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VISUAL COUNTERACTION OF NAUSEOGENIC AND DISORIENTING EFFECTS OF SOME WHOLE-BODY MOTIONS - - A PROPOSED MECHANISM

Fred E. Guedry, Jr.

February 1977

NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
PENSACOLA, FLORIDA

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SUMMARY PAGE

THE PROBLEM

It has been indicated that the nauseogenic and disorienting effects of several kinds of provocative motion stimuli can be ameliorated by visual reference to the Earth. The purpose of the present experiment is to investigate a hypothesis concerning the mechanism of this beneficial effect.

FINDINGS

The results demonstrate that the aftereffects of large-field optokinetic stimulation can nullify the nauseogenic and disorienting effects of Coriolis cross-coupled vestibular stimuli. It is hypothesized that large-field optokinetic stimulation in a particular head plane modifies activity in the central nervous system as though the semicircular canals in that plane had been stimulated. A previous study illustrated that such semicircular canal stimulation would completely nullify the disturbing and disorienting effects of Coriolis cross-coupled stimulation according to theoretical expectations. The results provide inferential support for the hypothesis and suggest that predictability of disorientation and nauseogenic disturbance are reasonably well handled by current theory when the conditions of motion are fairly well specified.

INTRODUCTION

Several studies have indicated that the presence of external visual reference to the Earth reduces the incidence of disturbance and motion sickness produced by vestibular Coriolis cross-coupled stimuli (4,15) and swing motions (11). These laboratory observations are consistent with advice sometimes offered to sailors and aviators concerning the beneficial effects of viewing the horizon. The mechanism whereby an external visual reference ameliorates otherwise nauseogenic vestibular inputs has not been elucidated even though its efficacy has been reasonably well established (at least under laboratory conditions).

Consideration of several sets of recent findings (3,7,9) suggests a potentially relevant hypothesis. Specifically, it is hypothesized that large-field optokinetic stimulation can modulate activity in the vestibular nuclei in patterns that simulate input patterns from specific sets of semicircular canals, and activity in the vestibular nuclei that is nauseogenic because of inputs from the semicircular canals and otoliths can be altered by interaction with these optokinetic inputs to yield a pattern that will be synergistic and neither disorienting nor nauseogenic. This paper adduces evidence and presents experimental observations that, by inference, support this hypothesis.

PROCEDURE

SUBJECTS

Two groups of subjects participated in this study. The first group (Group I) consisted of ten persons, 20 to 54 years of age, most of whom had had some previous experience observing phenomena associated with unusual vestibular stimulation. Group II consisted of six naval officers awaiting assignment into flight training. None had had extensive flight experience or previous experience in laboratory studies of this nature.

APPARATUS

A rotation device was used in which subjects were seated at the center of rotation with heads positioned to place the horizontal semicircular canals in the plane of rotation. On the rotation device was a frame ordinarily used to support an encapsulating cover for the rotation device, but in the present experiment the cover was removed so that there was an unobstructed view of Earth-fixed surrounds, except for thin vertical struts supporting the top of the rotation device. Surrounding the rotation device was a concentric, 28-sided, equilateral polygon, formed by 28 vertical boards, each 28.6 cm wide (12.86° visual angle), comprising an Earth-fixed surround of black and white stripes. Luminance levels of the white and black stripes were 0.075 fL and 0.0074 fL, respectively. Distance of the center of each board from the center of rotation was about 127 cm.

METHOD

Group I was tested according to the schedule depicted in Figure 1. The rotary structure was accelerated at 0.26 rad/sec^2 to a constant velocity of 1 rad/sec in an anticlockwise direction. Subjects viewed the Earth-fixed stripes during angular acceleration and for 60 seconds of constant velocity. At this time, they closed their eyes and then executed a 30-degree right lateral head tilt, so as to complete the head tilt within about 2 seconds after closing their eyes. When the head movement was completed, they were asked to describe sensations and any disturbance induced by the head movement. Following this, they were instructed to keep their eyes closed and to return their heads to upright position very gradually so as to avoid disturbance. An occipital headrest served to insure that upright forward gaze position was in fact attained. When this was accomplished, rotation was sustained for an additional 60 seconds at 1 rad/sec, and then with eyes still closed, subjects executed a second 30-degree right lateral head tilt. As before, subjects described their sensations and any disturbance, but this time they also compared the effects of the first and second head movements. Rotation was terminated after reports had been recorded.

Group II was also tested according to Schedule 1 (Figure 1), but in addition, they were tested according to Schedule 2 (Figure 1) after an intervening rest interval of about 1 hour. The procedure for Schedule 2 was very similar to that of Schedule 1 except that the eyes remained closed throughout the initial acceleration, for 60 seconds of constant velocity at 1 rad/sec, and additionally, until the first 30-degree right head tilt had been completed and its effects reported. After this, the eyes were opened, the head was gradually returned to upright, and then whole-body rotation continued for 60 seconds with subject observing the Earth-fixed surrounds. Just before the second 30-degree right head tilt was executed in Schedule 2, the eyes were again closed. Thus, in both Schedules 1 and 2, all 30-degree right head tilts were executed a) with eyes closed, b) with the rotation device rotating at constant velocity of 1 rad/sec, and c) after the device had been at constant velocity for at least 60 seconds.

RESULTS

Results of the study are presented in Tables I and II. Results of Group I and II subjects from the Schedule 1 procedure (Table I) illustrate that the second head movement (HM2) was more disturbing and produced greater tumbling effects than did the first head movement (HM1). In thirteen of sixteen subjects, greater effects were reported when the head movement was executed after the eyes had been closed for 60 seconds. In Schedule 1, two subjects who reported HM1 > HM2 had waited several seconds between closing the eyes and executing the head movement, and one of these (II-5) had made a substantial forward head tilt before making his lateral tilt. The third deviant subject, II-6, was not deviant in regard to disturbance, but reported slightly greater motion experience with HM1 than with HM2. This subject reported that he had been actively tracking stripes; upon questioning, Subject I-10 reported having done the same.

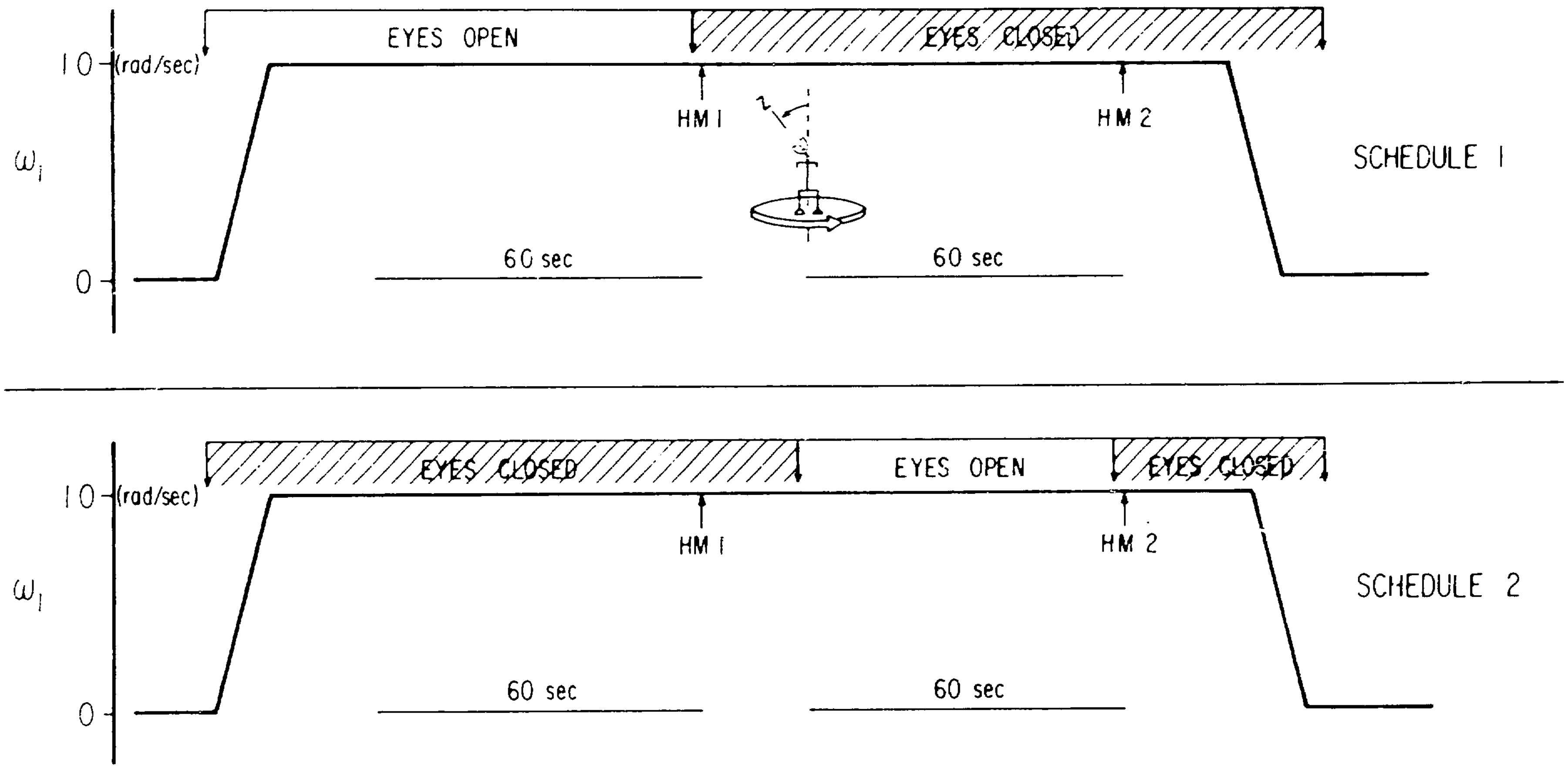

Figure 1

Timing of each head movement (HM) relative to profile of vehicular angular velocity (ω_1) and periods of optokinetic stimulation in Schedules 1 and 2. Optokinetic stimulation occurred when the eyes were open while the vehicle was rotating. Inset figure in Schedule 1 illustrates the 30-degree right head tilts that were always made with eyes closed.

Table I

Results from Schedule 1

Group	Subject	Comparison	Comments on 1st HM	Comments on 2d HM
	1	2 > 1	no effect	disturbance and tumble
	2	2 > 1	no effect	disturbance and tumble
	3	2 > 1	slight tumble no disturbance	tumble and disturbance
	4	2 > 1	slight dizziness	disturbance
I	5	2 > 1	no effect	tumble/no disturbance
	6	2 > 1	slight tumble	tumble/disturbance
	7	2 > 1	no effect	tumble/dizzy
	8	2 > 1	slight tumble	tumble/disturbance
	9	2 > 1	no effect	tumble/no disturbance
	10	1 > 2	delayed disturbance	little effect
	1	2 > 1	slight forward tumble disturbance	tumble/disturbance
	2	2 > 1	slight effect	tumble
II	3	2 > 1	little effect	effect slightly greater than 1
	4	2 > 1	no effect	slight tumble
	5	1 > 2	tumble/no disturbance	confused sensation
	6	2 > 1 (disturbance) 1 > 2 (perceived motion)	slight backward fall	slight forward fall/ queasy

Table II

Results from Schedule 2

Subject	Comparison	Comments on 1st HM	Comments on 2d HM
1	1 > 2	tumble	no effect
2	1 > 2	tumble/falling	no effect
3	1 > 2	tumble/falling	less tumble (neither disturbing)
4	1 > 2	falling/confusing	no effect
5	1 > 2	forward tumble	much less than 1
6	1 > 2	forward tumble	slight dizziness

In Schedule 2, subjects were specifically instructed to maintain forward gaze and to avoid tracking individual stripes. Results of Schedule 2 are presented in Table II where it is apparent that HM1 consistently produced greater effects than HM2. Since, in Schedule 2, HM1 was executed after the eyes had been closed for more than 60 seconds, the results from Schedule 2 are in agreement with those from Schedule 1; i.e., when a head movement generating vestibular Coriolis cross-coupled stimulation was executed immediately after a strong optokinetic stimulus, the disturbance and disorientation experience was either absent or substantially less than that experienced when the same vestibular stimulus was delivered following a period in darkness. When head movements generating vestibular Coriolis cross-coupled stimulation were executed immediately after optokinetic stimulation, there were nine reports of no effect, i.e., no disturbance or tumbling sensation of any kind, whereas head movements executed after a period of darkness always yielded reports of tumbling or disturbance, or both. Of the 22 comparisons represented in Tables I and II, 19 indicated lesser effect when the cross-coupled stimulus occurred immediately after the optokinetic stimulation.

DISCUSSION

Following prolonged (e.g., 60 seconds) constant speed rotation in an anticlockwise direction, if the head is tilted laterally toward the right shoulder, there is a sensation of forward tumble or diving toward the Earth. This experience can be very disturbing, especially if the eyes are closed or if the observer is encapsulated in a rotating chamber. The Coriolis cross-coupled stimulus that generates this experience is illustrated in Figure 2. The ω_1 vector at the top of Figure 2 represents the direction and magnitude of whole-body rotation; the shaft of the ω_1 vector should be conceptualized as being aligned with gravity and also with the axis of the rotation device. The smaller set of arrows depicted in the head illustrates the Coriolis cross-coupled stimulus to horizontal and vertical semicircular canals, and the resultant of these vectors, the heavy vector with the curved arrow around it, shows that the individual would experience forward tumble. Assuming that the rotation rate (ω_1) is 1 rad/sec or about 10 rpm, the head tilt would induce an instantaneous sensation of 0.52 rad/sec (~ 5.2 rpm) forward tumble. This stimulus is disturbing for several reasons: 1) A sensation occurs that is unexpected; i.e., a lateral head tilt is executed but a forward tumble is experienced. 2) The semicircular canals indicate forward tumble while the otolith organs indicate incompatible lateral tilt. 3) Forward tumble or diving toward the Earth when it really occurs requires a quick emergency reaction. Each of these points is a different way of describing an input that constitutes a threat to control of motion which, in turn, ultimately represents a threat to survival. Thus, disturbance by this form of stimulation is understandable from a functional point of view. However, exactly the same Coriolis cross-coupled stimulus can be induced without disturbance (cf. Ref. 7). A head movement made during or very shortly after the angular acceleration that commences rotation is not disturbing for reasons illustrated in Figure 3. The angular acceleration before the head movement produces a cupula deflection in the horizontal canals such that the true rotation velocity (ω_1) is experienced. When the head is tilted, a Coriolis cross-coupled stimulus to the vertical and horizontal semicircular canals identical to that illustrated in Figure 2 occurs, but when resolved vectorially with the cumulative effects

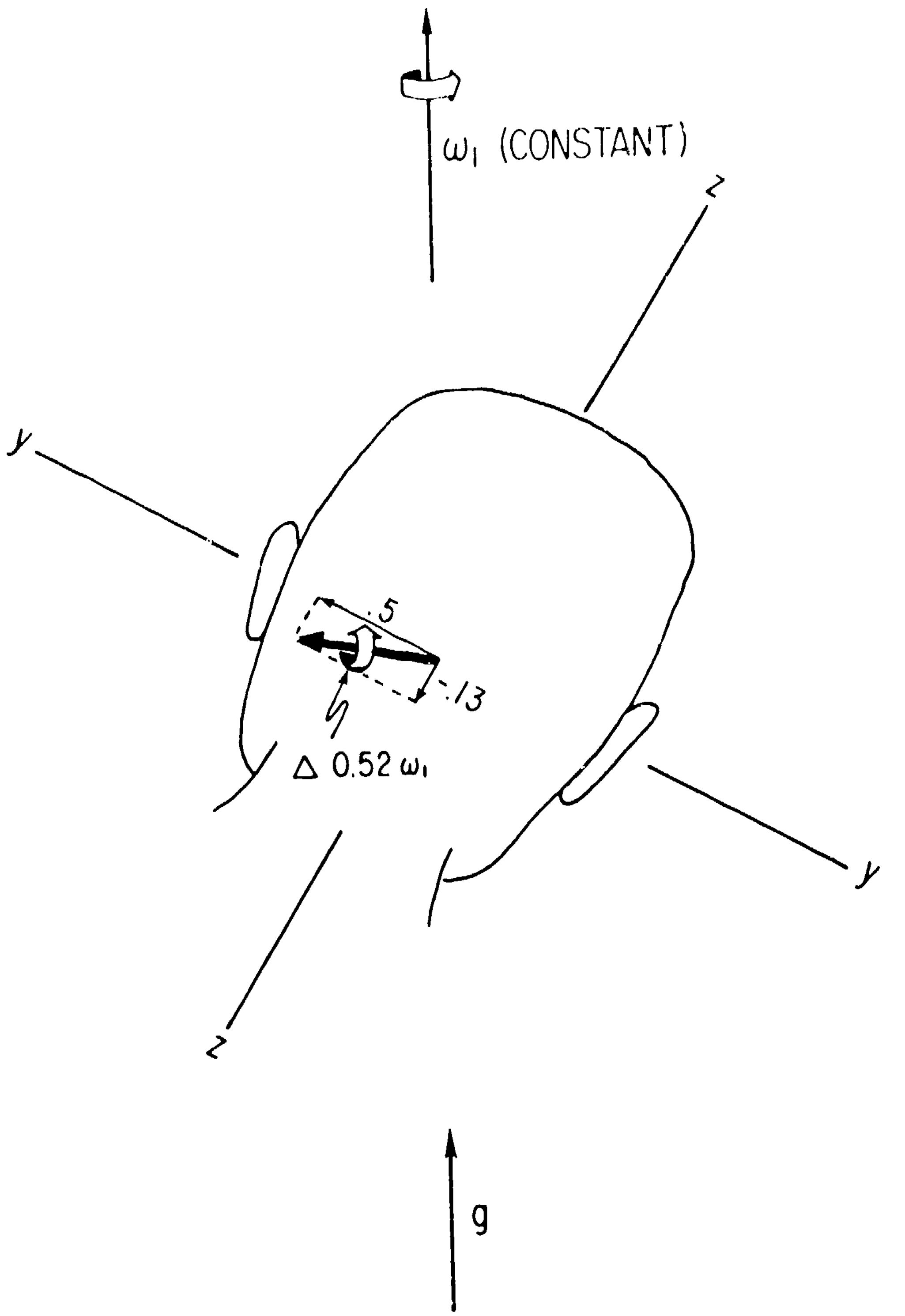

Figure 2

Angular impulse vectors applied to the y- and z-axes from Coriolis cross-coupling effects produced by 30-degree right head tilt during whole-body rotation at 1 rad/sec yield a resultant angular impulse from cross-coupling effects as shown by the heavy vector with the curved arrow around it. This stimulus amounts to a fast angular velocity change from zero to 0.52 rad/sec that is experienced predominantly as forward tumble.

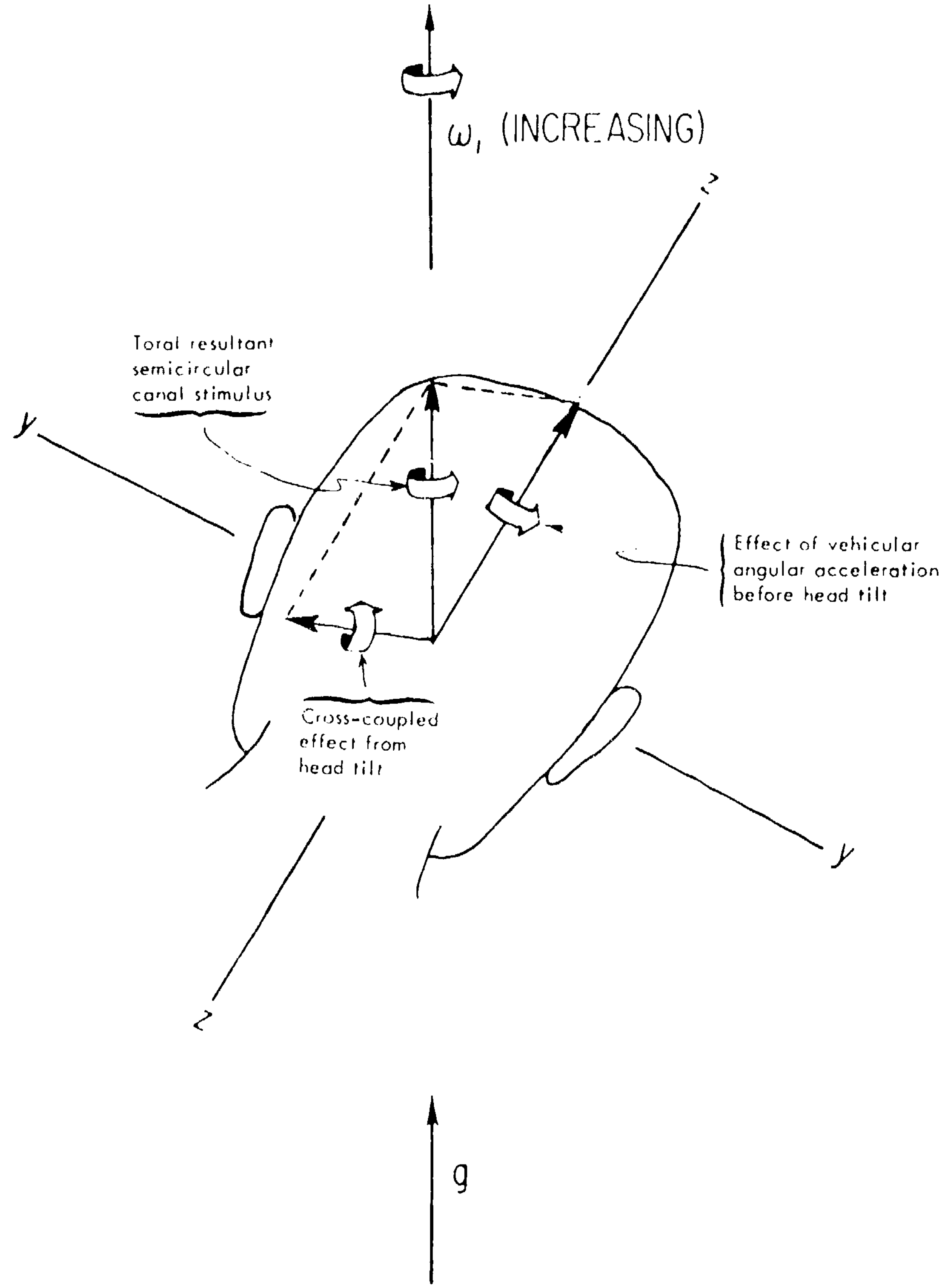

Figure 3

Illustrating the resultant angular impulse to the semicircular canals at completion of a fast head movement during vehicular angular acceleration made when $\dot{\omega}$ = 1 rad/sec. The total resultant vector, considering both Coriolis cross-coupling effects and cumulative effects of vehicular angular acceleration, is located relative to skull by inputs to the VN from all six semicircular canals such that it remains aligned with the axis of the rotation device which, in turn, is aligned with gravity (Guedry & Benson, 1976).

of the vehicular angular acceleration on the horizontal semicircular canals, the resultant input vector remains exactly aligned with gravity and the axis of rotation, and its magnitude matches perfectly the velocity change that has actually occurred. The resultant semicircular canal input to the vestibular nuclei indicates rotation about an axis that is aligned with gravity and therefore with the gravity vector as located by the otolith system; for these reasons, there is no disorientation or nauseogenic disturbance with this particular condition (cf. Ref. 7).

The observations that constituted the present experiment were based upon the hypothesis that large-field optokinetic stimulation in a particular plane simulates vestibular nuclei activity that would be produced by semicircular canal stimulation in the same plane. It is further presumed that this effect persists for some time (yet to be determined) after the optokinetic stimulus has been terminated by closing the eyes. The hypothesized effect is illustrated in Figure 4. Because the head was upright just before the head movement, the Earth-fixed vertical stripes swept past the eyes in a direction to generate an optokinetic nystagmus about the z-axis. Then the eyes were closed and shortly thereafter, the head movement was made. In Figure 4, the persistence of modulation of the vestibular nuclei (VN) by the optokinetic influence is represented by the dashed arrow on the z-axis, hypothesized to interact with the VN effects of Coriolis cross-coupled stimulation of the semicircular canals to yield a final VN output that is essentially like that represented in Figure 3, i.e., veridical, synergistic, and not disturbing.

Evidence indicates that the presence of optokinetic afternystagmus is dependent upon the patency of spontaneous vestibular inflow to the vestibular nuclei (3). Other evidence has established that VN activity is modulated by large-field optokinetic stimulation (9) although available data are insufficient to establish patterns of activity in the VN. The present results suggest that large-field optokinetic stimulation that generates nystagmus in the horizontal head plane actually matches the particular pattern of modulation of VN activity that would be produced by stimulation of the horizontal semicircular canals. However, the exclusive reference to VN in this paper is for simplicity of expression and not intended to exclude important vestibulocerebellar (and other CNS) interactions which are known to influence oculomotor activity (10,12, 16) and also to play a role in motion sickness (13,14). Both the cerebellum and the vestibular nuclei receive direct neural pathways from the vestibular endorgans; groupings of cells in both appear to respond to specific ampullar nerves (17), and there is a two-way interaction between the VN and the cerebellum. The vestibulocerebellum projects back onto cells in the vestibular nuclei and regulates their activity through the discharge of cerebellar Purkinje cells. The activity of some Purkinje cells appears to depend upon the synergistic nature of visual and vestibular inputs. Some Purkinje cells in the flocculus fire selectively when targets are moved relative to a stationary head or when the targets are oscillated in unison relative to the Earth, but the firing rate is relatively unaffected when the visual-vestibular inputs would drive the eye in the same direction, e.g., when the head oscillates relative to an Earth-fixed visual target (10,12). Considering these various results (3,7,9-12), it seems plausible that the ameliorative influence of the optokinetic aftereffect on the Coriolis cross-coupled

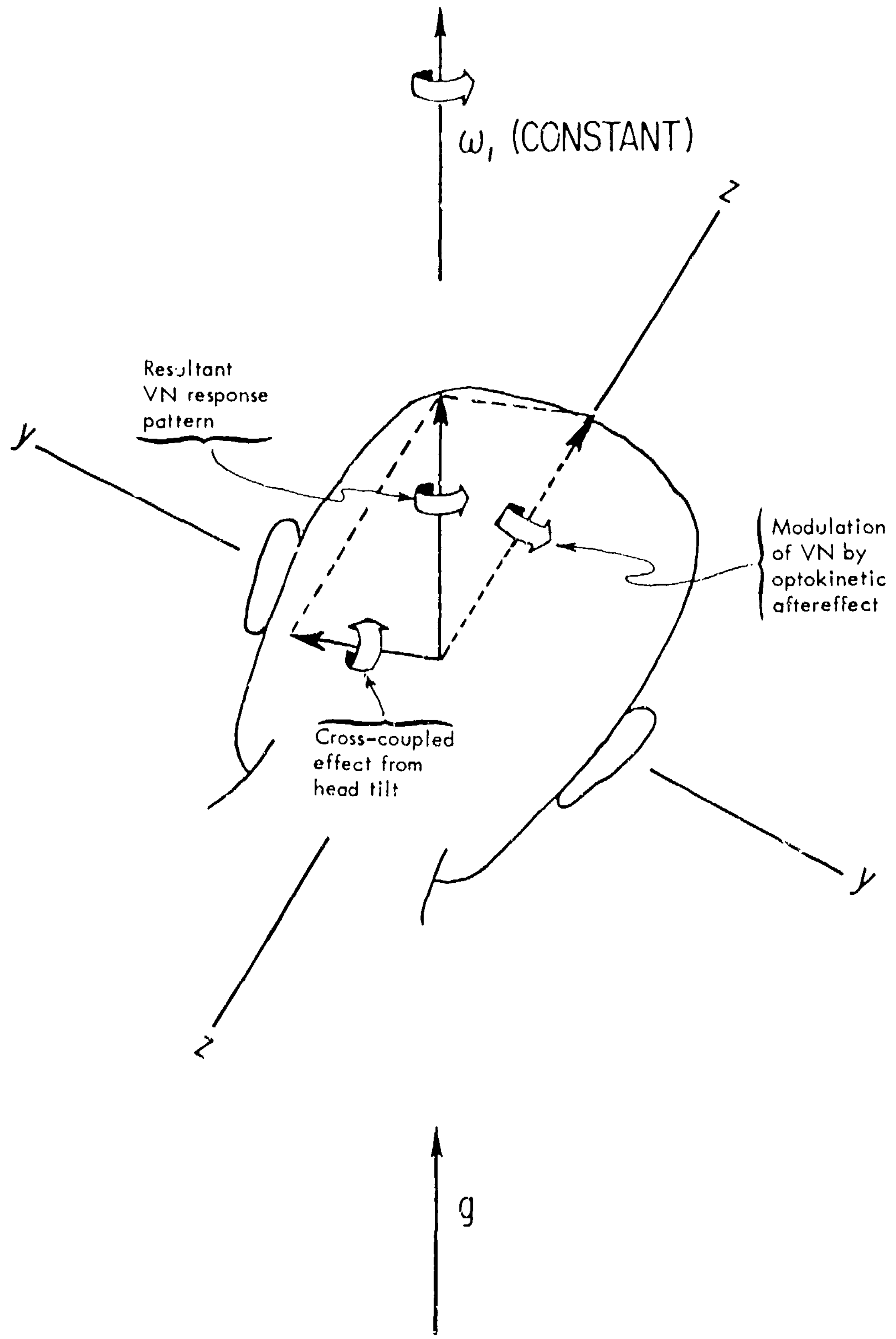

Figure 4

Hypothetical resultant VN response pattern from 30-degree right head tilt made with eyes closed during vehicular rotation at constant angular velocity (ω_1) of 1 rad/sec, but immediately after 60 seconds of optokinetic stimulation. Z-axis vector represents hypothetical modulation of VN activity by optokinetic aftereffects as though horizontal (lateral) semicircular canals had been stimulated. Resultant vector is aligned with gravity and with the axis of vehicle rotation.

semicircular canal input was attributable to the particular pattern of ongoing VN activity when the Coriolis cross-coupled stimulus was delivered.

In the present experiment, the initial angular acceleration was followed by prolonged constant angular velocity before any head movement was made to introduce a Coriolis cross-coupled stimulus. The primary semicircular canal response, cupula deflection, to the semicircular canal stimulus generated by the initial acceleration would terminate within about 45 seconds. Thus, residual input to the vestibular nuclei from semicircular canal stimulation by the initial vehicular acceleration was probably negligible by the time that either the first or second head movement was made in either Schedule 1 or Schedule 2. Except for the optokinetic aftereffects, the response to all head movements in the present experiment should have been about as represented in Figure 2. However, such responses were encountered only when there was no preceding optokinetic stimulus, HM2 in Schedule 1, and HM1 in Schedule 2.

The results inferentially support the hypothesis that led to the present experiment. There were a few deviant responses, and one or more of the following factors seems to have been involved in each of these: 1) There was a delay between closing the eyes and moving the head; 2) the subject was actively following the optokinetic stripes; or 3) the subject reported weak effects in both conditions (with and without preceding optokinetic stimulation). In connection with the third point, some individuals experience only a very mild tumble sensation and no disturbance with the magnitude of the vestibular cross-coupled stimulus used in this study. For such individuals, an ameliorating influence, whatever the source, is difficult to discern.

The present observations are insufficient to establish whether or not individual decisions to voluntarily follow the optokinetic stripes were a significant factor in influencing results. However, this may be important. It has been indicated (5, p. 226) that stationary subjects, surrounded by a rotating striped cylinder, consistently experience whole-body rotation or circular-vection (cf. Refs. 1,2) only when they observe a head-fixed marker that would partially suppress optokinetic nystagmus but maximize retinal slippage or smear. It is possible, then, that this condition maximizes optokinetic modulation of activity in the vestibular nuclei. This may account for the consistency of the ameliorative optokinetic aftereffect in Table II; in Schedule 2, subjects were specifically instructed to maintain forward gaze and to avoid purposely following the stripes.

The results of the present experiment suggest once again that predictability of disorientation and nauseogenic disturbance are reasonably well handled by current theory when the conditions of motion are fairly well specified. They also reaffirm the point that understanding of motion conditions that produce either disorientation or nauseogenic disturbance requires evaluation of immediate and sequential combinations of stimuli to several sensory-motor systems involved in the control of motion. These kinds of observations place in perspective those occasional scientific ventures that seek to discover that single, exclusive, noxious, motion receptor or that single, provocative, stimulus frequency band that induces motion sickness. Such ventures have contributed empirical data that will share with observations like the present ones in developing a comprehensive model for predicting disorientation and nauseogenic disturbance induced by various conditions of motion. This study and a preceding study (7) have illustrated that the renowned nauseogenic qualities of a Coriolis cross-coupled vestibular stimulus can be dispelled by the introduction of other stimuli that alter patterns of activity in the vestibular nuclei. In the preceding study, it appeared that an intralabyrinthine vestibular nuclei conflict was manipulated by addition of a vestibular stimulus to dispel the nauseogenic disturbance, whereas in the present study the vestibular nuclei conflict was apparently manipulated by introduction of a dynamic visual input to obtain the same end. It is known that vestibular stimulation not only alters spinal-motor activity, but that ascending spinal messages alter activity in the vestibular nuclei and the vestibular-cerebellum. Recent results indicate that disorientation and vestibulo-ocular reflexes from some vestibular stimuli can be modulated by spino-vestibular feedback (8), and it may be that the nauseogenic potential of vestibular stimuli is subject to similar manipulation (cf. Ref. 6), a possibility to be investigated in future studies.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

It has been indicated that the nauseogenic and disorienting effects of several kinds of provocative motion stimuli can be ameliorated by visual reference to the Earth. The purpose of the present experiment is to investigate a hypothesis concerning the mechanism of this beneficial effect.

The results demonstrate that the aftereffects of large-field optokinetic stimulation can nullify the nauseogenic and disorienting effects of Coriolis cross-coupled vestibular stimuli.

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20. Abstract (cont.)

It is hypothesized that large-field optokinetic stimulation in a particular head plane modifies activity in the vestibular nuclei as though the semicircular canals in that plane had been stimulated. A previous study illustrated that such semicircular canal stimulation would completely nullify the disturbing and disorienting effects of Coriolis cross-coupled stimulation according to theoretical expectations. The results provide inferential support for the hypothesis and suggest that predictability of disorientation and nauseogenic disturbance are reasonably well handled by current theory when the conditions of motion are fairly well specified.

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VISUAL COUNTERACTION OF NAUSEOGENIC AND DISORIENTING EFFECTS OF SOME WHOLE-BODY MOTIONS - - A PROPOSED MECHANISM. NAMRL-1232. Pensacola, FL: Naval Aerospace Medical Research Laboratory, 16 February.

It has been indicated that the nauseogenic and disorienting effects of several kinds of provocative motion stimuli can be ameliorated by visual reference to the Earth. The purpose of the present experiment is to investigate a hypothesis concerning the mechanism of this beneficial effect.

The results demonstrate that the aftereffects of large-field optokinetic stimulation can nullify the nauseogenic and disorienting effects of Coriolis cross-coupled vestibular stimuli. It is hypothesized that large-field optokinetic stimulation in a particular head plane modifies activity in the vestibular nuclei as though the semicircular canals in that plane had been stimulated. A previous study illustrated that such semicircular canal stimulation would completely nullify the disturbing and disorienting effects of Coriolis cross-coupled stimulation according to theoretical expectations. The results provide inferential support for the hypothesis and suggest that predictability of disorientation and nauseogenic disturbance are reasonably well handled by current theory when the conditions of motion are fairly well specified.

Optokinetic stimulation

Vestibular stimulation

Motion sickness

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