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Cognitive Load and the Functional Field of View

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In an experiment that kept visual display factors constant but which varied cognitive load, it was found that cognitive load modulated the functional field of view. When given a high level of foveal (cognitive) load, the functional field of view was only about 2 deg in diameter, whereas a low level of foveal load resulted in a functional field of about 4 deg diameter. The shrinkage of the functional field appeared to be rather generalized and not a true tunnel-vision effect.

INTRODUCTION

In recent years, many studies have been reported in both the human factors and the psychological literature on the abilities of the operator or subject to successfully perform more than one task efficiently within a relatively brief period of time. Although different descriptors and various techniques have been employed, studies of workload, dual-task stimulation, time sharing, secondary-task performance, divided or distributed attention, etc., have generally had as two of their major goals the assessment of performance limitations within reasonably complicated environments (e.g., cockpits) and the improved conformance of various systems to the capabilities of the human information processor.

An accurate assessment of foveal and parafoveal visual performance is particularly critical given the demands placed on pilots and air traffic controllers. There have been several excellent reviews of this literature, notably, Moray, 1979; Ogden, Levine, and Eisner, 1979; Whitaker, 1979; and Williges and Wierwille, 1979.

Many kinds of tasks have been employed to assess human performance; however, a task that has not been examined comprehensively is one in which the subject or operator must distribute visual attention both foveally and parafoveally within a single fixation pause and must make two independent timed responses to the foveal and parafoveal stimuli. One specific question that should be addressed is: What would be the effect of increasing the cognitive load of the foveal (primary) stimulus without increasing visual complexity on the performance of a secondary (peripheral) visual task? Does an increase in foveal cognitive load result in a shrinkage of the functional field of view?

Polyak (1941) was one of the first researchers to discuss not only the structure of the retina, but its function as well. Other researchers have discussed the possibility that the retina may be partitioned into functional divisions (Trevarthan, 1968; Schneider, 1969).

Mackworth was one of the first researchers

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to appreciate the retina as a dynamic system. He defined the functional field of view as

> the area around the fixation point from which information is being briefly stored and read out during a visual task. When there is too much information, the useful field contracts to prevent overloading of the visual system. The useful field is therefore varying in width from moment to moment according to the amount of information in the display. The useful field cannot exceed the normal physiological limits set by the ordinary visual acuity limits (Mackworth, 1965, p. 67).

Mackworth referred to this contraction of the visual field to prevent overloading the system as *tunnel vision.* Bursill (1958) and Teichner (1968) have presented related arguments on "attentional fields" and have provided some discussion of the sensitivity of attentional fields to task demands.

Despite the many different tasks employed in dual-task simulation, time-sharing, and workload studies (see Ogden et al., 1979), there have been very few studies that have examined performance during a single fixation of the eye. Generally, those few studies that have examined dual-task performance within a single glance have intentionally manipulated the visual complexity of the foveal task or have confounded the cognitive and visual aspects of the foveal task (Chakin, Corbin, and Volkman, 1962; Webster and Haslerud, 1964; Mackworth, 1965; Engel, 1971, 1974; Ikeda and Takeuchi, 1975; Holmes, Cohen, Haith, and Morrison, 1977).

The present study was primarily an attempt to assess the effects of a cognitive load manipulation of a foveal task on peripheral task performance while foveal visual factors were held constant. This was accomplished by using a character-classification foveal task (Posner and Mitchell, 1967). A reaction-time measure, which has not typically been employed in functional field research, was used in this study, as was an accuracy measure. The reaction-time measure was considered important since many operators are under some speed stress in addition to an accuracy requirement.

If the cognitive load manipulation was effective, we would then need to determine whether this manipulation affected peripheral task performance about equally at all peripheral locations, or whether a high level of cognitive load had a greater detrimental effect on the more eccentrically located material. The latter would indicate a true tunnel-vision effect.

METHOD

Subjects

The subjects were 32 undergraduates (18 females and 14 males) who were enrolled in an introductory psychology course and participated in the study in order to fulfill a course requirement. Subjects participated for a total of about 50 min. All subjects were right-handed and were required to read the 20/13 line of a Snellen chart without error before being accepted into the experiment.

Apparatus

Three channels of a four-channel tachistoscope were used to present the fixation, test, and post-exposure fields. The three fields each had a luminance of 32 cd/m^2. The tachistoscope was slightly modified to accommodate the white stimulus cards. The modified stimulus (exposure) field of the tachistoscope measured approximately 11 deg of total visual angle, horizontally and vertically.

The reaction-time apparatus that was used for the character-classification (foveal) task consisted of a digital clock counter and a small metal box with three pushbuttons arranged in a vertical *V*. The middle button was not used in this experiment, but served as a finger rest that was equidistant between the two functional buttons. When the subject pressed a large foot pedal, the tachistoscope and the clock counter were both pulsed. Pressing either the left or right button of the reaction-time box stopped the clock counter and simultaneously started the second timer cycling. The subject's vocal response to the peripheral line discrimination task stopped the second timer. This was accomplished by means of a microphone and voice-activated relay.

Stimuli

The foveal stimuli were vertically arranged pairs of uppercase press-on letters (24-point Helvetica medium) that had been positioned on 20.3 cm × 36.8 cm white posterboard cards. For both the physical (low foveal load) and category (high foveal load) conditions, the symmetrical uppercase letters *A*, *I*, *O*, *T*, *V*, and *X* were used. The letters were 0.6 cm high and between 0.5 and 0.7 cm wide, except for the letter *I*, which was 0.1 cm wide. The line width of all letters was 0.1 cm. At a viewing distance of 86 cm, the letters subtended 24 min of visual angle in height and from 20 to 28 min in width, except for the letter *I*, which subtended 4 min in width. The letter pairs were centered on the card, one letter being just above fixation and one letter being just below. The letters were separated vertically by a distance of 0.4 cm.

There were 192 stimulus cards, 96 for each of the two foveal loads. Half of the cards in each deck had a vertical line and half had a horizontal line on the card in addition to the letter pair. When displayed in the tachistoscope, the peripheral line could appear at one of 24 retinal locations, that is, at 1.66, 3.33, or 5.0 deg from fixation along any one of eight meridians (see Figure 1). The horizontal and vertical lines were the lowercase *l* (24-point Helvetica medium). Each line was 0.6 cm long and 0.1 cm wide, and when displayed in the tachistoscope subtended a visual angle of 24 min in height and 4 min in width. Certain retinal eccentricities were chosen because the modified tachistoscope allowed a visual field that was approximately 11 deg in diameter. This meant that 5 deg was the most eccentric location from fixation that could be employed without getting too close to the edges of the field. The three values chosen were in equal increments from the fixation point.

Design

The repeated measures design contained five independent variables. Retinal eccentricity (1.66 deg, 3.33 deg and 5.0 deg), meridian (8 levels, see Figure 1), type of foveal response (same or different), and type of peripheral response (horizontal or vertical) were manipulated within subjects. The fifth independent variable, foveal load (physical or category match) was manipulated between subjects.

Each subject contributed 96 observations in a test session. Trials were run in two blocks of 48 each with a 2-min rest period between blocks. Each subject contributed 4 replications of each of the 24 treatment combinations of retinal eccentricity and meridian under one level of the foveal load variable. Since 32 subjects were tested, there were 128 observations per cell in the experiment.

Procedure

During a 5-min dark-adaptation period, the instructions were read to the subject. The subject was then given from 5 to 6 min of practice (about 25 trials) in order to become familiar with the equipment and procedure. During this warm-up period, an exposure duration was determined that would be employed throughout the test trials for that subject. Although an individual exposure duration was to have been determined for each subject, all subjects performed satisfactorily at a duration of 25 ms. The duration had to be rapid enough so that subjects would make a reasonable percentage of errors on the peripheral task, but not so rapid that the error rates would be too high, which would result in many observations being lost from the reaction-time dependent measure.

The subject sat in front of the tachistoscope

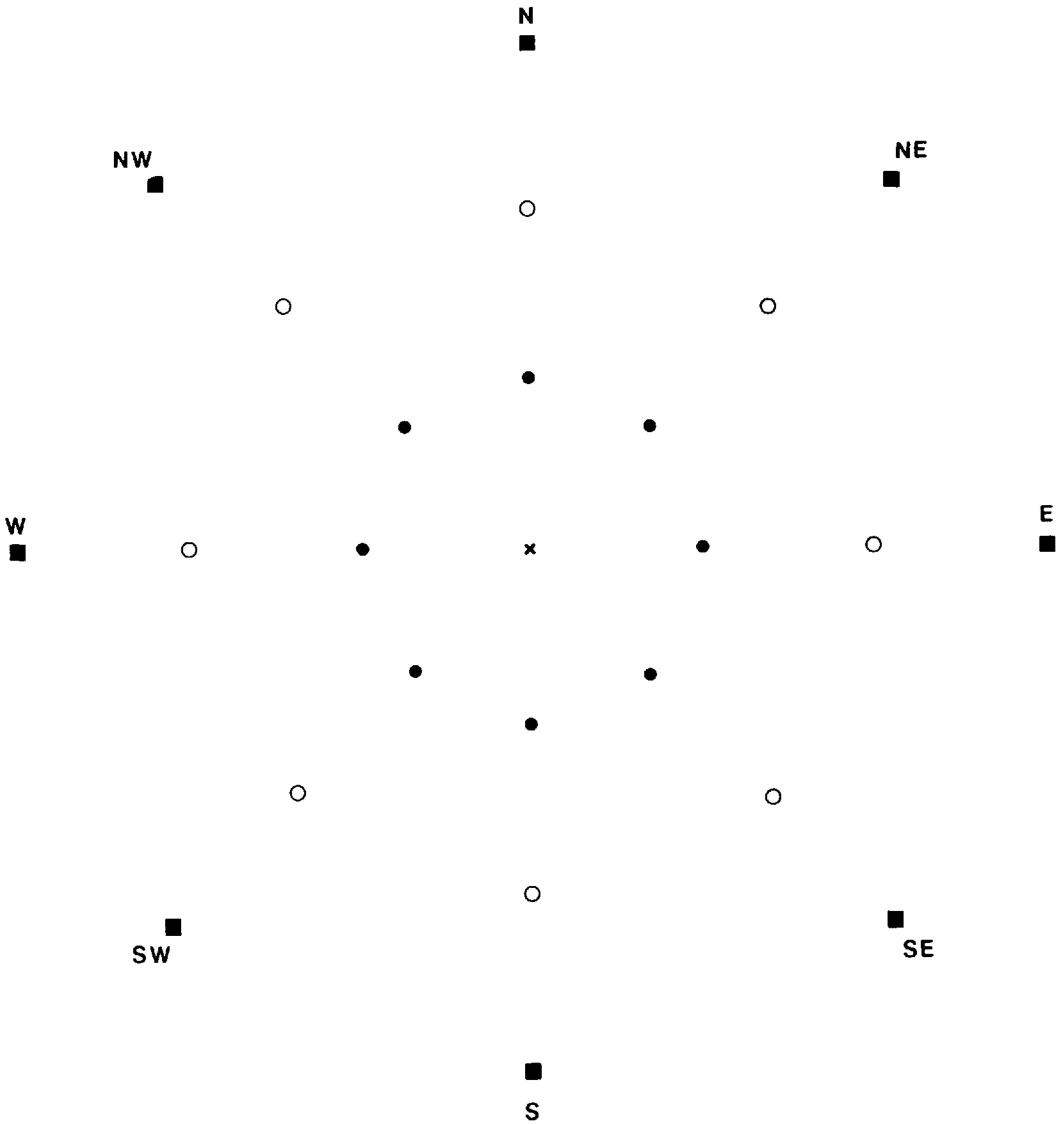

Figure 1. *A schematic of the 24 retinal locations at which stimuli were presented.*

and focused on a small black fixation dot that was centrally located on the lighted fixation field. Subjects were told that steady fixation was critical and that it was important that they be both fast and accurate on the foveal and peripheral tasks. It was made clear that their accuracy and reaction-time performance was being monitored for both the foveal and peripheral tasks. The experimenter emphasized neither the foveal nor the peripheral task; however, subjects were instructed to always respond to the foveal material (character classification) before making the response to the peripherally exposed line.

Located on the table in front of the subject was the reaction-time box with three buttons, and the microphone that was wired to the relay. The unused third button served as a "home" button. When the subjects heard a 1-s warning tone, they had 2 s to press the foot pedal to initiate a trial. They could begin a trial at any point during this 2-s interval. If the subject failed to hit the pedal within 2 s, the subject would have to wait approximately 14 s for the next tone.

RESULTS

There were four basic data analyses: foveal task reaction time, foveal task errors, peripheral task reaction time, and peripheral task errors. It was crucial that a significant effect of foveal (cognitive) load be demonstrated in the foveal character-classification task. This was critical because of the basic prediction that a high level of foveal load (category match) would result in a shrinkage of the functional field for a secondary peripheral task relative to a low level of foveal load (physical match). The first analysis of variance of mean reaction times was of the form subjects × foveal load (category or physical match) × type of response (same or different). Foveal load was manipulated between subjects. The overall mean reaction time for correct response trials was 947 ms. Erroneous foveal responses, which constituted only 7.6% of the data, were not used in the analysis, nor were reaction times that exceeded the overall mean by 70%. This rather conservative criterion resulted in a discarding of less than 1% of the data.

The foveal load variable was significant, $F(1,30) = 8.07, p < 0.01$. The mean reaction time for the physical match was 860 ms. For the category matches, the mean reaction time was 1021 ms, or 161 ms longer. This result basically replicates other character-classification experiments (Posner and Mitchell, 1967).

There was no significant difference in type of response, $F(1,30) = 2.1$, although subjects were 13 ms faster on the same responses (934 ms compared with 947 ms). Slightly faster responding for "sames" has typically been found (e.g., Posner and Mitchell, 1967; Bamber, 1969). The interaction between foveal load and type of response did not approach statistical significance, although there was a slight tendency for the difference between same and different responses to be larger under the category-match level of foveal load. Clearly, category matches were considerably more difficult as assessed by reaction time.

An analysis of variance was also performed on the foveal error data. The foveal load variable just failed to reach the conventional alpha 0.05 level, $F(1,30) = 3.40, p < 0.08$. This was not surprising, given the rather low error rate of 7.6%. Subjects averaged 5.4% errors on the physical matches and 9.9% errors on the category matches. The nonsignificant result accounted for 10% of the variance in the subject × foveal load × type of response analysis. Neither the type of response nor the interaction approached statistical significance. Taken together, these reaction-time and error data demonstrate that subjects found the category matches more difficult.

The next analysis of peripheral reaction time was crucial to the original hypothesis that a difficult foveal (cognitive) load would result in a smaller functional field of view. This analysis of variance was of the form subjects × foveal load × retinal eccentricity × meridian × type of peripheral response (vertical or horizontal). Erroneous responses on either the foveal or the peripheral task were not used in the reaction-time analysis. Foveal load was the only variable manipulated between subjects. Foveal load had a significant effect on subjects' performance on the peripheral line orientation task, $F(1,30) = 5.63, p < 0.05$. When subjects were given a physical-match foveal task, they averaged 536 ms on the peripheral line orientation discrimination task. However, when given a category-match foveal task, subjects averaged 586 ms on the peripheral line orientation discrimination task (Figure 2). This main effect of foveal load accounted for a fairly impressive 16% of the total variance. A difficult foveal task (one that results in more foveal errors and slower foveal response times) is detrimental to peripheral processing.

The retinal eccentricity variable was highly significant, $F(2,60) = 17.4$, $p < 0.001$, accounting for 21% of the variance. The three reaction-time means for this variable were 536, 560, and 587 ms for the 1.66-deg, 3.33-deg, and 5.0-deg eccentricities, respectively. This increase in reaction time as a function of increasing retinal eccentricity can be described very nicely by a straight line with a slope of 15 ms/degree of visual angle.

The meridian variable did not approach statistical significance. Subjects were about equally proficient at recognizing the line orientations along the eight meridians. Neither type of foveal response nor type of peripheral response (horizontal or vertical) was statistically significant. Several three- and four-way interactions were significant at the 0.05 level, although none of them accounted for more than 2% of the total variance.

Although the reaction-time data as discussed so far have clearly demonstrated that the functional field of view is considerably smaller when a fairly difficult foveal (cognitive) load is imposed than it is when subjects are given a rather easy foveal load, there was little evidence for a true tunnel-vision effect (Figure 3). The interaction between foveal load and retinal eccentricity was not significant. As has been stated, a true tunnel-vision effect would require not only that a category-match foveal task have a greater detrimental effect on peripheral processing than would a physical-match foveal task, but also that this reaction-time disparity should grow larger as retinal eccentricity increases. Figure 3 clearly shows that the two functions

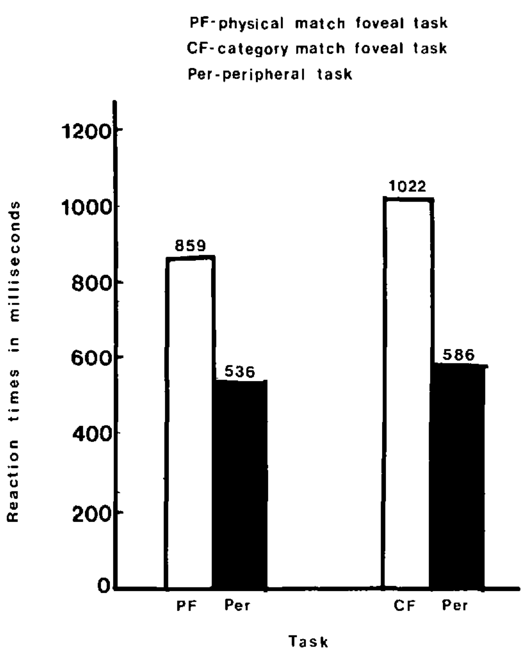

Figure 2. *Mean reaction times for the foveal character-classification task and the peripheral task.*

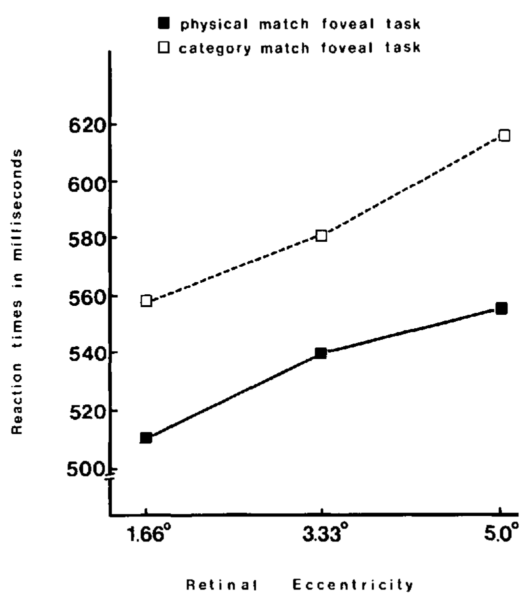

Figure 3. *Mean reaction times for the peripheral line orientation discrimination task.*

have very nearly the same average slope. The slope of the function for the subjects who received the physical-match foveal task was 13 ms/degree of visual angle. The slope of the other function was nearly 18 ms/degree of visual angle. Also, the mean reaction time for the physical matches at the most eccentric locations (5.0 deg) was slightly less than the mean reaction time for the category matches at the least eccentric locations (1.66 deg).

It should be mentioned that there was some suggestion of a tunnel-vision effect when the two functions are compared only at the 3.33-deg and 5.0-deg locations. Here the slope was slightly greater under the category condition. For the sake of completeness, an analysis of variance was performed on a reduced data set with the 1.66-deg eccentricity deleted. This analysis failed to yield a statistically significant interaction but, of course, one-third of the data had to be discarded.

An analysis of variance was also performed on the peripheral error data. The overall peripheral error rate was 17.7%. There was no main effect of foveal load, although subjects did make a greater number of errors on the peripheral task when the foveal load was greater (18.8%, as compared with 15.1%). This was not terribly surprising given the much smaller data set than that employed for the reaction-time analysis. The major reason for employing reaction time as the principal dependent measure was the greater sensitivity of a reaction-time measure.

The retinal eccentricity main effect was very large, $F(2,60) = 3.12, p < 0.001$, which accounted for 50% of the variance. Subjects made only 9.7% errors at the 1.66-deg eccentricity, but made 15.3% and 25.9% errors at the 3.33-deg and 5.0-deg eccentricities. One of the secondary purposes of the study was to determine the visual angle at which performance breaks down or reaches unacceptable levels. It would appear that subjects have a very difficult time on the peripheral task beyond about 3-3.5 deg in any direction from fixation. The increase in errors as a function of increasing retinal eccentricity was nearly linear, as was the reaction-time function, suggesting that subjects were not engaging in a speed-accuracy trade-off. Although the interaction between foveal load and retinal eccentricity did not approach statistical significance, there was a slight tendency in the direction of a tunnel-vision effect (see Table 1). No other interactions were significant, nor did any account for more than 1% of the variance.

Even though there was no evidence for a speed-accuracy trade-off, there was some concern caused by the rather substantial differences in the number of observations per cell in the reaction-time analysis due to the large differences in error rates. As a check on the seriousness of the problem, a weighted means check was performed on the reaction-time data. Each cell in the experiment was weighted by the number of errors made under that treatment combination. By doing this for all cells and then summing across appropriate rows of columns and dividing by the appropriate sums of the weights, it was possible to calculate adjusted marginal means. In no way was the pattern of these adjusted means different from the nonadjusted (original) means. In fact, the absolute values of the reaction-time adjusted marginal means were seldom more than 2 or 3 ms different from the nonadjusted values. This was not surprising given the relatively large number of observations per cell and the overall robustness of the analysis of variance.

As an additional check to determine if reaction-time means showed a grossly different pattern on erroneous trials, the reaction-time distribution for erroneous responses was examined. As can be seen by examining Table 1, simply adding a constant of about 41 ms to the physical-match correct trial data at each of the three eccentricities will make the correct trial and incorrect trial means equiva-

TABLE 1

Mean Reaction Times for Correct and Incorrect Trials, and Error Rates at the Three Retinal Eccentricities

Foveal Load	*Retinal Eccentricity (deg)*	*Mean Peripheral Reaction Time (Correct Trials) (ms)*	*Mean Peripheral Reaction Time (Incorrect Trials) (ms)*	*Mean Peripheral Task Percentage Error**
Physical	1.66	514	560	7.6 (8.3)
Physical	3.33	539	583	14.3 (16.7)
Physical	5.0	556	600	23.4 (30.5)
Category	1.66	559	603	11.7 (13.3)
Category	3.33	581	618	16.4 (19.6)
Category	5.0	617	644	28.3 (39.5)

* Values in parentheses are error rates corrected for guessing.

lent. Likewise, adding a constant of about 36 ms to the category-match correct trial data will make the correct trial and incorrect trial means equivalent.

If one were to assume that the incorrect response times represent some amount of guessing, then subjects do not appear to make their guesses more rapidly than they make their correct responses. These data again show that although reaction time is the principal measure, reaction-time and error rates are rather equivalent measures in the present experiment. If the data from Table 1 were plotted, the slopes for the correct trial and incorrect trial reaction-time means would be almost identical for the physical-match comparison and also for the category-match comparison.

Figure 4 depicts the functional fields for the peripheral task when subjects receive a low level of foveal load or a high level of foveal load. These are 90% correct iso-sensitivity contours. The various points along one of the contours represent visual angles at which accuracy performance is essentially equal. The points were determined by linear interpolation. It was felt that this was justified since performance deteriorated in approximately a linear fashion with increasing retinal eccentricity and since speed-accuracy trade-off did not seem to be operative.

The contours were arrived at in the following manner. If, for example, a subject made 5% errors at the 1.66-deg eccentricity along a particular meridian, and 15% errors at the 3.33-deg eccentricity along the same meridian, then the corresponding 90% correct (10% error) point for that subject would be half the distance between 1.66-deg and 3.33-deg, or 2.5-deg.

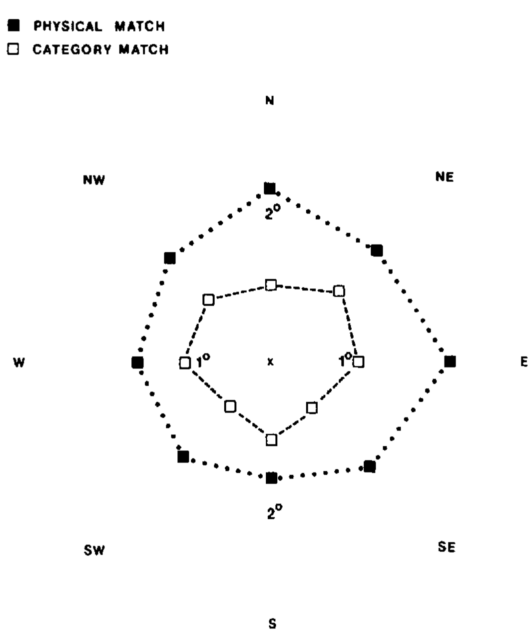

Figure 4. *90% correct iso-sensitivity contours for the peripheral line orientation discrimination task.*

Obviously there is nothing magical about 90% correct; however, this was within a range of performance that included all subjects, and was also a rather strict (conservative) criterion. Several individual contours were drawn in order to compare these with the overall contours to get an indication of individual differences. There were indeed individual differences, but they were sufficiently small to suggest that these "overall" contours might help to provide at least an approximate picture of the size and shape of the useful field of view for this kind of task. Again, these contours are only meant to be suggestive.

DISCUSSION AND CONCLUSIONS

The most important result to emerge from this study was the finding that peripheral visual processing is impaired more when the subject must also process a high foveal (cognitive) load as opposed to a low level of foveal load. This study was able to demonstrate this shrinkage of the useful field of view, using a foveal task that did not manipulate visual complexity, numerosity, visual angle, etc., as had most earlier studies. Instead, visual factors were held constant, and cognitive load was varied by using physical- and category-match levels of a character-classification task.

In a related study, Williams and Lefton (1981) found that the functional field of view for a parafoveal character-classification task was smaller for a category match than for a physical match. The functional field was somewhat wider in that study than in the present study. That particular study, however, did not manipulate meridian; instead, all presentations were along the horizontal axis. In an unpublished study, the author has found that the functional field of view for parafoveal letter recognition was larger when the subjects had to choose from a small set size (2 letters) as opposed to a large set size (24 letters). These studies that manipulated cognitive load, along with earlier studies that have varied "perceptual" components of the display, clearly show that the functional field is sensitive to various manipulations of task demands.

The human information processor can deal effectively with impressive amounts of information. Nonetheless, there are limits on processing capabilities, and these must be carefully assessed, particularly when the person is involved in potentially dangerous situations, for example, flying an airplane or controlling air traffic.

This study attempted to assess the abilities of normal subjects to respond separately to simultaneously presented foveal and peripheral stimuli. When the cognitive load of the foveal (primary) task was increased, performance on the peripheral (secondary) task was clearly impaired. The data suggest that the functional or useful field of view becomes smaller as the cognitive load is increased. Cognitive load was manipulated without increasing visual complexity. Generally, these results support those of Williams and Lefton (1981).

The data do not, however, support a strong "tunnel-vision" position. Holmes, Cohen, Haith, and Morrison (1977) have also questioned the robustness of the tunnel-vision concept. A strict definition of tunnel vision would require that a high cognitive load on a foveal task exert proportionally more of a deleterious effect on peripheral material that is more eccentrically located than on material closer to the fovea.

Because peripheral stimuli were presented along eight meridians and at three locations along each meridian, it was possible to plot iso-sensitivity contours. In addition to portraying the smaller functional field size under high cognitive loading, the contours also were circular in shape.

It appears that parafoveal areas can be considered as extensions of the fovea. Although it is true that performance deteriorates as one gets farther from the fovea, the present study as well as a number of others (Bouma, 1973; Schiepers, 1980; Rayner and Morrison, 1981) suggest that performance deteriorates gradually rather than precipitously.

In this context, it is worth noting that there has been an increased awareness of the importance of the near periphery in areas as diverse as visual search/target acquisition (Greening, 1976), reading speed (Poulton, 1962; Rayner and Morrison, 1981), and picture viewing (Loftus and Mackworth, 1978; Saida and Ikeda, 1979; Nelson and Loftus, 1980).

The functional field of view is a nearly circular region of several degrees of visual angle surrounding the fovea. It is a region of moderate acuity that is capable of carrying out moderate- to high-level kinds of processing. The functional field is elastic in the sense that its size will change according to processing demands. Reasonably difficult visual-cognitive tasks will result in a generalized shrinkage of this useful field size.

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