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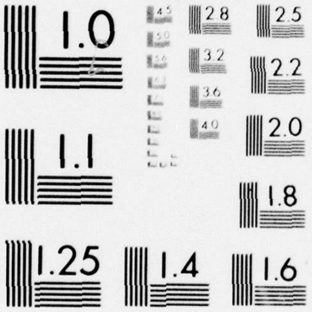
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Spatial Orientation from Motion-Produced Blur Patterns:

Detection of Divergence Change

Thomas [illegible]
Marcia [illegible]

⑭ Report 1978-4

⑥ SPATIAL ORIENTATION FROM MOTION-PRODUCED BLUR PATTERNS: Detection of Divergence Change ,

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

An observer in motion often experiences motion-produced blur patterns when the relative angular velocities of the visual environment become appreciable. These blur patterns vary in form according to the type of motion producing them and thus are potentially important sources of visual orientation information. Unless an observer is looking straight to the side of his moving craft or perpendicularly to the path of a moving surface, typically the individual blur lines making up the pattern diverge or converge

(continued)

on his retina. Thus if the plane of motion changes, the divergence changes also and the divergence change becomes an important cue for orientation bearing information on motion parameters such as altitude change.

This experiment measured human thresholds for divergence change in the form of sinusoidal expansion and contraction of downward-moving 16-line element patterns on the face of an oscilloscope. The objective was to determine whether blur pattern divergence change sensitivity was acute enough to be of any practical value in visual orientation using display information.

In order to more fully characterize this potential visual capability thresholds were measured at five different frequencies of divergence change (1/4, 1/2, 1, 2 and 4 hz.) and at two different vertical pattern velocities (8 and 16°/sec). This also allowed separate assessments of the contributions of variables related to the form of the motion path and of those related to pattern motion <u>per se</u>. Also, a foveal and a peripheral retinal locus were studied and divergence changes were superimposed either upon parallel pattern motion or upon a pattern motion that diverged ten degrees at the display extremes, thus providing a check of the generalizability to other parts of the retina and of the visual field.

Observers proved to be very sensitive to divergence change and could easily use it for visual orientation improvement in a large number of situations. Sensitivity was greater for higher-frequency oscillations and for slower-moving patterns. A comparison of high-velocity and high-frequency patterns with low-velocity and low-frequency patterns which would have the same element paths but slower motion indicated that either motion sensitivity <u>per se</u> or form information such as path curvature could underly the obtained thresholds.

Foveal viewing provided the best sensitivity; however, the 30-degree peripheral condition was not far behind. Divergence change was only slightly more detectable when it was superimposed on parallel rather than diverging trajectories, indicating that divergence change in parts of the blur pattern that already have divergence is still useable.

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INTRODUCTION

When an observer and a part of his environment are in relative motion with angular velocities that exceed a few degrees per second, there is appreciable motion-produced blurring of the textures that he sees. Textural elements such as points appear to be elongated in the direction of motion. The resultant blur patterns, patterns of semi-parallel streaks, are uniquely related to certain aspects of the motions that produced them and often the observer is able to perceptually assess his own history of motion using the information that is present in them. The first prerequisite of course is that he is able to detect the pertinent information. The present study is addressed to this issue and asks whether, when there is a small change in the divergence angle between the blur lines, the human observer is able to detect it.

Such divergence changes occur primarily when the observer and the target change separation; they can occur under various conditions of eye movement or when a craft rolls or pitchs (Harrington and Harrington, 1977).

The major questions that were addressed in this study were: 1) To what degree are human observers sensitive to changes in divergence of simulated blur patterns? 2) Is divergence change information useful in the periphery of the retina as well as the fovea? 3) What are the effects on blur pattern divergence sensitivity of the frequency of divergence change and of the angular velocities of the elements producing the blur patterns? In practice divergence of a blur pattern can change very slowly as when a pilot flies lower and lower when landing or it can change quite rapidly as when a pilot flies over a sharp rise in the ground.

The simulation was carried out using hybrid computer-generated patterns displayed on an oscilloscope. These patterns consisted of 16 illuminated elements that moved down the screen with an angular velocity of 8°/second or 16°/second. The elements of the pattern would alternately diverge and then converge as downward movement continued as though each was mounted on the bellows of a sinusoidally squeezed accordian that moved also in the downward direction. The purpose of this choice of stimulus for measuring divergence change thresholds was to allow more easy generalization from these parameters to the more complex situations encountered in practical design. Sinusoidal expansions and contractions of the pattern were chosen because with fourier analysis it is possible to break down any complex divergence change into component sinusoidal changes. Then, knowing the frequency response of the human operator, we can assess his ability to process divergence change under the particular conditions in question.

In the experiment reported here five different frequencies of sinusoidal divergence change were employed and also two different angular velocities of pattern movement were used.

DESCRIPTION OF THE EXPERIMENT

Subjects

There were ten subjects for this experiment; all were students at the University of Nevada, Reno, and they were paid for their participation. Subjects were run individually for a total of approximately five hours. All had normal visual acuity.

Procedure

During a session subjects were seated in a darkened viewing booth 29 inches from a 5-inch diameter circular scope and familiarized with the two fixation points (central and peripheral - 30° left) that they would use during the experimental trials. Subjects' eyes were monitored to ensure their maintaining the appropriate fixation.

There were two sub-experiments conducted using the same subjects. The first considered thresholds for detecting divergence change (thresholds being the points at which the subjects changed their judgments about the pattern) with angular velocity (8 and 16°/sec) and frequency of horizontal oscillation (1/4, 1/2, 1, 2, or 4 hertz) varying. One fixation point (central) and one divergence value (0° at the beginning of a trial) were used. The second sub-experiment determined threshold for divergence change with speed held constant (at 16°/sec); two fixation points were used (central and 30° peripheral), and there were two divergence values at the beginning of a trial (0° and 10°). Figure 1 shows two different displays, one where divergence change is superimposed on parallel trajectories (0° divergence angle) and one where divergence change is superimposed on a 10° divergence of the element trajectories. Five frequencies of oscillation were again used.

At the start of a trial subjects were shown a pattern of moving elements on the screen and instructed to "Say no, if the elements appear to be moving along a path with a constant angle; say yes, if the elements appear to be moving along a path with a constantly changing angle. During each trial, a pattern of elements moving along a constant path may gradually begin to move along a changing path. As soon as you notice any amount of change, respond with "yes"...(a sample was given)...A pattern of elements moving along a changing path may begin to move along a constant path. As soon as you notice the path becoming more constant, say "no"...(a sample was given)... Sometimes the pattern of elements will remain the same during the entire trial. Therefore, you must be somewhat certain that you notice a change before you respond."

Threshold was measured as the mean stopping point (averaged over the ascending and descending trials), and analysis was based on these means (summing over the twenty trials per condition).

Equipment and Stimulus Generation

The stimuli were electronically generated and presented on an oscilloscope. Figure 2 shows the arrangement. In common synchronization with a digital clock a vertical sawtooth provided the downward motion of the trace, a 16-step generator provided the horizontal levels necessary for each of the 16 vertical sweeps to be positioned and a 32-step square pulse generator stepped through a memory that was loaded to provide one "on" location per vertical line, thus giving one element on each vertical line when the trace modulation was turned on. Divergence of the vertical lines employed in other experiments was induced by mixing some of the vertical signal with the horizontal signal so that as the trace moved downward its horizontal component increased to spread out the lines at the bottom. Curvature of the patterns, employed in a previous experiment, was produced by introducing a controlled amount of signal from a memory that had been programmed to give the appropriated magnitudes of offset, into the horizontal deflection. Curvature change was previously brought about by sinusoidally attenuating the horizontal signal to the oscilloscope. In this experiment divergence change was caused by sinusoidally attenuating the horizontal gain of the oscilloscope.

In this experiment the rate of pattern advance was variable, assuming one of two values under control of the experimenter. Subjectively the impression was of up-and-down motion imposed upon the flow of the elements as though one were looking at individual elongated bars on the ground below a helicopter changing altitude sinusoidally while in forward flight (see Figure 2).

RESULTS

Two analyses of variance were performed. The results of the first appear in Table 1 where the effects of subjects, angular velocity of the pattern and frequency of lateral pattern oscillation are assessed. All of the main effects are highly significant but the interactions are not except for velocity and frequency.

The second analysis measured the effects on threshold of four variables: subjects, whether the pattern had a constant divergence even when no oscillation was present, central versus peripheral viewing and frequency with which the pattern oscillated horizontally. The results of this analysis appear in Table 2. Again, all of the main effects are significant but only the fixation by frequency interaction appears to be.

In Figure 3 the effects of horizontal oscillation frequency on threshold for the detection of divergent-covergent (or expansion-contraction frequency) oscillations are shown for the two separate pattern velocities. Changing the frequency of oscillation has a pronounced and regular effect on threshold with the higher frequencies being detected at much lower amplitudes.

Also in Figure 3 it can be seen that decreasing the pattern velocity allows detection at a more sensitive level with this advantage being regularly stronger as the frequency of horizontal oscillation is lowered.

In Figure 4 the effects of peripheral vs central viewing and of whether the divergence oscillation was superimposed on a constant divergence (10° divergence angle) as opposed to being superimposed on otherwise parallel trajectories (0° divergence angle) are shown again at the five different frequencies of oscillation.

Central viewing shows an appreciable advantage over peripheral viewing which seems to decline as the horizontal oscillation frequency increases. Also there is a small but regular tendency for thresholds to be lower when the oscillation is superimposed on parallel trajectories rather than appearing on trajectories that are already diverged.

Table 3 shows reformulated results from an earlier experiment on the detection of curvature change. These are included here for comparison with the present results. This will be undertaken in the discussion section.

Table 1

ANALYSIS OF VARIANCE SUMMARY

SOURCE	DF	SS	MS	P
Subjects	9	2,176.67	241.85	<.01
Angular Velocity	1	228.31	228.31	<.01
Error (1)	9	115.25	12.81	
Frequency	4	12,051.3	3,012.83	<.01
Vel.x Freq.	4	323.64	80.91	<.05
Error (2)	72	2,463.47	34.21	

Table 2

ANALYSIS OF VARIANCE SUMMARY

SOURCE	DF	SS	MS	P
Subjects	9	8,072.77	896.97	<.01
Initial Divergence	1	257.87	257.87	N.S.
Error (1)	9	481.25	53.47	
Fixations	1	8,689.57	8,689.57	<.01
Div. x Fix.	1	12.65	12.65	N.S.
Error (2)	18	2,141.61	118.98	
Frequency	4	53,576.7	13,394.2	<.01
Div. x Freq.	4	137.96	34.49	N.S.
Fix. x Freq.	4	2,164.39	541.10	<.01
Div. x Fix. x Freq.	4	22.10	5.5	N.S.
Error	144	7,786.05	54.07	

Table 3

CURVATURE CHANGE (mm)

Central Viewing

hz	8°/sec	16°/sec
1/4	7.6	9.7
1/2	5.7	7.6
1	3.6	5.3
2	2.8	3.3
4	2.3	2.8

Peripheral Viewing

(30° Left)

hz	8°/sec	16°/sec
1/4	10.2	13.5
1/2	7.4	10.4
1	5.8	7.1
2	4.8	6.1
4	3.3	4.6

DISCUSSION

The major finding of this experiment was that the blur pattern parameter of divergence change is well within the range of human useability. In the following the effects of the separate variables under study on this useability will be discussed and, although the experiments were not geared toward discovering the underlying mechanisms of divergence change detection *per se* some information pertinent to the question of mechanisms was forthcoming and will be noted as well.

Frequency of Oscillation

Figure 3 shows the relation between the expansion-contraction frequency and threshold for the detection of horizontal oscillation (divergence change threshold). There is a very strong relationship with thresholds appearing to decrease asymptotically to approximately one millimeter foveally. This value is one of the most impressive that was encountered in the investigations on blur patterns so far. Translated from the experimental context to actuality this distance would correspond to a movement 100 feet below a pilot of on the order of 1.5 inches which in turn would signal a change in altitude of about two feet. It is possible that this figure could be significantly improved if the grain of the blur pattern were made appreciably finer as in fact happens with naturally-occurring blur patterns. Previous work of Harrington (1967) showed that as static lines with disparate slopes (such as are found in divergent or convergent blur patterns) are packed more closely together, it becomes easier and easier for observers to detect the divergence. The blur patterns used in this experiment were somewhat coarse the elements being packed with an approximate density of only one element per square inch. This is a much coarser pattern than one would be likely to encounter in nature except under very unusual circumstances.

There are several possible explanations for why the threshold rises so dramatically at the slower horizontal oscillation frequencies below 2 hertz. One of these is that the horizontal component of velocity becomes too slow to be detected by a human visual system. It seems unlikely perhaps that the visual system would partition the motions of the particles into horizontal and vertical components in the same way an oscilloscope does and presently there is no completely definite answer as to whether or not this could happen, but there are experiments which hint strongly at this alternative. Psychophysically Hershberger, Stewart and Laughlin (1976) experimentally pitted cues that would lead to perception of one direction of projected rotary motion against cues that should cause perception of motion in the orthosonal direction. Their analysis indicated that both horizontal-related cues and vertical-related cues had significant effects but that there was no interaction, implying that in this case there was functional independence between some horizontally tuned system and a vertically tuned one. Physiologically also there are an infinity of possible mechanisms based on current knowledge that could lead to a horizontal-vertical dichotomy in processing.

When the data of this experiment is compared with psychophysical data from velocity threshold experiments there is a close match under the speculation that horizontal movement is the pertinent stimulus variable in divergence change detection. When the sinusoidal oscillation used here to produce divergence change has a frequency of one hertz then the corresponding excursion on the display in the horizontal direction corresponds to a visual angle of about 5 minutes of arc which implies that the horizontal velocity component is about 5 minutes of arc per second. At one-quarter the frequency, or 1/4 hertz, the velocity is only about one minute per second. Aubert (1886) measured velocity thresholds for moving lines and found that with a stationary point visible nearby the thresholds were on the order of one or two degrees per second and that without a stationary reference point they were twice that high. Thus it appears evident that the horizontal velocity component could well be the key variable in divergence change detection and, as Figure 3 shows, that a lack of adequate velocity sensitivity could lead to the sharp rise in threshold evident at lower oscillation frequencies. If this is true however the explanation fails to encompass the significant and regular difference between divergence change detection in the faster 16 degrees/second patterns and those with half that vertical velocity.

In the curvature change experiment reported elsewhere (Harrington and Harrington, 1978) it was found that thresholds conceivably could have been limited by the amount of curvature in the patterns if one entertained the parallel assumption that to detect curvature change, observers were simply attending to the alternate emergences of concave-right and then concave-left curvature and that the amount of curvature present when below-threshold curvature changes were present was simply inadequate for detection. Comparison with the data of Pettee (1978) and with Valle (1956) for detection thresholds for curvature of static lines as a function of line length showed that such could be the case. Similarly here calculations show that the maximum curvatures on the screen at threshold values of divergence change are in the appropriate threshold range.

As was the case in the curvature change experiment, it is possible to isolate the variable of absolute curvature present on the screen even though maximum curvature in the patterns does depend upon the frequency of the horizontal component of oscillation because a sinusoidal track of higher frequency necessarily has sharper curves at the peaks and although the curvatures of the trajectories depends on the velocity of the pattern. A faster vertical component stretches the sinusoidal trajectory out and thereby lessens the sharpness of its curvature. This separation of trajectory curvature from frequency and velocity is done by comparing patterns of similar frequency and velocity with the responses to patterns of half the horizontal frequency and half the vertical velocity. The result is that the trajectories traced by the elements is exactly the same and thus has the same inherent curvatures; the elements merely move on that pattern twice as fast. Figure 5 shows such a comparison in which the data seen plotted in Figure 3 have been replotted shifting the 16degree per second curve one unit to the left to bring respective patterns of the two classes into vertical alignment such that each vertically aligned pair will have identical trajectories. When this comparison was made for the curvature change data it was found that there were no differences in curvature thresholds for the two patterns if the shapes of the trajectories in the patterns were the same; therefore, trajectory curvature was potentially implicated. Here however it is clear that even though two given patterns may have identical paths of travel for their elements the pattern exhibiting the higher frequency and higher vertical velocity will be detected more easily.

Figure 6 however suggests that the shape of the pattern may interact with the vigour of its internal dynamics. The comparisons of like-shaped but different-speeded patterns of Figure 5 are replotted to show that the relation between trajectory shape and the difference between threshold responses for different-speed patterns exhibits roughly asymptotic behavior as the sinusoidal element paths on the screen become shorter and concurrently the curvatures of the patterns become sharper. The possible importance of the vigour of relative motion, meaning primarily the frequency of the horizontal component, can also be inferred from Figure 7 comparing the results of the curvature change experiment with those from this divergence change study. Compare in terms of their differing pattern parameters, the displays from the two experiments. For a given vertical pattern velocity and a given horizontal oscillation frequency the curvature change patterns will have more overall curvature since all of the tracks have a specific and equal amplitude of oscillation. The divergence change paths however never have any curvature of the central motion path since the display divides the curvatures in one direction that lie on the left of the display from their mirror image changes on the right. Maximum curvature equal to the corresponding measure for curvature in the curvature change experiment is found to be one cm. from each extreme horizontal margin of the display with intermediate amounts of curvature being found between the center and the extremes. However the divergence change patterns trade this relative lack of overall curvature for considerably more relative internal motion. While elements in curvature change displays always move horizontally together a particular distance, elements in the divergence change displays on opposite sides of the screen move away from each other producing twice the amount of relative movement.

Figure 7 compares threshold responses for horizontal oscillation for the divergence change and the curvature change experiments. Results are quite comparable at higher frequencies of horizontal oscillation but when this side-to-side drift becomes slower, then there is considerably more sensitivity to divergence change even though the overall pattern curvature is less and the frequency of oscillation is the same. It would seem that greater relative motion in the pattern may be responsible for the greater sensitivity. Perhaps the most tenable speculation about this interaction would be that at higher frequencies the dynamics of the eye movement systems and feedback systems, having poor low-frequency responses, pass the higher frequencies adequately but are likely to drift along with the lower frequencies. In the divergence change situation there is relative movement of twice the veclocity because the elements are moving apart from each other and this movement cannot be ignored by a visual system that has trouble keeping track of the positions of slowly-moving things because there is relative movement on the retina in both directions, so that rather than keeping track of absolute position, now the task becomes one of keeping track of relative position. Kinchla (1967) has speculated on the basis of his work that there are two kinds of motion perception. The first is "absolute" wherein there is no external reference and the second is "relative" in which some external reference is present in the patterns. Here the curvature change patterns have attributes of the former and the divergence change patterns have attributes of the latter. Related to this dichotomy and bearing on the experimental results is the finding of Gottsdanker (1962) that acceleration detection is better if there is a nearby stationary landmark in the pattern. In these experiments of course the landmark would be a nearby pattern element that, in addition to being stationary, moved toward some other element, thus making the reference even more emphatically point to relative movement between the two. Whether these latter contributions to the idea of relative versus absolute movement would show an interaction with movement frequency is not known; however, the dynamic characteristics of the visual system in general would suggest it.

Fixation

The patterns were projected onto different retinal areas in order to determine whether the use of the blur pattern parameters under study would be feasible in peripheral vision. Figure 8 shows that there is a definite central viewing advantage. Whereas it was previously noted that threshold in central viewing would asymptote at on the order of one millimeter of peak-to-peak excursion it can be seen in the figure that in the periphery the threshold peak-to-peak excursion of an element 1 cm from the edge of the display would asymptote at perhaps four or five times that value and that at lower frequencies of oscillation the peripheral retina, while still fairly sensitive, shows an even greater disadvantage.

This difference probably results, in terms of the previous discussion of mechanisms, from the lesser peripheral acuity and sensitivity to curvature and components of lateral velocity in the pattern and was an expected finding.

The implication of this central-peripheral difference and of the absolute sensitivities in general is that for very sensitive perceptual tasks involving divergence change, for example altitude change detections, foveal viewing should be employed but that for coarser judgments a display in the periphery of the visual field would be adequate.

Divergence Bias

Since the major emphasis of the experiment has been toward investigating patterns that might be seen directly below or in certain other restricted viewing areas, and because the divergence was superimposed on parallel trajectories such as are found directly below a craft, a separate condition was included to provide an initial test of the generality of the foregoing results. In this condition the divergence change oscillations were superimposed on trajectories that had a maximum at the outer extents of the screen of 10 degrees divergence. This case would be encountered in actual flight if for example the pilot were to look to the front of the craft or to the front and to the side as he flew over a small hill.

The results of this phase of the investigation are shown in Figure 4. The extremely small decrease in sensitivity to divergence change with the 10° divergent trajectory may be the most important point emerging from the figure in that a high degree of similarity apparently exists between these separate locations in the visual field and thus the generalizability of the results likely includes the majority of the other portions of the visual field as well. However a small but regular advantage can be seen of the parallel modulated pattern over the one whose bias divergence was 10 degrees. It is felt that this is probably due to the fact that parallel trajectories are a very special case and as such have divergence change cues peculiar to themselves such as uniformity of acceleration up and down the patterns. If this is true then the advantage seen is probably not a function of the amount of "carrier divergence" upon which the changes are superimposed (which would correspond to different angles of regard around in the visual field). Experiments employing other values of modulated divergence would need to be carried out to answer this point.

Subjective Appearance

Viewing the divergence change patterns when the change was above threshold gave pronounced visual impressions of a surface that moved sinusoidally closer and farther away as it moved along beneath (or beside depending on the viewer's perceptual set). When the divergence change was below threshold the appearance was of flying over a surface looking down and maintaining a straight and level attitude. When the ten-degree divergence was present the impression was the same except that the surface involved appeared to be tilted.

The visual sensations were by-and-large what would be predicted by the "decoding principles" of Johannson (1972). Johannson notes that a number of his movement patterns, employing only a few elements in each case, obeyed his principle of minimum object change where the preferred perception is to see an object that does not change its own dimensions but rather changes its location or orientation. This in fact was the case in this experiment and a rigid surface perhaps analagous to the ground or to a subway wall was seen.

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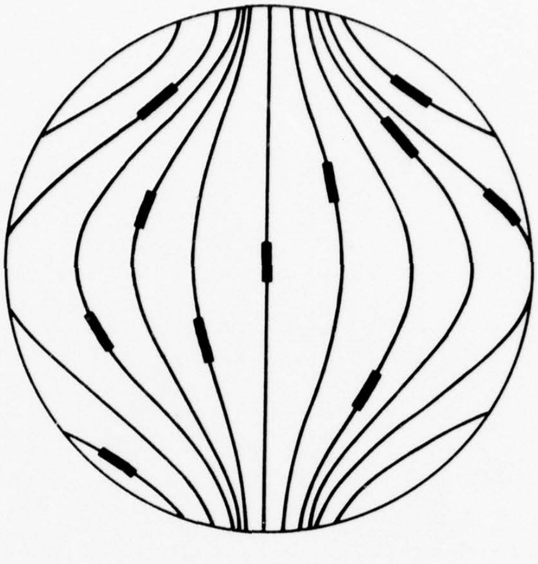
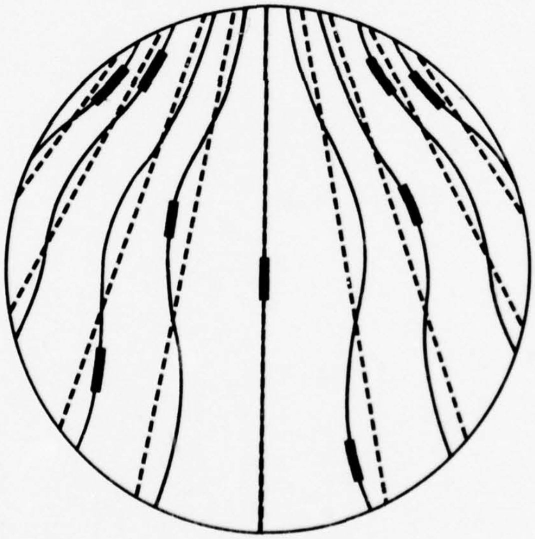


Display with divergence change superimposed on parallel trajectories



Display with divergence change trajectories superimposed on 10° of divergence

FIGURE 1

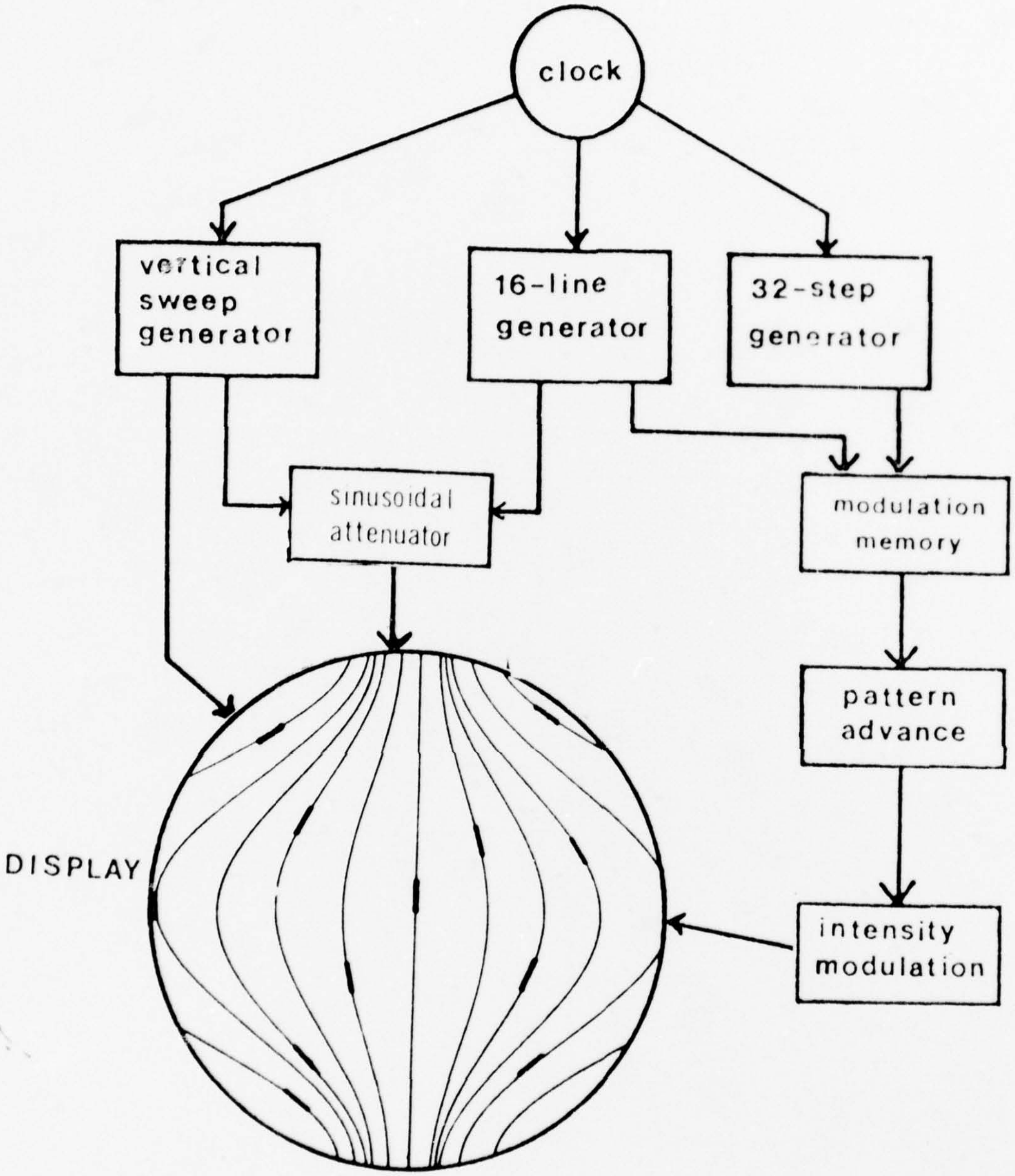
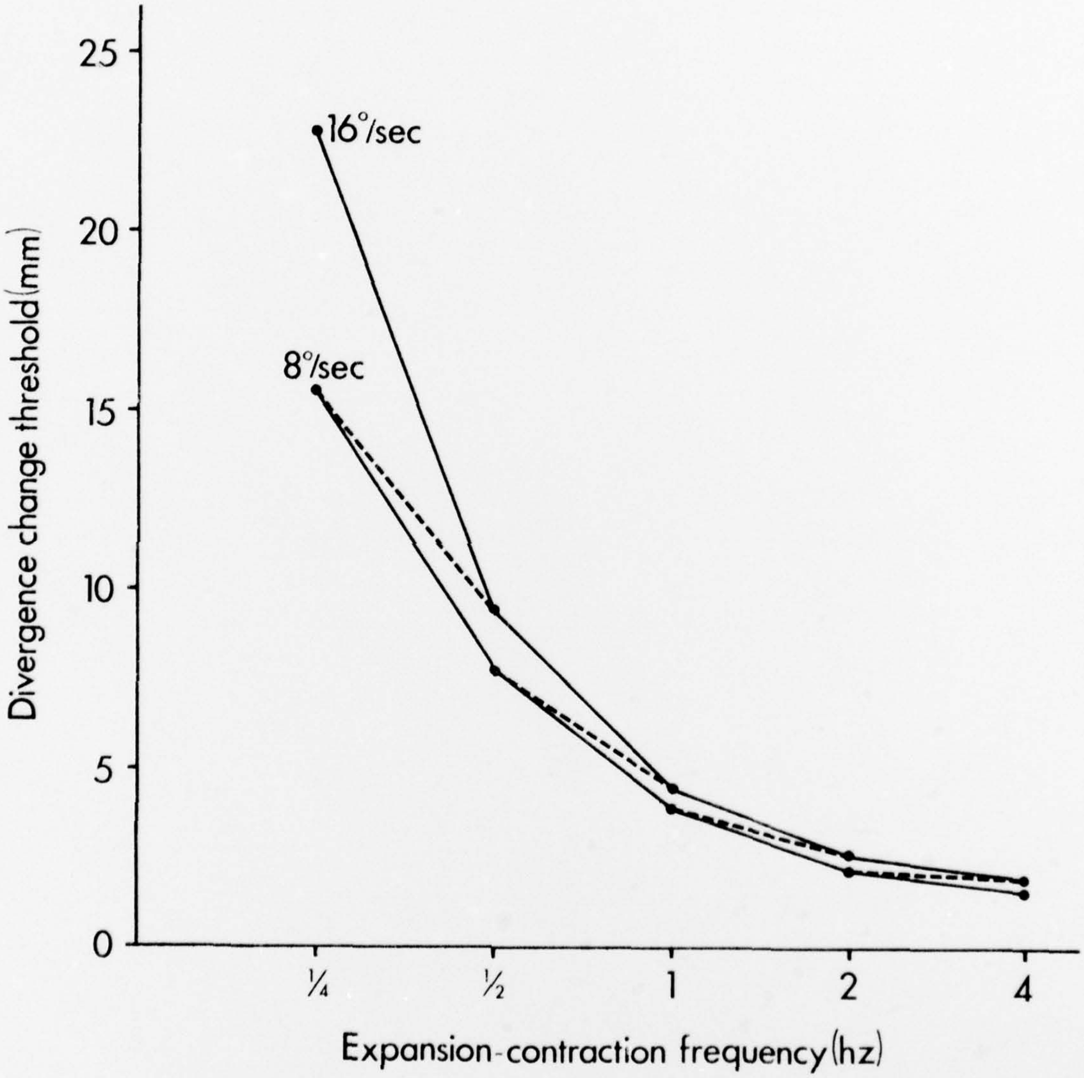


FIGURE 2

Schematic diagram of the synthetic blur pattern generator. In common synchronization with the clock, vertical lines on the display are produced by the vertical sweep generator, displaced successively from left to right by the 16-line generator and modulated to produce one element per line by the 32-step generator, the memory and the intensity modulator. Divergence change is produced by mixing sinusoidally varying amounts of sweep signal with the horizontal displacement generator's signal.



Divergence change threshold (mm)
0
5
10
15
20
25
16°/sec
8°/sec
¼
½
1
2
4
Expansion-contraction frequency (hz)

FIGURE 3

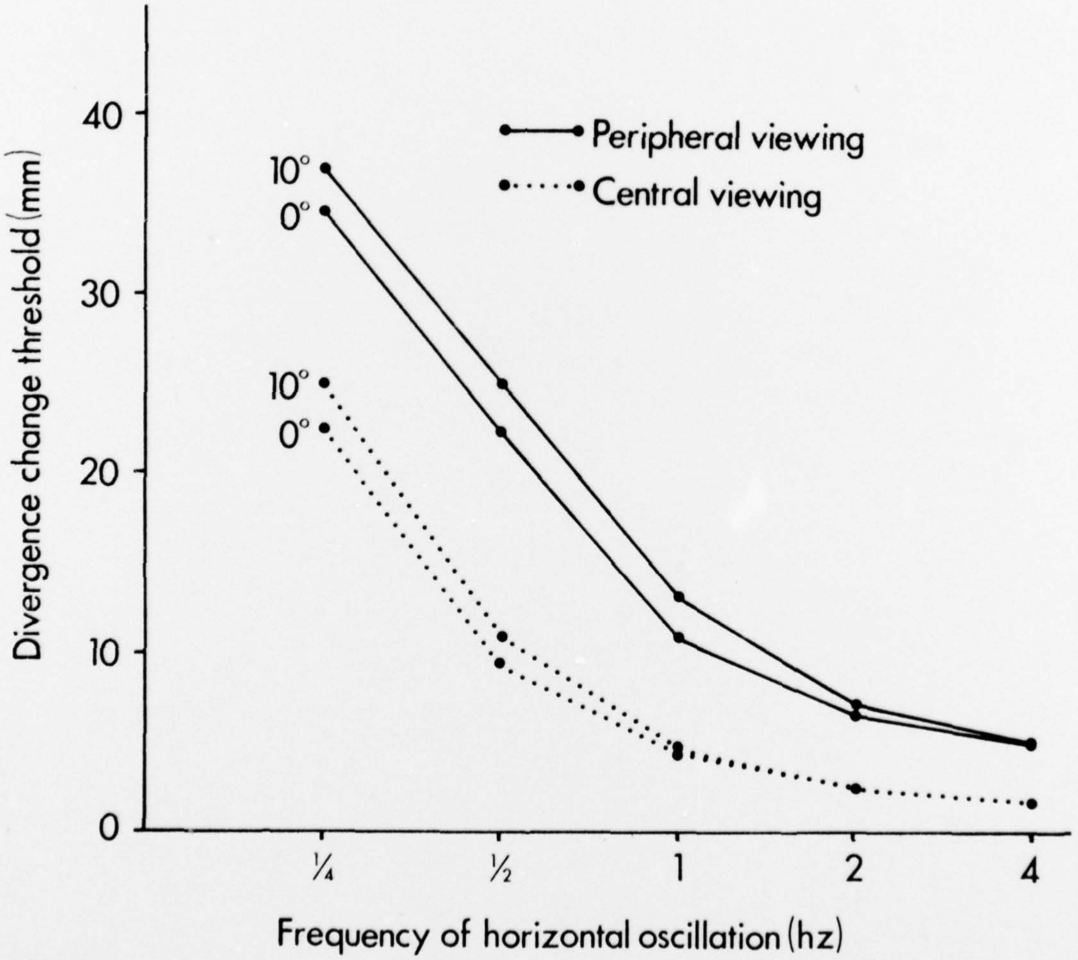
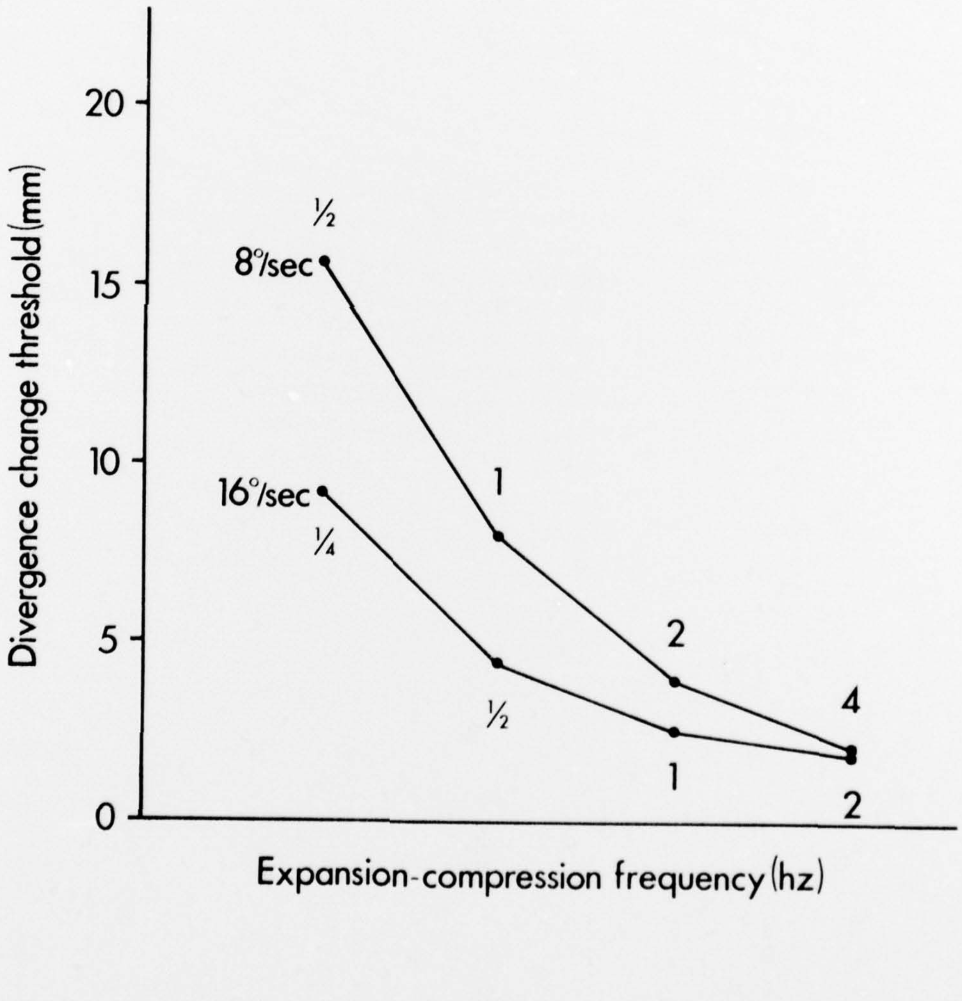
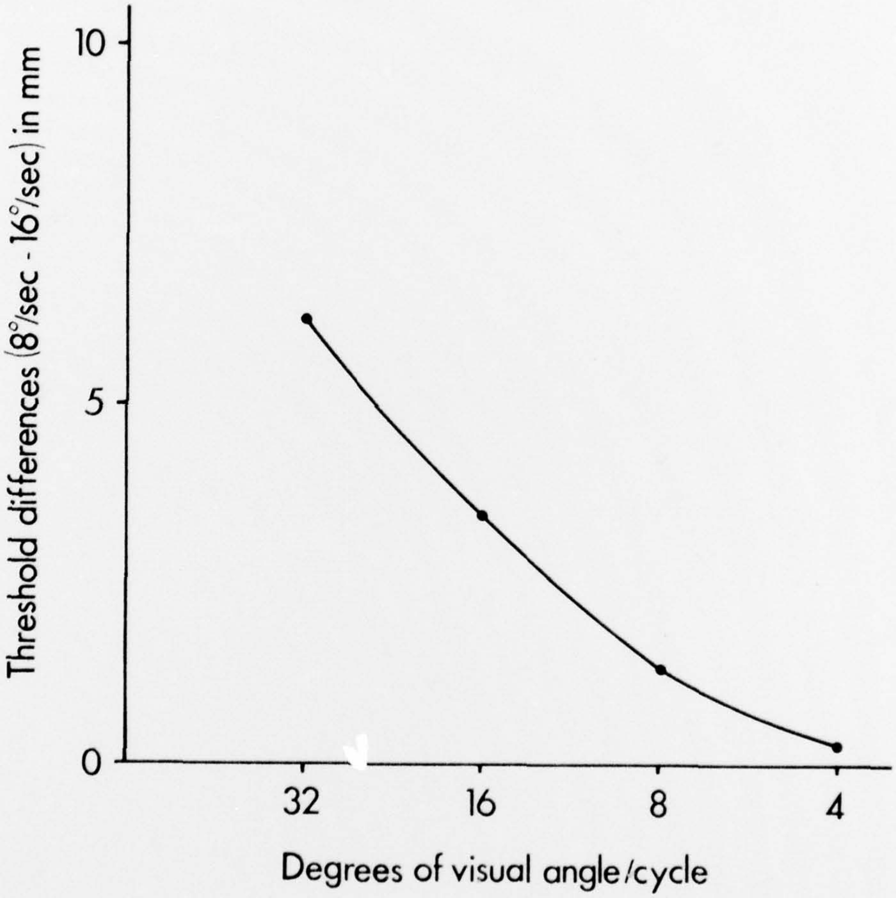

Divergence change threshold (mm)
40
30
20
10
0
10°
0°
10°
0°
Peripheral viewing
Central viewing
¼
½
1
2
4
Frequency of horizontal oscillation (hz)

FIGURE 4



Divergence change threshold (mm)
20
15
10
5
0
½
8°/sec
1
2
4
16°/sec
¼
½
1
2
Expansion-compression frequency (hz)

FIGURE 5



10
5
0
Threshold differences (8°/sec - 16°/sec) in mm
32
16
8
4
Degrees of visual angle/cycle

FIGURE 6

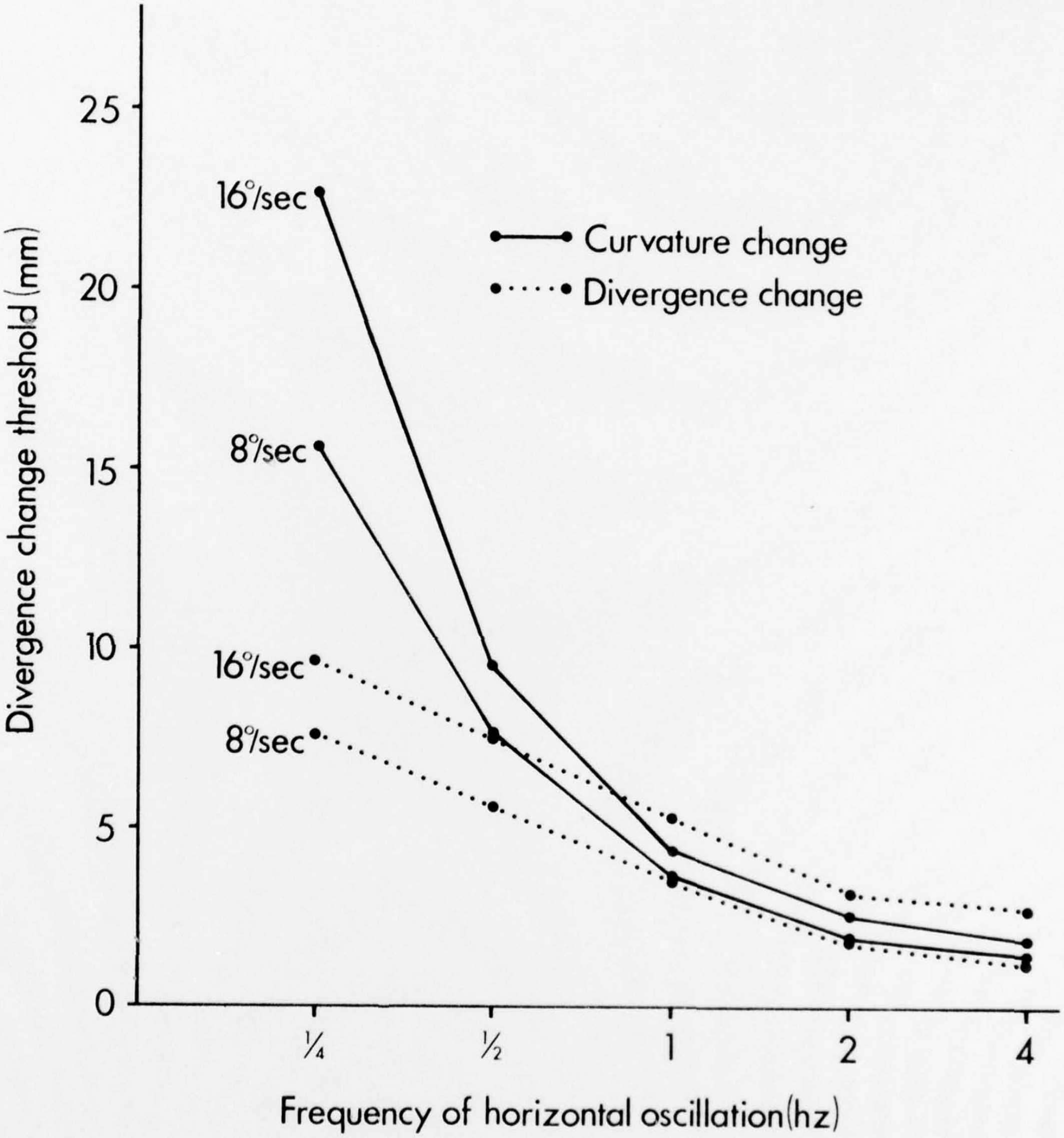
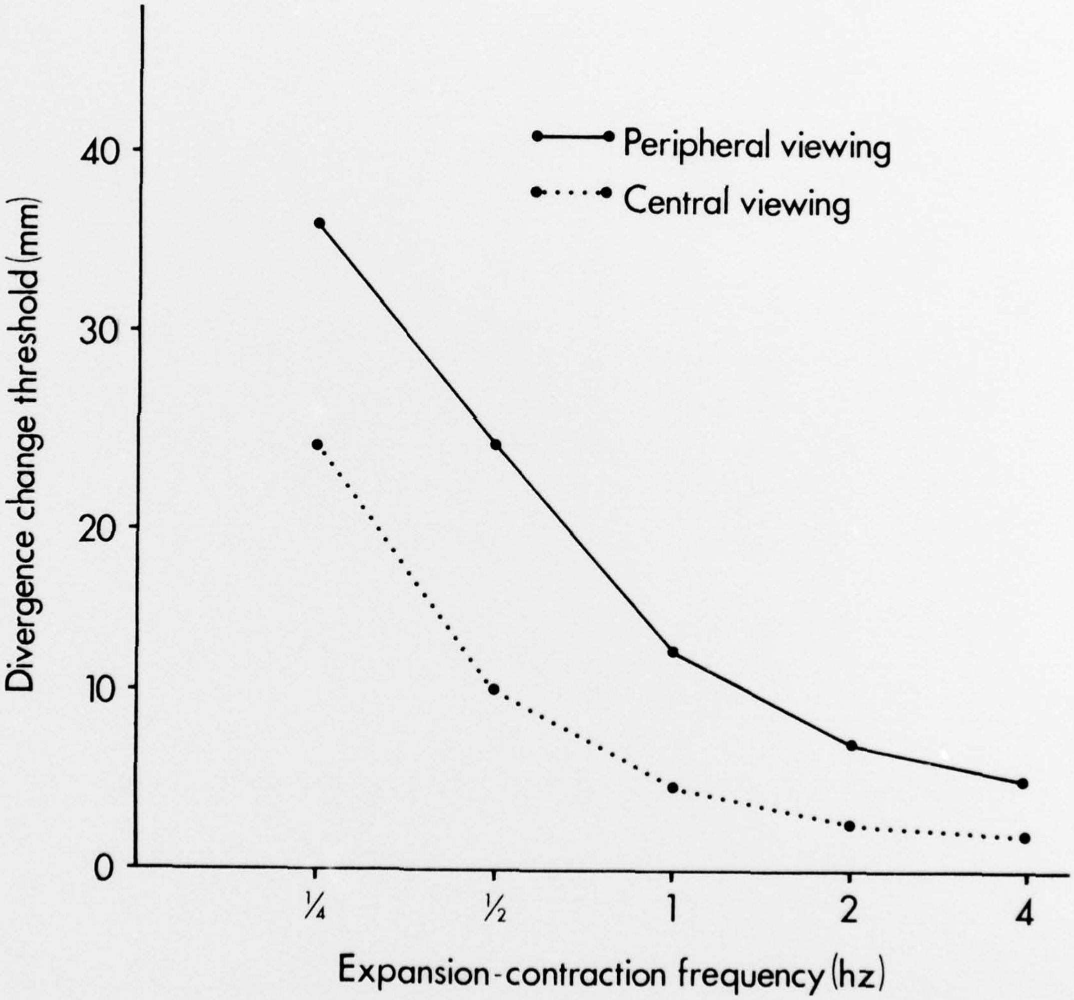

Divergence change threshold (mm)
25
20
15
10
5
0
16°/sec
8°/sec
16°/sec
8°/sec
Curvature change
Divergence change
¼
½
1
2
4
Frequency of horizontal oscillation (hz)

FIGURE 7



Peripheral viewing
Central viewing
Divergence change threshold (mm)
40
30
20
10
0
¼
½
1
2
4
Expansion-contraction frequency (hz)

FIGURE 8

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