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DIFFERENTIAL THRESHOLDS FOR MOTION IN THE PERIPHERY

by James M. Link and Leroy L. Vallerie

Prepared by
DUNLAP AND ASSOCIATES, INC.
Darien, Conn.
for Electronics Research Center

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ABSTRACT

A study was conducted to determine the differential thresholds for rotary and linear motion in the periphery. Isograms were developed based on threshold estimates obtained from ten subjects using the psycho-physical method of limits. The results of this study indicated that differential thresholds for rotary and linear motion were found to increase as a linear function of eccentricity angle. Threshold isograms for both types of motion are elliptical in shape with the horizontal axis approximately twice as long as the vertical axis. Based on statistical analysis, there appears to be no real difference between rotary and linear motion. Subjects, however, reported a preference for rotary motion. Thresholds decreased logarithmically as a function of changing speed. Age of the subject appears to be a highly significant factor which influences the perception of motion. At high display velocities, subjects reported the occurrence of interference factors such as blur, fusion, strobing and flicker. These factors were particularly noticeable with the linear display.

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DIFFERENTIAL THRESHOLDS FOR MOTION IN THE PERIPHERY

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Dunlap and Associates, Inc.

INTRODUCTION

Advances in our aerospacecraft capabilities have required man to perform an increasing number of difficult, continuous control tasks based on visual information presented to him on conventional displays designed for viewing with central vision. Typical examples of such tasks are landing high performance aircraft during poor weather conditions and maneuvering or rendezvousing spacecraft using multi-dimensional control systems. The time required to move and refocus the eyes in visually switching between information sources seriously restricts the rate with which man can acquire information and hampers his control performance (Vallerie, 1967; Wulfeck, Weisz, and Raven, 1958; Travis, 1948). In an effort to eliminate the detrimental effects of visual switching, displays have been developed for viewing with peripheral vision. Majendie (1960), for example, proposed to use such displays to "provide flight intelligence to the pilot without distracting his attention from other tasks, without preventing him from looking freely about, either through the windscreen or within the cockpit, so that he can take appropriate corrective action from the information provided without serious interruption to his other tasks."

Both simulator and flight tests have indicated that valuable information can be obtained through peripheral vision "while" central vision is used to scan other information sources; e.g., looking for the runway and, at the same time, receiving control information by means of a peripheral display (Vallerie, 1967, 1968; Moss, 1964a, 1964b; Holden, 1964; Keston, Doxtades and Massa, 1964; Fenwick, 1963; Brown, Holmquist and Woodhouse, 1961; Chorley, 1961; Majendie, 1960). In this case, the operator is required to switch only his attention to information presented in his periphery instead of wasting precious time in redirecting and refocusing his eyes on spatially separated conventional displays.

Research carried out by Vallerie (1967), for example, clearly demonstrated that control performance deteriorates as visual switching increases and that peripheral displays can be used to overcome its adverse effects.

The utility of peripheral displays, therefore, is well established and a number of displays employing motion, as the primary encoding stimulus, have been developed to facilitate aircraft control especially during final approach and landing (Vallerie, 1968; Reede, 1965; Fenwick, 1963; Chorley, 1961). Displays incorporating other than motion, as the primary encoding stimulus, have not been given serious consideration because of their relatively limited discriminability in the visual periphery and their incompatability with anticipated operational environments. For example, displays requiring shape and pattern recognition, in addition to being relatively poor in the periphery, would suffer from accelerative forces and vibration; displays utilizing changes in color, brightness, or flicker rate would be affected by the level of ambient illumination in cockpits while a velocity display involving motion would be satisfactory under a wide range of illumination. Research carried out by Salvatore (1968) also indicated that velocity information is more accurately assessed in the periphery than in the fovea.

Additional support for the use of motion as the primary stimulus for encoding peripheral displays is based in the physiological structure of the peripheral retina. A moving object, for example, causes the neural receptors to fire at their maximum excitation level continuously while a stationary object causes the receptors to fire at their maximum level for only a brief period at the beginning of excitation. The level then decreases to a lower steady state. Neural receptors in the periphery are also connected in groups to a single synapse to produce summation of impulses. Hence, perception of moving objects is enhanced by both high excitation and summation of neural impulses which helps to explain their attention-getting quality (Polyak, 1957; Granit, 1931; Adrian, 1928).

Few studies have been conducted dealing with the perception of motion in the periphery. Most of these studies have been concerned primarily with the definition of absolute thresholds of motion and the decreased sensitivity of peripheral vision (McColgin, 1960; Gordon, 1947; Klein, 1942). Apparently, no research has been conducted to determine differential thresholds for motion in the periphery, i.e., detection of changes in the rate of motion. McColgin, (1960), for example, mapped the periphery in terms of the absolute threshold of motion. He found that the threshold increases linearly as a function of eccentricity angle for both linear and rotary motion. Threshold isograms for both rotary and linear motion were elliptical in shape with the horizontal axis approximately twice as long as the vertical axis.

The purpose of this study is to determine the differential thresholds for rotary and linear motion in the periphery. With definitive data on this visual ability, it will be possible to better assess the adequacy of motion cues for encoding information presented in the periphery, to determine the type and range of motion most suited for peripheral displays, and to select optimum locations for positioning them in the operator's visual field.

METHOD

Differential thresholds for linear and rotary motion were measured using ten subjects and the psycho-physical method of limits under controlled laboratory conditions. Three reference velocities were employed; these were 7.98 cm/sec., 19.95 cm/sec., and 31.92 cm/sec. Twenty-three different locations in the peripheral retina were investigated as illustrated in Figure 1. All possible combinations of motion, reference velocities, and retinal locations were presented to each subject in a different random order.

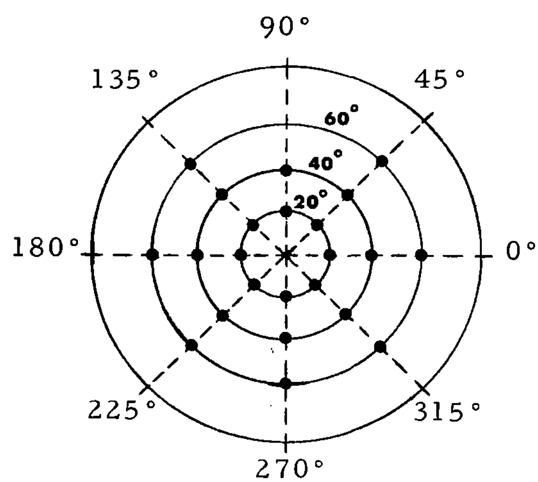

Figure 1. Location of Test Positions in the Visual Field.

Motion Displays

The two displays, employed in the study, were similar to standard aircraft instruments and were of the same areal size. They were constructed of translucent lucite plastic and coated with flat black paint except for that portion of the display representing the moving element or "hand." The rotary display is illustrated in Figure 2. It was 7.62 cm. in diameter and contained a moving element which was 2.54 mm wide and 7.62 cm long. The hand rotated at its center in a counter-clockwise direction. The linear display is illustrated in Figure 3. Its dimensions were 5.97 cm. wide by

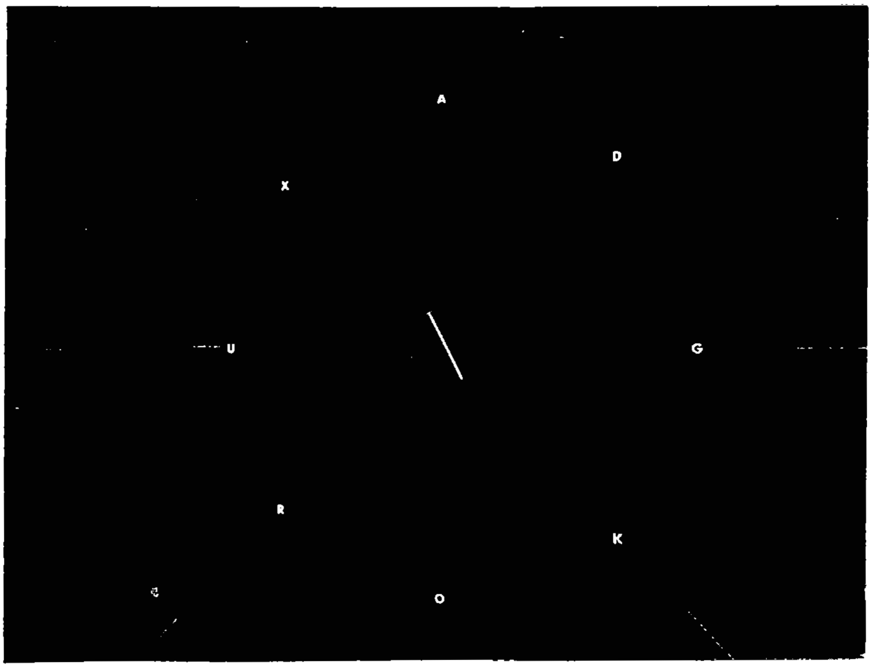

Figure 2. Rotary Motion Display.

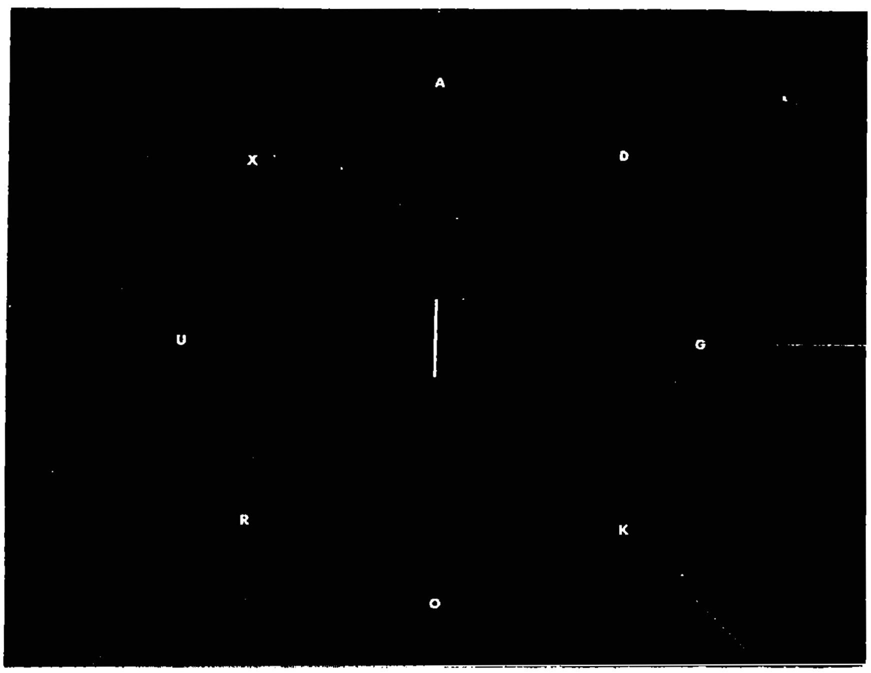

Figure 3. Linear Motion Display.

7.62 cm. high and contained a hand identical to that used in the rotary display except that it moved from right to left in a linear fashion. The visual area subtended by the background and hand were identical for both displays. The displays were driven by a variable speed motor. Display velocity was varied and controlled by means of pre-set potentiometers and a motor controller. Presentation time was maintained at three seconds by an electronic timer which automatically alternated between the pre-set reference velocity and the differential velocity or test speed. A tachometer generator and digital voltmeter was used to measure and monitor the speeds of the displays. They were situated at a distance of 71.12 cm. from the subject's eyes. A head and chin rest was used to stabilize the display image in the visual field.

Subjects

Ten subjects were selected from the staff of Dunlap and Associates, Inc. Selection was based on the results of visual tests carried out with a Ferre-Rand Perimeter and Keystone Telebinocular. All subjects who participated in the study possessed normal central and peripheral vision without the use of corrective lenses. Their ages ranged from 22 to 45 years.

Procedure

Each subject received standard instructions. They contained an explanation of the study's objectives, the method of response, and the necessity of maintaining the designated fixation point. Twenty minutes of practice was provided before the first session and a five-minute warm-up prior to each subsequent session. A typical session lasted for a period of 30 minutes.

The method of limits was employed to measure the differential thresholds for each location in the visual field. Each reference velocity was presented for a period of three seconds and then immediately followed by a three-second test period in which the speed was increased to a slightly higher rate. The reference velocity was then repeated immediately for a period of three seconds and followed again by a test period containing a still higher rate. During the test period, a tone was presented to the subject by means of earphones. The tone signaled the subject to respond either "yes" indicating that a change in speed was noticed, or "no" indicating no change was seen. The tone also served to mask auditory cues produced by changing the motor speed. Speed was increased in step-wise increments until the subject verbally reported a difference between the reference and the test rates of motion. Threshold estimates were also obtained by starting with a test speed noticeably higher than the reference and descending in step-wise increments until the subject reported that both rates appeared identical to one another. Six threshold estimates were obtained: three in an ascending order and three in a descending order. Differential thresholds for both types of motion at any one retinal position were then calculated by averaging the mid-points of the speed intervals between the positive and negative reports given by the subjects.

RESULTS

Differential thresholds for both linear and rotary motion were calculated by averaging the threshold estimates for each reference velocity and test position in the periphery. In general, thresholds for both types of motion were found to increase linearly as a function of eccentricity angle along each radius of the visual field. Figure 4, shows the average threshold for all radii plotted as a function of eccentricity angle. Threshold values are expressed in the standard Weber form $\frac{\Delta V}{V}$. Because of the linear increase in threshold with eccentricity angle, it was possible to interpolate between known threshold values along each radius in order to calculate points of equal threshold in the visual field. These data were then plotted in the form of isograms as shown in Figures 5 through 10. The general shape of the isograms, regardless of the reference velocity and type of motion, is elliptical with the horizontal axis approximately twice as long as the vertical axis.

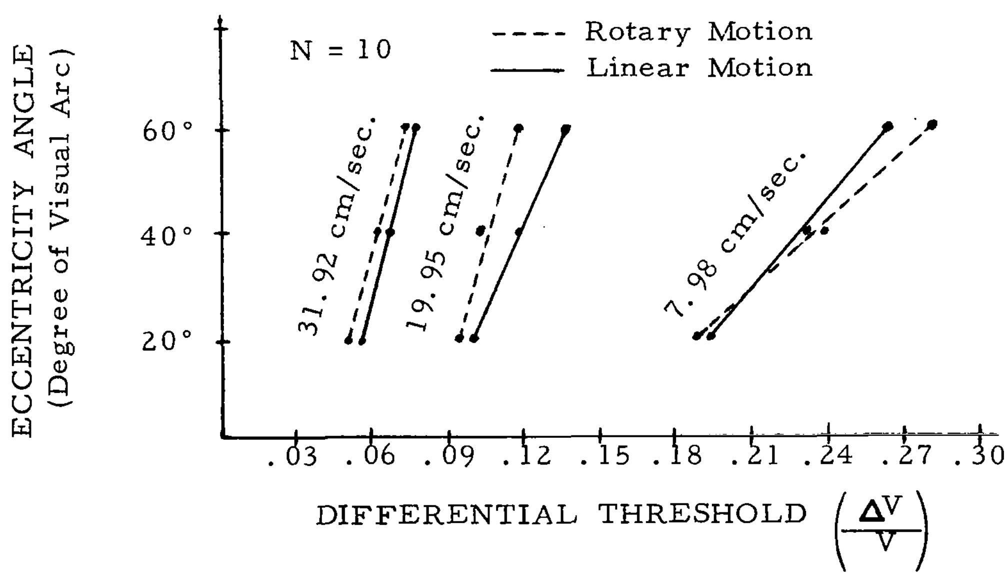

Figure 4. Differential Threshold as a Function of Eccentricity Angle.

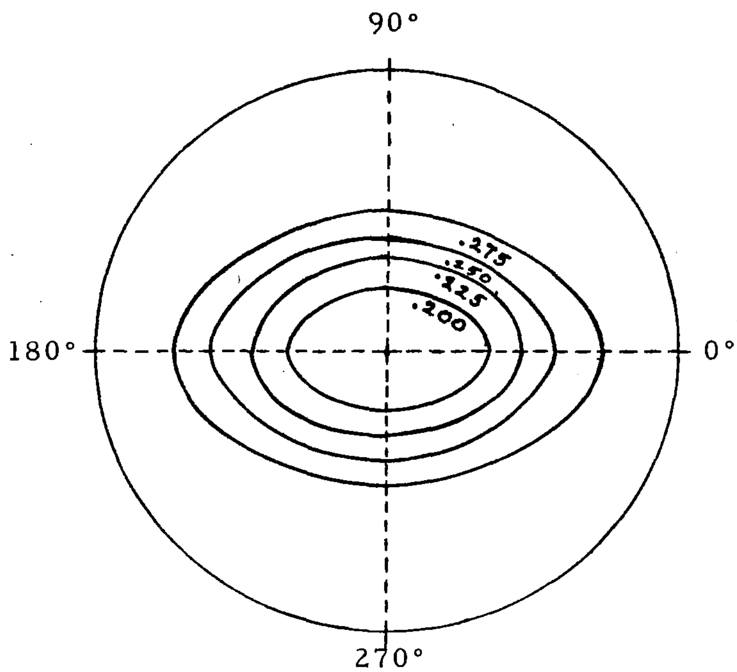

Figure 5. Differential Threshold $\left(\frac{\Delta V}{V}\right)$ Isograms for Linear Motion at the Slow Reference Velocity (7.98 cm/sec).

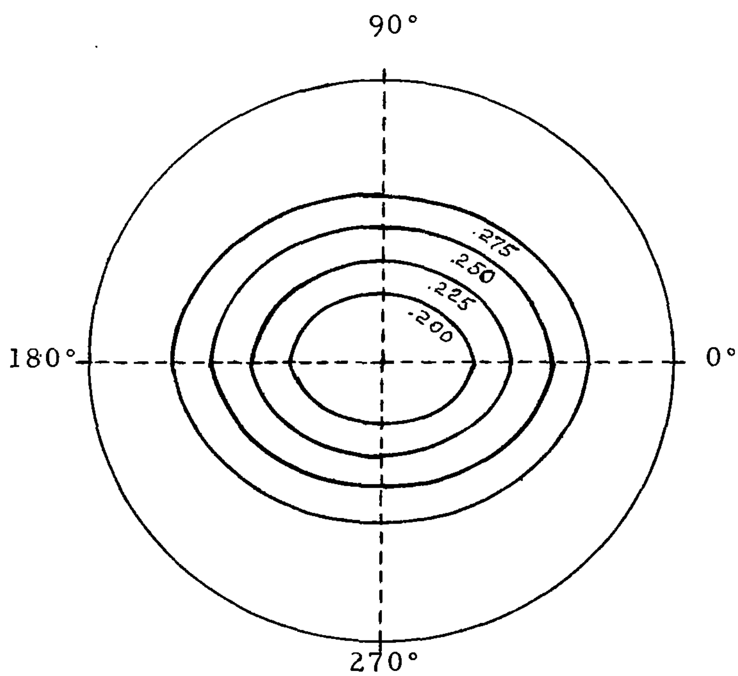

Figure 6. Differential Threshold $\left(\frac{\Delta V}{V}\right)$ Isograms for Rotary Motion at the Slow Reference Velocity (7.98 cm/sec).

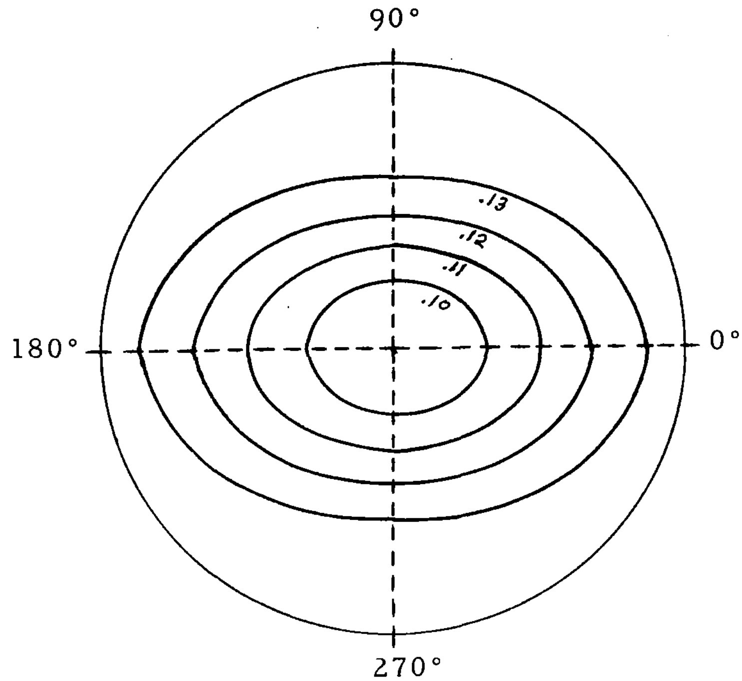

Figure 7. Differential Threshold $\left(\frac{\Delta V}{V}\right)$ Isograms for Linear Motion at the Medium Reference Velocity (19.95 cm/sec).

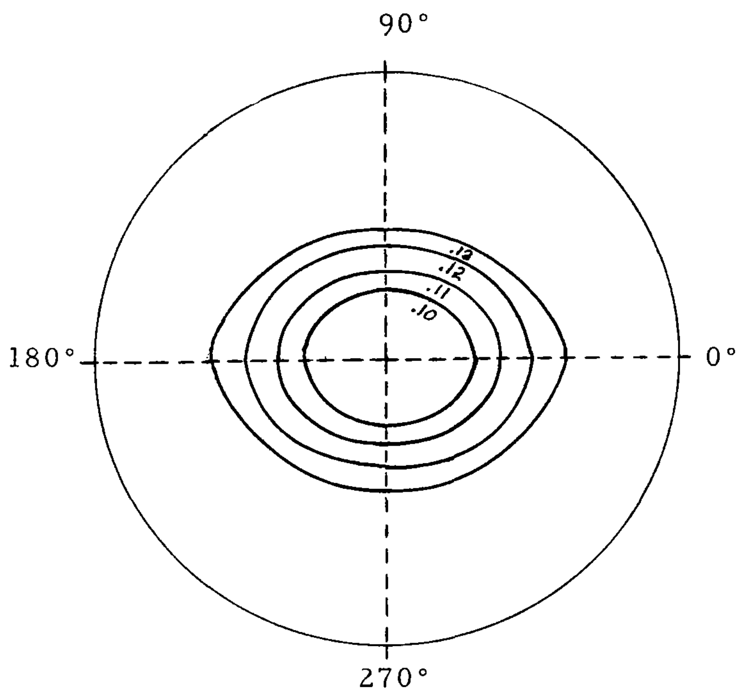

Figure 8. Differential Threshold $\left(\frac{\Delta V}{V}\right)$ Isograms for Rotary Motion at the Medium Reference Velocity (19.95 cm/sec).

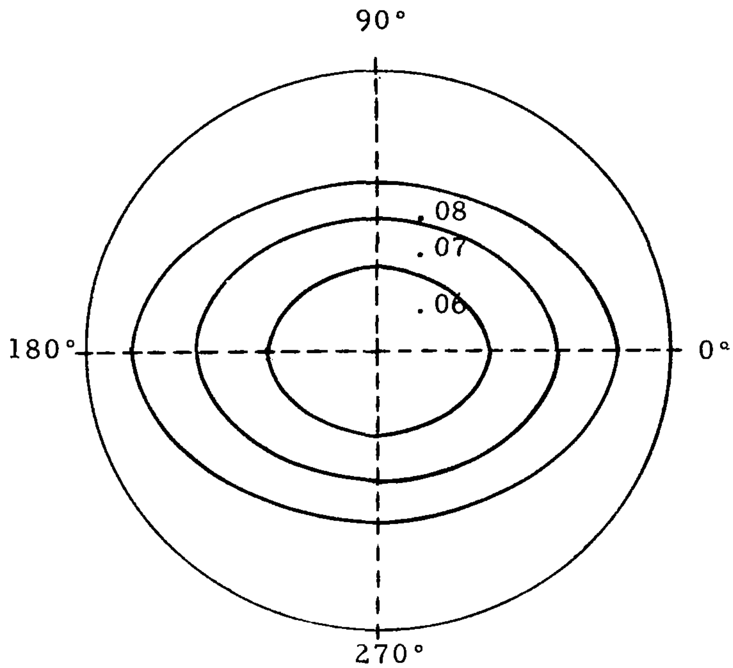

Figure 9. Differential Threshold $\left(\frac{\Delta V}{V}\right)$ Isograms for Linear Motion at the High Reference Velocity (31.92 cm/sec).

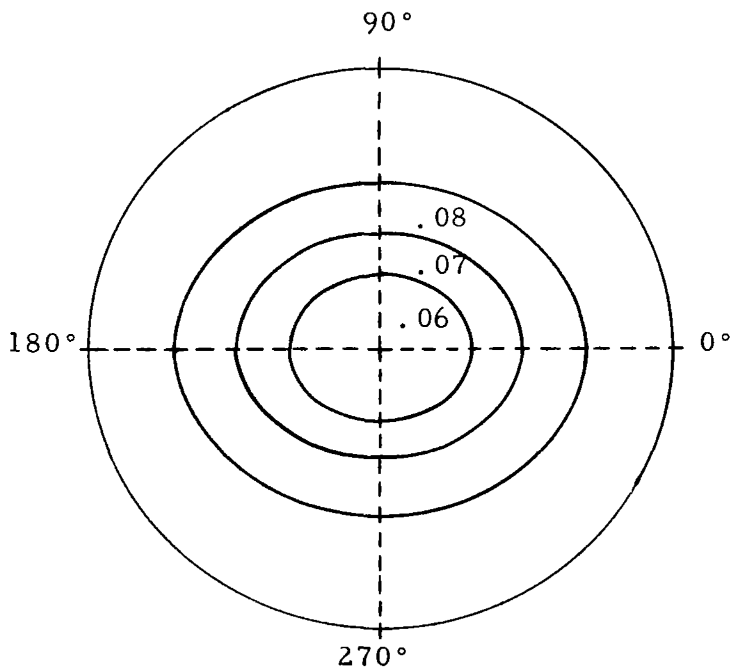

Figure 10. Differential Threshold $\left(\frac{\Delta V}{V}\right)$ Isograms for Rotary Motion at the High Reference Velocity (31.92 cm/sec).

This indicates that the subjects' ability to detect changes in motion was better on either side of this line of sight than above or below it.

Threshold isograms for the slowest reference velocity (Figures 5 and 6) indicate that there was little difference in performance with the two displays near the center of the visual field. However, from about 40 degrees outward, thresholds for rotary motion were lower than those for linear motion along the vertical axis. In contrast, the opposite was true at the medium and high reference speeds, especially along the horizontal axis, as illustrated in Figures 7 through 10. When thresholds were quite different across the entire visual field, thresholds for linear motion were generally lower than those for rotary motion. One exception occurred in the area near 20 degrees at the medium speed where there was little difference between the two types of motion. As shown in the isograms for the high reference velocity, threshold values for rotary motion approached but never quite equaled those for linear motion as the eccentricity angle increased.

An analysis of variance was conducted to test the differences between types of motion and reference velocities. The results of the analysis are contained in Table I. The analysis indicated that the difference between

TABLE I - SUMMARY OF THE ANALYSIS OF VARIANCE

Source	df	MS	F
Display	1	158.61	1.27
Position	22	197.33	N. A.
Velocity	2	732.90	4.18*
Subjects	9	1734.66	991.23*
D x P	22	8.74	1.08
D x V	2	105.79	0.32
D x S	9	125.24	
P x V	44	7.05	0.94
P x S	198	15.16	
V x S	18	175.20	
D x P x V	44	6.71	0.80
D x P x S	198	8.11	
D x V x S	18	326.64	
P x V x S	396	7.53	
D x P x V x S	396	8.44	
Within	6900	1.75	
TOTAL	8279		

*Significant at the .05 level or better

the two types of motion was not significant and could be attributed to chance fluctuation of the threshold estimates. Only two factors, reference velocity and subjects, were found to be significant. Scheffe's test revealed that only the difference between the slow and medium speeds could be accepted as real and accounts for the significance of the speed factor in the variance analysis. Dividing the subjects into two age groups, 21 to 30 and 31 to 45 years, average thresholds were found to be 1.85 cm/sec. and 2.29 cm/sec., respectively. The difference between these means was highly significant. Age, therefore, appears to have an adverse affect on the perception of motion as is the case with many other visual functions. This finding, therefore, was not completely unexpected. Further research, however, will be required to investigate this effect more thoroughly.

The effect of speed on differential threshold was of particular interest in this study. In Figure 11, threshold is plotted as a function of reference velocity. In accordance with Fechner's "law," the differential threshold $\left(\frac{\Delta V}{V}\right)$ decreased. in a logarithmic fashion, as a function of reference speed regardless of the eccentricity angle and the motion type; i.e., the percent change in speed, required for detection, decreased at higher display speeds. This relationship between threshold and reference speed was hypothesized and not unexpected since other psycho-physical functions also assume this same general form.

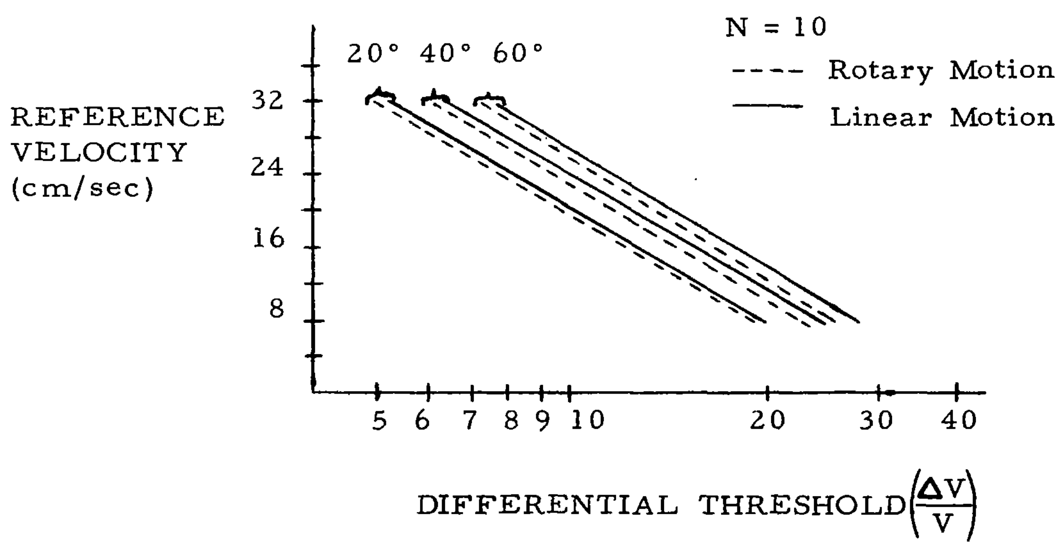

Figure 10. Differential Threshold as a Function of Reference Speed for Three Eccentricity Angles.

DISCUSSION

The results of the study clearly demonstrated that the ability to differentiate changes in the rate of motion decreases from near the fovea to the outermost areas of the periphery. Isograms for both rotary and linear motion were found to be elliptical in shape with their horizontal axis extending approximately twice as far as the vertical axis. Similar isograms were reported by McColgin (1960) for the absolute thresholdsof motion in the periphery. These findings might be explained by several hypotheses and established facts regarding the physiological structure of the retina. Polyok (1957) and Granit (1930), for example, suggest that two contributing factors are the decrease in the number of receptors in the periphery and the summation of impulses resulting from the synaptic convergence of neurons of the peripheral receptors. In addition, Polyak (1957) also indicated that the decrease in sensitivity from the fovea to the periphery may result from differences in the responsiveness of cones located in different areas of the retina. Wolf (1959) hypothesized that the elliptical shapes of the threshold isograms may be caused by the pattern of retinal innervation in relation to the blind spot. While these hypotheses suggest several explanations for the present findings, the lack of additional physiological data limits their acceptability. Additional research, therefore, is required before the response characteristics of the peripheral field can be adequately explained.

A comparison of the differential thresholds for rotary and linear displays was considered feasible since the visual area subtended by both displays was equal. Furthermore, the reference and test velocities employed in the study were the same for both displays. With the rotary display, tip speed was suggested as being the most significant determinant in the perception of rotary motion by McColgin (1960). Additional support for this contention was provided by the reports of the subjects in this study. Hence, tip speed of the rotary display was equated with the speed of the linear display and the two compared quantitatively. Although there appeared to be a difference between the two displays based on the threshold isograms, a statistical comparison indicated that this difference was not significant. Introspective reports of the subjects, however, indicated a preference for rotary rather than linear motion. Typically, subjects said that rotary motion was "... more easily seen," "... easier on the eyes," "... more comfortable to view." Similar statements concerning the subjects' preference for rotary motion were recorded by McColgin (1960).

Reference velocity was found to be a significant factor affecting the threshold estimates. However, only the difference between the slow and medium velocities could be accepted as real. The absolute threshold at the high velocity fell between those obtained at the slow and medium velocities. A confounding factor which may account for this unexpected result was that all subjects reported the occurrence of interference phenomena at the high speed, especially with the linear display. These phenomena consisted of blurring, fusing, strobing and flicker. Two subjects also indicated that, occasionally, two displays appeared in their field of view simultaneously. Of these two displays, one was seen to travel at an extremely high rate, while the other moved in a stroboscoptic manner. One subject reported blur and fusion while viewing the linear display at the medium reference speed. Blurring and fusing with the rotary display at the high velocity were also reported by a few subjects. The occurrence of these phenomena are not understood. Blurring may be explained in terms of flicker fusion. However, further research is required to develop specific explanatory hypotheses and to study them under controlled conditions in the laboratory. It appears appropriate to state, however, high velocities should be avoided in the design of peripheral vision displays.

SUMMARY AND CONCLUSIONS

A study was conducted to determine the differential thresholds for rotary and linear motion in the periphery. Isograms were developed based on threshold estimates obtained from ten subjects using the psycho-physical method of limits. Based on the results of the study, the following conclusions can be made:

1. Differential thresholds for rotary and linear motion were found to increase as a linear function of eccentricity angle.

2. Threshold isograms for both types of motion are elliptical in shape with the horizontal axis approximately twice as long as the vertical axis.

3. Based on statistical analysis, there appears to be no real difference between rotary and linear motion. Subjects, however, reported a preference for rotary motion.

4. Thresholds decreased logarithmically as a function of reference speed.

5. Age of the subject appears to be a highly significant factor which influences the perception of motion.

6. At high display velocities, subjects reported the occurrence of interference factors such as blur, fusion, strobing and flicker. These factors were particularly noticeable with the linear display.

DESIGN IMPLICATIONS AND RECOMMENDATIONS

Based on the results of study, it is possible to make specific recommendations with regard to the design and location of peripheral displays in the visual field. It was demonstrated that the ability to discriminate changes in the rate of motion is relatively good in the periphery, even out to 60 degrees in the visual field. Motion, therefore, appears to be a suitable stimulus dimension for encoding peripheral displays.

There was no significant difference found between linear and rotary motion. Although the subjects who participated in the study stated a preference for rotary motion, in view of their performance data, either type of motion appears to be adequate for providing control information to vehicle operators. The type of motion employed in peripheral displays should be based on the consideration of the operational situation and the type of control information it will present to the operator. For example, there appears to be no simple way for presenting directional information such as aircraft pitch and roll, utilizing a rotary display. Linear displays, such as the Collins PCI and the Smith PVD have been successfully employed for this purpose.

At high velocities, the subjects witnessed the occurrence of certain interference phenomena such as blurring, strobing, fusing, and flicker, especially with the linear display. These phenomena can not be easily explained without further investigation. However, they do suggest that display velocity should be limited to some value below 30 cm/sec. if these phenomena are to be avoided in the operational situation. Although an absolute upper limit can not be determined on the basis of this study, it should probably be limited to approximately 20 cm/sec., the medium reference velocity investigated. Only one subject reported blurring and fusing at this velocity with the linear display.

The results of the study also indicated that performance was approximately twice as good along the horizontal as compared to the vertical meridian, i.e., isograms of differential motion thresholds were elliptical in shape, approximately twice as wide along the horizontal axis. Since performance degrades at a slower rate along the horizontal axis, displays may be located at greater angular distances from the normal line of sight for the same level of performance. For this reason, peripheral displays are best located on either side of the operator and as near level as possible with his normal line of sight. The angular distance, of course, should be kept to a minimum in order to assure the highest degree of performance.

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