SYSTEM OPERATOR USE OF PERIPHERAL VISION IN A DYNAMIC ENVIRONMENT

by

Joseph Patrick Fitzgerald

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STATEMENT BY AUTHOR

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SIGNED: Joseph P. FitzGerald

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

Roger J. Weldon
Roger J. Weldon
Professor of Systems Engineering

September 8, 1968
Date

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ABSTRACT

Research was conducted to investigate the extent to which man, as a system operator in a complex environment, is able to utilize his peripheral vision to obtain information for performing a central task. Background information and past research applicable to this practically unexplored, dynamic aspect of peripheral vision is presented. An experimental apparatus which simultaneously presented and controlled stimuli on the display was developed, using a tape recorder to provide for uniformity of presentation. Data generated in this experiment was automatically recorded in digitalized, computer-compatible format. Description of the experimental problem, which consisted of two subtasks, is presented. Computer-aided analysis of the data obtained from four subjects failed to support significantly the hypothesized existence of a non-linear inverse functional relationship between performance on the experimental tasks and the size of the peripheral angle subtending the peripheral information. Possible reasons for this result are discussed. Significant differences were noted between subjects, and due to learning. Experimental parameters requiring closer control or attention in future investigations are identified.

CHAPTER 1

INTRODUCTION

In the great majority of man-machine systems in use today, the operator of the system is peculiarly dependent upon his sense of vision. Although he often receives inputs through other sensory channels such as the auditory and tactual senses, vision is usually the major source of the information an operator must have in order to exercise effective control of a system.

Dual Function of the Visual Sense

Vision is superior to the other sense channels in two ways, and for purposes of this thesis the distinction between the two ways is important. Vision on the one hand provides a human operator with very precise detail about stimuli in a system display or about objects in the environment surrounding the system. To obtain this precision of detail the operator moves his eyes, or his head and eyes, to bring the image of a viewed object onto the foveal area of his retina. The foveal area of the retina of the eye is the area in which maximum visual acuity or discrimination is achieved (Davson 1962). In more common language then, it is said that the operator "turns his eyes upon" an object or simply he "looks at" an object. In terms used extensively throughout this thesis, the operator uses his "central vision" to obtain the precision of detail he may require.

On the other hand, vision excells as an information medium by providing a very broad observational coverage of the environment about a system. The extent of this coverage varies for different species of organisms and for man the coverage is limited to approximately 180°. In man this coverage furthermore does not yield the precise detail visual information that his central vision affords. Because of this loss of precise detail and because of other characteristics of the extended visual coverage of the environment, such vision is given the name of peripheral vision.

Major Usefulness of Peripheral Vision

Peripheral vision is considered somewhat as downgraded vision and has been rather neglected in research and in discussion of its practical usefulness. The point of view upon which this thesis is based is that peripheral vision is not a downgraded vision, although it is quite different from central vision. Nor is it a useless evolutionary remnant from earlier stages of human development. Rather, the point of view is that peripheral vision has a special and important function in the action of man, and hence has an important role in the tasks of a system operator as he discharges his control function in a system, simple or complex.

The first function of peripheral vision is that of an alerting device to inform the system operator of events in the environment which should be given the detailed scrutiny of central vision. In modern terminology peripheral vision carries out the function of "target acquisition" for the operator. It alerts him to the fact that some area in the total visual field should be closely scrutinized, and furthermore indicates the exact direction in which that area lies.

The second function of peripheral vision is to assist in the maintenance of a stable orientation of the external environment. While the eyes are turning, and central vision is examining portions of that external environment in detail, peripheral vision, in conjunction with information from the proprioceptive and kinesthetic senses about the positions and attitudes of the head and eyes, forms a stable orientation picture of the overall external environment (McCormick 1964).

Peripheral vision also provides the system operator with important information or cues which prompt the execution of operating action on his part. For one reason or another it may not be possible, nor may it be practical, for the operator to turn his eyes to some portion of the environment for information, or the needed information may not be obtainable from one selected area, but may come from the total scene which lies before the operator. Under such conditions the essential information from which control of the system ultimately proceeds must be obtained by means of peripheral vision. This third function of peripheral vision is most critical in a continuously operating situation requiring control of a complex system in a complex environment. Activities such as driving an automobile or piloting an aircraft are examples of situations where the operation is continuous and may be so exacting that central vision is required to be maintained upon a relatively small area of the visual field immediately to the front of the operator. In such complex situations the demands for information about other areas in the visual field must be filled by means of peripheral vision. This particular function of peripheral vision then is the one studied in this thesis in an effort to determine how well man can utilize this visual capability in a complex system.

Visual Experience

In order to specify more exactly the area of interest in this thesis, it is first necessary to develop in greater detail the concepts of central and peripheral vision. As briefly mentioned above, the psychophysiological phenomenon of sight provides man with two disparate kinds of visual experience, namely, central vision and peripheral vision. The distinction between the two is not easily made since it is based upon several physical characteristics and visual capabilities which gradually change with retinal location from center to extreme periphery. Hence, although there is clearly a difference between central and peripheral vision, there is considerable difficulty in specifying an exact locus or natural line where one ceases and the other begins.

The most practical way to differentiate between central and peripheral vision is to describe each type in terms of its different properties and then to arbitrarily divide the visual field, or the retina, into two or more regions, each having a range of properties suitable for investigation or description. Central vision is traditionally defined as that vision obtained from the receptor cells of the fovea which is located in the area of the retina known as the macula lutea. Situated approximately in the center of the retina, the fovea contains only the cone type of receptor cell. Peripheral vision, on the other hand, is that vision obtained from receptor cells situated in the non-foveal retina. Both types of receptor cells are present in this area, with the rods predominating and the cones becoming less numerous toward the periphery of the retina (Graham, Bartlett, Brown, Hsia, Mueller and Riggs 1965).

Rod and cone receptor cells in the retina of the human eye differ functionally from each other. Cones specialize in providing detail vision and the perception of color and since the fovea consists entirely of densely packed cones, it is in this area of the retina that maximum visual acuity is achieved. On the other hand, rods, the primary contributors to peripheral vision, are exclusively light-dark sensors affording colorless vision to the observer, and providing him with greater sensitivity to minimal stimuli, but less visual acuity. To gain an understanding of the reason for this functional difference among retinal receptors, one need only consider the manner in which they are connected to the central nervous system. While there is a one-to-one relationship between foveal cones and neural paths to the central nervous system, peripheral receptor cells normally are grouped so that a single neural connection services a more extended receptive area in the peripheral retina. The former neural arrangement is conducive to pinpoint discrimination in the central nervous system whereas the latter configuration precludes such discrimination because of the sharing of the same neural path by many peripheral receptors (Graham, et al. 1965). Hence, a clear anatomical basis for the different properties and characteristics of central and peripheral vision is seen to exist.

Assuming that an observer is engaged in some activity requiring the use of his sense of sight, his normal functioning combines both central and peripheral vision into a smoothly integrated, visual experience. Then, depending on the nature of one's research interest in the visual perceptions involved, those perceptions as a practical expediency may be classified as "static" or "dynamic". To distinguish between these two aspects of vision, static vision can be denoted as the perceptual state achieved by presenting instantaneous or static stimuli to the observer or by maintaining stimuli in a stable position on his retina. Dynamic vision, on the other hand, refers to the visual perceptions which the observer experiences when he is presented with moving or changing stimuli.

Dynamic Peripheral Vision in the Man-Machine Environment

This thesis is concerned with dynamic peripheral vision in the systems environment, i.e., with a system operator's use of moving stimuli in his peripheral visual field to assist himself in the performance of a task which requires steady central visual fixation. Such movement may occur when the operator alone is moving, or when he is stationary and objects in his visual field are in motion, or when both the operator and objects in his visual field are simultaneously moving. Dynamic peripheral vision enables the operator to sense movements and changes occurring in his surroundings; having sensed them, he may then turn his eyes and thus his central vision toward them for further detailed investigation as necessary. If, however, his central task is such as to preclude this shifting of his central vision, or if the moving objects in his peripheral visual field are too envoloping for detailed inspection, then the operator must employ his peripheral vision to obtain a comprehensive view of his total visual field. The failure to use information obtainable only by means of peripheral vision may not be a failure in vision itself, but may simply be due to an operator's failure to integrate such information with his central task. While these possibilities are acknowledged, no attempt is made in this thesis to investigate whether variability in dynamic peripheral vision is due to variability of visual power or is a function of some central integrative activity.

Examples of the use of what has been introduced above as dynamic peripheral vision are plentiful and easily experienced. Perhaps the most common example of the role of dynamic peripheral vision is the part it plays in the everyday occurrence of driving an automobile. The responsible, mentally alert driver relies upon his dynamic peripheral visual input to provide aiding information which he uses in safely operating his vehicle. The traffic signals and road signs, the other vehicle converging on an upcoming intersection from another direction, the continually changing flow patterns, locations and directions of other vehicles -- all are peripheral cues which prompt, and sometimes indeed dictate, precautionary or evasive action to be taken by the driver. Piloting of military aircraft such as helicopters and high performance jet aircraft in support of combat operations is another example of a situation wherein the use of dynamic peripheral vision is indispensable to efficient performance.

To lend some substance to the claim concerning man's oftentimes unwitting reliance upon peripheral vision, it is interesting to consider here the extensiveness of peripheral vision in the visual field as compared to central vision. To effect this comparison, it is hypothesized that a hemisphere of 180° constitutes the total human visual field. It is also assumed that the observer's eye is located at the exact center of this hemisphere and that a perfect cone of vision with its apex at the eye is obtainable for any solid visual angle up to 180°. Table 1 then gives the relation between selected visual angles and the areal percentages of the hypothesized total hemispheric visual field which those solid angles subtend. In reading this table, one should bear in mind that the macula lutea, the area wherein central vision is generally taken to lie, accounts for a visual angle of only 6° to 10° (Graham, et al. 1965). From Table 1 it can be seen that the visual field subtended by a visual angle of 10° constitutes less than 1% of the total visual field. In general, it can be concluded from Table 1 that central vision accounts for only a small percentage of the observer's visual field and that the utilization of peripheral vision is therefore of considerable importance, especially in a complex environment.

Table 1. Visual Field Areas Subtended by Various Solid Visual Angles, in Terms of Percent of a 180° Hemispheric Visual Field.

Solid Visual Angle In Degrees	Percent of Total Hemispheric Visual Field
5	.09
10	.33
20	1.52
30	3.48
45	7.60
60	13.38
90	29.27
120	49.96
180	100.00

Human Factors in Systems Engineering

The approach of this thesis is that dynamic peripheral vision is an important human factor which must be considered in engineering complex systems intended to be controlled by a human operator. Information concerning this dynamic aspect of man's visual activity is deemed valuable to the systems engineer in analyzing existing man-machine systems and in designing new ones. The point of view taken here is that complex systems involving, for example, vehicular control, multiple target tracking or extensive visual displays can be more effectively engineered through consideration of this visual phenomenon.

This thesis then is a report of experimental work done to develop a means of testing the utilization of dynamic peripheral vision by individuals performing a fairly complex task. Hopefully the information obtained in this research will begin to fill the void which presently exists concerning this phenomenon.

Thesis Outline

Chapter 2 of this thesis contains a review of the more important visual characteristics of peripheral vision. It also summarizes the pertinent points of selected previous experimental efforts which are considered to contribute useful background information or to possess special relevance to the topic investigated here.

Chapter 3 outlines the experimental task used in this research and any assumptions made concerning it.

Chapter 4 then provides a description of the development and physical arrangement of the implementing apparatus and the procedures used in this pilot study of dynamic peripheral vision.

The final chapter of this thesis, Chapter 5, is devoted to the discussion of findings and results obtained from the pilot experiment and to recommendations for further research in this field.

CHAPTER 2

HISTORY AND LITERATURE

Prior to conducting the research reported in the following chapters of this thesis, a search of available reference material was made. The objectives of this survey of the literature were twofold: first, to determine what research has been done specifically in dynamic peripheral vision, and second, to develop pertinent background information against which man's peripheral visual performance or capabilities under moving visual field conditions can be effectively studied.

The literature search was not specifically intended to gather a comprehensive resume of all obtainable information concerning the physiological and psychological aspects of peripheral vision. Such an undertaking was not felt to be within the purview of this investigation. Still, it was considered appropriate that a review be given of the more important visual properties and limitations which are characteristics of peripheral vision. A presentation of these selected basic facts is therefore given in this chapter prior to the discussion of the stated objectives of the literature search.

Characteristics of Peripheral Vision

In the literature, material concerning the visual properties of peripheral vision is most frequently presented in terms of one or more of the following areas of interest: visual acuity, sensitivity to light, perception of movement, and sensitivity to color stimuli.

Visual acuity, the ability to discriminate the fine details of observed objects, is known to be a function of many factors. Prominent among them is the variation in visual acuity due to retinal location of the optical image formed by the object (Graham, et al. 1965). As previously explained in Chapter 1, the relationship between retinal receptor cell and neural connection varies from one-to-one in the fovea to a far greater ratio in the periphery. Recalling that the degree of visual discrimination increases as the ratio of receptor cells to optic nerve fibers approaches unity, it is characteristically the case that, under normal intensities of illumination, visual acuity at the fovea is far greater than peripheral visual acuity. Figure 1 shows this relationship between foveal and peripheral visual acuity as a function of degrees of eccentricity of image location from the fovea.

For low levels of illumination, Figure 1 is not representative of man's visual capacities. Under such conditions, the retina of the eye automatically adjusts itself to these low levels by a process known as dark

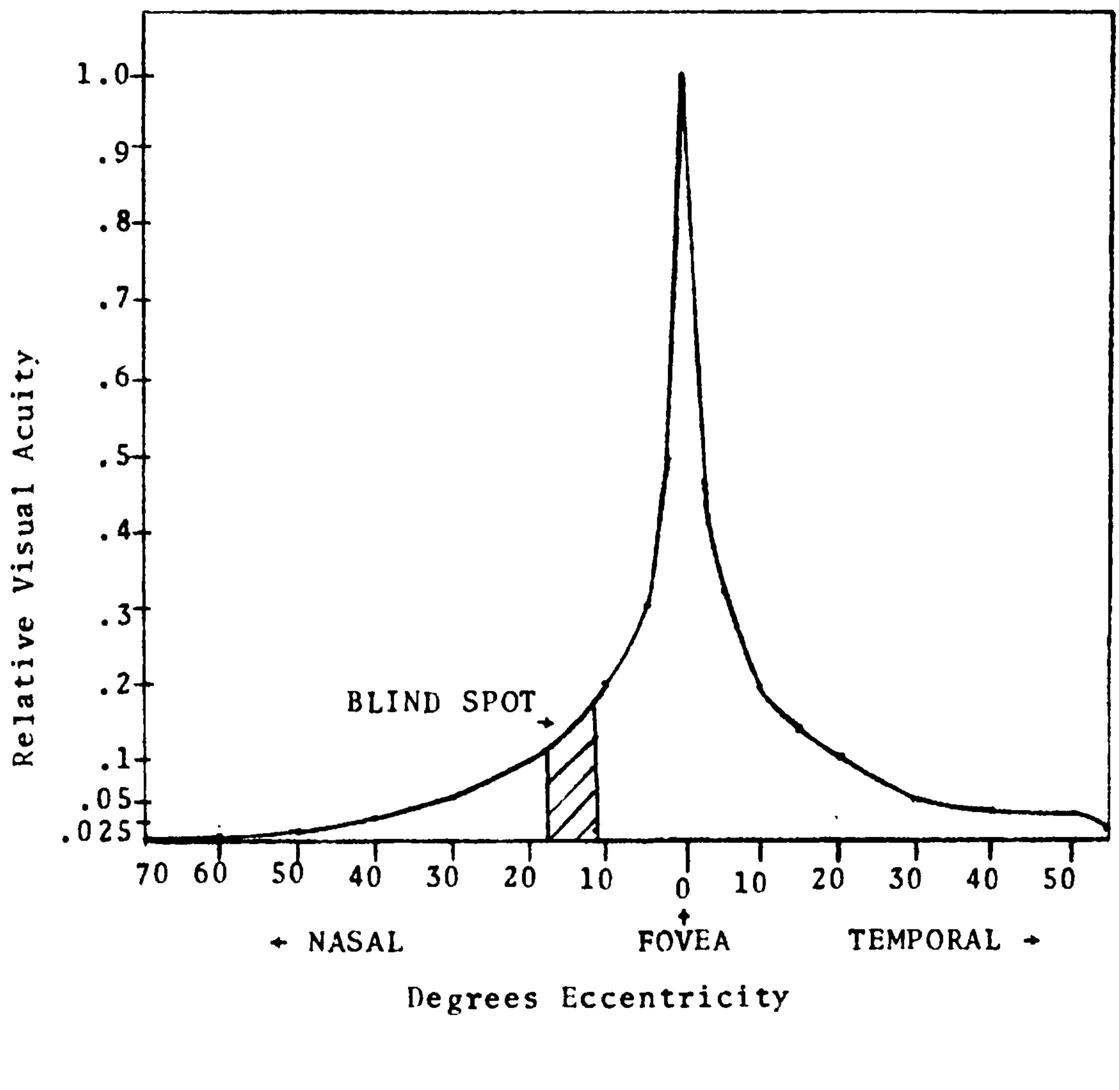


Figure 1. Variation of Visual Acuity as a Function of Retinal Image Location (From Duke-Elder).

adaptation. In undergoing this adaptive process, however, different characteristics of vision result with respect to the foveal and peripheral retina. On the one hand, the peripheral retina is known to have a high proportional density of light-sensitive rod receptor cells and hence has the capability of responding to lower levels of illumination than the foveal retina. Thus, in dark adaptation, the rods of the peripheral retina provide vision which is highly sensitive to light but unresponsive to color and very low in visual acuity. On the other hand, the foveal retina is known to be completely free of rods and thus to have a higher light threshold than the peripheral retina (Graham, et al. 1965). In dark adaptation, the fovea also demonstrates an increase in sensitivity but quantitatively the change is less than a small fraction of the much greater change which occurs peripherally. Thus, while some increase in foveal sensitivity to light is obtained in dark-adapted vision, color vision and maximal visual acuity are lost due to the failure of the low levels of illumination to satisfactorily stimulate the foveal receptors. Cone receptors adapt immediately to a reduction in illumination intensity; the rods adapt to some degree within a matter of seconds of the onset of low level illumination but full dark adaptation of these receptors is not usually obtained for a period of 10 to 30 minutes (Graham, et al. 1965).

The perception of movement, like visual acuity, varies with such factors as degree of illumination, background contrast and size of the observed object. When these factors are held constant, however, the angular motion of the moving object and, again, the retinal location of the moving image play the major determining role in the perception of movement (Davson 1962). The visual power of detecting movement is greatest at the fovea and diminishes toward the periphery of the retina, the curve resembling in its general form that for visual acuity (Figure 1). In the peripheral field, the angular velocity threshold of a moving object must be increased for movement to be appreciated; the increase required is small over a fairly wide range of eccentricity until, in the far periphery, it becomes quite pronounced (Duke-Elder 1944). Figure 2 shows this relation between angular velocity threshold for detection of movement and eccentric retinal location. It should be noted that, although there is a decrease in sensitivity to movement from the fovea to the periphery, the capacity for the detection of movement remains relatively high out to a peripheral angle of approximately 70°. This sensitivity to movement across such a considerable width of visual angle is a prime contributing factor to man's ability to utilize dynamic peripheral vision to his advantage.

As is the case for the other areas of interest reviewed in this section, sensitivity to color vision in the

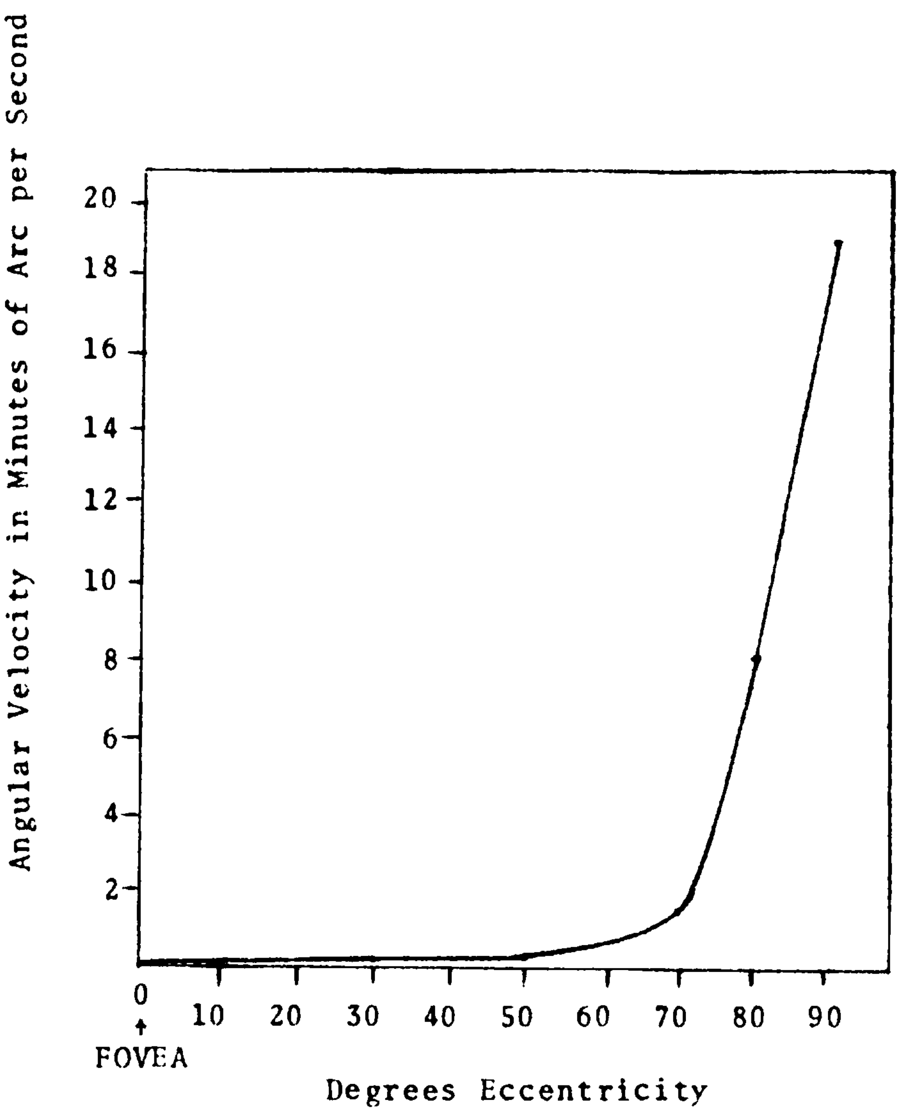


Figure 2. Angular Velocity Threshold for Detection of Movement As a Function of Retinal Image Location. (From Duke-Elder)

periphery varies with retinal position and state of adaptation (Graham, et al. 1965). In the light-adapted eye under moderate and equal subjective intensities of light stimulation, four general regions are prevalent with respect to peripheral color fields. From approximately 65° temporal eccentricity to the extreme periphery, vision is achromatic or colorless. Below this visual angle, the visual fields of color vary according to color. Green has the most extensive blind area and is visible out to about 35° temporal eccentricity. The visual field for the colors red and yellow is limited to approximately 55°. The color blue has the widest color field with visibility extending to a temporal visual angle of 65°. As a final note, it is emphasized that the regions prevail only under the illumination and light-adaptation conditions indicated. Variations in these parameters have marked effects on the color sensitivity of the retina. If, for example, the intensity is increased, it is observed that the color fields are also increased and, with the exception of the color green, may extend all the way to the periphery with the proper illumination levels (Duke-Elder 1944).

Research in Dynamic Peripheral Vision

Of all the literature reviewed only the report of Rabin, Bahm, Beard, Boyd, Brasch, Fannin, LeCompte, Lamont and Owens (1966) treated the concept of dynamic peripheral vision as it has been previously specified in Chapter 1. In their unpublished group study, they reported a pilot experiment which they conducted with the objective of measuring a subject's utilization of dynamic peripheral vision. A subject was presented with the central task of signaling with a push button the moment a moving target entered a central intercept region coming from any direction of the periphery of a large visual display. The subject used his peripheral vision of the moving targets to assist in determining the approach and proper moment to signal the entry of the target into the central region. Although the reported data are few and may be biased because they were taken from only three subjects who were members of the study group, the preliminary findings of this pilot experiment indicated that a utility limit existed beyond which the peripheral visual field could not be usefully employed in a dynamic environment.

Research Applicable to the Dynamic Visual Environment

Peripheral vision has been studied and evaluated in several instances under highly dynamic conditions. White and Jorve (1956) reported that peripheral vision was completely lost and tunnel vision ensued among unprotected individuals who were subjected to positive (foot-to-head) accelerative forces of approximately 3.5 *g*. They also reported that protective devices such as *g*-suits were found to reduce this visual impairment due to such acceleration.

In related, later studies, White (1958) discovered that man's visual capabilities were more durable under transverse (chest-to-back) accelerative forces. It was found that man could be exposed to such transverse acceleration forces up to a magnitude of 12 g without experiencing the visual effects of greyout (loss of peripheral vision) and blackout (loss of central vision) which result from decreased blood supply to the retina under positive acceleration conditions. White (1960) further demonstrated that accelerative stress had a consistent and progressively worsening effect on peripheral acuity and peripheral threshold luminance. Threshold levels were found to triple at a force of 3 g and to quadruple at a force of 4 g.

In other research conducted, Simons and Hornick (1962) tested peripheral vision and several other performance indicators in an environment of low frequency, high amplitude vibrations varying in peak acceleration intensity from .15 to .35 g. It was reported that during transverse (side-to-side) vibration, frequencies of vibration of 1.5 and 2.5 cycles per second at an intensity of .15 g elicited significant losses in peripheral vision among those tested; no further decrement in peripheral vision was observed for the higher vibration intensities up to .35 g. They also found that longitudinal (front-to-back) vibration had no such detrimental effect on peripheral vision.

Mackworth (1965) tested ability to detect similarities between a target in central vision and targets presented in the visual periphery. He reported that the task was easily performed when similar peripheral targets alone were displayed; however, with the addition of extra peripheral targets, he observed a serious decline in performance which he ultimately attributed to the occurrence of tunnel vision in the subject. His discussion of these observations was particularly interesting. To explain the observed decrement in performance, the concept of a "useful visual field" was introduced, i.e., an area around the central fixation point where visual information could be temporarily stored and read out during a visual task. Under this hypothesis, when too much information had been presented, the useful visual field was said to contract to prevent overloading of the visual system, in a manner conceptually not unlike the normal pupillary reaction to bright light. Mackworth (1965) thus concluded that tunnel vision occurred due to priority being given to central vision by the contraction of the useful visual field in eliminating unwanted visual signals. Although this particular study of peripheral visual noise was conducted using static test stimuli, it seems appropriate in this instance to assume that Mackworth's observations would have applicability to a dynamic visual environment. Such an assumption agrees in part with the preliminary findings of Rabin, et al. (1966)

concerning the limited utility of the visual periphery in complex, dynamic visual fields involving a central task.

In another static experiment which might have some bearing on dynamic visual environments, Fry and Alpern (1952) studied the effect of peripheral glare upon a subject's perception of a central task. They found that peripheral glare caused a decrease in the perceived brightness of a central test object; this decrease was accounted for in terms of a veiling luminance produced by stray light falling on the central portion of the retina. In connection with the findings of this research, it appears reasonable to expect that the detrimental effects or peripheral glare upon a central task would persist in a dynamic environment as well.

Insight into man's sensitivity to peripheral movement was provided by McColgin (1960). Randomly locating an aircraft type instrument with a standard altimeter hand at various positions in the subject's peripheral field, he investigated four types of movement, namely, clockwise and counter-clockwise rotation, vertical and horizontal motion. The results of this research indicated that there was no difference between the ability to sense clockwise and counter-clockwise rotation. It was also observed that vertical motion was somewhat more easily perceived than horizontal motion in the area adjacent to the horizontal axis, extending out to approximately 70° on either side of the vertical axis. Except for this area of the visual field, there was no significant difference noted between sensitivity to horizontal and vertical movement.

Summary

The literature search which formed the basis for this chapter revealed an abundance of information concerning work done in various and diverse aspects of what is herein called static peripheral vision. The work of Rabin, et al. (1966), however, stands alone in its efforts to evaluate the use of peripheral vision of moving objects as an aid to performing a central task in a complex environment. The other works cited in this chapter were selected for mention because of the possible applicability, direct or implied, of their particular findings to the concept of dynamic peripheral vision. Each of these references pertains in some way to an aspect of the subject of interest of this thesis and hence, taken collectively, they serve to generate at a minimum an appreciation for the complexity of the visual phenomenon which is under investigation.

CHAPTER 3

EXPERIMENTAL DESIGN

The overall purpose of the research reported here was to develop a method for investigating man's utilization of dynamic peripheral vision. To accomplish this objective it was necessary to devise an experimental task which fulfilled a dual requirement. First, the experimental task had to control eye movements so as to keep the subject's central vision relatively fixed upon some "central" area. In addition, there was the requirement that some task be performed the execution of which depended upon the subject's knowledge of moving stimuli in the peripheral field of vision. The task devised for these purposes was therefore one which consisted of two subtasks. The first of these subtasks required continuous central vigilance and the second required the utilization of information obtained from the peripheral field. Measurements were taken of the level of performance on both of the subtasks.

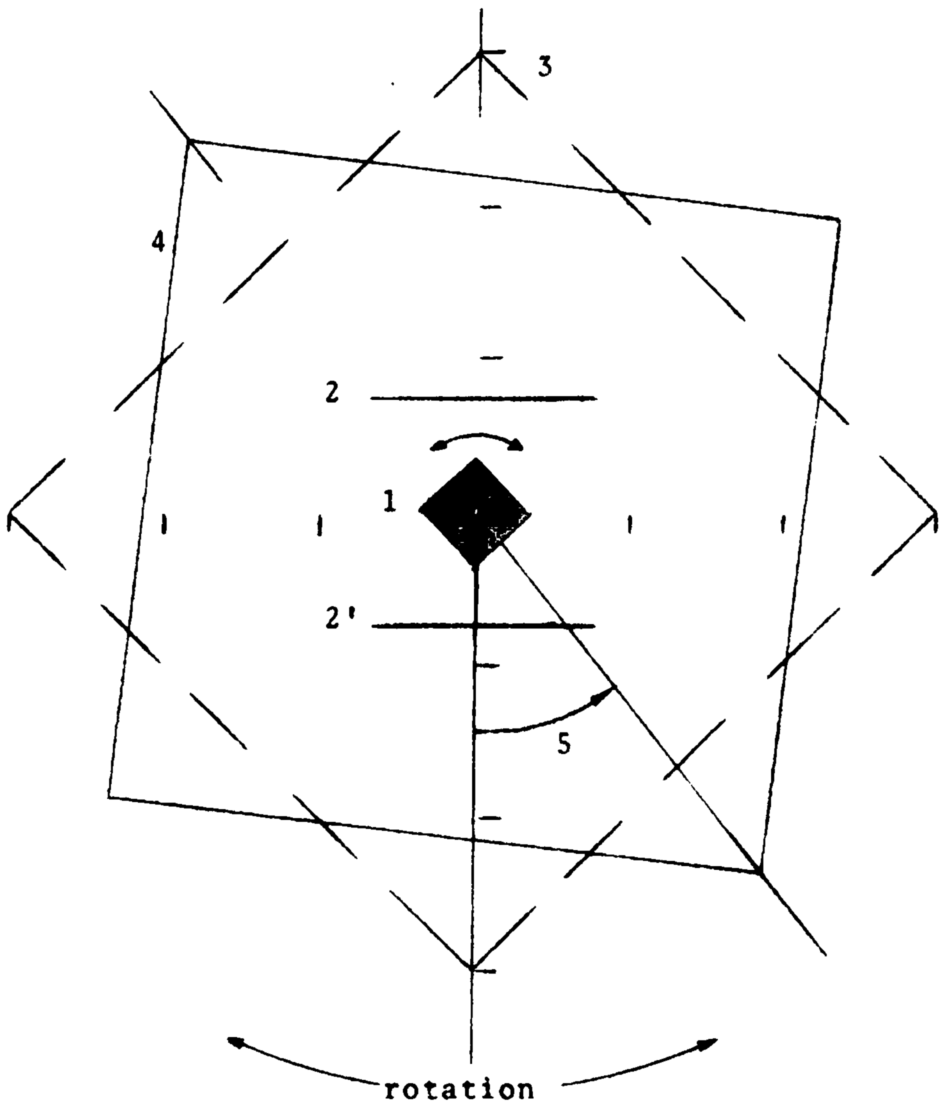
Experimental Tasks

For the first subtask the subject was presented with a small square figure normally in a central location which was displaced upward or downward along a straight vertical axis in a random manner by a programmed external source. The subject was required to apply forward or backward force to a control knob to counteract the displacement motion of this small square, and thus to keep that figure within the bounds of specified upper and lower limits on the display. The limits were shown by heavy black horizontal lines on the display. The displacing motions of the square were rapid enough to require continuous monitoring to keep it located between the limiting lines.

For the second subtask an outline of a larger figure was presented to the subject. This square was concentric to the small square in the visual field. Both the small central and the larger peripheral squares could be rotated about their common center in a clockwise or counterclockwise direction. The rotational movement of the small central figure was controlled solely by the subject; the rotational movement of the larger peripheral figure was controlled solely by an external source and was programmed to be random within a trial but repeatable from trial to trial. The subject was required for his second subtask to apply clockwise or counterclockwise torque to the same control knob to rotate the small central square so as to keep it rotationally congruent with the larger peripheral square at all times.

The subject was expected to keep his eyes centered on the small central square in order to sense its vertical movements and rotational position, and to depend upon his peripheral vision to sense the direction and speed of the rotational movements of the larger peripheral square. Since shifting of visual center, which might occur in such a task, needed to be prevented in order to get reliable measurements of the sensing of the peripheral field, the speed of vertical change of the small square was made rapid enough to require continuous monitoring of that figure in order to successfully carry out the first experimental subtask.

Figure 3 shows the configuration of the display of the square figures and their movements which provided the experimental tasks for the subjects. The small square at 1 was to be kept from moving above the horizontal line 2 or below the horizontal line 2'. The position of the small square above or below the mid-line of the display was one of the measurements continuously taken during each trial. The larger peripheral square, shown in its original position by the dashed line 3, was rotated by the external program, for example, to the position given by the solid line 4. The subject was to sense such rotational movement of the larger square and then cause the small central square to rotate so that it remained congruent with the larger figure. The angle θ at 5 was the measure of the amount by which the subject had not fulfilled this subtask. This angle was the other measurement continuously taken during each trial.



1. Small central figure in starting position at center of display.
2-2'. Limits within which vertical deflections of 1. must be held.
3. Starting position of peripheral figure.
4. Peripheral figure after counterclockwise rotation.
5. The angle θ, representing the angular difference in orientation between 1. and 4.

Figure 3. Labeled Graphical Depiction of the Experimental Task.

Experimental Hypotheses

Two hypotheses were taken to underlie the experimental work reported in this thesis. The statement of these hypotheses, however, requires first the definition of the term "peripheral angle". The peripheral angle of a stimulus or an object is defined as the angle at the focal point within an observer's eye between the central axis of his visual field and a line to the stimulus or object in question. The central axis of the visual field is taken to be a line from the center of the fovea through the center of the pupil of the eye. For this experiment in which rather large peripheral angles were used, the accuracy of measurement of this angle was only to the closest 5°. Sometimes, the peripheral angle is also referred to as the angle of eccentricity (Duke-Elder 1944).

The first hypothesis of this research was that there is some inverse non-linear functional relationship between the peripheral angle of an object and the goodness of performance of a task, which performance requires perception of the movement of that object. In terms of Figure 3 then, there is hypothesized an inverse non-linear relationship between the angle θ and the peripheral angle of the larger square 3.

The second hypothesis of this research was that individuals differ in their capacity to utilize information from their peripheral visual field to aid in the performance of a central task.

Measures

As previously mentioned, the angle θ which the subject allowed to exist between the orientations of the central and peripheral figures was adopted as a measure to be used in evaluating the stated hypotheses. With respect to the stated objective of this research, the assumption was made that the angle θ constituted a valid, reliable measure of the amount of utilization made of dynamic peripheral vision while engaged in a central task. Hence, the smaller the angular difference in orientation between figures maintained by the subject, the greater was the measure of his utilization of peripherally acquired vision. It was therefore possible to test the above hypotheses by varying the peripheral angle subtending the peripheral figure and then noting the subject's performance for each figure presented.

The deflected position of the central figure above or below the specified limits was taken to be a measure of how faithfully the subject confined his central vision to the center of the display during the experiment. The more closely he held the small figure at the center of the vertical axis, the better was the measure of the subject's fulfillment of the requirement to maintain his central vision at the center of the display.

Experimental Variables

From the preceding discussion in this chapter, two response variables can be identified in this experimental design. The first of these is the vertical deflection of the small central square which the subject permitted during his trials. Although the amount of deflection permitted by each subject admittedly depended in part upon his motor skill, the variation or stability of this deflection from peripheral angle to peripheral angle was assumed to be an indicator of how well the subject kept his eyes centered as the peripheral angle was changed.

The second response variable is the angle θ which the subject permitted between the rotational positions of the two square figures. Again, the amount of angular difference allowed admittedly depended upon the motor skill of the subject; however, the relative measure of his performance at greater and lesser peripheral angles was assumed to demonstrate the extent to which the subject could obtain and utilize information about moving peripheral objects.

The chief manipulated variable for this experiment was the size of the peripheral angle of the peripheral square figure. Two other unavoidable factors which must be assumed to have entered into such an experiment were the variability of the subjects and the effects of subjective learning, boredom, fatigue, et cetera. The latter effects are summarized as the "order effect" in the statistical analysis of this experiment.

CHAPTER 4

EXPERIMENTAL APPARATUS AND PROCEDURE

The apparatus developed to implement this experiment constitued a rather complex system consisting of over twenty-three electronic or electro-mechanical components plus miscellaneous hardware, interconnections and switches. A complete listing of this equipment is made in Appendix A.

The physical arrangement and operation of the experimental apparatus is best described in terms of five interacting functional areas: 1) the man-machine interface, 2) the task presentation system, 3) the control coordination system, 4) the data acquisition and 5) the data logging system. Such disjunction of the general experimental system facilitates description of the apparatus in sufficient detail with minimal overlapping references between these somewhat arbitrarily specified areas.

Man-Machine Interface

The man-machine interface area was composed of the viewing screen for the experimental task and the subject's seating and control position. The display screen was a plexiglas hemisphere with radius of 18 inches, coated on its outside surface with a rear-projection material and mounted vertically with the center of the display a distance of 47 inches above the floor. The vertical and horizontal axes were graduated in 10° increments from the center of the screen to its periphery. Approximately 7° above and below the center, a dark line 4 inches in length was drawn parallel to the horizontal axis to specify the limits of the acceptable control area with respect to the vertical deflections of the small square.

Seated in an erect position, the subject viewed the experimental task display from inside the hemisphere. His eyes were at the center of the hemisphere and thus his total visual field could be filled in a controlled manner. An adjustable chair and an adjustable chin rest with head strap were provided so that the subject's eyes could be so positioned at a geometric center of the hemisphere. Left and right armrests were built into the viewing screen mounting for the subject's comfort and ease of accomodation to his experimental surroundings.

A Measurement Systems, Incorporated, model 437 isometric joystick was attached to the viewing screen mounting and positioned within easy reaching distance of the right armrest. This device was used by the subject in his experimental task, providing him with both deflection and rotational control of the small square figure. Clockwise and counterclockwise torque by the subject on the control handle caused corresponding rotation of the central figure, the speed of rotation being proportional to the torque he exerted. Simultaneously, the subject was able to counteract the externally-applied vertical deflections of the central figure by a push or pull upon the control handle.

Task Presentation

Two Nikkormat standard slide projectors were used to project independently the two images, one the small central square the other the large peripheral square, onto the subject's viewing screen. To provide for the independently controlled rotation of the two task figures, two specially fabricated rotating mechanisms were positioned in the separate optical paths between each projector and the screen. The principal component in each of these two image rotating mechanisms was an optical device known as a Dove prism. Rotation of a Dove prism in the beam of a projector lens system has the effect of rotating the projected image double the angle of the rotating prism. By using this principal the required axial control of rotation of the image projected through the prism onto the viewing screen was obtained. The other parts of the mechanism included a rotatable mounting for the Dove prism and a mechanical system of pulleys, gears and electric motor to effect control of the prism itself. The drive for the mechanical system was provided by a direct-current, reversible electric servomotor.

The only essential difference between the two projection systems of the small central square and larger peripheral square was the presence of an image deflection device in the optical path of the former figure. This device was required to produce the vertical displacement of the square. This deflection device was fabricated by attaching a 3/4 inch square glass mirror to the indicator needle of a standard Triplett microammeter. The central figure was projected onto the movable mirror and reflected by it into the center of the viewing screen. Small voltages applied to the microammeter caused movement of the meter needle; the movement of the mirror attached to the needle thus provided the desired vertical deflections of the central figure. This device proved to be most delicate to balance and was highly susceptible to even the slightest air movement in the vicinity of the mirror. It was therefore necessary to enclose the image deflection device in a container to isolate it from sources of unwanted disturbance.

Figure 4 shows the relative locations and interconnections of the various components of the task presentation system with respect to the subject's viewing position.

Control Coordination

An Ampex Corporation model SP-300 instrumentation tape recorder was utilized as the external source controlling the experimental task. The particular item used had four channels available and two modes on each channel: a direct mode to record and reproduce audio signals; a frequency modulation mode to record and reproduce small

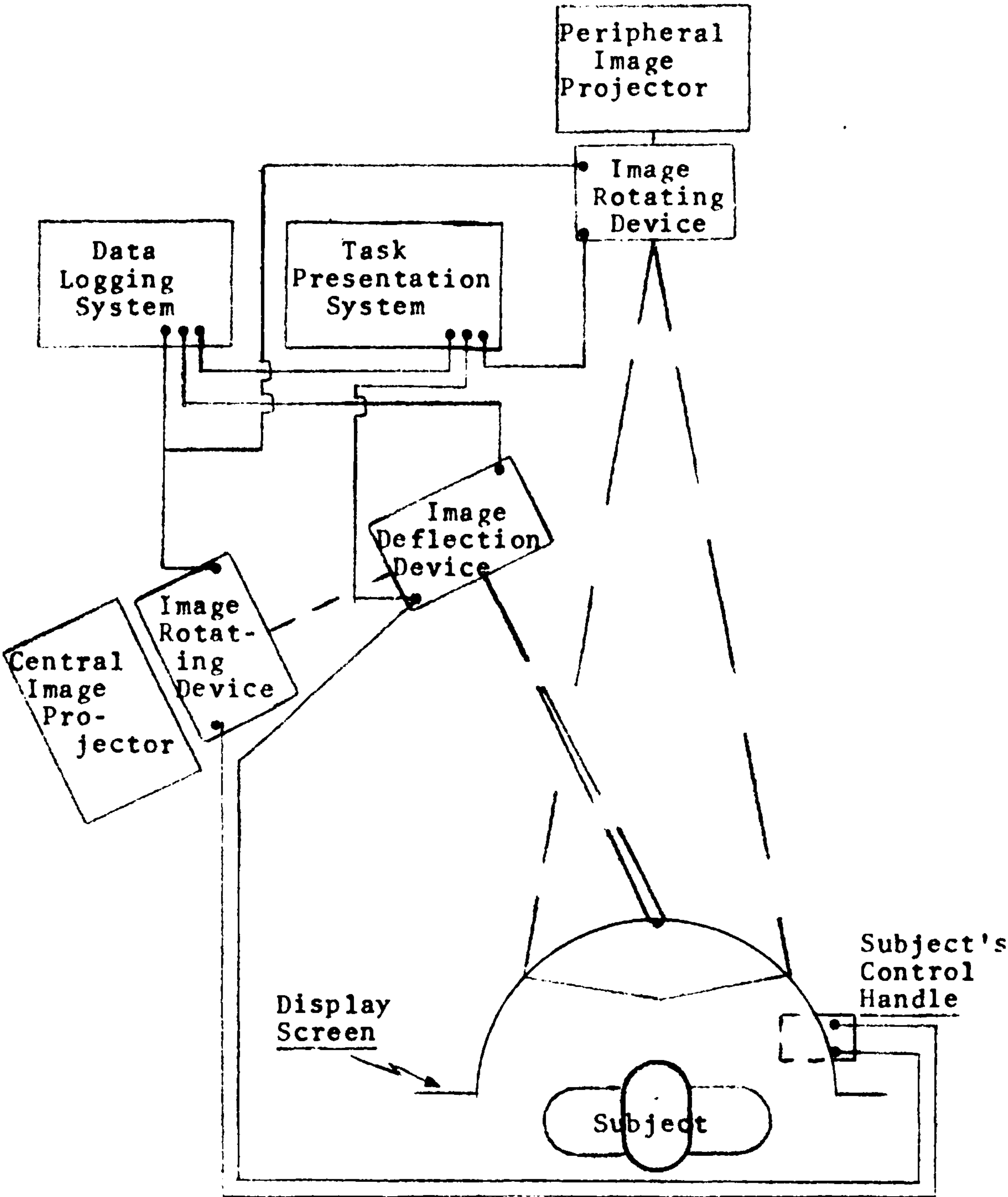


Figure 4. Schematic Diagram of the Principal Components and Interconnections of the Experimental System.

positive or negative signals. The four channels were programmed in the following manner:

1. Channel 1 was utilized in the direct mode to record verbal instructions for the subject.

2. Channel 2 was recorded in the frequency modulation mode with the opposing direct current control signals necessary to effect random rotational movement in the peripheral figure.

3. Channel 3 was also recorded in the frequency modulation mode with the varying and opposing direct current control signals necessary to cause random deflections in the central image.

4. Channel 4 was recorded in the frequency modulation mode with a known voltage for the length of the programmed tasks to indicate the start and termination of an experimental trial.

During a trial, channel 1 was first played alone to give the subject his instructions for participating in this experiment. A written copy of these instructions is presented in Appendix B. When the subject was ready to proceed with the experimental trial, the signals from channels 2, 3 and 4 were concurrently fed into the experimental system. The output of channel 2 was such that it required amplification in order to drive the servomotor of the peripheral image rotating device. The required amplification was obtained by first feeding the output control signal through a Burr-Brown Corporation model 1635 power amplifier which added a nominal gain of 10 to the input signal. The output of channel 3 was fed through a voltage reducing network directly to the microammeter of the device which produced the vertical deflections of the small central square. The known and constant signal recorded in channel 4 was present on the tape for only the exact duration of the experimental task as recorded on channels 2 and 3. This output signal from channel 4 was transmitted directly to the data logging system to identify the exact span of time over which data was taken during an experimental trial.

The actual making of the task tape was a fairly involved and painstaking process requiring almost perfect control of the level and duration of the signals recorded. However, the advantage of standardizing the experimental task and minimizing the variability in its presentation to each subject by simple rewind and playback of the magnetic tape more than compensated for the difficulty experienced in the preparation of the task tape.

Data Acquisition

In order to obtain data on θ, the angular difference between the orientation of the large peripheral square and that of the small central square, a method was devised which utilized two Selesyn servomotors connected in series. When installed in such a manner, these servomotors act together to completely block an applied signal when their motor shafts are 90° out of phase. For either decreasing or increasing phase difference between the shafts, more and more signal is passed until, at 0° or 180° difference, the applied signal is completely passed. This property of two Selesyn servomotors was used by affixing one to each of the image rotating devices positioned in front of the projectors. Appropriate gearing was provided so that an angular difference of 45° in figure orientation permitted the maximum level of a known signal to pass through the Selesyn servomotors; 0° angular difference in the figures blocked the signal completely.

A pure sine wave of 400 hz was utilized in the Selesyn servomotor circuit. The output of this circuit was then rectified into a direct current voltage and recorded in the data logging system. By previously calibrating the direct current voltage readings against known angular differences in the central and peripheral figures, it was thus possible to transform observed direct current voltages into the desired measure of utilization of dynamic peripheral vision.

For data regarding the subject's restriction of his central vision to the central figure, the instantaneous sum of the direct current voltages applied to the microammeter of the deflection device was recorded. Previous calibration of voltage reading and related deflection position was also accomplished to enable a judgment to be made with respect to the subject's performance of this part of his task.

As explained above the output of channel 4 of the control tape recorder was used solely as an index in the data logging system output to identify the data values recorded during each trial.

Data Logging System

The recording device used to collect the data generated in this experiment was a standard Hewlett-Packard Dymec Division model DY-2010H data logging system. Through its automatic scanning capability the device was programmed to sample sequentially each of twenty-four input channels every 4.5 seconds during an experimental trial. Every fourth channel was connected in parallel so that eight separate readings were obtained in a sampling period for the three direct current data voltages described in the preceding section of this chapter. The data collected by this logging device was recorded on magnetic tape in a computer-compatible format. This feature was most desirable from the viewpoint of computer processing of the large quantity of data collected during each experimental trial.

Subjects

For this pilot experiment four male students at the University of Arizona with backgrounds in engineering or science were selected as subjects. Their ages ranged from twenty-two to thirty years. All subjects were licensed and experienced motor vehicle operators who did not require the use of corrective eyeglasses for their operator's license to be legally valid. None of the subjects had previous knowledge of the movements programmed for either figure of the experimental task or of the order in which the different-sized peripheral figures would be presented during a session.

Procedure

The total experimental work done by a subject during one day was considered to be a session; each session consisted of four individual trials, each lasting three minutes. Each subject was tested for a total of four sessions.

For each individual trial of a session, the size of the peripheral square, and thus the peripheral angle, was changed. Four peripheral figures of different sizes were arbitrarily selected for presentation in the experimental task. The peripheral angles associated with the chosen peripheral figures were 30°, 40°, 55° and 70°, respectively; this factor is hereafter called "angles". The order of presentation of the different figures within each session for each subject was determined by means of a four by four Latin Square. Use of the Latin Square removed the trial-to-trial variability among angles which could have occurred due to such factors as experimental adaptation, learning or fatigue on the part of the subject.

At the start of each session, the subject adjusted his chair height and the position of the installed chin rest in order to center his eyes in the hemispheric viewing screen. Utilizing a stereo headset and tape-recorded verbal instructions the subject was then completely informed concerning the precise nature and dual aspects of his central task in this experiment. A point of particular emphasis to each subject was the fact that he was to conscientiously apply himself to the accomplishment of both orientation and deflection control of the central figure. Prior to any trial, the subject was allowed to practice with the isometric control handle to familiarize himself with its exerted force requirements and reactions. No trial commenced until the subject indicated he had had sufficient practice and was ready to proceed. When the subject had so indicated his readiness, the data logging system was first activated and then the task tape was played through to completion without interruption. The significant data needed from the experiment was recorded automatically on magnetic tape by the data logging system.

At the end of each trial the data logging system was stopped and the subject was temporarily dismissed for a rest period. During this pause, the task control tape was rewound to its starting position and a different-sized peripheral square was introduced into the task presentation system. This substitution required simply a change of the object slide and a refocusing of the peripheral image projector. The subject then resumed his viewing position and prepared for the next trial.

This procedure was repeated until the subject completed the four scheduled trials of a session. The subject was then excused until the next session after being reminded not to discuss the experiment until testing had been completed.

Analysis of Variance

A multiple Latin square analysis of variance due to the experimental system's manipulated variables was conducted. The factors considered were: 1) days or squares, 2) subjects within days, 3) treatments and 4) order of treatments within days. Results of this analysis are contained in Chapter 5.

CHAPTER 5

FINDINGS AND CONCLUSIONS

To clarify the following discussion of this chapter it is considered appropriate here to briefly re-specify what is meant when reference is made to the "subtasks" of this experimental problem. The first subtask, or Subtask 1, is defined to be the exercise of control of the vertical deflections of the central task figure; the second subtask, or Subtask 2, is specified to be the maintenance of rotational congruence between the central and peripheral task figures.

The basic data collected in the experiment consisted of approximately 335 digitalized, absolute-valued measurements of the error permitted in each subtask by the subject during each 3 minute trial. Using this data collection scheme, a total of slightly less than 43,000 data values was obtained during the course of the experiment. The handling of this number of data was obviously a most suitable application for the digital computer. Since the data were automatically recorded on magnetic tape in a computer-compatible format by the logging device, a short program was written to process the data tapes for the computation of the absolute error means of each subject's performance readings on each subtask for each experimental trial.

The computing machine used for this processing and for subsequent machine analyses of this data was a Control Data Corporation model 6400 computer operated by the Computer Center of the University of Arizona. A complete listing of the means thus obtained is given in Appendix C.

Performance Analysis

Because of the absolute-valued nature of the data obtained in the experiment, it was necessary to carry out a "square-root" transformation of the absolute error means shown in Appendix C before they could be analyzed. This transformation served to somewhat "normalize" the absolute error data. Utilizing the transformed values of the absolute error means, performance on each subtask of the experimental problem was separately analyzed. These analyses were made as a multiple Latin square analysis of variance by means of the pre-programmed computer routine, ANOVA 44, written by Weldon (1965). The Latin square design was used to remove the order effect upon treatment, which was the size of the peripheral square. The analysis of variance results are given in Table 2 for Subtask 1 and Table 3 for Subtask 2. In both analyses, the results showed that the effect of increasing the size of the peripheral square did not significantly change the performance level on either subtask. This was unexpected and surprising, and the matter will be discussed at some length below. There was, as had been expected,

Table 2. Results of the Analysis of Variance of Performance of the First Experimental Subtask Requiring Compensatory Control of the Vertical Deflections of the Central Task Figure.

Source	df	SS	MS	F
Treatments	3	.1131	.037	ns
Days	3	3.0290	1.0096	18.6*
Order within days	12	.6378	.0531	ns
Subjects within days	12	12.9276	1.0773	19.9*
Error	33	1.7908	.0542	
Total	63	18.4983		

*Significant at the .01 confidence level.

Table 3. Results of the Analysis of Variance of Performance of the Second Experimental Subtask Requiring the Maintenance of Rotational Congruence between the Central and Peripheral Task Figures.

Source	df	SS	MS	F
Treatments	3	.0032	.0010	ns
Days	3	.2071	.0690	8.12[a]
Order within days	12	.2008	.0167	ns
Subjects within days	12	.6004	.0500	5.88[a]
Error	33	.2816	.0085	
Total	63	1.2931		

[a]Significant at the .01 confidence level.

a significant difference of performance due to subjects within days, and a significant difference due to days, this latter factor being a learning effect.

The "order within days" effect was shown in Tables 2 and 3 not to be significant for either subtask. This effect therefore could have been removed from the analysis and the analysis then made as if there were no order effect. Such a step would have changed the analysis from a multiple Latin square design to a complete factorial design and thus would have permitted the use of Tables 4 through 7 in evaluating the results of the experiment.

Entries in Tables 4 through 7 are mean values of the absolute errors permitted by each subject during the experiment. Due to the physical set-up of the data acquisition and recording system, units for the values shown in Tables 4 and 6 are different than those for Tables 5 and 7. For the former group, the unit of measurement was "millivolts"; for the latter group, the unit of measurement was "volts". For analysis purposes, however, the relative size of the mean values in each of these tables may be taken as a comparative score of performance on the subtask to which the particular table applies. The smaller the numerical value of a mean deviation score, the better is the subject's performance for the treatment or session identified by that score. Tables 4 and 5 contain mean deviation scores on Subtasks 1 and 2, respectively, presented in terms of subject and treatment. Tables 6 and 7 also contain mean deviation scores for the two subtasks, presented, however, in terms of subject and session. Overall mean deviation scores are also given in these tables for subjects, and for subjects within treatments or sessions as applicable. Study of Tables 4 through 7 demonstrates the existence of the learning effect already mentioned above. Study also indicates that the individual subjects differed considerably, but that there was no significant overall effect on performance due to the changes made in peripheral angle.

Discussion

It was indeed a surprising result that no overall effect upon performance on either subtask was revealed due to changes in treatments. This finding is not consistent with the literature on peripheral vision as reported in Chapter 2 of this thesis. The research reported there is quite consistent in its findings that various visual properties and capabilities tend to degrade as the peripheral angle increases. In attempting to analyze this somewhat perplexing result and the underlying reasons for it, the following observations were considered as particularly applicable to this problem.

First there were quite obviously too few sessions of experimental trials to bring each subject's rate of learning to a relatively stable state. The experimenter was aware of this factor, but because of the length of time needed to

Table 4. Comparative Representation of Mean Deviation Scores* on the Experimental Subtask Requiring Control of the Vertical Deflections of the Central Task Figure in Terms of Subjects and Treatments.

Subjects	Treatments** 1	2	3	4	Overall Means by Subject
1	21.46	22.21	19.31	19.42	21.22
2	31.29	30.48	30.60	30.24	30.65
3	32.02	31.01	29.79	31.11	30.92
4	22.43	26.26	18.41	25.76	24.46
Overall Means by Treatment	26.80	27.49	24.52	26.63	

*Unit of measurement is "millivolts".

**Treatments 1, 2, 3 and 4 correspond respectively to peripheral angles of 30°, 40°, 55° and 70° defining the angular location of the peripheral task figure.

Table 5. Comparative Representation of Mean Deviation Scores[*] on the Experimental Subtask Requiring the Maintenance of Congruence Between the Central and Peripheral Task Figures in Terms of Subjects and Treatments.

Subjects	Treatments[**] 1	2	3	4	Overall Means by Subject
1	.112	.181	.118	.099	.128
2	.208	.240	.259	.194	.226
3	.039	.031	.182	.052	.070
4	.143	.083	.063	.156	.113
Overall Means by Treatment	.126	.135	.149	.125	

[*]Unit of measurement is "volts".

[**]Treatments 1, 2, 3 and 4 correspond respectively to peripheral angles of 30°, 40°, 55° and 70° defining the angular location of the peripheral task figure.

Table 6. Comparative Representation of Mean Deviation Scores[a] on the Experimental Subtask Requiring Control of the Vertical Deflections of the Central Task Figure in Terms of Subjects and Sessions.

Subjects	Sessions 1	2	3	4	Overall Means by Subject
1	24.21	20.11	17.88	22.69	21.22
2	35.56	33.60	28.52	24.94	30.65
3	31.69	32.56	30.94	28.49	30.92
4	25.82	28.94	22.62	20.48	24.46
Overall Means by Session	29.32	28.80	24.99	24.15	

[a]Unit of measurement is "millivolts".

Table 7. Comparative Representation of Mean Deviation Scores* on the Experimental Subtask Requiring the Maintenance of Congruence Between the Central and Peripheral Task Figures in Terms of Subjects and Sessions.

Subjects	Sessions 1	2	3	4	Overall Means by Subject
1	.170	.209	.068	.062	.128
2	.319	.150	.253	.180	.226
3	.164	.057	.022	.036	.070
4	.162	.128	.053	.108	.113
Overall Means by Session	.204	.136	.099	.097	

*Unit of measurement is "volts".

obtain, construct and assemble the components of the apparatus into an operating experimental system, the available time for experimental trials was seriously limited. Nevertheless, it did seem reasonable to expect that some indication of the hypothesized decline in performance would have been obtained even in the early testing stages of this experiment if in fact it was present.

Secondly, it is conjectured that the total size of the more peripheral figures may have counterbalanced the expected degradation in performance due to the larger peripheral angles. In this respect there was actually much more length and breadth of line, and less brightness, in the more peripheral figures, due partly to the angle of incidence of the projection onto the hemisphere and partly to the fact that continuous lines were used for all peripheral figures. Third, because the angular speed of rotation of the peripheral figures was the same for all sizes, the absolute speed of rotational movement of the more peripheral figures in the experimental problem was greater. This increase in absolute speed may have increased the perceptibility of the more peripheral figures so as to offset the expected decline in performance for the greater peripheral angles. A fourth possibility in that the human motor aspect of the task, i.e., the motor skill required to execute the task, was sufficiently demanding so as to mask a change in the difficulty of the perceptual requirements. This possibility is mentioned here for completeness of discussion even though it seems unlikely. It seems unlikely because the motor part of the task was the same for all treatments. These four factors are all physical aspects or properties of the experimental design and hence can be readily manipulated or altered in succeeding experimentation to determine their actual contribution, if any, to the results observed in this research.

A fifth factor which could have contributed to the results of this experiment was the possibility of an interference between the two subtasks as the subjects attempted to execute them. The occurrence of this effect was reported in discussion with those who served as subjects in the experiment. They reported "seeing" the need to rotate the central square or the need to correct the vertical position of that square but not both needs at the same time. In older terms there was apparently a conflict between the subtasks for the attention of the subject. Nothing, however, was found in the data to substantiate the influence of this factor but it seems that data to bear on this point could be obtained in future experimentation.

Conclusions

Among the numerous man-machine systems in use today there are many with operator tasks so specific or simple that central vision suffices for the visual information needs of operators performing those tasks. There are other system operator tasks, however, in which a more or less complex environment is involved. In such tasks a breadth of peripheral vision and, it should be noted here, a breadth of operator regard or attention become important. Examples of such tasks are the operation of moving vehicles, of material handling devices such as cranes and of systems with expansive, complex visual displays such as manned space vehicles. It was to the complexity of this kind of task that this thesis was directed.

Although the experiment of this thesis did not succeed in finding a functional relationship between peripheral angle, as defined for this research, and the measure of performance selected for study, yet it has made a contribution in the following way. First, it has introduced new equipment usage and procedural techniques for studying peripheral vision. With respect to this particular design, the experiment has suggested certain parameters, specifically, 1) the size of the surface area of the peripheral figure and 2) the speed of the absolute motion of that display, which need to be more carefully controlled in future experiments. It has again raised the question whether two measurable tasks, in this case Subtasks 1 and 2, can be antagonistic to each other even though they involve the same visual field and fixation point, and are controlled by different but compatible control forces applied to the same control handle. Unfortunately, the experiment has not provided an answer to this question.

Nevertheless, it appears from the experiment, and from the comments of those serving as subjects, that the techniques used here provide a means not only to study peripheral vision as such, but perhaps also to study the organization of visual inputs to the system operator. It would seem then that a step has been taken to study a level of organized complexity more in keeping with that which confronts numerous system operators than has been customary in previous human factors research.

APPENDIX A

LIST OF EQUIPMENT USED

LIST OF EQUIPMENT USED

In this appendix the major components of the system developed to implement this experiment are listed, each followed by a brief description in parentheses of its particular function in the experiment:

1. Data Acquisition System, Hewlett-Packard Co., model HP-2010H, consisting of a model DY-2901A Input Scanner, a model DY-2401C Integrating Digital Voltmeter and a model HP-2546 Magnetic Tape Recorder Set, 1 each: (Automatic logging of experimental data).

2. Instrumentation Tape Recorder with remote control, Ampex Corp., model SP-300, 1 each: (Programming of subject's instructions and experimental task and control signals).

3. Isometric Hand Control, Measurements Systems Inc., model 437, 1 each: (Subject's control device).

4. Variac Autotransformer, General Radio Co., type W10MT3, 1 each: (Excitation source for subject's hand control).

5. Power Amplifier, Burr-Brown Inc., model 1635, 1 each: (Amplification of experimental task signal).

6. Power Amplifier, Burr-Brown Inc., model 1633, 2 each: (One for amplification of subject's control signal, one spare).

7. Dual DC Power Supply, Hewlett-Packard Co., model 6205B, 2 each: (Power source for Burr-Brown power amplifiers).

8. Unit R-C Oscillator, General Radio Co., type 1210-C, 1 each: (Generation of control signal used in circuit to detect difference in orientation of experimental task figures).

9. Unit Amplifier, General Radio Co., type 1206-B, 1 each: (Amplification of control signal for orientation difference detection circuit).

10. Autosyn Synchrotransformer, Bendix Aviation Corp., 2 each: (Series-connected to permit detection of difference in orientation of experimental task figures).

11. Slide Projector, Nikkormat, model GC-1, 2 each: (Projection of experimental task figure images).

12. Image Rotating Mechanism, Hand Fabricated, consisting of a Dove prism, a pulley and gear train, an Electro-Craft Corp. model E6000 DC Servomotor and assorted bearings, 2 each: (Controlled rotation of experimental task figure images).

13. DC Microammeter, Triplett Co., model 420 with light-weight mirror attached to pointer needle, 1 each: (Deflection of small central figure image).

14. Stereo Hi-Fi Headset, Calrad Corp., model HP-2, 2 each: (One for subject's use, one for experimenter's monitor position).

15. Plexiglas Hemisphere, Specially Fabricated, 1 each: (Display screen for experimental task).

16. Adjustable Chin Rest, House of Vision Inc., 1 each: (Subject's head positioning device).

17. Display Screen Mounting, Hand Fabricated, 1 each: (Self-explanatory).

18. Adjustable Secretary's Chair, Steelcase Inc., 1 each: (Subject's seating apparatus).

19. Camera, Nikon F 35mm, with assorted lenses, 1 each: (Production of experimental figure image slides).

20. DC Power Supply, Hewlett-Packard Co., model 6200B, 2 each: (Production of experimental task tape).

APPENDIX B

SUBJECT INSTRUCTIONS

SUBJECT INSTRUCTIONS

You are about to participate in an experiment designed to investigate the extent to which you can usefully employ moving peripheral visual signals to assist you in performing a central task. The exact nature of this task will be explained to you immediately following a briefing on the experimental apparatus before you.

First, insure that the subject's chair height allows you to comfortably place your chin upon the chin rest. Then make fine adjustments with the chin rest adjusting screw so that your line of sight falls directly on the center of the viewing hemisphere. The center of the display is marked by the crossed black lines. On the viewing screen you observe two figures: the one, a small square figure located in the center of the display, the other, an outline of a larger square which is located at some angle in the periphery of the display and is centered about the smaller figure. You also see two short horizontal lines spaced approximately 1-1/2 inches above and below the mid-line of the display.

Next, grasp the shaped control located in the right hand port of the viewing screen mounting. This control is an isometric joystick allowing you to control both upward and downward vertical displacement and axial rotation of the

the small square figure only. You have no control over the peripheral figure. Forward or backward force on the joy-stick handle controls vertical deflection of the small central figure while clockwise or counterclockwise torque on the control handle produces respective rotation of that figure about the center of the display. Acquaint yourself now with the effects produced in the display due to forces which you apply to the control handle. Practice with it until you feel familiar with its operation and advise me accordingly.

Your task in the actual experiment is essentially one of simultaneous tracking and control. The small figure at the center of the display will be randomly deflected up-ward and downward away from center along the vertical axis of the display. One part of your task is to apply control force on the joystick handle to counteract the external deflections of the central figure and thereby maintain its position within the limits marked by the horizontal lines above and below the center of the display. Random clock-wise and counterclockwise rotation of the peripheral figure about the center of the display will also occur during the experimental trial. The other part of your task then is to maintain rotational congruency between the peripheral and central squares. This is accomplished by sensing the move-ment of the peripheral figure and then compensating for it through rotational movement of the small central square.

For example, if you sense that the peripheral figure is slowly rotating in a clockwise direction, you should cause the central figure to be rotated in a similar direction at the same rate in order to maintain the desired congruency of orientation.

It is expected that you will attempt to perform both aspects of your experimental task to the best of your ability, and that you will not disregard one in favor of the other. Furthermore, the importance of confining your central vision to the center of the display is stressed since alternation of your visual fixation point between the central and peripheral figures during a trial will render invalid and useless the data obtained during that trial.

If you have any questions, please ask them at this time. Please do not discuss any aspect of this experiment with others until the experiment has been completed.

Thank you for your cooperation.

APPENDIX C

TABLE OF EXPERIMENTAL DATA

In this appendix the means of the absolute-valued error deviations recorded for each subtask are listed. Listing is by subjects and experimental session.

Session 1

Subject	Treatment*	Subtask 1 Mean Deviation**	Subtask 2 Mean Deviation†
1	1	29.03	.161
1	2	26.41	.254
1	4	20.93	.059
1	3	20.49	.206
2	2	33.44	.337
2	3	39.46	.527
2	1	35.18	.246
2	4	34.17	.167
3	3	32.80	.474
3	4	28.16	.104
3	2	31.85	.043
3	1	33.98	.035
4	4	28.28	.168
4	1	24.58	.290
4	3	24.45	.049
4	2	25.97	.142

*Treatments 1, 2, 3 and 4 correspond respectively to peripheral angles of 30°, 40°, 55° and 70° defining the angular location of the peripheral task figure.

**Units for the data listed for Subtask 1 is "millivolts."

†Units for the data listed for Subtask 2 is "volts."

Session 2

Subject	Treatment*	Subtask 1 Mean Deviation**	Subtask 2 Mean Deviation†
1	2	20.96	.370
1	3	21.49	.144
1	1	18.98	.171
1	4	19.04	.153
2	3	31.35	.073
2	4	33.81	.209
2	2	35.01	.177
2	1	34.25	.140
3	4	33.78	.083
3	1	30.82	.042
3	3	30.20	.069
3	2	35.47	.033
4	1	25.12	.146
4	2	29.29	.108
4	4	33.02	.156
4	3	28.36	.101

*Treatments 1, 2, 3 and 4 correspond respectively to peripheral angles of 30°, 40°, 55° and 70° defining the angular location of the peripheral task figure.

**Units for the data listed for Subtask 1 is "millivolts."

†Units for the data listed for Subtask 2 is "volts."

Session 3

Subject	Treatment*	Subtask 1 Mean Deviation**	Subtask 2 Mean Deviation†
1	3	19.60	.078
1	4	17.07	.060
1	2	18.06	.044
1	1	16.80	.091
2	4	29.84	.252
2	1	30.13	.268
2	3	26.82	.287
2	2	27.29	.207
3	1	31.41	.035
3	2	30.79	.019
3	4	32.96	.008
3	3	28.60	.028
4	2	28.37	.021
4	3	20.04	.047
4	1	20.30	.093
4	4	21.80	.051

*Treatments 1, 2, 3 and 4 correspond respectively to peripheral angles of 30°, 40°, 55° and 70° defining the angular location of the peripheral task figure.

**Units for the data listed for Subtask 1 is "millivolts."

†Units for the data listed for Subtask 2 is "volts."

Session 4

Subject	Treatment[a]	Subtask 1 Mean Deviation[aa]	Subtask 2 Mean Deviation†
1	4	20.64	.123
1	1	21.05	.025
1	3	25.66	.046
1	2	23.41	.056
2	1	25.60	.180
2	2	26.20	.241
2	4	23.16	.150
2	3	24.80	.148
3	2	25.93	.030
3	3	27.57	.057
3	1	30.89	.045
3	4	29.59	.014
4	3	20.81	.056
4	4	19.97	.249
4	2	21.43	.083
4	1	19.72	.045

[a]Treatments 1, 2, 3 and 4 correspond respectively to peripheral angles of 30°, 40°, 55° and 70° defining the angular location of the peripheral task figure.

[aa]Units for the data listed for Subtask 1 is "millivolts."

†Units for the data listed for Subtask 2 is "volts."

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