reported an ocular nystagmus associated with a time-variant linear acceleration in the absence of, but following shortly after, stimulation by angular acceleration. In these cases, however, the attribution of the response to one form of acceleration stimulus to the exclusion of the other remains subject to question.

When a device, the Coriolis Acceleration Platform (CAP), capable of producing linear acceleration without angular motion became available to the U. S. Naval Aerospace Medical Institute, the present study was undertaken to determine if ocular nystagmus could be demonstrated in response to a sinusoidal linear acceleration stimulus as a basis for future frequency response analyses of the oculovestibular system. The demonstration of a highly systematic nystagmus unequivocally keyed to linear acceleration in the absence of potentially confounding angular accelerations would be of obvious practical and heuristic value.

PROCEDURE

SUBJECTS

Four males with no apparent defects in hearing or equilibrium served as subjects for this experiment. Three of the subjects (the authors) had previous experience on the device, and all were acquainted with the procedure and objectives of the experiment.

APPARATUS

The linear acceleration stimuli used in this experiment were generated by the CAP. This device consists of a cylindrical room 20 ft in diameter, identified as Slow Rotation Room II (SRR-II), centered on the rotational axis of the device and a 40 ft horizontal track superstructure identified as the Radial Track Assembly. An over-all view of the SRR-II capsule and the Radial Track Assembly is presented in Figure 1.

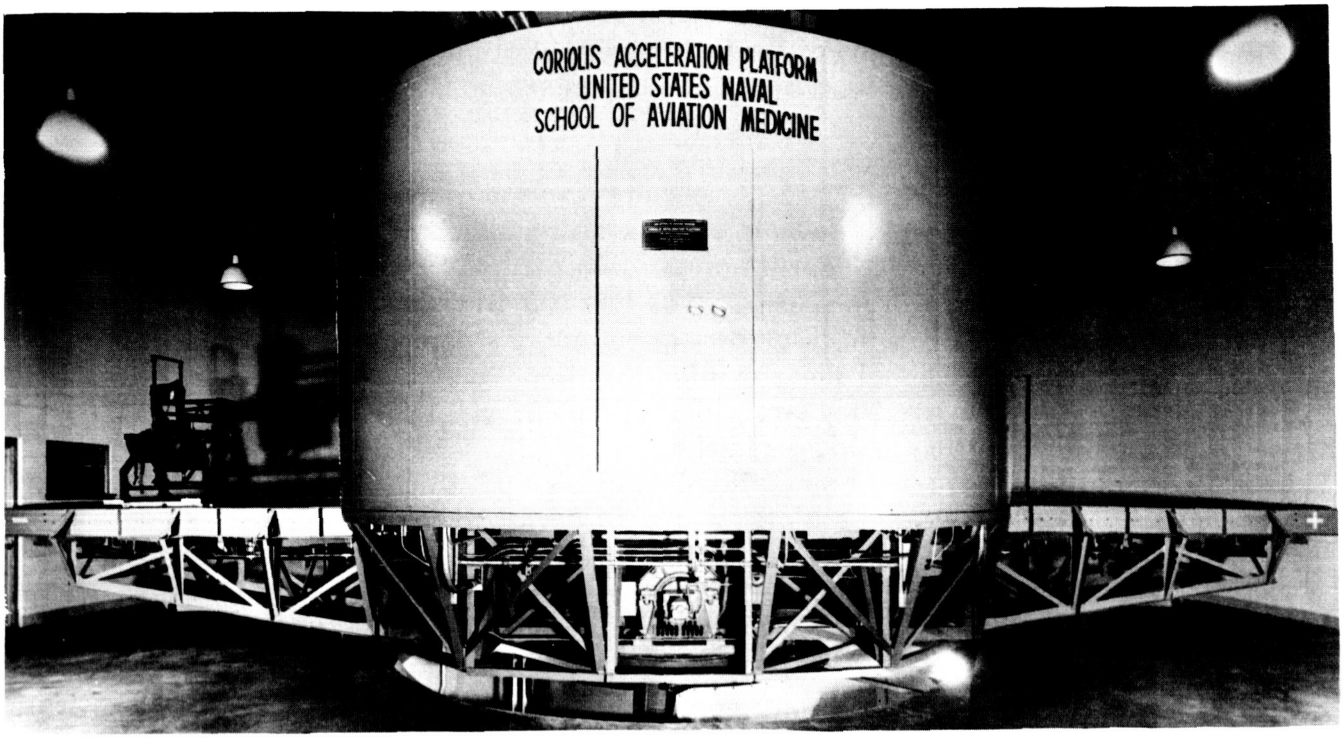


Figure 1

General view of Coriolis Acceleration Platform. The device comprises Slow Rotation Room II, the enclosed central portion, and Radial Track Assembly, the track extending through the room and projecting outward on both sides. Both angular and linear motions may be programmed independently or simultaneously.

The general configuration of the track assembly as viewed from one end of the track superstructure is shown in Figure 2. As may be seen, removable wall hatches and floor panels permit free passage of the track assembly through the interior of the SRR-II

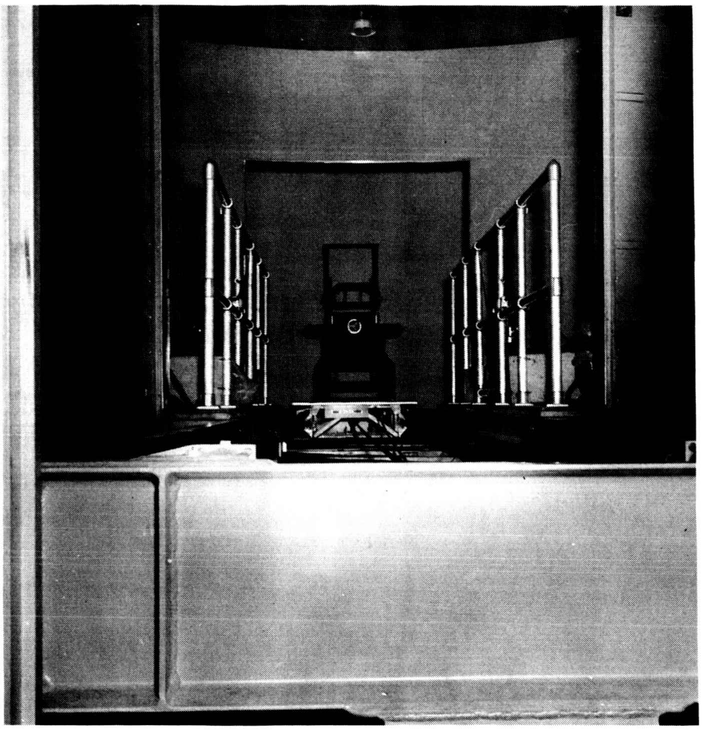


Figure 2

View looking along the Radial Track Assembly. The platform is shown carrying an experimental chair.

capsule. An experimental cab 4 ft x 4 ft x 4 ft (Figure 3) is mounted on a 4 ft x 4 ft track carriage which is wheel-supported on twin "vee"-rails on the track superstructure. The cab is designed so that it can be statically rotated about any of its three axes and attached to the track carriage to preposition the subject relative to the acting linear acceleration.

Motive power for the track carriage with attached cab is provided by a DC motor located on the rotational axis of the device immediately beneath the "vee"-rails. The DC motor is drum-coupled to the track carriage by means of a pretensioned wire cable. The torque motor drive system is operated as a closed-loop power servomechanism with position feedback established by a potentiometer attached to the motor shaft. Static and dynamic control of the instantaneous displacement of the track carriage is provided by DC command signals proportional to the desired position-time profile. The maximum ratings of the device are such that linear motions can be produced with ± 20 ft displacement, ± 16 ft/sec velocity, $\pm 3\ g$ acceleration, and 1 cps oscillation frequency with the condition that each maximum rating serves as the operational limit for any combination.

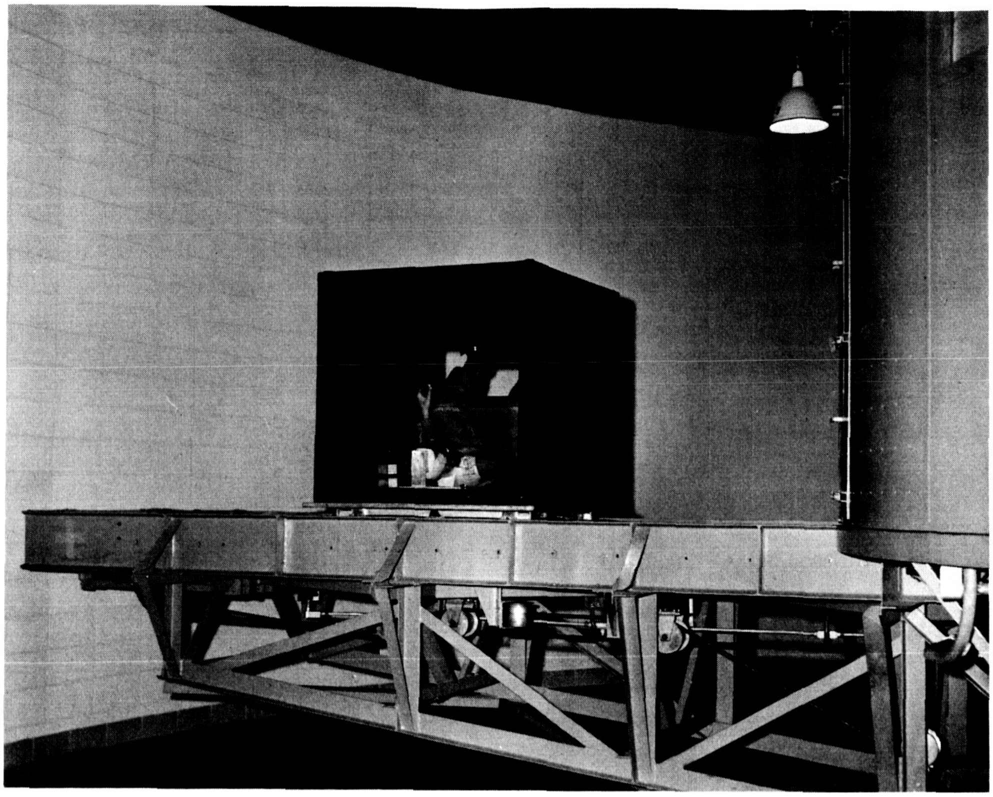


Figure 3

View showing the subject's cab used in the present study. The subject is shown in the Mode 1 body orientation (see text).

As an empirical check of the magnitude and direction of the linear accelerations produced during the test trials, a triaxial linear accelerometer was positioned at the subject's head level and oriented so that the appropriate accelerations could be recorded. A high-gain preamplifier for physiological recording was also located within the cab. Direct current corneoretinal potentials, reflecting horizontal and vertical eye displacements, were amplified, filtered to reduce interference from muscle artifacts, and recorded on an 8-channel, direct-writing recorder located in a nearby control room.

EXPERIMENTAL STIMULI

The stimuli in this experiment consisted of three sequentially applied oscillations of variable frequency and constant magnitude peak acceleration. The frequencies employed were 0.2, 0.4, and 0.8 cps with the peak track displacement adjusted so that the peak acceleration level could be maintained constant for all frequencies at 18.6 ft/sec^2 or 0.58 g. The actual and normalized characteristics of the stimulus profiles are presented in Table I; the normalized parameters are derived as a ratio of the relevant magnitude to the corresponding magnitude at 0.2 cps.

Table I

Comparison of Actual and Normalized Magnitudes of Three Linear Acceleration Stimuli

Motion Parameter	Stimulus No. 1 Actual	Stimulus No. 1 Normalized	Stimulus No. 2 Actual	Stimulus No. 2 Normalized	Stimulus No. 3 Actual	Stimulus No. 3 Normalized
Frequency (cps)	0.2	1	0.4	2	0.8	4
Peak displacement (ft)	±11.75	1	± 2.94	0.25	± 0.74	0.06
Peak velocity (ft/sec)	±14.77	1	± 7.38	0.50	± 3.69	0.25
Peak acceleration (ft/sec^2)	±18.56	1	±18.56	1	±18.56	1

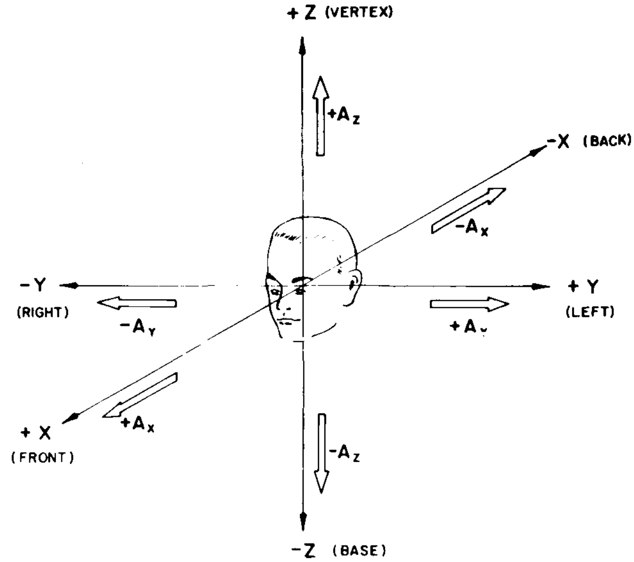
EXPERIMENTAL METHOD

Each subject was exposed to each of the three experimental frequencies while oriented in four positions relative to the direction of the linear acceleration vector. The basic notation used to describe the stimulus kinematically is summarized in graphic and equation form in Figure 4. The x, y, and z head axes denote the front-back, left-right, and vertex-base dimensions, respectively, of the skull while the frontal, sagittal, and horizontal head planes are mathematically identified as the yz, xz, and xy planes of the head, respectively.

The components of the resultant linear acceleration of the head acting along the x, y, and z head axes are denoted as A_x, A_y, and A_z, respectively, in the directional sense denoted in Figure 4.

The four basic orientations used in this study included: Mode 1. - the subject lying on his back and oriented so that the sagittal xz head plane was at right angles to the direction of the linear track motions; Mode 2. - same as Mode 1 except subject sitting upright; Mode 3. - the subject lying on his back and oriented so that the hori-aontal xy head plane was at right angles to the track motions; Mode 4. - the subject sitting in an upright position and oriented so that the frontal yz head plane was at right angles to the track motions.

Each subject was exposed to three experimental frequencies under the conditions of eyes open and eyes closed. Two of the subjects were presented the experimental frequencies in an ascending order (0.2, 0.4, and 0.8 cps) and two in a descending order (0.8, 0.4, and 0.2 cps). For one subject of each pair, horizontal and vertical nystagmus were first recorded with eyes closed, then with eyes open; for the other, the recording sequence was reversed. Since it is known that fixating in the direction of the fast component of an anticipated nystagmus can facilitate or modify such nystagmus, the subjects were instructed to maintain a straight-ahead gaze at all times during cab oscillation.



FRONTAL PLANE	SAGITTAL PLANE	HORIZONTAL PLANE
$\bar{A}_{YZ} = \lvert\bar{A}_{YZ}\rvert\angle\phi_X$	$\bar{A}_{XZ} = \lvert\bar{A}_{XZ}\rvert\angle\phi_Y$	$\bar{A}_{XY} = \lvert\bar{A}_{XY}\rvert\angle\phi_Z$
$\lvert\bar{A}_{YZ}\rvert = (A_Y^2 + A_Z^2)^{1/2}$	$\lvert\bar{A}_{XZ}\rvert = (A_X^2 + A_Z^2)^{1/2}$	$\lvert\bar{A}_{XY}\rvert = (A_Y^2 + A_X^2)^{1/2}$
ϕ_X = ARC TAN$(-A_Y/A_Z)$	ϕ_Y = ARC TAN (A_X/A_Z)	ϕ_Z = ARC TAN(A_Y/A_X)

Figure 4

Schematic diagram giving basic notation in pictorial and equation form for the linear acceleration stimuli acting on the subject.

Initially the subject's head was fixed by means of a standard aviator's helmet secured to the cab frame. It was evident, however, that excessive freedom for rotary motions of the head existed. For this reason, the subject was secured in the cab in one of the four basic body orientations with his head rigidly fixed by means of an individual, custom-molded, plaster cast (Figure 5) and with his body fixed securely to the seat by straps.

The nystagmus recording circuits were then calibrated by having the subject fixate alternately two target points of known angular separation. Once the calibration procedure was complete, the experimental cab was sealed, insuring that the cab was completely light-tight. The subject was then oscillated at one of the predetermined test frequencies. Recording was begun following oscillation for sixty seconds to minimize any biological transient effects that might be associated with the onset of the stimulus. After sixty seconds of sinusoidal oscillation the subject was instructed to open or close his eyes as the experimental conditions required, and recording was continued for another sixty seconds. The usual procedures of "chatter" and performance of mental arithmetic were used to encourage maximal nystagmic response. A rest period of at least two minutes was allowed before the next experimental run.

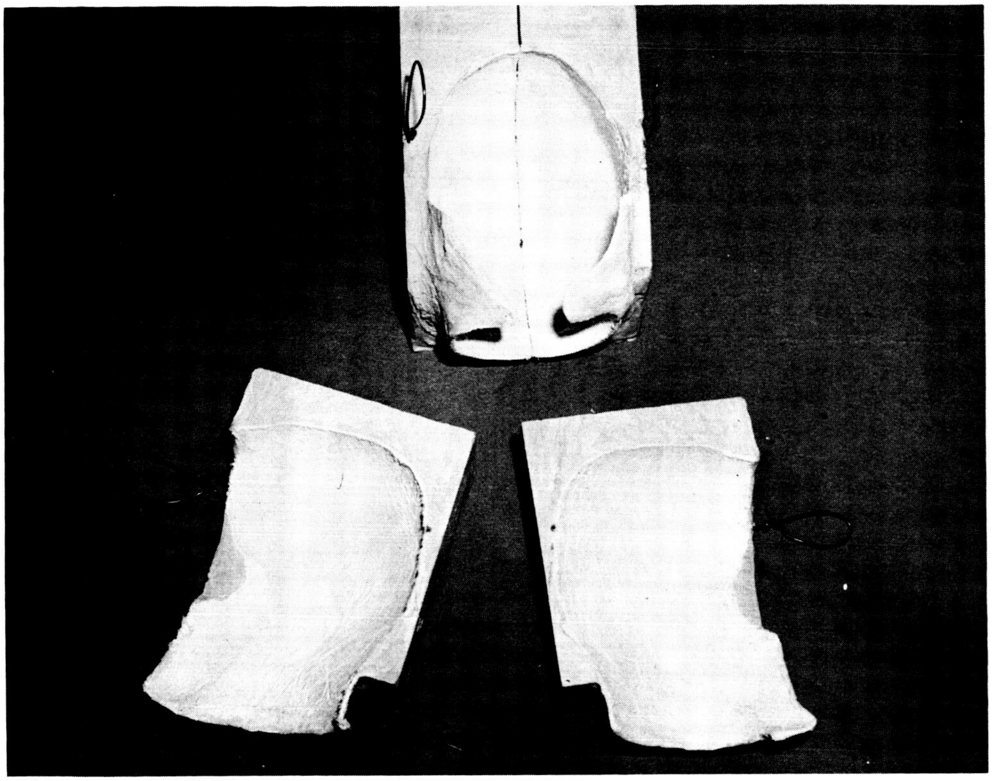


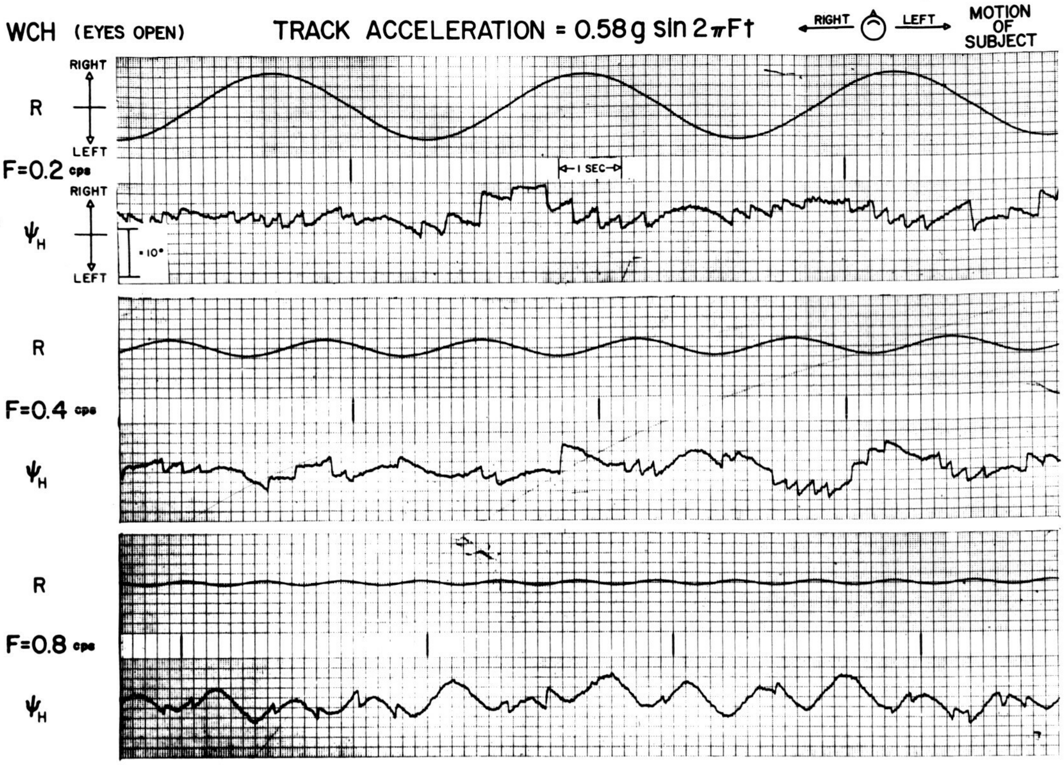
Figure 5

Assembled and disassembled plaster molds used to fix the subject's head to the experimental platform. The molds were cast individually to ensure full constraint.

Following completion of the experimental trials for nystagmus recordings, the experimental design was replicated with the subjects instructed to view a 7 1/2 in. by 1/32 in. luminous line target (aligned with the z axis in Modes 1 and 2, with the y axis in Modes 3 and 4) and report their impressions of target movement. On the trials where the eyes were closed, reports of postural sensations were obtained.

RESULTS

Horizontal nystagmus was found to be elicited by the periodic linear acceleration stimulus in certain body orientations. Vertical nystagmus was not observed during any of the stimulus conditions of this experiment. Typical tracings of horizontal nystagmus obtained when the resultant of the track and gravitational accelerations were acting in the horizontal plane of the head (Mode 1 orientation) with the eyes open are reproduced in Figure 6. Essentially similar responses were obtained in the eyes closed condition as shown in Figure 7. A pronounced horizontal nystagmus was also observed when the resultant acceleration vector was varied sinusoidally in the frontal plane of the head (Mode 2 orientation) as may be seen in Figure 8. Neither the horizontal nor the vertical nystagmus expected in the Modes 3 and 4 orientations could be observed (see Figure 9).



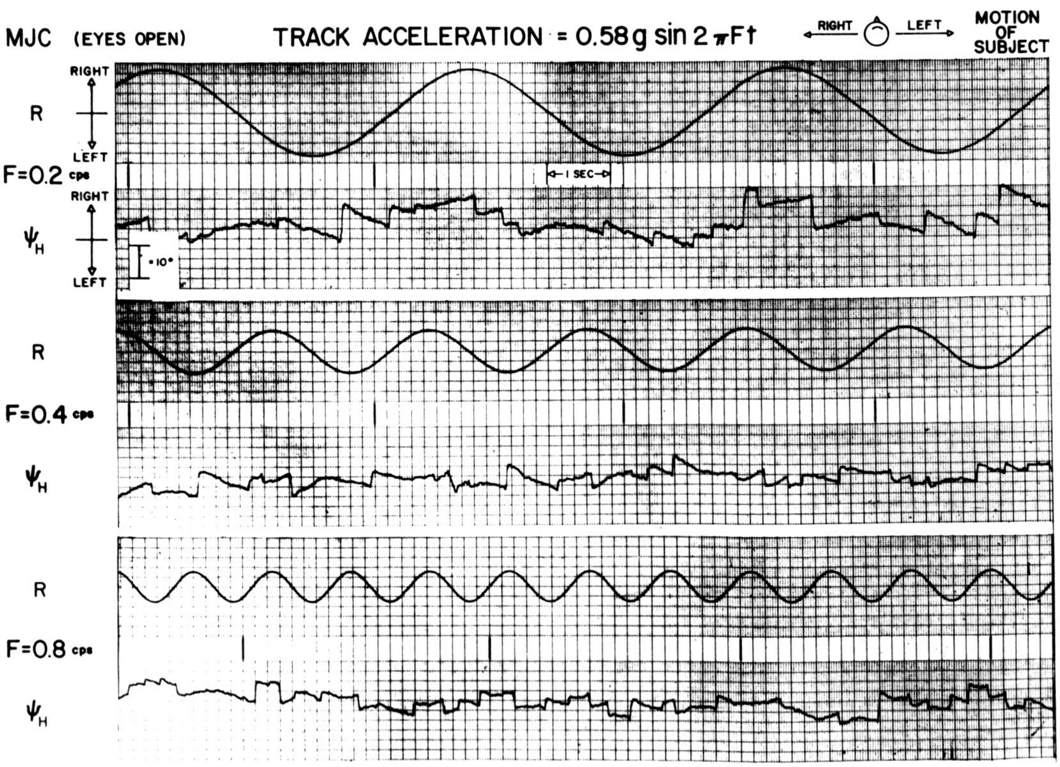


Figure 6

Horizontal nystagmus recorded from subjects with their eyes open for three different stimulus frequencies. The track acceleration component is directed along the y head axis while lying on the back (Mode 1). The sinusoidal waveform identified as R in each record describes the instantaneous displacement of the track.

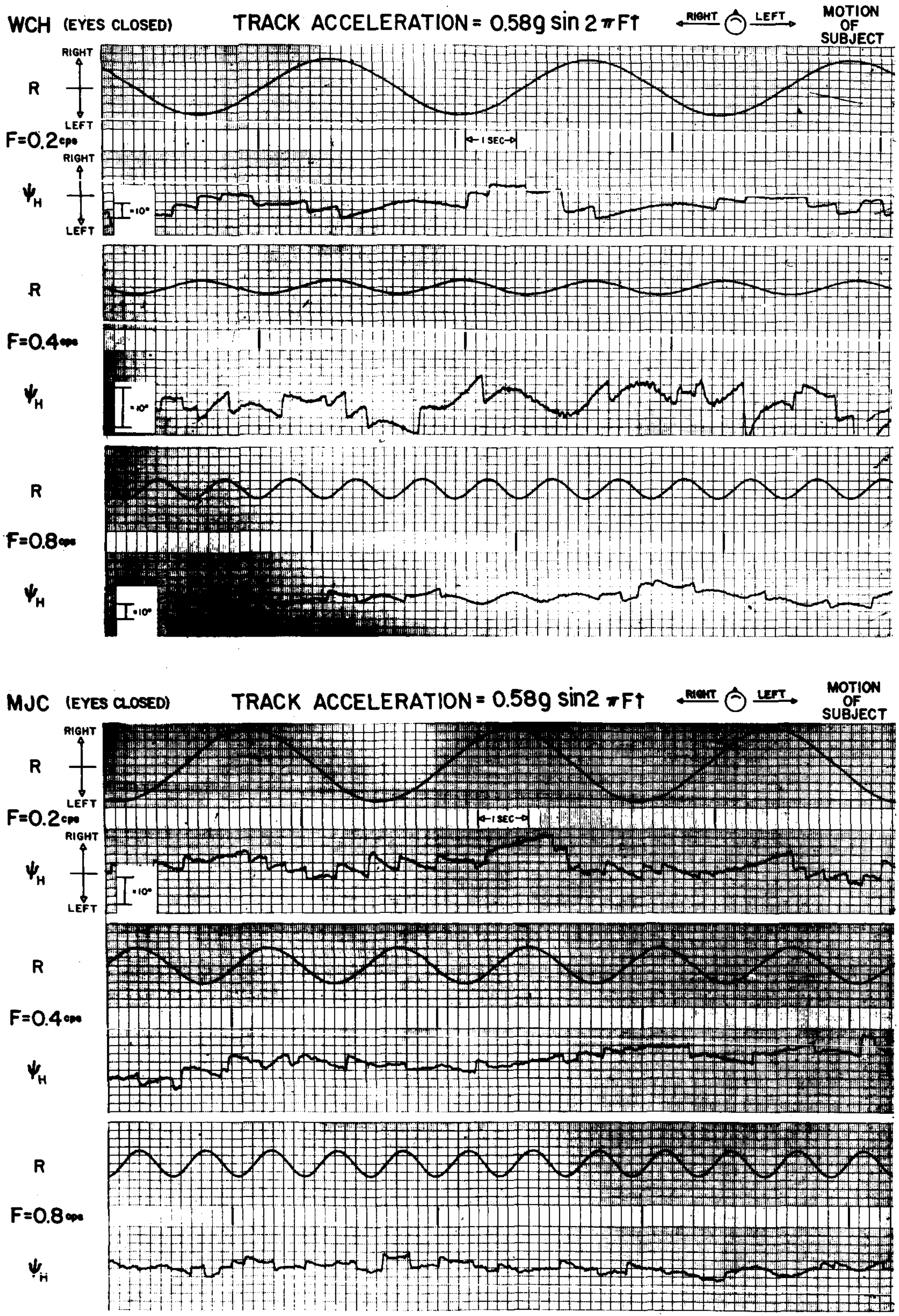


Figure 7

Horizontal nystagmus recorded from the same subjects in the same body orientation (Mode 1) as in Figure 6 but with eyes closed.

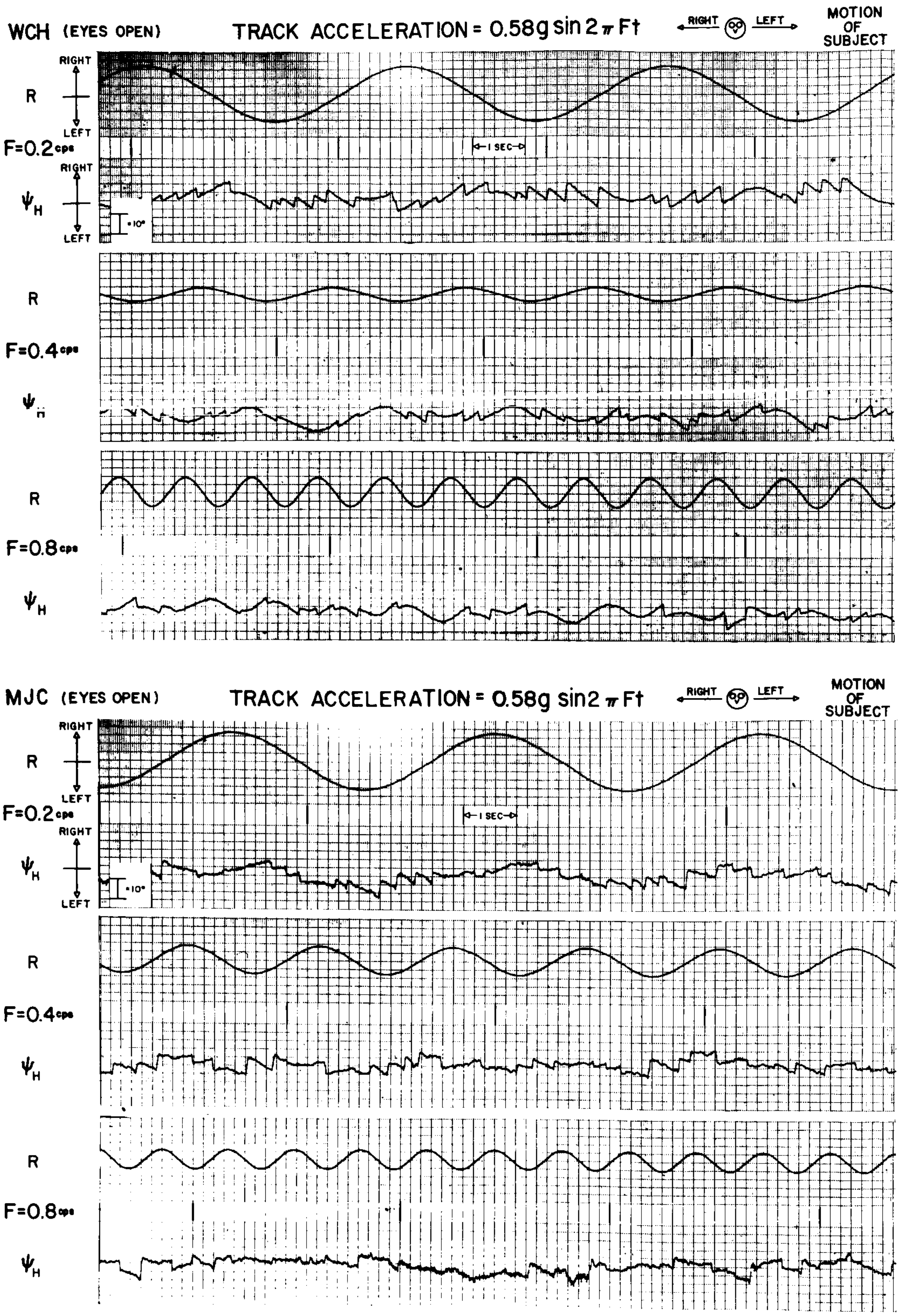


Figure 8

Horizontal nystagmus recorded from subjects with eyes open. The track acceleration component is again directed along the y head axis although they are seated erect (Mode 2).

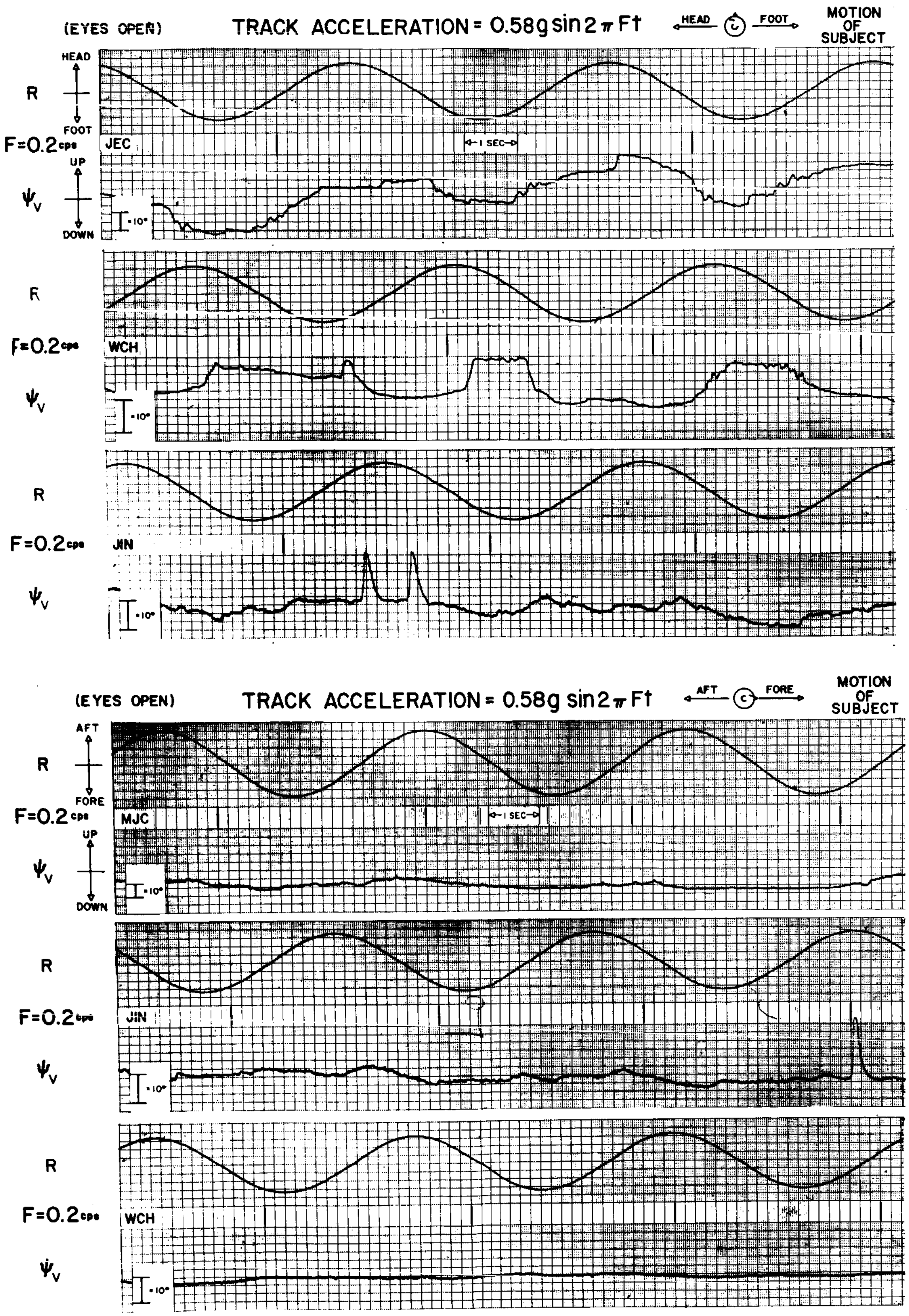


Figure 9

Vertical eye movements recorded from subjects with the track acceleration directed along the z head axes (Mode 3 above) and the x head axes (Mode 4 below). The absence of vertical nystagmus is in marked contrast with the horizontal nystagmus elicited by y-axis stimulation (Modes 1 and 2).

The recordings of the nystagmic response to sinusoidal linear oscillation acceleration stimuli for the Modes 1 and 2 orientations were analyzed to determine both phase shift and magnitude of peak slow component velocity. The phase shift or lag of the nystagmic response behind the stimulus was measured as the distance from the point at which the stimulus acceleration was zero to the transition point at which the slope of eye displacement was zero (i.e., velocity of the slow component was zero) and the results were expressed in electrical degrees, where one degree equals 1/360 of a cycle. This method of measurement has been described in detail in an earlier report (8) on the frequency response of the semicircular canals. Peak slow component velocity was determined by measuring the slope of the individual nystagmic responses and selecting the maximum value. A summary of the results is presented in Table II.

Table II

Mean Slow Component Velocity (Ψ) and Phase Shift Angle (ϕ) of Ocular Nystagmus as a Function of the Frequency of a Sinusoidal Linear Acceleration Stimulus

	Frequency (cps)					
	0.2		0.4		0.8	
Subject	Ψ (deg/sec)	ϕ (deg)	Ψ (deg/sec)	ϕ (deg)	Ψ (deg/sec)	ϕ (deg)
MJC	9.16	25.46	7.84	26.04	7.17	30.28
n*	74	74	54	66	48	50
JEC	8.09	27.60	7.26	40.20	7.69	30.47
n	45	48	34	34	23	12
WCH	11.91	25.41	12.81	32.98	15.34	47.57
n	54	56	64	77	24	59
JIN	5.33	25.72	7.99	22.68	9.32	24.38
n	24	28	18	6	20	6
Group mean	9.20	25.96	9.61	31.48	9.33	38.04
n	197	210	170	183	115	127
Pooled S.D.	3.03	9.38	2.50	11.12	2.89	16.01

*n = number of measurements on which mean is based.

The subject means contained in Table II were obtained by combining the values obtained for eyes open and eyes closed for body orientations Modes 1 and 2. Lack of any statistical difference between these conditions permitted this grouping.

POSTURAL AND VISUAL SUBJECTIVE SENSATIONS

The visual impressions of the luminous line target may be summarized as follows: During Modes 1 and 2 stimulation the line target remained directly ahead of the subject for all experimental frequencies. The visual target possessed predominantly the quality of apparent velocity; that is, it appeared to move with the observer as he experienced movement to the left or right. Apparent displacement, that is, lag or lead of the sensation of postural displacement by the target, or apparent tilting of the target either CW or CCW, was either not observed or was minimal. During Modes 3 and 4 stimulation, as in the case of the other two body orientations, the target remained directly ahead of the subject and moved back and forth with him. However, it did not appear to be displaced above or below the subject at any time during the test trials.

The postural sensations may be summarized as follows: In Modes 1 and 2 the subjects perceived primarily a pure translation, or side-to-side motion, in the horizontal plane. In Modes 3 and 4 the sensations were similarly of fore-and-aft displacement along the track. In a number of instances there was a tendency to report a brief yawing, rolling, or pitching sensation, depending upon orientation, at the point of maximum displacement, but generally the sensations were described as simple translatory movements.

DISCUSSION

The eye motion recordings of this study, marked by precisely defined fast and slow components with directional transitions tightly keyed to the stimulus, show clearly and definitively that linear acceleration is an adequate stimulus to produce nystagmus. This horizontal nystagmus was elicited whenever the head was oriented with its sagittal xz plane at right angles to the direction of sinusoidal track accelerations. In effect, horizontal nystagmus resulted when the y (left-right) head axis was aligned with the direction of motion for both the erect and supine postures. Horizontal nystagmus was not observed for the orientations where the track acceleration acted at right angles to either the frontal yz or horizontal xy head planes, i.e., for accelerations directed along the x and z head axes, respectively.

In contrast, it was not possible to record observable vertical nystagmus under any of the four stimulus conditions of the study even with greatly increased recording sensitivity. During various related pilot studies other body orientations which involved statically tilting the three cardinal head planes relative to the direction of motion were used. In no case was vertical nystagmus recorded. At most, there sometimes occurred sinusoidal variations of the baseline which had little repeatable correlation with the amplitude-time profile of the stimulus.

The characteristics of the observed horizontal nystagmus and its relationship to the acceleration A_y acting along the y head axis can be summarized as follows: Each change in direction of the A_y stimulus was accompanied by a change in direction of the slow component of eye velocity. The time-course of these changes was such that the reversals in the direction of nystagmus (marked by zero eye velocity) lagged slightly behind the reversals in the direction of the A_y stimulus (marked by zero acceleration). The polarity sense of these reversals was such that acceleration to the left produced nystagmus with the slow component of eye velocity to the right, and vice versa. The instantaneous slow component of eye velocity described a sinusoidal waveform closely resembling that of the sinusoidal A_y stimulus.

The frequency dependence of the nystagmus data as derived from a magnitude and phase analysis of the slow component of eye velocity (Table II) can be described as follows: The mean peak eye velocity remained constant at approximately 10 deg/sec at F = 0.2, 0.4, and 0.8 cps so that this parameter can be considered independent of frequency over the denoted stimulus range. The directional transitions in eye velocity showed a relatively small increase in phase lag as the stimulus frequency was increased, i.e., mean phase angles of approximately 26°, 31°, and 38° at 0.2, 0.4, and 0.8 cps, respectively.

With the three particular stimulus configurations chosen for this study, frequency served as the independent variable with the condition that the peak acceleration was held constant throughout. With simple harmonic motion, the peak velocity parameter of the stimulus is inversely proportional to the driving frequency while the peak displacement parameter is inversely proportional to the square of the frequency. Thus, as indicated by the normalized magnitude data of Table I, when the stimulus frequency was raised from 0.2 to 0.8 cps (a fourfold increase), the peak velocity and peak displacement were reduced to 1/4 and 1/16, respectively, of their values at 0.2 cps. As far as the motion parameters proper are concerned, only the peak acceleration remained constant. It is apparent, then, that the peak value of the slow component of eye velocity, which also remained relatively constant, is keyed to the acceleration parameter rather than to the velocity or displacement parameters of the simple harmonic motion stimulus.

One further observation of primary concern involves the decay time of the nystagmus following removal of the stimulus. The experimental procedure was such that upon completion of the nystagmus recording sequence, the track carriage was brought to a stop within two to five seconds. The decay of the nystagmus was so rapid that its termination was almost coincidental with termination of the stimulus. This observation, combined with the constant peak amplitude and minimal phase shift data observed over the relatively high stimulus frequency region, indicates that the biological sensing mechanism or mechanisms responsible for elicitation of the nystagmus have a relatively fast response time when stimulated in this mode.

The nystagmus data presented in this study arose from a stimulus condition in which a linear acceleration vector (due to track motion) of variable magnitude acted along a single fixed morphological axis. The authors have also induced horizontal nystagmus by exposing subjects to a counterrotation-type stimulus defined by a linear acceleration vector of constant magnitude rotating at constant angular velocity in a given morphological plane. This stimulus was produced by linearly oscillating the

CAP track platform at constant frequency, ω rad/sec, while simultaneously rotating the device at constant angular velocity, $\dot{\Theta}_v$ rad/sec, with the special condition that ω was identical to $\dot{\Theta}_v$. In addition, by varying the peak track displacement, while holding track frequency and rotational velocity constant and equal, it was possible to obtain different constant magnitude levels of the rotating linear acceleration vector. The actual stimuli thus obtained were equivalent to counterrotation of a subject at 12 RPM in 0.3, 0.4, and 0.5 *g* centripetal acceleration fields.

A record presented in Figure 10 shows the horizontal nystagmus produced by such a stimulus rotating through the horizontal xy head plane (again, simultaneous recording from appropriate electrodes failed to show vertical nystagmus). The characteristics of the horizontal nystagmus elicited by counterrotation included periodic reversals in direction and a slow component of eye velocity of sinusoidal waveform. More importantly, the horizontal nystagmus produced by this counterrotation was tightly keyed to the instantaneous component of the constant magnitude linear acceleration vector acting along the y head axis. This component, A_y, was of sinusoidal form and fully equivalent to the translatory-type stimulus used in the present study.

Thus for counterrotation at this rate, each reversal in the direction of A_y was followed by a reversal in direction of the horizontal nystagmus; acceleration to the right produced nystagmus with a slow component to the left, and vice versa. (The phase relationship between the nystagmus and A_y can be observed in Figure 10 by noting that A_y has a waveform identical to that of the "stimulus reference" channel shown, except for a 90-degree phase lag.) In essence, the nystagmus elicited by linear acceleration generated through counterrotation was very similar to that elicited by translation of harmonic motion form along the y axis.

The nystagmus of this study also closely resembles that recorded when a subject is exposed to sinusoidal angular acceleration of variable frequency about an Earth vertical axis. In the latter case each reversal in direction of the angular acceleration stimulus is accompanied by a reversal in the direction of the nystagmus with an angular acceleration to the subject's right (about the z head axis) leading to nystagmus with a slow component of eye velocity to the left, and vice versa. In addition, the waveform of the instantaneous magnitude of the slow component of eye velocity follows the sinusoidal waveform of the angular acceleration stimulus.

However, two important differences in nystagmus characteristics result for the two stimulus conditions. For sinusoidal angular accelerations in the vicinity of 0.2 cps, it has been shown that the directional nystagmus transitions lag the driving angular acceleration or torque producing the response by 80 to 90 degrees (4,8). Further, the peak magnitude of the slow component of eye velocity decreases as the frequency is raised. In general, the magnitude and phase characteristics of the slow component of eye velocity for frequencies near and above 0.2 cps are such that sinusoidal angular oscillations must be of constant peak velocity form to produce constant peak velocity nystagmus; for frequencies far below 0.2 cps they must be of constant peak acceleration form to produce a nystagmus with constant peak velocity. That is to say, the transduction

NYSTAGMUS PRODUCED BY LINEAR ACCELERATION
— COUNTER ROTATION —

ACCELERATION STIMULUS: CONSTANT MAGNITUDE VECTOR ($|\bar{A}|$)
ROTATING THROUGH THE HORIZONTAL XY HEAD PLANE (0.2 CPS RATE)

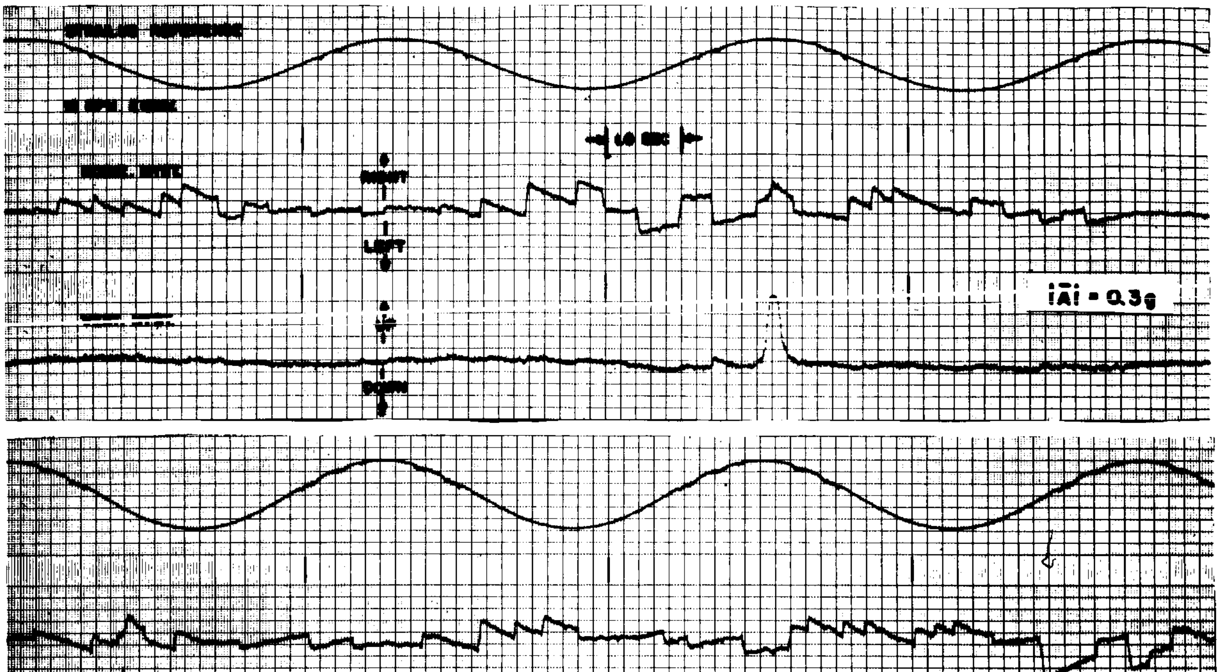


Figure 10

Horizontal nystagmus produced by rotation of a constant magnitude linear acceleration vector through the horizontal xy head plane at constant angular velocity. The stimulus is equivalent to counterrotation of a subject at a constant 12 RPM rate in centripetal acceleration fields of 0.3, 0.4, and 0.5 g as denoted at the right in each recording. The reversals in the direction of the slow phase of nystagmus are keyed to the reversals in direction of the linear acceleration component acting along the y axis which occur at the instant of maximum displacement on the stimulus reference curve.

processes are frequency dependent, keyed to acceleration at very low frequencies and to velocity at the higher frequencies. In the same context the nystagmus elicited by the sinusoidal linear accelerations of this study becomes analog to an acceleration transduction process in the 0.2 to 0.8 cps stimulus range since no change in nystagmus peak velocity occurred. It should also be obvious that this mode of response will not extend to very low frequencies since in the limit, i.e., in the static acceleration environment, nystagmus becomes nonexistent. It may be concluded that a dynamic change in acceleration, i.e., jerk, along the y head axis is required to elicit the nystagmus.

A comparable interpretation of the visual and postural illusions can be made. It may be noted that the direction of the resultant of the track and gravitational accelerations was changing continuously during each oscillation cycle. With the peak track acceleration of 0.58 g the maximum deviation of the resultant linear acceleration vector from Earth vertical was 30 degrees and occurred at the instant of peak displacement to either side of the oscillation center. The stimulus was perceived primarily as translatory motion and not as body tilt. Conversely, when a static linear acceleration vector is reoriented relative to the body, as in centrifuge experiments, the stimulus is perceived primarily as body tilt. It may be hypothesized that perception of body tilt is frequency dependent: When the morphological orientation of a linear acceleration stimulus is changed rapidly, a sensation of motion arises; when changed slowly or held constant, a sensation of tilt arises.

The results have operational significance in that the potential for the occurrence of horizontal nystagmus during a transition from one linear acceleration level to another exists whenever man is oriented so that the transition produces a change in acceleration along the y (left-right) head axis. Such nystagmus would arise typically for passengers seated sideways in vehicles with linear motion characteristics described by relatively sudden changes in acceleration or deceleration along the fore-and-aft axis. From the rapid decay of the nystagmus observed in this study, it would be expected that this nystagmus would exist only during the acceleration transition period.

The results also have experimental significance in that any study performed on an angular-motion-type research device where horizontal nystagmus is a primary response variable must consider that dynamic variations in the linear acceleration element of the over-all vestibular stimulus can contribute to the response. Stated more specifically, time variations of the component of the resultant linear acceleration which acts along the y head axis, whether due to <u>magnitude</u> changes in centripetal, tangential, or linear Coriolis accelerations or to morphological <u>directional</u> changes of the same accelerations as well as of the gravitational field itself, may elicit horizontal nystagmus. Further, the nystagmus elicited by such stimuli may act in concert or in opposition to the horizontal nystagmus produced concurrently by the angular acceleration element of the environment and lead to either an attenuation or amplification of the over-all nystagmus response.

These data demonstrate definitively the production of a systematic horizontal ocular nystagmus in response to a dynamic change in linear acceleration, jerk, acting along the y head axis. The response or decay time characteristics as well as the phase and magnitude characteristics of the nystagmic response to periodic linear acceleration differ markedly from those of the comparable response to periodic angular acceleration. However, these differences neither prove nor disprove that the horizontal semicircular canals, acting in a physical mode not identical to the classical concept of cupula-endolymph flow, respond to periodic linear acceleration stimulation. More data, particularly on the response to low-frequency, high-level, linear acceleration stimuli, will be required before it becomes feasible to attempt to specify the responsible biological sensing system, e.g., otolith or canal receptors.

REFERENCES

1. Benson, A. J., and Bodin, M. A., Interaction of linear and angular accelerations on vestibular receptors in man. IAM Report No. 323. Farnborough, Hants: RAF Institute of Aviation Medicine, 1965.

2. Guedry, F. E., Orientation of the rotation-axis relative to gravity: Its influence on nystagmus and the sensation of rotation. Acta otolaryng., Stockh., 60: 30-48, 1964.

3. Hixson, W. C., and Niven, J. I., Application of the system transfer function concept to a mathematical description of the labyrinth: 1. Steady-state nystagmus response to semicircular canal stimulation by angular acceleration. NSAM-458. NASA Order No. R-1. Pensacola, Fla.: U. S. Naval School of Aviation Medicine, 1961.

4. Hixson, W. C., and Niven, J. I., Frequency response of the human semicircular canals. II. Nystagmus phase shift as a measure of nonlinearities. NSAM-830. NASA Order No. R-37. Pensacola, Fla.: U. S. Naval School of Aviation Medicine, 1962.

5. Jongkees, L.B.W., and Philipszoon, H. J., Nystagmus provoked by linear accelerations. Acta Physiol. Pharmacol. Neerl. 10:239-247, 1962.

6. Lansberg, M. P., Guedry, F. E., and Graybiel, A., Effect of changing the resultant linear acceleration relative to the subject on nystagmus generated by angular acceleration. Aerospace Med., 36:456-460, 1965.

7. McCabe, B. F., Nystagmus response of the otolith organs. Laryngoscope, 74: 372-381, 1964.

8. Niven, J. I., and Hixson, W. C., Frequency response of the human semicircular canals. I. Steady-state ocular nystagmus response to high-level sinusoidal angular rotations. NSAM-459. NASA Order No. R-1. Pensacola, Fla.: U. S. Naval School of Aviation Medicine, 1961.

9. Woellner, R. C., and Graybiel, A., Counterrolling of the eyes and its dependence on the magnitude of gravitational or inertial force acting laterally on the body. J. appl. Physiol., 14:632-634, 1959.

Unclassified
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Linear acceleration						
Rotating linear vector						
Counterrotation						
Sensation						
Nystagmus						
Peak velocity of slow component of nystagmus						
Phase lag						
Vestibular apparatus						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ______."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ______."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ______."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

Unclassified
Security Classification

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* U. S. Naval Aerospace Medical Institute U. S. Naval Aviation Medical Center Pensacola, Florida	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Elicitation of Horizontal Nystagmus by Periodic Linear Acceleration

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

5. AUTHOR(S) *(Last name, first name, initial)*

Niven, Jorma I.; Hixson, W. Carroll; and Correia, Manning J.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
17 December 1965	19	9

8a. CONTRACT OR GRANT NO. NASA Order No. R-93	9a. ORIGINATOR'S REPORT NUMBER(S) NAMI-953
b. PROJECT NO. MR005.13-6001	
c. Subtask 1	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* 128
d.	

10. AVAILABILITY/LIMITATION NOTICES Qualified requesters may obtain copies of this report from DDC. Available, for sale to the public, from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia, 22151.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

Four subjects in each of four different body orientations were exposed to periodic linear acceleration stimuli produced by simple harmonic translation of 0.2, 0.4, and 0.8 cps cyclic frequency along an Earth horizontal axis. Highly systematic horizontal nystagmus was demonstrated in response to these stimuli as well as to linear accelerations of rotating vector form equivalent to counterrotation in a constant magnitude linear force field. Vertical nystagmus could not be demonstrated for similar stimuli. The magnitude of the slow component of nystagmus and the phase lag of the nystagmic response behind the linear acceleration stimulus were found to differ from those associated with periodic angular stimulation of the semicircular canals in a comparable frequency range. Regardless of stimulus form, the effective stimulus element for elicitation of horizontal nystagmus appeared to be dynamic change in the linear acceleration component directed along the subject's y (left-right) head axis.

DD FORM 1 JAN 64 1473

Unclassified

Security Classification