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VISUAL-VESTIBULAR INTERACTIONS: II. THE DIRECTIONAL COMPONENT OF VISUAL BACKGROUND MOVEMENT

Fred E. Guedry, Jr., J. Michael Lentz, Ralph M. Jell, and Joel W. Norman

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COMPONENT OF VISUAL BACKGROUND MOVEMENT

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SUMMARY PAGE

THE PROBLEM

Legibility of displays moving with the head and body can be degraded by the vestibulo-ocular reflex (VOR). The purpose of the present study is to examine characteristics of motion in the peripheral visual field that interact with vestibular stimuli and alter the visibility of head-fixed displays.

FINDINGS

The main experiment employed three different velocities (relative to the head) of background movement (peripheral visual stimuli); they were +18 deg/sec, 0 deg/sec, and -18 deg/sec at the end of prolonged deceleratory vestibular stimuli. Control experiments indicated that a small part of differences in visual suppression of vestibular nystagmus previously attributed to differences in background motion during angular accelerations and angular decelerations may have been attributable either to secondary nystagmus or to some as yet unaccounted for difference in response to acceleratory and deceleratory stimuli. However, considered together, the results of the main study and of the control studies clearly support the conclusion previously reached that visual suppression of the VOR and visual performance are inferior when peripheral optokinetic stimuli and vestibular stimuli are discordant (i.e., presented separately, these stimuli would produce nystagmus of opposite directions) and superior when they are concordant. Following prolonged acceleratory vestibular stimuli in our studies, the velocity of background movement relative to the head was 180 deg/sec. Thus, our observations encompass a range of background velocities from -18 deg/sec to 180 deg/sec. The results indicate that peripheral optokinetic stimuli are effective in interacting with vestibular stimuli over a range of velocities far exceeding the range that is effective in inducing maximal optokinetic nystagmus in man. This finding suggests a functional role for peripheral retinal smear in visual function in addition to the generation of optokinetic nystagmus and circularvection effects.

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INTRODUCTION

Visual suppression of the vestibulo-ocular reflex (VOR) is particularly important when an individual views head-fixed visual targets during whole-body motion. Relatively unexplored are visual-vestibular interactions in which there is prominent background movement relative to a head-fixed target during vestibular stimulation, and this is an area of potential relevance to control of modern high-performance aircraft especially when helmet-mounted (head-up) instrument displays are used.

In a previous study (5), we reported that visual performance and nystagmus suppression were superior when relative background movement was concordant with the vestibular stimulus and substantially poorer when optokinetic and vestibular inputs were discordant. This was accomplished by rotating the subject whose task required fixation of a head-fixed display on a turntable, while an external (Earth-fixed) surround was visible. During acceleration, Earth-fixed peripheral visual stimuli constitute an optokinetic drive that would be concordant with (i.e., directionally the same as) vestibular nystagmus, a condition that had been shown (2,10) to augment vestibular nystagmus; yet under our circumstance, in which subjects sought to view a head-fixed display, vestibular nystagmus was visually suppressed very effectively. During deceleration, however, vestibular nystagmus is of opposite direction to the optokinetic drive by the relative movement of the Earth-fixed surround, and under this circumstance, a number of subjects were unable to suppress vestibular nystagmus by voluntary effort to view the head-fixed display. The present experiment further explores these visual-vestibular interactions. By commencing deceleration from different offset angular velocities, essentially equivalent deceleratory vestibular stimuli can be generated with different rates and directions of Earth-fixed background movement. This study seeks to determine whether or not low rates of background movement, +18 deg/sec, 0 deg/sec, -18 deg/sec, would differentially affect visual suppression of a strong vestibular stimulus induced by an 180 deg/sec velocity change. Thus, the question is whether or not a strong vestibular stimulus is differentially suppressed by voluntary visual fixation of a head-fixed target when it is viewed against different background movements, none of which matches the vestibular input, but one of which is directionally concordant with it. A planned feature of particular importance in this experiment was that the differences in peripheral background movement would be introduced when the vestibular nystagmus was of about the same magnitude for each of three conditions of background movement.

PROCEDURE

SUBJECTS

Twelve naval aviation officer candidates volunteered to serve as subjects. All had recently passed a flight physical examination and were in good health (none required corrective lenses). All subjects indicated that they were free of drugs or medication for the 24 hours preceding the testing.

APPARATUS AND METHOD

Electronystagmography was used to record eye movements. Electrodes were affixed in the standard position for recording horizontal eye position and were allowed to stabilize for 30 min before recording commenced.

The subject was seated erectly on a Stille-Werner RS-3 rotation device with an open circular frame superstructure. Within the device a visual acuity chart (Figure 1) was fixed at a distance of 68 cm directly in front of the seated subject approximately at eye level and was transilluminated. The light emitted by the continually transilluminated display was maintained at a low level to reduce light reflected onto the Earth-fixed peripheral surround and also to reduce contrast level within the display to facilitate visual blurring during vestibular nystagmus. To further reduce the dispersion of light onto the external surround, flat black baffles (9 cm x 9.5 cm) were mounted on the left and right sides of the acuity chart and extended perpendicularly from the chart approximately 9.0 cm (Figure 2). The chart consisted of six numbered rows of black stripes which had a target brightness of 0.074 fL/white space and 0.009 fL/black stripe. Within a row each black stripe and each white space between stripes subtended a specific visual angle: row 1 = 5 min, row 2 = 6 min, row 3 = 8 min, row 4 = 10 min, row 5 = 14 min, row 6 = 21 min. The six rows of black and white stripes were centered in a white rectangle, 7.5 cm x 10 cm, which itself was centered in a black square, 38 cm x 38 cm (25 deg x 25 deg). The entire rotating device was surrounded by vertical Earth-fixed black and white boards (the optokinetic surround), each subtending a horizontal visual angle of 12.86 deg. At selected times the Earth-fixed optokinetic surround was illuminated by two sets of lights which provided a brightness of 0.0074 fL/black board and 0.075 fL/white board.

S's task was to report changes in visual acuity by calling out the number which corresponded to the lowest numbered row on the transilluminated display that was clearly visible. Clearly visible was defined as being of the same visual clarity as that of the lowest visible row before rotation commenced. If S detected any blurring in this row, he was to advance to larger numbered rows until one restored initial visibility. In a few cases blurring occurred so rapidly that S found it necessary to skip several rows in order to recover acuity. When row 6, the uppermost row, blurred, a report of "7" was used and an arbitrary acuity score of 30 min was assigned. As vestibular input subsided and vision cleared, Ss then signaled lower numbered rows. This procedure yielded a curve (or step function) representing the visual angle required to sustain clear vision, commencing at the onset of the vestibular nystagmus.

In addition to this method of assessing vision, magnitude estimates of blurring associated with the acceleration and magnitude estimates associated with the deceleration were obtained after each period of rotation. These retrospective magnitude estimates were obtained without benefit of practice. S was simply told that 1 would represent no blurring and 10 would represent maximal blurring, and to use numbers within this range to rate the magnitude of blurring experienced.

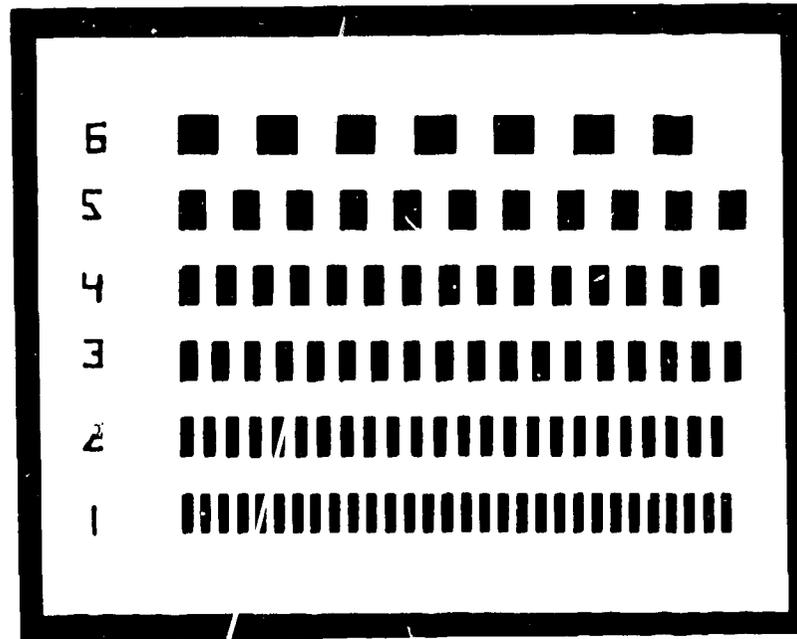


Figure 1

Head-fixed visual acuity chart. The narrow black border as shown here represents a much broader black background that surrounds the acuity chart. See text for dimensions.

Figure 3 is a representation of the three rotational sequences to which each S was exposed. The sequence test order was counterbalanced with the qualifier that any given S always started each A, B, and C sequence in the same direction (half of the S s started counterclockwise). Throughout each sequence, S viewed the transilluminated 'visual acuity chart.' In each sequence S signaled acuity during each 180 deg/sec velocity change and for 30 sec after each change (or until acuity for row 1 was regained after the velocity change).

At selected points in each sequence, the Earth-fixed optokinetic surround was illuminated. The initial acceleration in Sequences A, B, and C was 15 deg/sec² applied for 12 sec to accomplish a velocity change from 0 to 180 deg/sec. As soon as a constant velocity of 180 deg/sec was reached, illumination by the surround lights (see Figure 2) was commenced and sustained for 30 sec. Surround lights were then extinguished until the end of the prolonged deceleratory velocity change.

In Sequence A the prolonged deceleration, during and after which acuity was assessed, was from 180 deg/sec to 0 deg/sec. Therefore, when the optokinetic surround was illuminated, it was stationary relative to S , and only the eye movement from vestibular nystagmus generated an optokinetic-

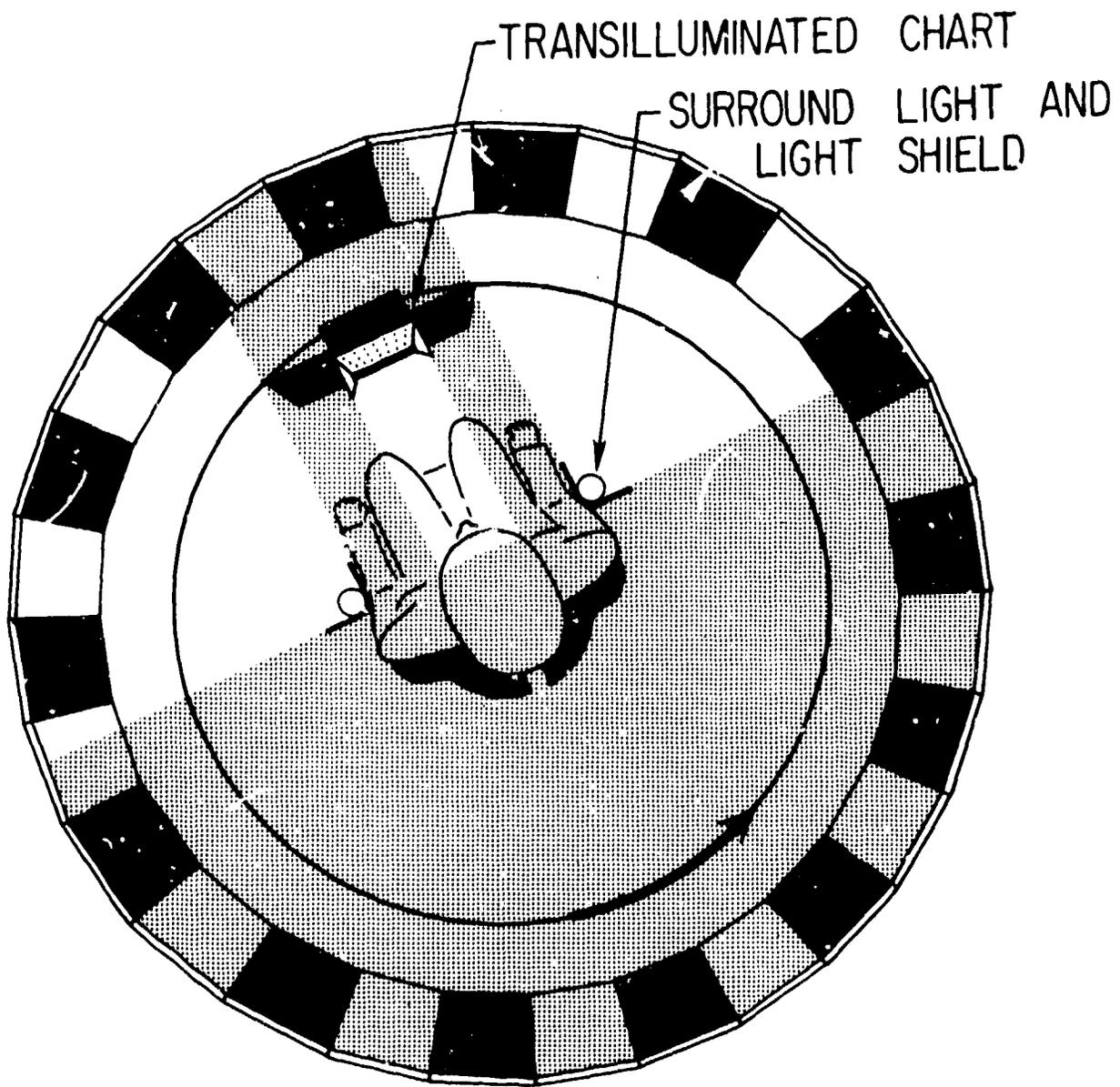


Figure 2

Illustration of rotating structure, head-fixed target, and peripheral view of Earth-fixed stripes.

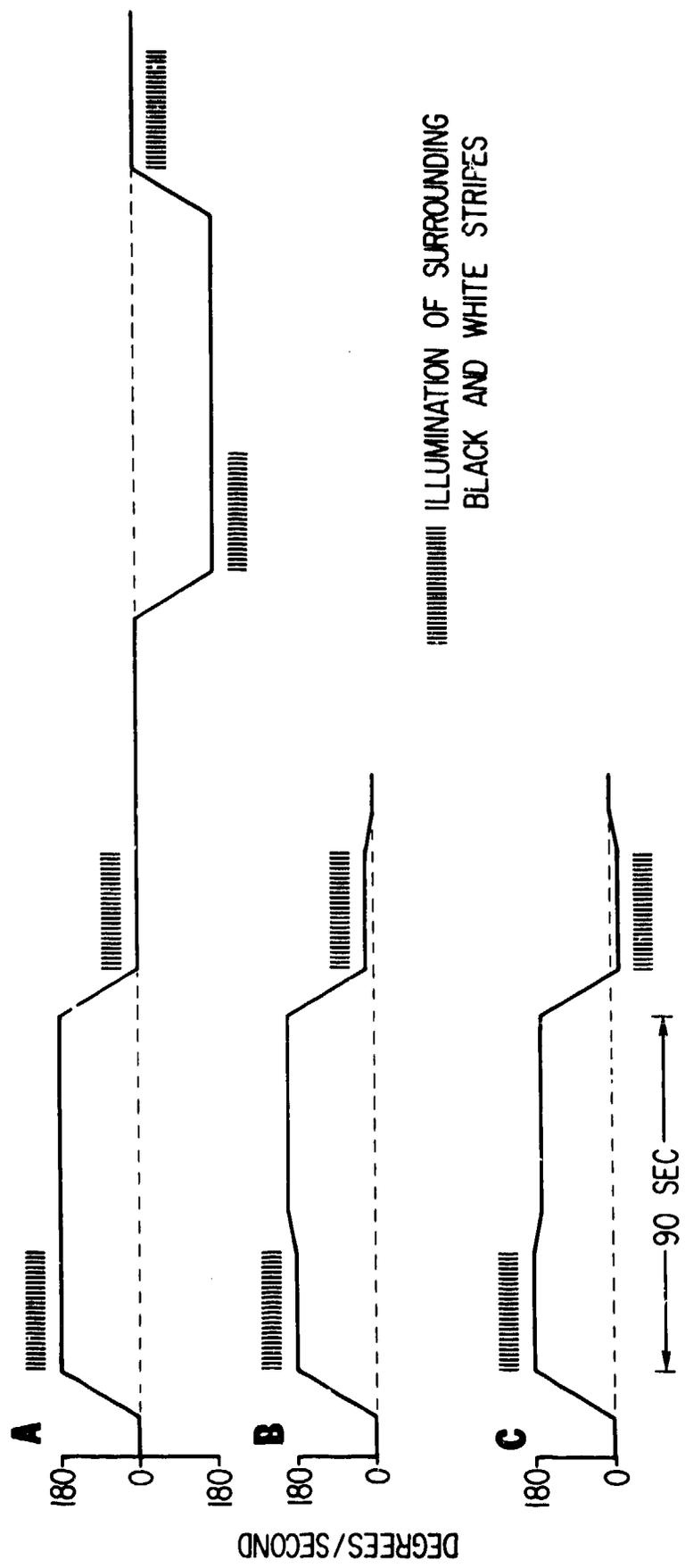


Figure 3
Angular velocity profiles in Sequences A, B, and C

like stimulus to the peripheral retina. In Sequence B an 18 deg/sec increment in velocity was introduced 60 sec prior to deceleration. Therefore, in this sequence the prolonged deceleration, during and after which acuity was assessed, was from 198 deg/sec to 18 deg/sec, yielding an 18 deg/sec peripheral optokinetic stimulus from the relative motion of the illuminated surround that was directionally opposite the vestibular response from this stimulus. In Sequence C an 18 deg/sec mid-course velocity decrement allowed the subsequent prolonged deceleration (180 deg/sec velocity change) to start at 162 deg/sec in one direction and to terminate at 18 deg/sec in the opposite rotation direction. Therefore, at the end of this prolonged velocity change, illumination of the surround induced peripheral optokinetic stimulation that was directionally concordant with the vestibular stimulus from the 180 deg/sec velocity change. Thus, in each sequence an equivalent semicircular canal stimulus was delivered by the deceleratory 180 deg/sec velocity change (15 deg/sec^2 for 12 sec), but because of the different initial velocities when the deceleration commenced, there were different terminal velocities (+18 deg/sec, 0, -18 deg/sec) when the surround was illuminated and therefore, different degrees of concordance/discordance of the visual and vestibular inputs.

RESULTS

Sequence A, which involved both directions of rotation for each S, was employed for two reasons: 1) to duplicate part of a motion profile used in our previous study (5) to determine whether or not visual performance and nystagmus measures would yield patterns of results similar to those of the previous study which employed a different visual display and a different time of introduction of the background illumination; and 2) to detect individuals who might have pronounced directional differences in vestibular responses. The results in Sequence A were remarkably similar to the results of the Sequence A counterpart of the previous study. Visual acuity loss and visually suppressed vestibular nystagmus during deceleration were markedly greater than during acceleration. No exceptional directional differences were observed in any S, and no S was eliminated for this reason.

The crucial comparison in the present study pertains to the effects of differences in background movement on visual acuity and vestibular nystagmus, differences which were introduced just after the prolonged decelerations in Sequences A, B, and C. Figures 4 and 5 present, respectively, plots of visually suppressed vestibular nystagmus and of visual acuity loss during and after the prolonged deceleration in Sequences A, B, and C. During the prolonged deceleration in each sequence, only the central display was visible, and the velocity change was equal (magnitude and direction) in the three sequences. Therefore, it was expected that responses during deceleration (before the optokinetic surround was introduced) would be roughly equal. To test this expectation, a 5-sec interval (7 sec - 11 sec) was selected for response summation to yield measures to compare Sequence A, B, and C responses just before the differential background movement was introduced. Within this interval for each sequence, nystagmus slow phase displacement of each S was summed to obtain a measure characterizing S's VOR within the interval. A similar sum of the visual angle required to sustain clear vision was obtained for each subject during the interval. Slight differences in responses among Sequences A, B, and C during this 5-sec interval

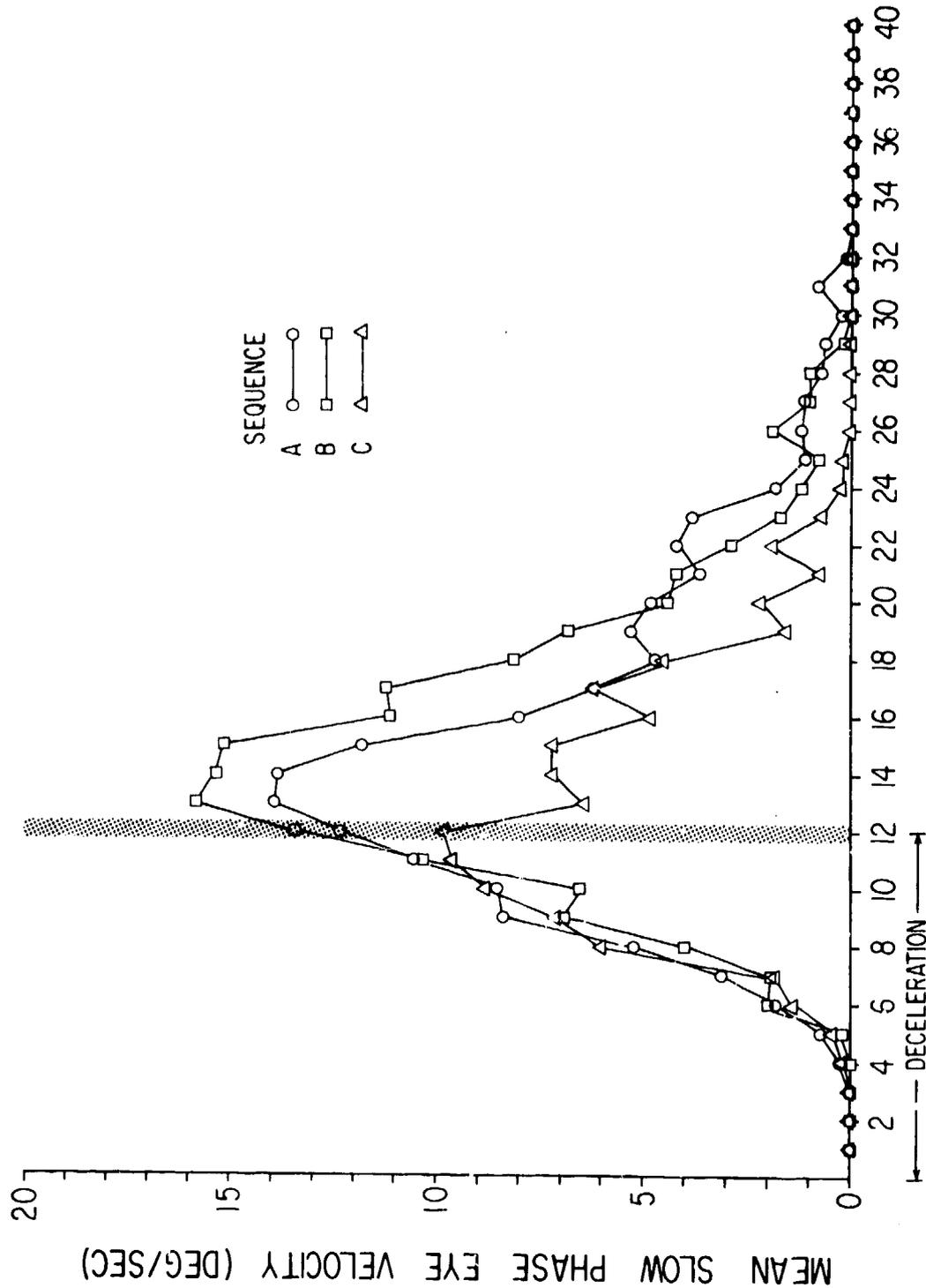


Figure 4

Visually suppressed vestibular nystagmus during and after prolonged decelerations in Sequences A, B, and C. Surround lights were on from 12 through 40 sec.

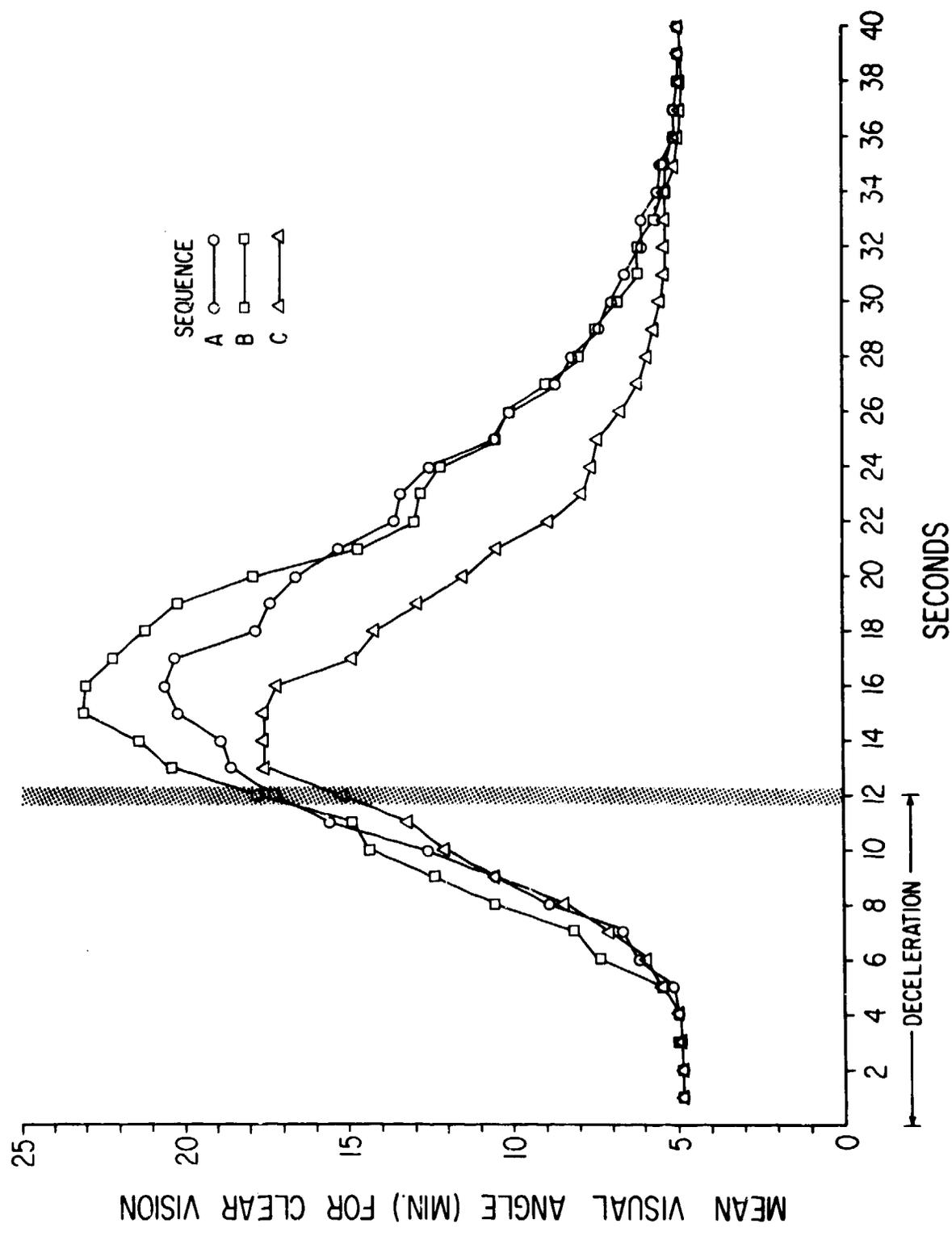


Figure 5

Visual acuity loss during and after prolonged decelerations in Sequences A, B, and C. Surround lights were on from 12 through 40 sec. Baseline of approximately 5 min visual angle was set by Line 1 (see Figure 1).

(7 sec - 11 sec) were not statistically significant for either slow phase eye velocity ($F = 0.39$, N.S.) or visual acuity loss ($F = 0.83$, N.S.). Thus, prior to the introduction of the surround lights, visually suppressed vestibular nystagmus and visual acuity were essentially equal. Background illumination was switched on manually at 12 sec. Allowing for human error in timing, the onset of background illumination is probably best represented by an interval $\bar{t} = 12 \pm 0.2$ sec; therefore, responses at 12 sec were omitted, and the interval selected for summation and statistical comparison during differential background movement was the 5-sec interval, 13 sec - 17 sec (Table I). During this interval the residual vestibular signal from the prolonged deceleration would still be strong and the surround lights would be on throughout. Analysis of variance indicated significant differences among Sequences A, B, and C for both slow phase eye velocity ($F = 6.49$, $p < .01$) and visual acuity loss ($F = 6.08$, $p < .01$) during this interval of background illumination by the surround lights. Differences among sequences for the other response measure, retrospective estimates of blurring, were also significant ($F = 7.93$, $p < .01$).

All of the mean differences in the two response measures compared in Table I by t -tests were in the expected directions: $B > A$, $B > C$, and $A > C$, although some of the mean differences were of marginal statistical significance. In Sequence B, background movement was in a direction to produce optokinetic nystagmus (OKN) opposite in direction to vestibular nystagmus, and Sequence B produced significantly more vestibular nystagmus and significantly more acuity loss than did Sequence C in which background movement would produce OKN of the same direction as the vestibular nystagmus. Acuity loss in Sequence A during the interval 13-17 sec was significantly less than in Sequence B (although the difference in vestibular nystagmus between A and C failed to reach substantial statistical significance). Thus, a fixed background yielded less acuity loss for the central display than did a background moving at 18 deg/sec in a direction opposite to the ongoing vestibular nystagmus. On the other hand, background movement in the same direction as the ongoing vestibular nystagmus, Sequence C, yielded less nystagmus (more visual suppression) and better visual acuity than were obtained with a fixed background (Sequence A) in the 13-17 sec interval.

Table I
Comparison of Response Measures for the Interval 13-17 Sec

Sequence	A	B	C
Mean Slow Phase Displacement	54.6	68.2	33.2
Mean Total Visual Decrement	98.6	110.0	84.8
<u>t-tests</u> ¹ (for related measures)	A vs B	A vs C	B vs C
Visual acuity loss	2.27**	1.88*	2.85***
Nystagmus	1.48	3.88***	2.78***

¹One-tail test, df = 11, *p < .05, **p < .02, ***p < .01

DISCUSSION

The results of this experiment support the conclusion that uniform motion over the peripheral visual fields can either enhance or degrade ability to see a head-fixed target, depending upon the relative direction of a concomitant vestibular stimulus. When a peripheral optokinetic stimulus and a vestibular stimulus are concordant in that each stimulus would produce nystagmus of like direction, voluntary effort to see a head-fixed target (and visual suppression of vestibular nystagmus) is enhanced. When peripheral optokinetic and vestibular stimuli are discordant in that the two sources of stimulation would produce opposite directions of nystagmus, voluntary ability to see a head-fixed target and visual suppression of vestibular nystagmus are degraded. Our results are consistent with and extend the findings of Benson and Ciine (1).

It is to be noted that our results are exactly opposite what might be expected from the enhanced nystagmus gain reported by Bohmer and Pfaltz (2) and by Melvill-Jones (10) for a concordant vestibular and optokinetic drive to nystagmus. Our apparently paradoxical findings are of course dependent upon the presence of a head-fixed target and upon what our Ss were attempting to do. In our study, S's task required voluntary effort to see a head-fixed target throughout each period of vestibular response which, at the end of the prolonged deceleratory stimulus in each sequence, required visual suppression of strong vestibular nystagmus. The mean slow phase velocity of visually suppressed vestibular nystagmus over Sequences A, B, and C at the end of the 12-sec deceleratory stimuli was 11 deg/sec, but without visual suppression (i.e., in darkness), the mean slow phase velocity would be on the order of 100 deg/sec. Considering the visually suppressed response at 12 sec, when the surround lights were turned on, there were discrepancies between background velocity and mean eye velocity approximately as shown in Table II.

Table II
Comparison of Eye and Background Velocities at 12 Sec

Sequence	$(\omega_B)^*$	$(\omega_e)^{**}$	$(\omega_B - \omega_e)^{***}$
A	0	11 deg/sec	-11 deg/sec
B	-18 deg/sec	11 deg/sec	-29 deg/sec
C	+18 deg/sec	11 deg/sec	7 deg/sec

*Background velocity (ω_B) that is directionally the same as vestibular slow phase velocity is designated as positive.

**Eye velocity (ω_e) at end of deceleration assumed to be equal in A, B, and C for the sake of discussion.

***Peripheral retinal slip ($\omega_B - \omega_e$). When negative, OKN and vestibular inputs are discordant.

Considering the figures in Table II alone, one might conclude either that it is the lesser magnitude of the difference between eye and background velocity or it is the sign of the difference between eye and background velocity that enhances the visual suppression of the vestibular nystagmus in Sequence C. However, when we consider results obtained during the prolonged accelerations of Sequences A, B, and C, we become inclined to believe that it is the relative direction rather than the magnitude of the velocity difference that is important. At the end of the acceleration, velocity of the background relative to the head was 180 deg/sec. With a slow phase eye velocity of 11 deg/sec, the difference between background and eye velocity would be +169 deg/sec, yet ability to suppress vestibular nystagmus and to see the head-fixed target was quite good. Actually, the average slow phase velocity at the end of acceleration was only about 5 deg/sec, so that the mean difference between eye velocity and background velocity was +175 deg/sec. The visual acuity loss during this stimulus was minimal; as a matter of fact, it was less than that found during and after the prolonged deceleration in Sequence C. This would suggest that the more nearly the background velocity matches the rate of turn signaled by the vestibular input, the better the suppression of vestibular nystagmus; but, though this may be true, the conclusion is unwarranted from our data. We must first account for the fact that nystagmus and acuity loss did not reach greater magnitudes during the 12 sec of acceleration when the surround lights were off.

We now suspect that very dim peripheral motion cues are capable of generating differential effects on visual suppression, depending upon their direction relative to vestibular input, and that this at least partially accounts for the low nystagmus output during and after our prolonged accelerations in the present experiment. The light baffles along-

side the transilluminated display (Figure 2) limited illumination of the external surround to a level that rendered S unaware of the external surround as he concentrated on the transilluminated display. However, the light from the display, as reflected by S, was sufficient for the striped surround to be faintly visible to a dark-adapted (5-10 min) observer whose attention was directed to detection of the surround. In view of the fact that optokinetic nystagmus can be elicited in man when illumination levels are below the levels of stripe detection (6), it is not unlikely that our results were influenced by a very faint illumination of the background even when our surround lights were off. This would at least partially account for the higher magnitude slow phase velocity during deceleration as compared with acceleration before the surround lights were switched on. Close inspection of Figure 4 shows that the slow phase velocity of visually suppressed vestibular nystagmus was roughly equal in Sequences A, B, and C up to 10 sec of deceleration. In Sequence C the background movement became concordant in direction with the vestibular input just after 10.8 sec. It may be a chance event, but the slow phase velocity of Sequence C appears to diminish systematically below that of Sequences A and B after 10 sec. This dropoff in response in Sequence C of 11 sec and 12 sec, just after the velocity zero-crossing but just before the surround lights were turned on, may be due to the very low-level, directionally concordant, peripheral optokinetic stimulation that was present during that brief interval.

As a further check to determine whether or not the acceleration/deceleration differences apparent in the present study and in our previous study might be due to factors other than differences in peripheral background movement, we made additional observations with other groups of subjects (see Appendix A). In one of these studies, 5 min of constant velocity elapsed between the acceleration and the deceleration, and there was no visual task or illumination during the initial acceleration. Visual acuity loss, assessed during deceleration with peripheral visual surround visible, was pronounced and equivalent to that found in the deceleration of Sequence A. Then after a rest period of at least 5 min, acceleration was commenced, with the visual surround visible, and visual acuity loss was slight, like that of the acceleration trials in the present study. This observation seems to eliminate secondary vestibular effects, which are dissipated in about 5 min, as a primary cause of the acceleration/deceleration differences we have found.

In another brief study (see Appendix A) probing our acceleration/deceleration differences, subjects were completely encapsulated. Under these circumstances, the visible background was the interior of the rotary structure and was, therefore, fixed relative to the head and to the transilluminated visual display during and after both the prolonged accelerations and decelerations. Under these circumstances, visually suppressed nystagmus and visual acuity loss were roughly equal during acceleration and deceleration, but differences were in the direction of greater responses (acuity loss and nystagmus) from the deceleration as compared with responses from the acceleration, with earlier peaking of the deceleratory response. The deceleration/acceleration response ratios for total slow phase displacement and total acuity loss were, respectively, 1.11 and 1.06 with the fixed background; whereas in the present study with the moving backgrounds, the ratios were

1.59 and 2.47 in Sequence A, 1.77 and 3.07 in Sequence B, and 1.32 and 1.70 in Sequence C. Thus, we conclude that part of the acceleration/deceleration differences in each sequence of the present study may have been due to some effect (perhaps: secondary vestibular reactions) other than differences in background motion stimuli, but we believe that differences in background motion account for the major portion of the acceleration/deceleration differences in visual performance and oculomotor control in the present and in our previous (5) study.

Still to be determined are the critical features of the sensory inputs that control the differences in visual suppression and visual acuity in these experiments. The panel containing our transilluminated display subtended an arc relative to S of 25 deg x 25 deg, a sufficient visual area to maintain foveal vision within its boundaries, while S was attempting to fixate the central display. Thus, velocity of foveal images was that of the eye relative to the head-fixed display (ω_e in Table II), whereas velocity of the peripheral image was the algebraic difference between eye velocity and background velocity ($\omega_B - \omega_e$ in Table II). If this is the critical information used in this oculomotor control, then it is when the foveal image velocity and the peripheral image velocity are directionally the same that ability to suppress vestibular nystagmus is enhanced, whereas when foveal and peripheral velocities are directionally opposite, then visual suppression is degraded. The sustained good visual suppression during the very high peripheral retinal velocities encountered at the end of our accelerations indicates that detectors of direction of motion over the peripheral retina must remain effective in fixation control at velocities greater than those that maximize optokinetic nystagmus. The critical sensory information may then be the relative inputs to the focal and ambient visual systems (cf. 7-9,13) which are compared in the central nervous system. However, there are alternative possibilities which may involve different sets of neural pathways from those employed by a central comparison of direction of foveal and peripheral retinal velocities. For example, it may be the perceived direction (cf. 11,12,14) of whole-body turn (in our experiments controlled by vestibular inputs) that presets the direction of peripheral retinal information that will enhance (or degrade) visual suppression of vestibular nystagmus when the individual is attempting to fixate a head-fixed target. Otherwise expressed, when the circular-vection effects from stimulation of the peripheral retina (3,4) correspond in direction to the vestibular input, then visual fixation of a head-fixed target is enhanced.

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APPENDIX A

Visual-Vestibular Interactions: Baseline Studies

INTRODUCTION

In several experiments on visual-vestibular interactions and legibility of head-fixed displays in motion environments we have emphasized potential influence of peripheral visual field motion on visual suppression of the VOR. In the experiment described in the main text, all comparisons of the effects of background movement involved deceleratory vestibular stimuli. Results indicated that relatively low rates of background movement had differential effects on suppression of the VOR by a head-fixed central display, depending upon the concordance or discordance of vestibular and peripheral optokinetic inputs, despite the fact that all vestibular stimuli were primarily deceleratory. However, in our initial experiments (5) we reported that visual suppression of the VOR and visual performance were disrupted far more during deceleration, when vestibular inputs and peripheral optokinetic inputs were discordant, than during acceleration, when they were concordant. Because the greatest differential effects we had observed were produced by comparison of acceleratory and deceleratory stimuli, we became concerned that some subtle difference between acceleratory and deceleratory stimuli or some miscalculation of secondary effects might have contributed to the large acceleration-deceleration differences we had found. The two experiments described in this appendix were control- or baseline-type observations conducted to check the potential influence on our results of effects other than differences in motion in the peripheral visual field.

EXPERIMENT A1

Having completed several experiments in which direction of visual background movement seemed to control the visual suppression of vestibular nystagmus and vision for a head-fixed target, we became concerned about the possibility that secondary vestibular effects might be contributing to our results, especially when the results of a deceleration (down-ramp) were being compared with results of an acceleration (up-ramp) in a velocity trapezoid waveform stimulus. The following testing sequence was run to determine whether the differential effect would still occur when substantial time for secondary vestibular effects to dissipate was provided.

SUBJECTS

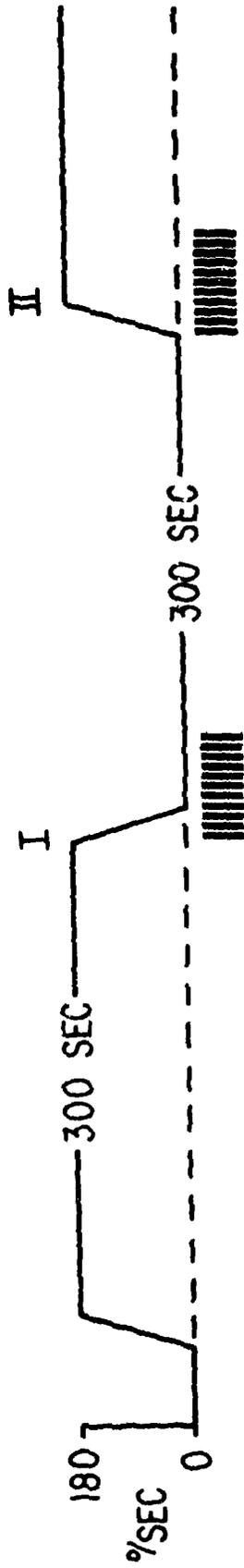
Four laboratory personnel participated as volunteers for this testing sequence.

APPARATUS AND METHOD

The apparatus is described in the body of the foregoing text. The acceleration/deceleration profile is shown in Figure A1. Prolonged (300 sec) constant velocity periods prior to each stimulus (I and II) were introduced to allow secondary effects to dissipate to ineffective levels.

The transilluminated visual acuity display light was first turned on approximately 10 sec prior to the first deceleration labeled I in Figure A1. The surround lights which illuminated the Earth-fixed external

 ILLUMINATION OF SURROUNDING
 BLACK AND WHITE STRIPES



A-2

Figure A1

Angular velocity profile for experiment A1. S was in a dark room and was instructed to keep his eyes closed. At 10 sec prior to Stimuli I and II the acuity target was transilluminated and S was instructed to open his eyes and fixate on the target. The Earth-fixed black and white stripes surrounding the device were illuminated in the interval indicated by the striped bars below the time line.

black and white striped boards were turned on just as this deceleration commenced. Forty seconds after the deceleration (I), surround lights and display lights were turned off and 300 sec of rest at zero velocity were given prior to the acceleration labeled II in Figure A1. Ten seconds before this acceleration, the transilluminated display was turned on and then, as the acceleration commenced, the surround lights were turned on. Loss of visual acuity during and immediately following the stimuli labeled I and II was the only response recorded for this experiment.

RESULTS AND DISCUSSION

A plot of the mean visual angle sustaining clear vision is presented in Figure A2. Each of the four subjects had acuity loss associated with the deceleration that was substantially greater than the acuity loss associated with the acceleration.

Since Stimulus Trials I and II were preceded by at least 30 sec of constant velocity rotation (actually zero velocity before Stimulus II), it seems unlikely that secondary effects could account for the differences in blurred vision in the deceleration versus the acceleration stimulus. It should also be noted that there was no optokinetic stimulus preceding either I or II, and so it is unlikely that either optokinetic aftereffects or vestibular secondary effects were of any substantial significance in the response measured. The results of this brief experiment support the notion that it is the concordance or discordance in the direction of vestibular and peripheral visual stimuli that has a differential effect on acuity for a head-fixed target.

EXPERIMENT A2

This experiment was conducted following our initial study on visual-vestibular interactions (5) and uses the stimulus profile of Experiment 2 of that report. The primary focus of this control experiment was to measure visual suppression of nystagmus and visual acuity losses while the subject and his head-fixed visual display were totally encapsulated. This condition specifically eliminates differences in peripheral background movement during acceleration and deceleration since the visible background as well as the target was head-fixed throughout the study and the only movement over the retina was that engendered by vestibular nystagmus.

SUBJECTS

Eighteen individuals (naval aviation officer candidates and laboratory personnel) participated as volunteers. All Ss indicated that they were free of drugs or medication for the 24 hours preceding the testing. The results from one S were not included in the data analysis due to an apparent vestibular imbalance (directional difference) of which he was unaware.

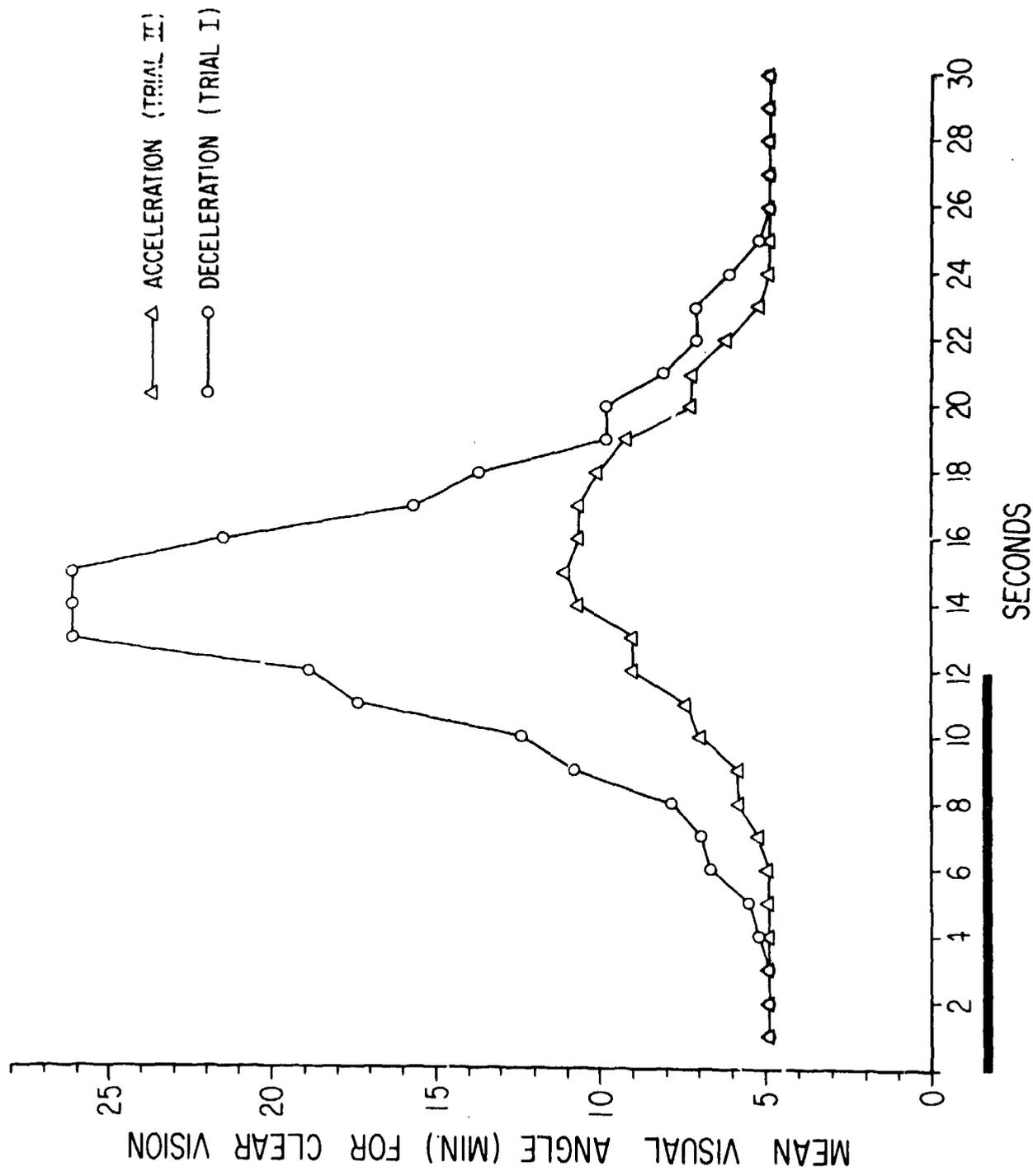


Figure A2

Mean visual angle sustaining clear vision during and immediately following the periods of acceleration (II) and deceleration (I). A baseline of approximately 5 min visual angle resulted from the lowest line (Line 1) on the chart (see Figure 1 of text).

APPARATUS AND METHOD

Apparatus and method details were identical to the study described in the main text, with two exceptions. The first pertained to the rotation device. The circular frame superstructure on the Stille-Werner rotator was fitted with a heavy black shroud to encapsulate the subject and exclude visual reference to the stationary Earth-fixed surround. The first ten Ss were tested on this rotator, and a second set of eight Ss were tested, encapsulated, in the Human Disorientation Device.* The second exception involved a change in the rotational stimulus profile (Figure A3). This stimulus sequence was used in our previous study (5) on this topic. In brief, all accelerations had the following characteristics: 15 deg/sec², 12 sec in duration to accomplish velocity changes from 0 to 180 deg/sec or from 180 deg/sec to 0. Intervals between accelerations and decelerations were 90 sec.

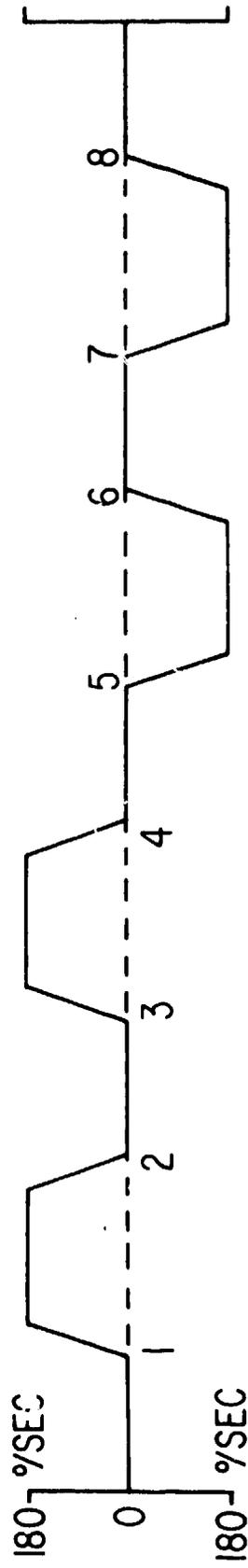
RESULTS AND DISCUSSION

Results of the two subject groups were nearly identical, and they have been combined for presentation. In the stimulus sequence used in this study, if secondary effects are estimated from an approximation of an adaptation model proposed by Young and Oman (15), primary responses as augmented by secondary effects would be very nearly equalized on Trials 3, 4, 7, and 8 (assuming a cupola long time constant of 16 sec and an adaptation time constant of 80 sec). Comparing Trials 3 and 7, both accelerations, with Trials 4 and 8, both decelerations, yields a comparison of effects of differential background movement when primary and secondary vestibular reactions are theoretically equivalent.

Figure A4 presents a plot of mean nystagmic slow phase eye velocities for these trials under the encapsulated condition (this control study) and a plot from the previous study (5) with external reference. A comparison of acceleration to deceleration responses in the encapsulated condition using total slow phase displacement summated across 40 sec yielded a difference of marginal statistical significance (t (related measures) = 1.83, $df = 16$, $p > .05$ two-tail, $p < .05$ one-tail). As is apparent in Figure A4, the differences between the acceleration and deceleration trials with encapsulation were much less than the differences found in our previous study (5) with external reference. The large differences between acceleration and deceleration responses with the external reference were clearly statistically significant ($p < .01$).

Figure A4 also presents a plot of the mean visual angle (min of arc) necessary to sustain clear vision. The comparison of acceleration to deceleration responses for the total visual acuity loss summated across 40 sec again produced a difference of marginal statistical significance (t (related measures) = 2.05, $df = 16$, $p > .05$ two-tail, $p < .05$ one-tail), and the contrast with the results of our previous study is again pronounced. Differences between acceleration and deceleration responses with the external reference were large and statistically significant ($p < .001$).

*Hixson, W. C., and Niven, J. I., A bioinstrumentation control center for the Human Disorientation Device. NSAM-848. Pensacola, FL: Naval School of Aviation Medicine, 1963.

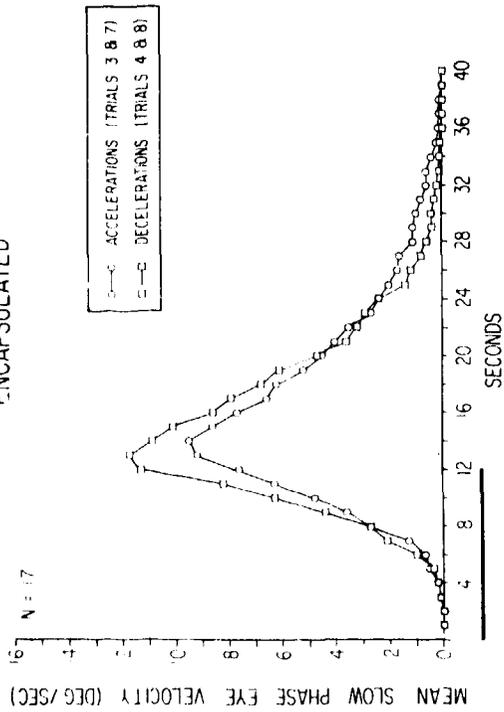


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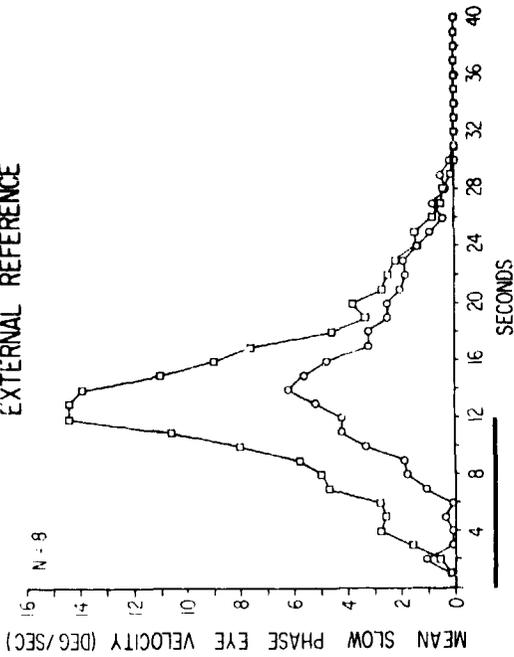
Figure A3

Angular velocity profile for Experiment A2. S's visual display was constantly transilluminated. No external visual reference.

PRESENT CONTROL STUDY
ENCAPSULATED

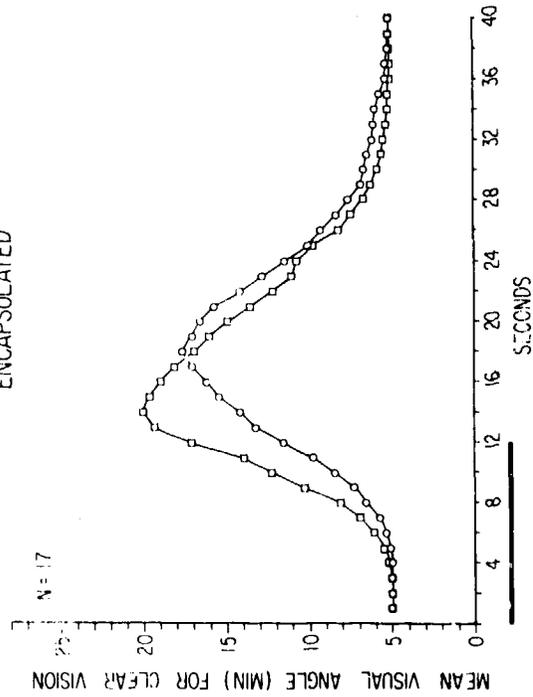


PREVIOUS STUDY (REF. 5)
EXTERNAL REFERENCE



4-7

PRESENT CONTROL STUDY
ENCAPSULATED



PREVIOUS STUDY (REF. 5)
EXTERNAL REFERENCE

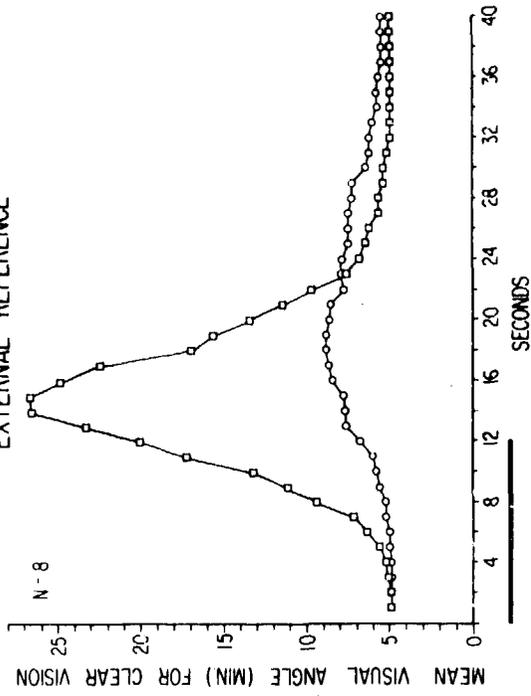


Figure A4

Mean slow phase eye velocity and mean visual angle sustaining clear vision during and immediately following periods of vestibular stimulation, marked by black bars below the time line. Responses from accelerations and decelerations are denoted by open circles and open squares, respectively. The plots on the left side of the page represent data from the present control study (encapsulated condition), while plots on the right side are from a previous study (external visual reference).

There was a statistically significant difference between acceleration and deceleration trials with regard to retrospective blurring estimates (t (related measures) = 4.61, $df = 16$, $p < .001$). The average retrospective blurring estimate for accelerations was 4.06 (S.D. = 1.95) and for decelerations was 5.41 (S.D. = 1.78). However, this difference (5.4 - 4.1) is small relative to the difference (7.8 - 2.3) found previously (5) with an external visual reference.

The elimination of background movement relative to the head-fixed display by encapsulating the subject reduced acceleration/deceleration differences in visual acuity loss and in suppressed vestibular nystagmus to levels that were of marginal statistical significance. Considering the results of this control experiment with encapsulated subjects in relation to results obtained in our other observations with an external reference, we retain our conclusion that uniform motion over the peripheral visual fields can either enhance or degrade ability to suppress vestibular nystagmus and to see a head-fixed target, depending upon the relative direction of the concomitant vestibular response. However, our control study results suggest that some other factor or factors may have contributed to the differences in visually suppressed nystagmus we found in comparing acceleration and deceleration responses.

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optokinetic stimulation can influence visual suppression of the VOR at velocities that far surpass effective production of optokinetic nystagmus. Twelve men participated in the main experiment and a total of 22 men participated in two control studies.



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