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VISUAL-VESTIBULAR INTERACTIONS: I. INFLUENCE OF PERIPHERAL
VISION ON SUPPRESSION OF THE VESTIBULO-OCULAR REFLEX
AND VISUAL ACUITY

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



June 1978

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NAVAL AEROSPACE MEDICAL RESEARCH LABORATORY
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Guedry, F. E., Jr. J. M. Lentz, R. M. Jell 1978 VISUAL-VESTIBULAR INTERACTIONS: I. INFLUENCE OF PERIPHERAL VISION ON SUPPRESSION OF THE VESTIBULO-OCULAR REFLEX AND VISUAL ACUITY. NAMRL-1246. Pensacola, FL: Naval Aerospace Medical Research Laboratory, 27 June. Legibility of head-fixed displays in some motion environments is partially dependent upon visual suppression of the vestibulo-ocular reflex (VOR). This study investigates the effects of differing relationships between peripheral background movement and whole-body motion on the VOR and on visual performance. The purpose of the study is to explore factors in motion environments that influence performance limits and also to develop procedures of potential usefulness in evaluating interacting visual and vestibular function. Visual performance and visual suppression of the VOR were markedly different, depending upon the relative direction of peripheral background movement. Visual suppression of the VOR and visual performance were disrupted to a far greater extent when vestibular inputs and peripheral optokinetic inputs were discordant than when they were concordant. Results have potential implications for head-up displays and suggest a procedure for evaluating visual/vestibular function.	Visual-vestibular Interaction Visual acuity Vestibulo-ocular reflex Nystagmus Optokinetic Vision Vestibular	1978 VISUAL-VESTIBULAR INTERACTIONS: I. INFLUENCE OF PERIPHERAL VISION ON SUPPRESSION OF THE VESTIBULO-OCULAR REFLEX AND VISUAL ACUITY. NAMRL-1246. Pensacola, FL: Naval Aerospace Medical Research Laboratory, 27 June. Legibility of head-fixed displays in some motion environments is partially dependent upon visual suppression of the vestibulo-ocular reflex (VOR). This study investigates the effects of differing relationships between peripheral background movement and whole-body motion on the VOR and on visual performance. The purpose of the study is to explore factors in motion environments that influence performance limits and also to develop procedures of potential usefulness in evaluating interacting visual and vestibular function. Visual performance and visual suppression of the VOR were markedly different, depending upon the relative direction of peripheral background movement. Visual suppression of the VOR and visual performance were disrupted to a far greater extent when vestibular inputs and peripheral optokinetic inputs were discordant than when they were concordant. Results have potential implications for head-up displays and suggest a procedure for evaluating visual/vestibular function.	Visual-vestibular Interaction Visual acuity Vestibulo-ocular reflex Nystagmus Optokinetic Vision Vestibular
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SUMMARY PAGE

THE PROBLEM

Legibility of head-fixed displays in some motion environments is partially dependent upon visual suppression of the vestibulo-ocular reflex (VOR). This study investigates the effects of differing relationships between peripheral background movement and whole-body motion on the VOR and on visual performance. The purpose of the study is to explore factors in motion environments that influence performance limits and also to develop procedures of potential usefulness in evaluating interacting visual and vestibular function.

FINDINGS

Visual performance and visual suppression of the VOR were markedly different, depending upon the relative direction of peripheral background movement. Visual suppression of the VOR and visual performance were disrupted to a far greater extent when vestibular inputs and peripheral optokinetic inputs were discordant than when they were concordant. Results have potential implications for head-up displays and suggest a procedure for evaluating visual/vestibular function.

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Dr. Lentz held an appointment under the Postdoctoral Research Associateship Program conducted by the National Research Council for the Naval Medical Research and Development Command.

Dr. Jell, Department of Physiology, The University of Manitoba, Winnipeg, Canada, during a sabbatical period worked with the NAMRL Perceptual and Behavioral Sciences Division under the sponsorship of the Office of Naval Research.

INTRODUCTION

Because the vestibulo-ocular reflex tends to counterrotate the eye relative to the head and to stabilize the direction of gaze in space, visual-vestibular interactions during natural movement typically serve to maintain clear vision for Earth-fixed targets at peak head velocities and frequencies that far exceed the tracking capabilities of the visual system (3). The natural and beneficial coordination of visual and vestibular functions becomes potentially disruptive in aircraft or other fast-moving vehicles when the individual's task may require data retrieval from a head-fixed display such as an instrument panel during maneuvers which stimulate the vestibular system. In this situation satisfactory data acquisition may depend upon visual suppression of the vestibulo-ocular reflex.

Ability to suppress inappropriate vestibulo-ocular reflexes is influenced by a number of factors, including the strength of the vestibular signal (13), the direction of the reflexive eye movement (5), the frequency and peak velocity of head oscillation (2), and the state of the central nervous system as it might be affected by either neurological disorder (1,18), or mild intoxication (14). In almost all available studies of visual suppression of the vestibulo-ocular reflex, vision has been restricted to head-fixed targets, and background movement of Earth-fixed surrounds has been intentionally excluded. Frequently, however, individuals operating moving vehicles have tasks that require visibility of head-fixed visual displays while there is visible relative movement in the peripheral visual field. Head-up displays including helmet-mounted displays constitute one example.

A number of results would suggest that optokinetic stimulation acting in concert with semicircular canal stimulation is likely to produce a stronger oculomotor response than would be obtained from either stimulus acting alone. For example, angular acceleration in darkness to a constant velocity of 60 deg/sec typically produces a maximum slow phase velocity of about 40 - 50 deg/sec (12), but when such vestibular stimuli are administered with concordant optokinetic stimuli, maximum slow phase velocity is about 60 deg/sec (20). The latter response, being the stronger of the two, might be less readily suppressed by introduction of a small head-fixed display centered in the moving (optokinetic) background. This fairly plausible presumption, however, is not necessarily correct. Effects of an optokinetic background may be changed when the observer's efforts are directed toward data retrieval from a head-fixed target. It is particularly called into question by findings (unpublished) of Benson and Cline (4), indicating that visual suppression of the vestibulo-ocular reflex by a head-fixed target during whole-body oscillation was improved by low-level illumination of the surrounding room which, by virtue of subject rotation, constitutes an optokinetic stimulus.

The present report is concerned with further study of visual suppression of the vestibulo-ocular reflex and visual acuity when a head-fixed display is viewed against an optokinetic background. The purpose of the study is twofold: 1) to determine whether or not previous findings (4) can be confirmed when more definitive and potentially more compelling background movement is present and if so, 2) to provide a fairly

simple short procedure for measuring differences in effects with differences in background movement. In connection with the latter goal, it has been suggested that visual motion inputs are processed by two neural systems, the one arising from foveal stimuli and responsible for active optokinetic nystagmus (OKN) and resolution of fine detail, and the other arising from the peripheral retina and responsible for passive OKN and the perception of body movement in space (16,17,19). Current clinical tests (9,18) do not address the potential role of the peripheral retina in altering visual-vestibular interactions. Thus a simple short procedure for measuring differential effects of background movement on visual suppression of the vestibulo-ocular reflex may provide refinement of current test procedures.

PROCEDURE

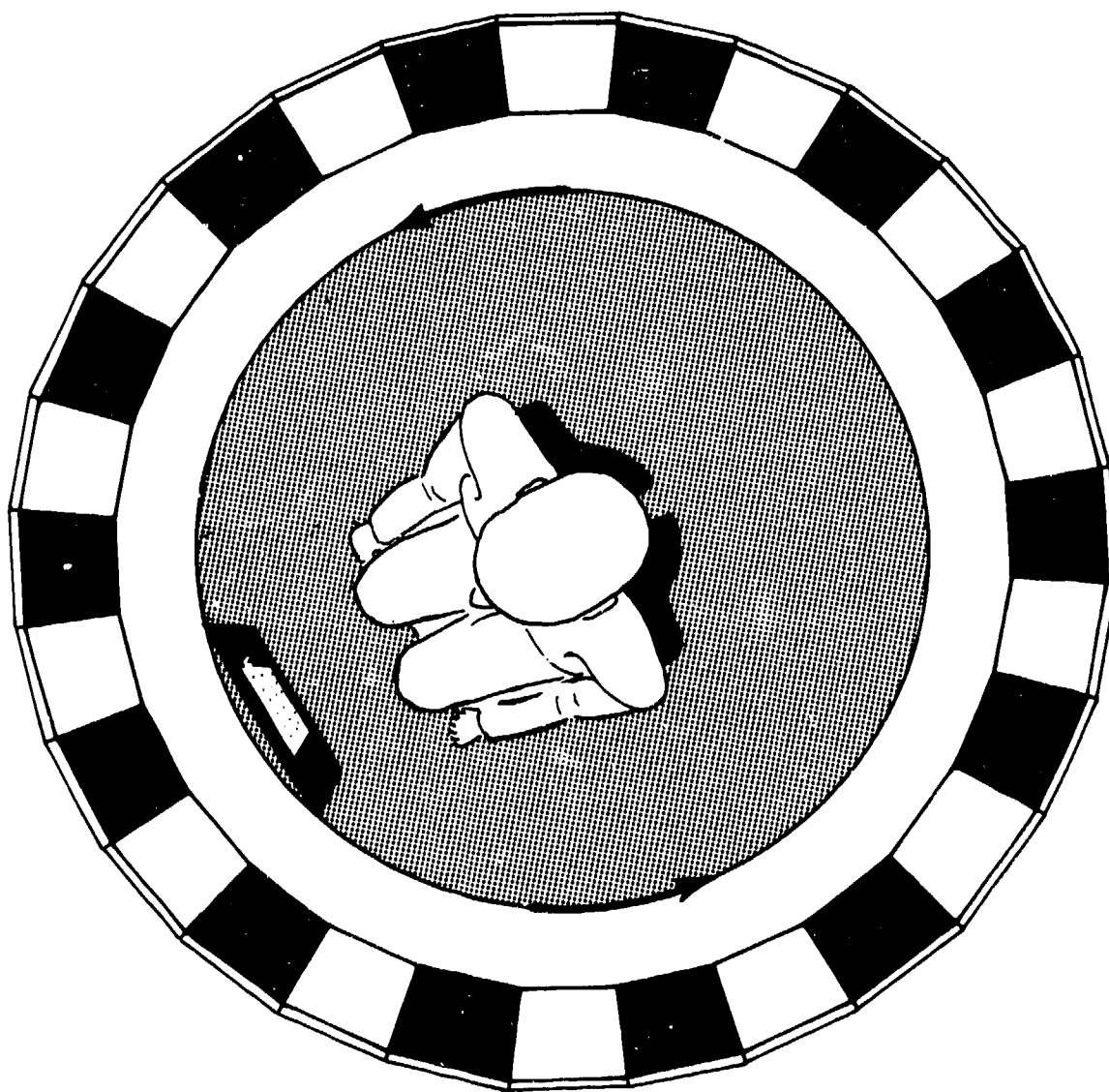
The procedure involves surrounding a rotation device with stationary (Earth-fixed) vertical black and white stripes, as illustrated in Figure 1. With a large head-fixed display mounted on the rotation device in front of a seated subject, commencement of rotation to the right, for example, stimulates the semicircular canals to produce nystagmus with slow phase left, and concordant optokinetic stimulation from the peripherally visible Earth-fixed stripes would also produce OKN with slow phase left. However, the subject's task is to sustain acuity for the head-fixed display, and to do this he must suppress the vestibulo-ocular reflex as it is influenced by the concordant optokinetic stimulus. Then after a sufficient interval when deceleration commences, the semicircular canals would generate nystagmus with slow phase right, opposite in direction to ongoing OKN from the background stripes. As the deceleration ends, the semicircular canal signal would be maximum and the entire field of view (head-fixed target as well as the Earth-fixed striped background) would be stationary. Thus, peripheral optokinetic inputs in conflict with the vestibular inputs are introduced during and for some time after the deceleration, while the subject's task again requires visual acuity for the head-fixed display which in turn requires suppression of the vestibulo-ocular reflex. Comparison of the ability to sustain clear vision and suppress the vestibulo-ocular reflex produced by the acceleration with effects produced by the deceleration provides a simple test of differential effects of variation in direction of background movement.

SUBJECTS

Eighteen naval flight officer candidates volunteered to serve as subjects (10 subjects — Experiment 1; 8 subjects — Experiment 2). All subjects had recently passed a flight physical examination and were in good health (corrective lens were worn by some individuals). Subjects indicated that they were free of drugs or medication for the 24 hours preceding the testing.

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 minutes before recording commenced.



OPEN ROTATING STRUCTURE. HEAD-FIXED TARGET.
PERIPHERAL VIEW OF EARTH-FIXED STRIPES.

Figure 1

Rotation device (shaded) surrounded by vertical Earth-fixed black and white stripes.
(Canopy top of rotation device not shown.)

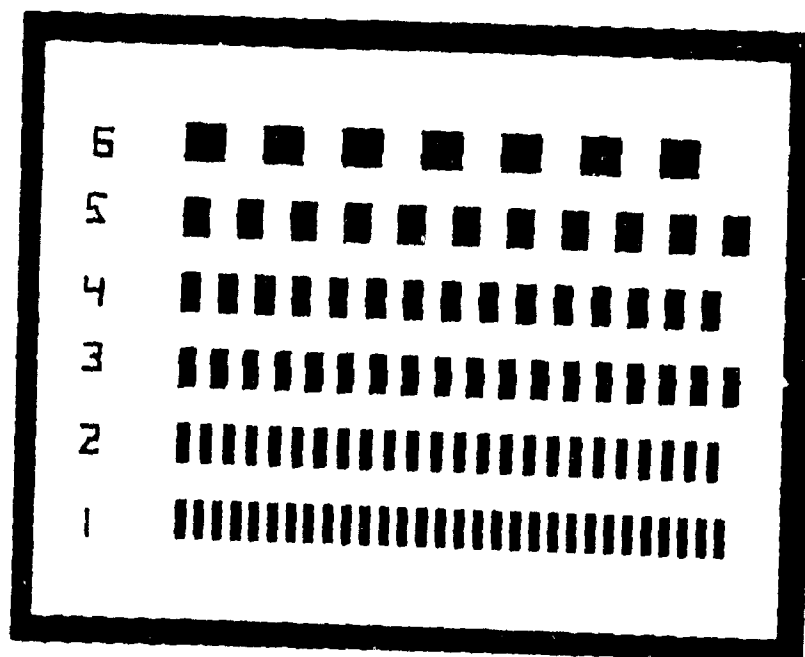


Figure 2

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.

Table 1

Summary of Response Measure Data and Comparisons

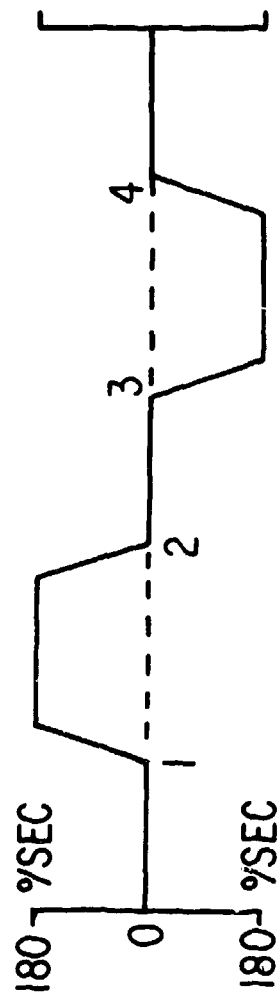
Response Measured		Accelerations (Concordant Stimuli)	Decelerations (Discordant Stimuli)	t***	df	p
		M (SD)	M (SD)			
Retrospective Blurring Estimate	Exp. 1	3.0 (1.7)	8.0 (1.1)	6.74	9	<.001
	Exp. 2*	2.3 (1.3)	7.8 (2.3)	7.85	7	<.001
	Exp. 2**	2.3 (1.2)	8.0 (2.2)	8.25	7	<.001
Acuity Measure***	Exp. 1	263.1 (90.9)	457.1 (133.7)	9.76	9	<.001
	Exp. 2*	265.8 (99.6)	398.5 (85.0)	8.71	7	<.001
	Exp. 2**	263.6 (94.7)	423.8 (87.7)	9.89	7	<.001
Nystagmus Slow Phase Velocity (Peak per subject per trial)	Exp. 1	14.7 (10.2)	26.8 (14.8)	5.76	9	<.001
	Exp. 2*	7.7 (3.0)	19.9 (9.6)	4.25	7	<.01
	Exp. 2**	7.1 (2.6)	20.7 (8.6)	5.24	7	<.01

*Accelerations - mean of Trials 3 and 7; decelerations - mean of Trials 4 and 8

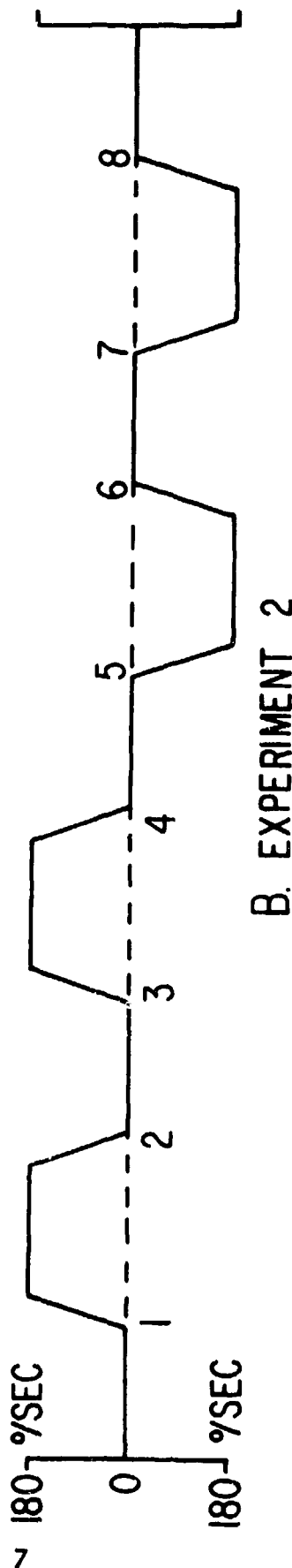
**Accelerations - mean of Trials 1, 3, 5, and 7; decelerations - mean of Trials 2, 4, 6, and 8

***Acuity measure - visual angle required to sustain clear vision integrated over 40 sec

****t-test for related measures



A. EXPERIMENT 1



B. EXPERIMENT 2

Figure 3

(A) Stimulus sequence, Experiment 1. (B) Stimulus sequence, Experiment 2. Each acceleration and deceleration is denoted by a trial number.

Experiment 2. The sequence of stimuli used in Experiment 1 was such that secondary nystagmus from each acceleration would be directionally the same as the primary nystagmus produced by the succeeding deceleration. It is therefore possible that primary nystagmus during each deceleration would be augmented by ongoing secondary effects in Experiment 1. Thus, differences in responses to accelerations and decelerations in Experiment 1 could be influenced by factors other than the direction of peripheral optokinetic stimuli. For this reason Experiment 2 was run, using the stimulus sequence shown in Figure 3B. In this sequence, if secondary effects are estimated from an approximation of an adaptation model proposed by Young and Oman (24), primary responses as augmented by secondary effects would be very nearly equalized on Trials 3, 4, 7, and 8 (assuming a cupula long time constant of 16 seconds and an adaptation time constant of 80 seconds). 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. Conditions in Experiment 2 were identical with those in Experiment 1, except for the stimulus sequence.

RESULTS

Plots of changes in vision and of concomitant nystagmus slow phase velocity for Experiment 1 are presented in Figure 4. During deceleration the peak visual angle required to sustain clear vision was more than double the corresponding measures taken during acceleration, and comparable differences were present in the slow phase velocity of nystagmus. Subjective estimates of blurring were similarly affected (see Table I).

Results from Experiment 2 closely paralleled the findings from Experiment 1. In Figure 5, mean responses from Trials 3 and 7, both of which were accelerations (see Figure 3B), can be compared with mean responses from Trials 4 and 8, both of which were decelerations. Primary responses during these accelerations (Trials 3 and 7) should be augmented by secondary reactions from immediately preceding stimuli about as much as the responses to the two decelerations (Trials 4 and 8) would be augmented by secondary reactions from their preceding stimuli. Nevertheless the results clearly show a two-fold quantitative difference between responses to acceleration and deceleration stimuli much like that found in Experiment 1. Figure 6 is simply a comparison of the mean responses from all acceleration trials with the mean responses from all deceleration trials in Experiment 2.

In both experiments the vestibular and peripheral optokinetic stimuli were directionally concordant during accelerations and directionally opposed (discordant) during decelerations. Statistical comparisons of mean responses during accelerations with mean responses during decelerations are presented in Table I for both experiments. Differences among retrospective estimates of blurring, visual angles required to sustain clear vision, and nystagmus slow phase velocity were all statistically significant.

DISCUSSION

In Experiments 1 and 2, visibility of head-fixed targets varied inversely with the velocity of visually suppressed nystagmus. Visual performance and nystagmus suppression were clearly superior when relative background movement was concordant with the

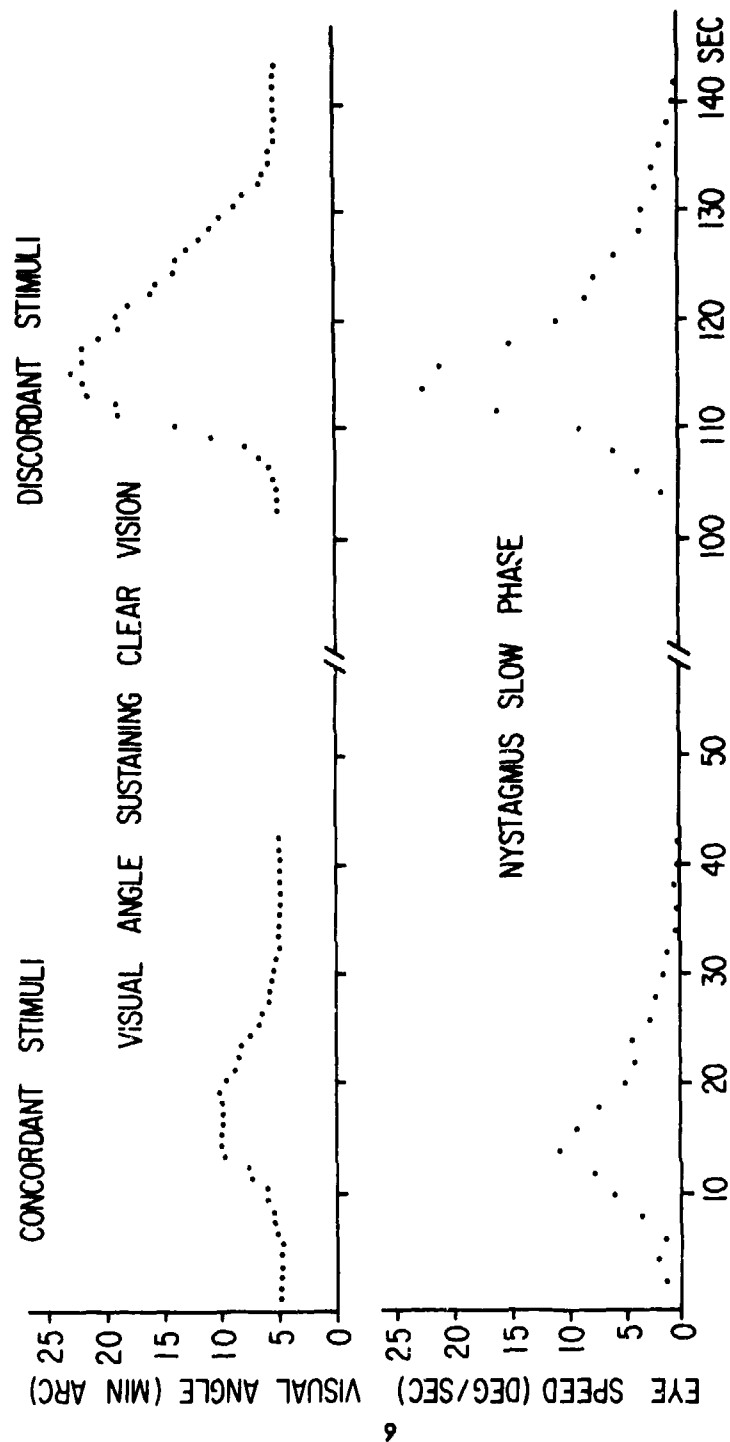


Figure 4

Changes in mean visual acuity and mean nystagmus slow phase velocity during acceleration and deceleration trials of Experiment 1. Displayed under concordant stimuli are mean responses (10 subjects) from Trials 1 and 3 (accelerations), and under discordant stimuli are mean responses from Trials 2 and 4 (decelerations).

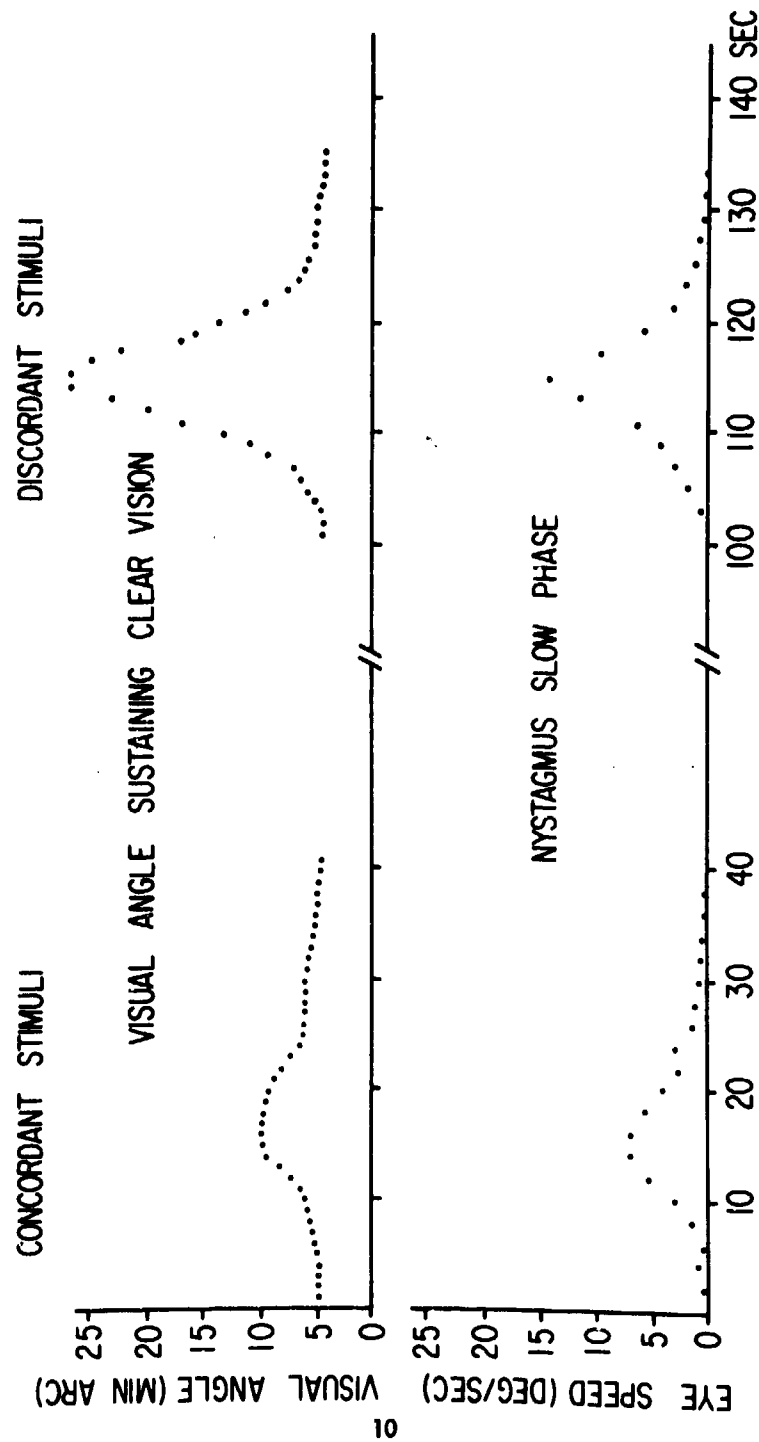


Figure 5

Changes in mean visual acuity and mean nystagmus slow phase velocity during selected acceleration and deceleration trials in Experiment 2. Displayed under concordant stimuli are mean responses (8 subjects) from Trials 3 and 7 (accelerations), and under discordant stimuli are Trials 4 and 8 (decelerations).

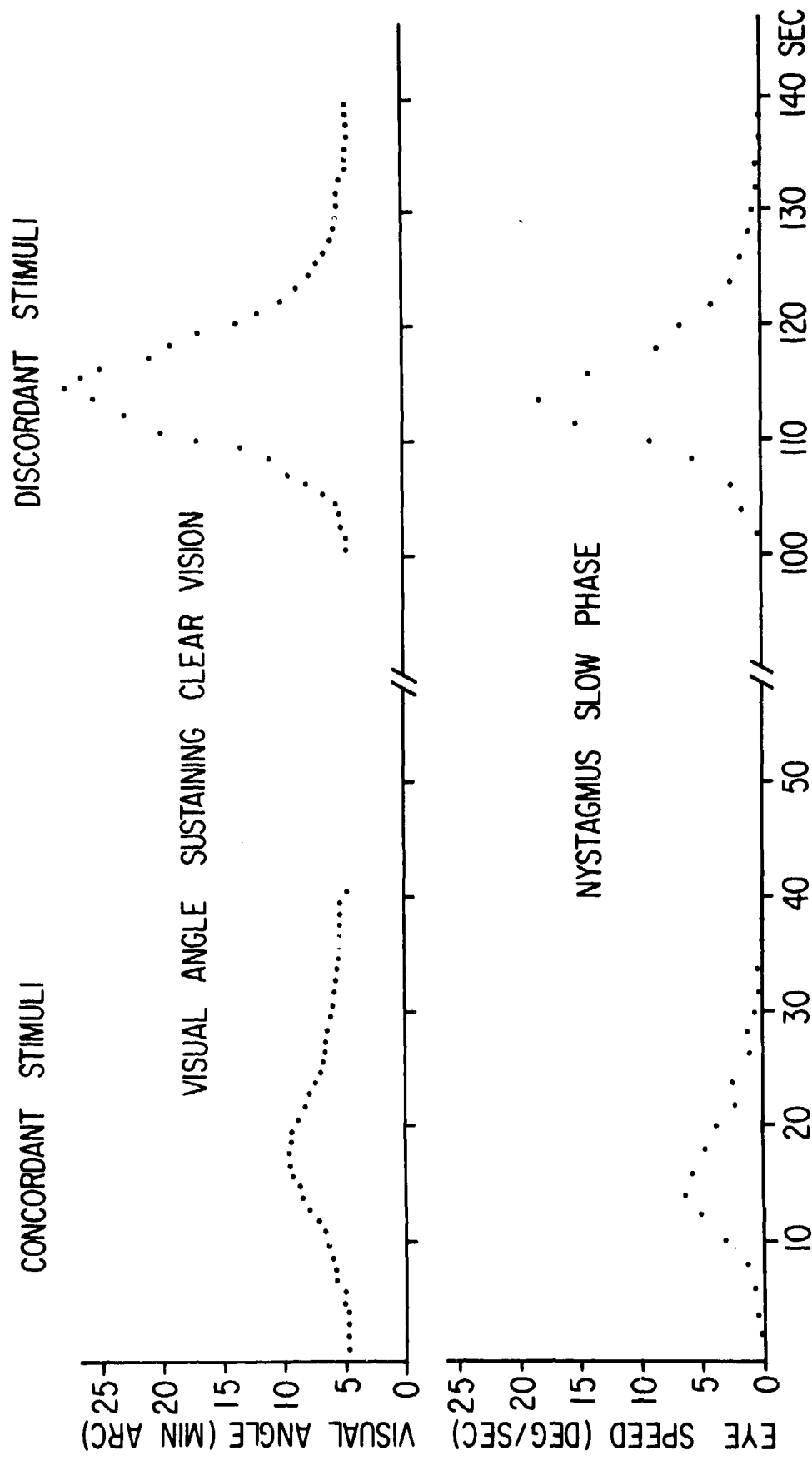


Figure 6

Changes in visual acuity and concomitant nystagmus slow phase velocity for Experiment 2. Displayed under concordant stimuli are mean responses from all acceleration trials, and under discordant stimuli are the results from all deceleration trials.

vestibular stimulus; i.e., when the background movement would produce an OKN that was directionally the same as the ongoing vestibular nystagmus. Experiment 2 suggests that these differential effects were not an artifact of augmentation of postrotatory vestibular nystagmus by secondary nystagmus from the preceding stimulus.

Benson and Cline (4) reported that during sinusoidal whole-body oscillation, visual acuity for a head-fixed display viewed against an Earth-fixed visual surround was superior to visual acuity for the same display when the observer was oscillated while encapsulated. Our results are consistent with this previous study (4) although, strictly speaking, our procedure did not compare fixed and moving backgrounds. The salient feature in our findings is that when peripheral optokinetic stimuli are discordant with vestibular stimuli, visual acuity (and visual suppression of the vestibulo-ocular reflex) is substantially poorer than when optokinetic and vestibular inputs are concordant.

The vestibular stimulus profile used in our study, a velocity ramp function, differs from the sinusoidal stimulus used by Benson and Cline, and it seems to afford some advantages for observing effects of these visual-vestibular interactions. In observations preliminary to undertaking this study, we used a sinusoidal stimulus, 0.02 Hz with peak velocity of ± 120 deg/sec. With low-frequency sinusoidal oscillation there is a relatively large stimulus-response phase angle; vestibular compensatory eye velocity is phase advanced relative to stimulus velocity as illustrated in Figure 7. The large phase angle means that the optokinetic stimulus is never truly matched to the vestibular response. During the stimulus cycle near peak turntable velocity the vestibular signal, though phase advanced, is directionally the same as the optokinetic stimulus. This directional concordance, despite the phase mismatch, is apparently sufficient to augment visual fixation of a head-fixed target when both the vestibular and optokinetic inputs are strong. However, the phase angle seems to introduce disruptive effects near zero turntable velocity, approximately in the interval indicated by the cross-hatching in Figure 7. Subjects in our preliminary runs reported slight but noticeable difficulty in maintaining visual fixation of the head-fixed target in this interval. Any difficulty in maintaining visual control during this interval is somewhat surprising because it is a time in which the vestibular velocity signal is either nil (zero-crossing) or very weak. However, it is also an interval in which the vestibular signal is opposite in direction to the optokinetic stimulus.

In our preliminary runs visibility of head-fixed targets during a period of oscillation with a visible background was compared with visual performance during a period of oscillation with the subject encapsulated to exclude background optokinetic stimulation. This fairly lengthy procedure revealed effects in some subjects similar to those reported by Benson and Cline, but in other subjects there was little or no difference in results with or without visible background movement.* Aside from the formalized background, the primary difference between the test situations was the frequency of oscillation. Our stimulus frequency, 0.02 Hz, introduced a greater stimulus-response phase

*A number of subjects achieved perfect performance scores in both conditions.

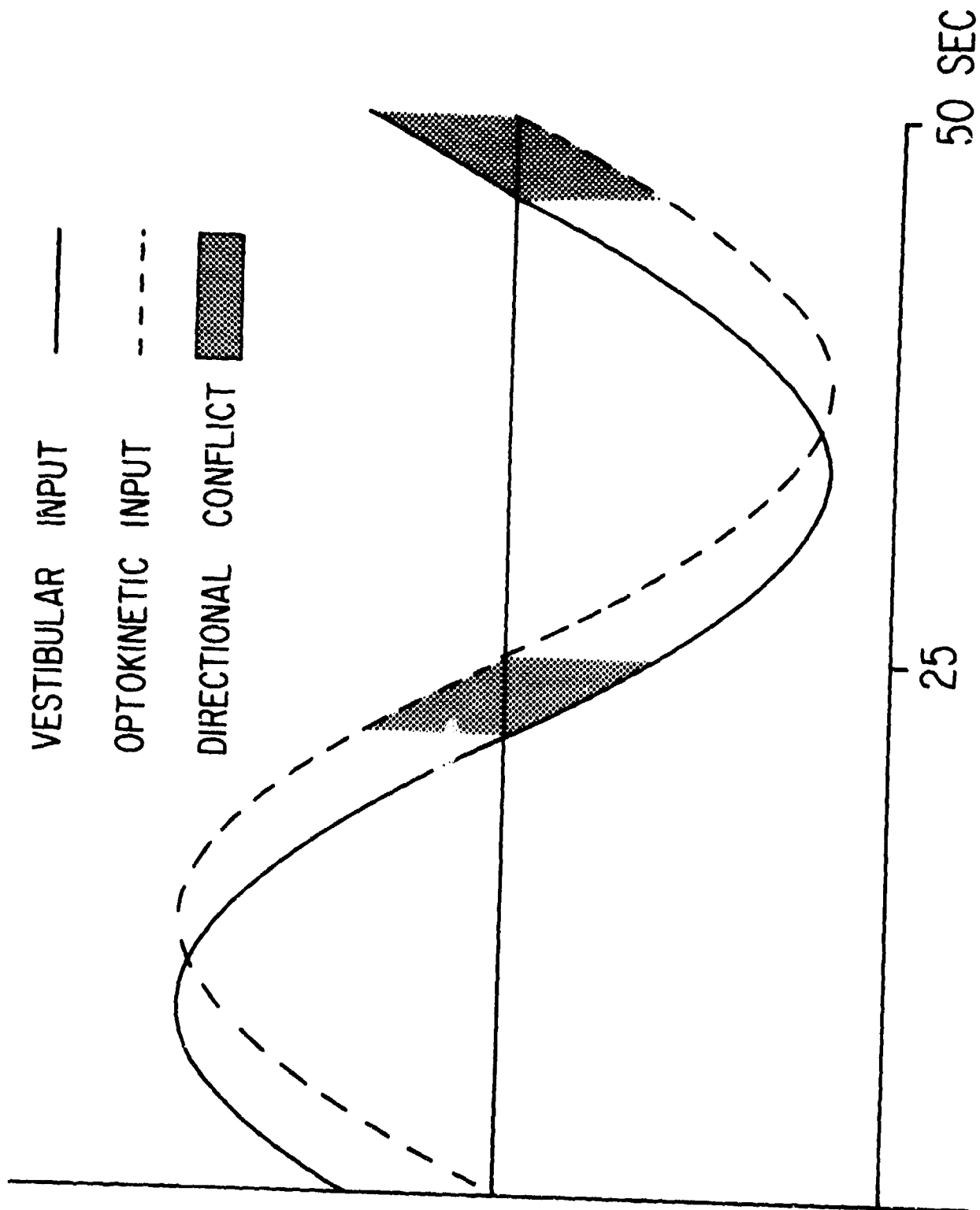


Figure 7

Low-frequency sinusoidal oscillation yields a phase difference between vestibular and optokinetic inputs. Shaded areas represent the times during which a directional conflict exists between the two inputs.

angle and hence greater discordance than the stimulus (0.033 Hz) used in the initial study (4). Moreover, the visual task (cf. 21) in our preliminary observations provided only one response every 7 seconds, and perfect scores could be attained despite some momentary periods of slightly blurred vision. For these reasons the visual task described above and the velocity ramp stimulus waveform shown in Figure 8 were adopted. A velocity ramp stimulus with a period of constant velocity between the acceleration and deceleration yields directionally concordant peripheral optokinetic and vestibular stimulation throughout the acceleration and directionally discordant stimulation throughout the deceleration. It is therefore a stimulus sequence that may well accentuate response differences under consideration. Figures 4, 5, and 6 show that vestibular nystagmus and related visual deficits begin to increase soon after the beginning of the deceleration; i.e., before the vestibular input has become strong. This suggests that vestibular-optokinetic directional discordance decreases ability to fixate head-fixed targets while directional concordance may improve this ability. Hence with this stimulus profile there may be an enhancement of the "fixation reflex" during acceleration, and there is a weakening of fixation during deceleration.

It is well known that the vestibulo-ocular reflex plays an important role in preserving visual acuity for Earth-fixed targets during head and whole-body movements (3). However, it is to be noted that the vestibulo-ocular reflex, in order to aid in foveation during head movement, requires adjustment, depending upon the proximity of voluntarily selected visual targets. During observation of a near object, eye movements to compensate for head rotation must be greater than eye movements during observation of far objects because the axis of eye rotation is displaced from the axis of head rotation even in natural head movements. Therefore, it is not unreasonable to suppose that peripheral retinal stimulation by background movement routinely aids in the adjustment of the vestibulo-ocular reflex to the specific requirements of voluntary visual pursuit during head and whole-body turning.

Recently there has been a strong revival of interest in the perceptual and neurophysiological effects of large-field movement. When surrounded by a large moving field, an observer may choose to gaze inattentively at the field without specifically trying to follow particular detail; under these circumstances, "passive OKN" is generated (16,17). If a small head-fixed target is placed in view in front of the moving field, the observer can suppress OKN, but a compelling illusion of self-motion, called circularvection (10,11), quickly commences. On the other hand, if the observer tries to follow the moving visual detail, then "active OKN" develops (16,17) which is intermittently stronger than passive OKN, but the illusion of self motion is intermittent, develops only slowly, and is not compelling. Moreover, when vision is restricted to moving central fields, whole-body motion is not perceived (6,10,11). Recent neurophysiological evidence indicates that large peripheral field movement induces activity in the vestibular nuclei as though the head were actually turning (15). It appears from these and other considerations that peripheral optokinetic stimulation plays a strong role in spatial orientation and perception of self motion, and of course that central (macular) vision is concerned with form perception and discrimination of fine detail (19). However, considering the probable evolutionary insignificance of the entire

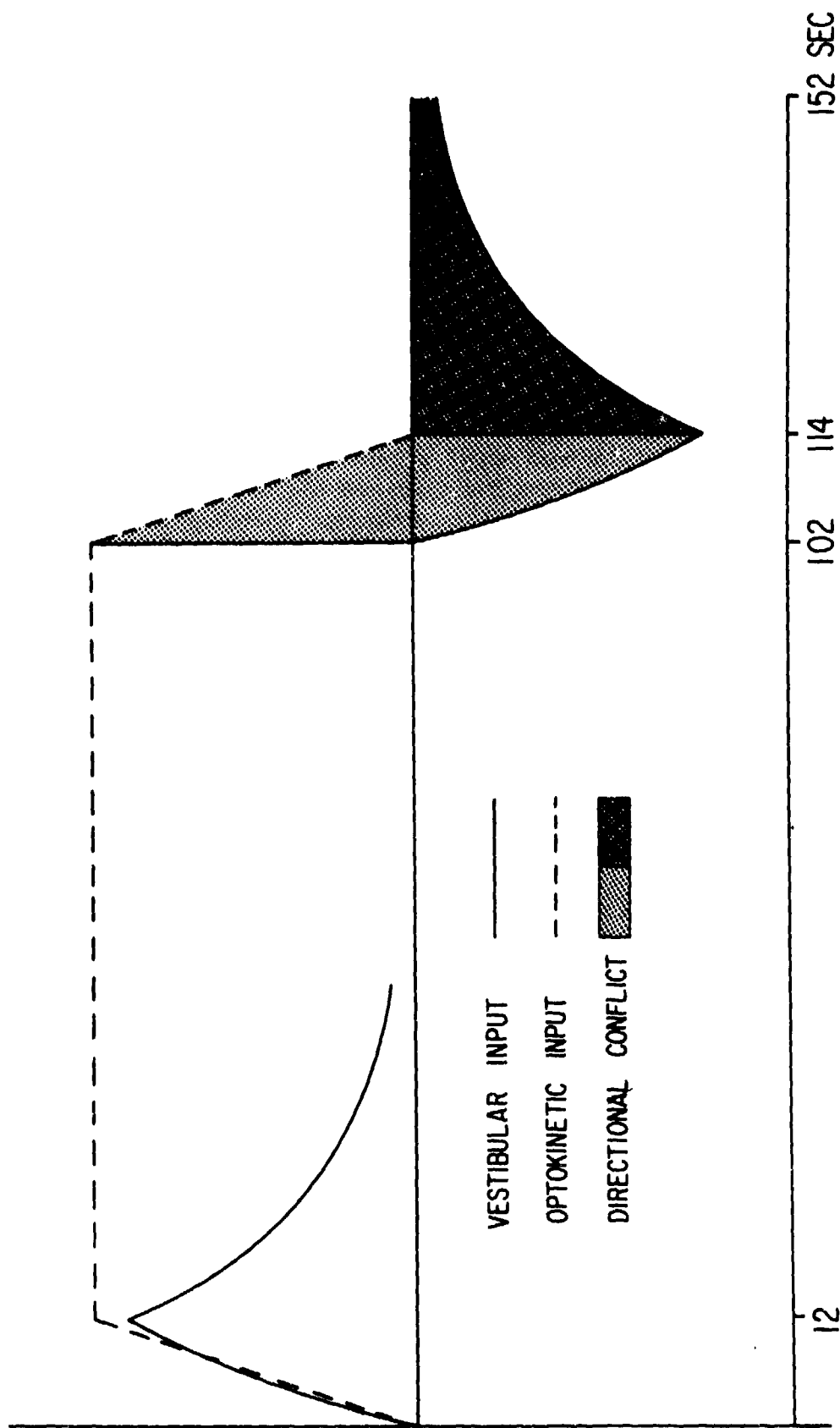


Figure 8

The velocity ramp stimulus used in Experiments 1 and 2. The vestibular and optokinetic directional conflict (shaded area) is present only during decelerations. In the initial portion of shaded area the vestibular and optokinetic inputs are directionally opposed. In the second portion of shaded area the vestibular inputs would drive the eyes relative to a stationary visual surround.

visual field moving relative to a fixed observer, it is reasonable to ask whether or not moving peripheral images might also have some effects on foveal vision in everyday life. The present results suggest that peripheral movement, in addition to playing a role in the perception of body motion relative to the Earth, may serve to enhance clarity of vision for voluntarily selected targets when visual and vestibular signals are concordant and, conversely, may reduce clarity of vision when peripheral optokinetic and vestibular signals are discordant.

When the head is stationary, smooth visual pursuit of a target is typically accomplished in everyday life against fixed backgrounds of considerable detail. For functional utility, visual pursuit, in which the target image remains relatively fixed on the fovea, must operate while images of the background scene traverse the peripheral retina (cf. 22). Recent results indicate that visual pursuit of a target light against a dim background of vertical stripes is better than visual pursuit of the target light in darkness (7). This suggests that when visual pursuit eye movement is to the left (counterclockwise), then clockwise image movement on the peripheral retina augments the fixation of the target on the fovea; and, conversely, when voluntary visual pursuit involves clockwise eye movement, then counterclockwise image movement over the peripheral retina augments the visual pursuit. These findings are consistent with some observations of Hood (16), indicating that the stripes on a small optokinetic display appear more distinct when a large striped background is moved in a direction opposite the moving stripes of the small display. The present results are somewhat paradoxical because we are dealing with a head-fixed target and the head is turning. When the head turns right, the vestibulo-ocular reflex would drive the eyes left. However, the voluntary effort is to fixate a target that is perceived as moving rightward relative to the Earth even though it is fixed relative to the head. According to Brewton et al. (7), fixation of rightward-moving targets is aided by CCW background movement while fixation of leftward-moving targets is aided by CW background movement. The direction of background movement during the accelerations in our experiments was appropriate, from this point of view, for improved fixation of the target, whereas it was inappropriate during the decelerations.

Legibility of Earth-fixed targets while the head turns on the neck requires foveation of the target image while the remainder of the visual field moves over the peripheral retina. However, owing to displacement of the eye-turn axes from the neck-turn axis, movement of peripheral images is not uniform even in natural head-on-neck turns; images from objects closer to the observer than the Earth-fixed target move in one direction while images from objects more distant than the target move in opposite direction. If movement in the peripheral retina influences control of voluntary fixation, it may be that foreground and background movements in opposite but appropriate directions would optimize target visibility during head turns. However, if the conditions that predominate in circularvection effects are also important in controlling foveation of voluntarily selected targets, then background movement ("depth periphery") as opposed to foreground movement may be crucial to the visual acuity effects under study herein. Foreground motion, according to Brandt et al. (6), does not generate circularvection effects. Otherwise expressed, it may be that background motion, because it generates body-turn sensations, must be concordant with vestibular inputs to augment foveal fixation,

and, conversely, when discordant with vestibular input, it is disruptive.

While many interpretations of these various considerations are possible, one interesting possibility is that any sensory input, visual or otherwise, which contributes to the perception of whole-body motion may play a role in determining which direction of peripheral retinal motion improves or degrades voluntary efforts at foveal fixation. It is proposed that movement over the peripheral retina induces the perception of whole-body movement and also influences the "fixation reflex." Typically this peripheral retinal movement information serves to adjust the vestibulo-ocular and colliculo-ocular reflexes to different eye velocities required by voluntarily selected visual targets of different distances from the subject. The efficiency of mechanisms which influence the foveation of moving targets can be degraded by conflictual visual and vestibular inputs and possibly by conflicts among any sensory inputs that influence the perception of whole-body motion. In support of this argument, one of the functions of the peripheral retina is to detect new objects of interest in the environment, which then begets a saccade leading to foveation of the new object. However, the direction and magnitude of the saccade depend upon the direction and angular velocity of the head relative to the Earth. Thus, sensory information indicating head velocity relative to the Earth would be important feed-forward information for generating accurate saccades, and the same information would be useful in maintaining foveation, once the target is attained.

The mechanism of alteration in vision is not clear. It is possible that the differences in acuity in the present study during concordant as opposed to discordant visual-vestibular stimulation are primarily controlled by retinal smear which in turn is attributable to greater nystagmus during the discordant visual-vestibular interactions. But why is the nystagmus greater? Is it because the discordance disrupts oculomotor control circuits responsible for visual suppression of vestibular nystagmus, i.e., diminishes the gain of hold circuits involved in voluntary fixation, or, alternatively, is the suppression poorer because foveal vision is reduced in some way? If there is validity in the latter conjecture, is the worsened foveal vision due to some form of saccadic suppression of vision (23), changes in accommodation (8), or is it attributable to some change in transmission of information in the optic nerve?

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depending upon the relative direction of peripheral background movement. Visual suppression of the VOR and visual performance were disrupted to a far greater extent when vestibular inputs and peripheral optokinetic inputs were discordant than when they were concordant. Results have potential implications for head-up displays and suggest a procedure for evaluating visual/vestibular function.

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