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PERIPHERAL VISION AND VISUAL ATTENTION.

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Peripheral vision and visual attention

by

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INTRODUCTION AND LITERATURE REVIEW

A person cannot respond to all of the stimuli which are generally present at any given time. Therefore, the person "selects" certain aspects of his environment to respond to, while "ignoring" or "attenuating" others. This selection of certain components of the present environment is called selective attention or just attention. As Korchin (1964) states, "the attentional field at any particular moment consists of focal and peripheral portions; the one accentuated, the other attenuated", (p. 58).

In experimental investigation of attention, a popular paradigm is to require subjects to perform two tasks simultaneously or attend to two signals simultaneously; one task (or signal) called the central task (primary signal), the other called the peripheral task (secondary signal). In studies using auditory signals, two messages are presented at the same time, the subject's task being to attend to one message while ignoring the other. These messages may both be presented to both ears (e.g., via a speaker) or one message may be presented to one ear and the other message presented to the other ear (via headphones). The latter is called dichotic listening (Cherry, 1953). To insure that the subject is attending to the primary message (designated by instructions), he is often asked to "shadow" this message. That is, to repeat aloud the primary message exactly as he hears it (Broadbent, 1952).

Broadbent (1958), one of the early investigators of dichotic listening, suggested that the primary message is attended while the secondary message is "filtered" out. This filtering was done on the basis of physical characteristics of the stimuli (male or female voice, location of the message, language spoken, etc.). Later experimental evidence showed that this type of a sensory filter could not explain existing data (see Norman, 1969). Certain aspects of the secondary message could "break into" or "intrude upon" the primary message (e.g., the subject's name spoken in the secondary message is almost always heard by the subject.) Thus, the secondary message, while not being attended to, was apparently being monitored to some degree, and on a level involving more than just physical characteristics of the message. It was proposed that the secondary message was not filtered out, but was "attenuated" (Deutsch and Deutsch, 1963; Treisman, 1964).

Experiments in visual attention have often employed a two-task situation also. Usually the subject is required to perform a central task and a peripheral task, these tasks being defined as such as a function of visual angle or spatial location. Thus, the subject might be asked to perform a central task such as tracking, or scanning a display panel, while at the same time responding to lights in the periphery of his visual field. Some studies restrict head and eye movements, while other studies have no such restrictions, leaving the subject free to scan. Despite the evidence from experiments in auditory attention (the secondary message is attenuated, not blocked) many investigators of visual attention refer to a decrement of performance on the peripheral task when simultaneously doing a central task (as compared to performance on the same peripheral task in the absence of a central task) as a change in perceptual processes. Peripheral stimuli are not responded to because they are not seen. This concept has been called "perceptual narrowing", "funnelling of vision toward the center", "tunnel vision", and "reduction of the range of effective cues".

The visual field of the average person is approximately 180° horizontally and 150° vertically (Gibson, 1950, p. 26), the greatest visual acuity possible at the center of the visual field (stimuli seen with the fovea) and acuity decreasing for stimuli located farther out from the center. However, a person does not have a subjective experience of a narrow "tunnel" of very acute vision surrounded by a much less detailed field of view. Instead the experience is that of a boundless visual field which is well integrated with no abrupt changes in visual acuity, when the person is free to make eye, head, and body movements (as is the normal situation).

When a person fixates a given object and makes no head or eye movements, there is a gradient of visual acuity as a function of visual angle. This gradient of acuity is due to the distribution of the light sensitive cells of the retina (rods and cones), the structure of the retina (variation in thickness of the layers of the retina, number of bipolar and ganglion cells), and such factors as the lesser amount of light striking the retina at the peripheral locations. Although it is convenient to describe visual stimuli as either central or peripheral, this distinction is an arbitrary one since the point where central vision stops and peripheral vision begins is not well defined (Polyak, 1941). In general, stimuli at or near the center of vision are called central (or focal) stimuli while stimuli at larger degrees of visual angle are called peripheral stimuli. While auditory stimuli can be divided into primary and secondary messages on the basis of being presented separately to either ear, being separated in location, language spoken, tonal qualities of voice, and other physical characteristics, visual stimuli are divided into central and peripheral stimuli on the basis of spatial location from a given central point.

When a person is asked to perform one or more tasks, how does he utilize his visual field? Leibowitz and Appelle (1969) state that "the existing literature has firmly established the fact that peripheral stimuli are more difficult to detect when attention is focused on a simultaneously presented foveal stimulus", (p. 390). However, experimental evidence has shown that this is not always the case (Bursell, 1958; Cornsweet, 1969; Hockey, 1970a, 1970b; Weltman and Egstrom, 1966). (These studies will be discussed in more detail below). While, in general, the performance of a central task causes a decrement in performance on a peripheral task, other factors than the presence or absence of the central task must be considered.

Easterbrook (1959) discusses what he calls the "range of cue utilization" as a function of drive level. As drive (arousal level) increases, Easterbrook suggests that the range of cue utilization narrows or shrinks. This is a perceptual change—in effect, the perceptual field becomes smaller, or the threshold for stimuli in the periphery increases. He points out that such a narrowing can be either facilitative or disruptive, depending upon the nature of the task. If the perceptual narrowing eliminates irrelevant cues (those cues not necessary to perform the task) then performance will improve with an increase in drive. If the narrowing eliminates relevant cues, then performance will be impaired as drive increases. Such an interpretation is in line with the classic Yerkes-Dodson law (Yerkes and Dodson, 1908) which states that there is an optimum level of arousal for any given task, and this level will be a function of the difficulty or complexity of the task.

Hockey (1970a) reviewed the literature on the effect of noise on performance. He suggests that noise can be considered to be a stimulus which raises the level of arousal, or drive. He defines complexity or difficulty of a task as a function of the number of cues necessary for a person to perform the task. In order to perform a difficult, complex task more cues are needed than to perform a simple, easy task. Hockey concluded that complex tasks are more likely to be impaired by noise, while simple tasks are improved under noise conditions. Hockey's findings are in agreement with Easterbrook's; however, Hockey doesn't state that the effects of noise or drive cause a perceptual narrowing--instead, he refers to it as an "attentional narrowing".

Several investigators have demonstrated what they consider to be "perceptual narrowing" under various conditions. Bahrick, Fitts and Rankin (1952) had subjects perform a central, tracking task, while at the same time watching for peripheral lights (located at 20° and 40° of visual angle). The addition of a monetary incentive produced an improvement in the tracking task and a decrement in the peripheral task. Bursell (1958) required the subjects to perform a central tracking task and respond to lights in the periphery, under normal room temperature (60°F - 70°F) or under heat stress (95°F - 105°F). He found a decrement in performance for the peripheral task under heat stress condition as compared to performance under normal conditions. However, this decrement didn't occur when the central task was made easier.

Weltman and Egstrom (1966) required novice divers to extinguish a lamp presented at 60° of visual angle while doing a central task (either mental arithmetic or dial watching). When tested on the surface of the water, the central task <u>didn't</u> inhibit performance on the peripheral task, but when actually diving under water (and presumably subject to great stress), the subject's performance on the peripheral task declined. This decrement in peripheral performance wasn't uniform across subjects, but occurred only in those subjects which the authors labeled as "anxious" (labeled as such after the experiment). Berkum (1964) manipulated real life situations in military conditions to appear to be dangerous to subjects (e.g., subjects in an airplane were led to believe that it might crash, and subjects in an artillery situation were led to believe that they might be fired upon with live ammunition). Under these conditions he found a restriction of the perceptual field as measured by performance tasks and paper and pencil tests. These experiments were performed with basic training recruits for subjects; however, when a later study was done using both experienced soldiers and basic training recruits, it was found that the experienced subjects actually performed better under such simulated dangerous conditions. Although Berkum interpreted his results to mean that perceived threat caused a perceptual narrowing, it appears that the subject's past experience is also important in determining how well he will perform and utilize available stimuli.

Leibowitz and Appelle (1969) demonstrated that performance of a central task resulted in an increase in luminance threshold for responding to stimuli presented peripherally. Best performance occurred when the subject fixated a central target which was constantly illuminated. When the subject was given the additional task of turning on again the fixation light when it went out, a brighter light in the same peripheral location was required for a response to occur. Webster and Haslerud (1964) found similar results. They had subjects fixate a light and either count out loud the number of times that the light flashed or the number of clicks they heard through headphones (the light not flashing) while watching for a light in the extreme periphery (70^{o} - 90^{o}). They found performance on the peripheral task to decline (more lights missed and longer reaction time to lights seen) under these conditions as compared to a condition of no central task. Webster and Haslerud concluded that the introduction of a central task impaired peripheral performance, but the impairment was due to an attentional (central) factor rather than a perceptual change in the retina, since both auditory and visual stimuli impaired peripheral visual detection.

Mackworth (1965) had the subjects fixate a small dot in the center of a screen and instructed them to attend to the entire screen. Three upper case letters were flashed on for 100 msec. and the subject was to report "yes" when the letter which occurred in the center also occurred on both sides. The distance of the two peripheral letters from the center was 1^{o}, 3^{o} and 5^{o} of visual angle at a viewing distance of 28 inches; and 2^{o}, 6^{o} and 10^{o} of visual angle at a viewing distance of 56 inches. Mackworth had three visual noise conditions. "No noise" displays contained only the three letters. "Line displays" showed one line of 17 letters and, "page displays" showed 22 lines of 17 letters or a total of 375 letters. For any given visual angle, the three target letters always occurred in the same positions on the display. Mackworth's results showed almost perfect scores under the "no noise" condition for all visual angles. Both noise conditions (line and page displays) caused a decrement in performance, especially at the larger visual angles. At the larger visual angles, the noise conditions caused performance to drop to below 20 percent in all cases. Mackworth interprets this to mean that visual noise causes "tunnel vision". However, the noise conditions Mackworth used make it difficult to say whether there was a tunnelling of vision or whether the subject simply couldn't <u>find</u> the target letters. Aside from adding visual noise, Mackworth also added the task of searching for the target letters imbedded within other letters.

Both Cornsweet (1969) and Hockey (1970a, 1970b) have challenged the interpretation of a perceptual narrowing under conditions of stress, arousal, increased drive, or an added central task.

Cornsweet (1969) takes the position that most studies which have shown detection of peripheral stimuli to decline with increases in arousal, anxiety, stress, etc. have used peripheral stimuli which were irrelevant to the task the subject was required to perform. Cornsweet performed an experiment in which the subject's task was to extinguish either of two lights when they were turned on by releasing the appropriate key. These lights were located approximately 5° on either side of a fixation point and were called the central lights. Two additional lights were placed at 90° visual angle from the fixation point, and were called the peripheral stimuli. On some trials, a peripheral light came on shortly (.3 sec.) before the central light came on, on the same side of the fixation point. Thus, a peripheral stimulus acted as a cue to which central light would appear, although the subjects were given no instructions regarding the peripheral stimuli. Under conditions of arousal (subjects were shocked), the subjects reacted quicker to the central stimuli when it was preceded by a peripheral stimulus, than they did when no peripheral stimulus was used. Some subjects said that they noticed the peripheral stimuli and utilized them, but even the subjects who said they didn't notice these stimuli, or were not aware of their significance, had shorter reaction times on those trials in which a peripheral stimulus appeared. Cornsweet interprets these results to mean that even under conditions of arousal, there is not a narrowing of the perceptual field for relevant stimuli.

Hockey (1970a) used a two-task situation. The primary task was a pursuit motor task, and the secondary task was a monitoring task of six lights placed in the periphery. The primary task was emphasized as being of major priority by the instructions given. The peripheral lights were of 600 msec. duration, were presented randomly both in time and location, and averaged six per minute. Performance on the central task was measured by amount of time on target. Performance on the peripheral task was measured by number of detections. Subjects were tested twice, once under a quiet condition (70 DB) and once under a noise condition (100 DB). (Subjects were trained for two days under quiet conditions before testing.) Performance on the central tracking task showed a decrement over time (40 min.) under the quiet condition but not under the noise condition. Performance on the monitoring tasks showed no changes over the same time period, but there was a noise by position interaction. The two peripheral locations which were closest to the center of the field of vision showed an improvement in detection performance under the noise condition, with the other four (more peripheral) locations showing a decrement in performance under the noise condition. Hockey interpreted these findings as support for the hypothesis that noise affects behavioral selectivity. There was not a simple improvement or impairment of performance, but rather a shift in efficiency over the various task positions. He describes this as an "attentional narrowing" in the secondary task. Thus there is not an overall impairment of performance on a secondary task, but a redistribution of attention or selectivity for the secondary task.

Since Hockey didn't restrict eye movements in this study, he postulated that the improvement for the more central positions could have been due to increased scanning because of (1) the favorable location of these positions (they are closest to the central task) or (2) the subjective probability of these locations being greater, since more signals are always detected in these positions as compared to the more extreme peripheral positions. In a subsequent study (Hockey, 1970b), Hockey manipulated probability of a signal occurring in a given position and insured that the subject saw all signals by leaving on the light until the subject responded to it. The results show that it was the subjective probability of a signal and not the location which accounted for the improvement in performance for peripheral signals closer to the central display. Hockey's second study also showed that peripheral sources are not disregarded in noise because they are peripheral, but because of their lower subjective probability of containing a signal. He thus rejects an explanation of a funnelling of vision or a perceptual narrowing and instead suggests that peripheral cues are neglected only if they are of little or no relevance to the central (or primary) task.

These studies investigating performance in a two-task situation under various conditions have produced equivocal results. While some studies have shown that the presence of a central task causes a decrement in performance of a secondary (peripheral) task, other studies found this not to be the case. Other factors, such as the difficulty of the central task, past experience, and arousal level seem to be important in assessing how the subject will perform while doing two visual tasks. In the Bahrick, Fitts, and Rankin study, and in Cornsweet's study, it is not clear whether the subject was even aware of the presence of the peripheral signals.

Even in the cases where the subject was fully aware of the relative importance of the central and peripheral tasks, it has not been demonstrated that a decrement in performance on the peripheral task is due to a perceptual narrowing, or a shrinkage of the range of effective cues. It appears more likely that a decrement on the peripheral task indicates an attentional (central) change. The subject may shift his attention (change strategies) toward the central task either because he believes it is the more important task (due to instruction, or lack of instructions) or because, in fact, it is the more important task.

The present study was designed to investigate the following questions. (1) What is the effect on performance of a peripheral task when the central task varies in difficulty? (2) If there is a decrement in performance level for the peripheral task, is this decrement due to a perceptual narrowing or an attentional narrowing? A difficult peripheral task was selected (identifying characters rather than simply responding to the onset of a light) in order to demonstrate that the peripheral retina is capable of processing more information than is commonly believed possible. Although some research has been done on form and color identification in the peripheral retina (Collier, 1931; Edwards and Antes, 1970; Gissler, 1926; Menzer and Thurmond, 1970; Zigler, Cook, Miller, and Wemple, 1930) the general conclusion of many psychologists (Gibson, 1966; Mackworth and Morandi, 1967; Neisser, 1967) is that the peripheral retina is capable of crude information processing only (color, motion, highly redundant stimuli), and functions mainly to guide foveal vision to informative stimuli.

STUDY I

In order to investigate the effect on performance of a peripheral task when the central task varies in difficulty, subjects were asked to identify visual characters at 10°, 20° or 30° of visual angle, while simultaneously performing one of three central tasks.

To determine whether any changes in the subject's performance in a two-task situation are due to an attentional factor rather than a perceptual factor, three sets of instructions were used. One set designated the peripheral task as the primary task, the second set designated both tasks as being of equal importance, and the third set designated the central task as the primary task. (Although in all cases the subject fixated a given point.) If, in fact, the performance of the central task causes a change in the subject's perceptual field, then instructions should have no effect on performance of either task. If the change is due to an attentional factor, then the different instructions should cause a change in performance for both the central and peripheral tasks.

It was predicted that performance at 30° of visual angle would be less than performance at 20° of visual angle which would be less than performance at 10° of visual angle, due to the gradient of visual acuity as one moves farther and farther into the periphery as the eye is fixated at a given point.

Method

Subjects

Subjects were six male undergraduates from the General Psychology course at Iowa State University. They were given extra credit toward their course grade for participating in the experiment. All subjects were tested for visual acuity with an Ortho-Rater (Type 71-21-42) and only those with 20/20 vision without glasses or contacts and with no history of visual abnormalities were used.

Apparatus

Visual stimuli were presented to subjects by means of Massey Dickinson Electroluminescent Displays. These displays are alpha-numeric modules composed of 14 elements, any of which can be activated in any combination, to light up in the shape of numbers or letters. Four such displays were used: one was called the "central display" or "central channel", the other three were called the "peripheral displays" or "peripheral channels". Each channel was capable of presenting a rapid sequence of visual characters. A programmed paper tape (Friden Tape-Talk) was read by a Block Tape Reader (Wang Laboratories) which in turn activated the appropriate elements of each display to give visual characters. The block reader (and hence the rate of presentation of the visual characters) ran at a speed of .5 seconds. Thus, the visual display was presented at the rate of two characters per second. Such a rate was fast enough to make the shadowing task very demanding, but slow enough to allow the subject to shadow without making a great many errors.

The actual visual stimuli were blue in color and readily seen in a semi-darkened room (3.30 foot-lamberts as measured by a Spectra Brightness Spot Meter, Model UB $1\frac{1}{2}^{\circ}$, manufactured by Photo Research Corp., Hollywood, California. This meter measures brightness by averaging over a given area. The average brightness was then adjusted with respect to proportion of area lit and total area to give the above value.). They subtended approximately $1\frac{1}{2}^{\circ} \times 2^{\circ}$ of visual angle at a viewing distance of 152.4 cm. Nine letters and six numbers were used as visual stimuli (Appendix A) both because they were easily identified by the subjects and because they were readily programmed on the available equipment. Six random orders of the 15 characters were programmed on the paper tape for each display and the tape was then connected together to form an "endless loop". Thus, the subjects were presented with six sequential random orders of 15 characters each, which continued to recycle. Each display module was switched so that at any given time the experimenter could have any single channel, or any combination of channels operating.

In addition to the central channel of visual stimuli, a central fixation light (G.E. 12-volt lamp, #757) was affixed immediately above the central channel. This light was independent of the display channels. The light was programmed to go off at various times and could be turned on again by a button activated by the subject. In addition to the above apparatus, a Beckman (Type RS, Dynograph Recorder) two-channel polygraph was used to measure reaction times and eye movements. A Bell & Howell (Model #785) tape recorder was used to get a record of the subject's "shadowing" performance which was later scored by the experimenter. A Grason-Stadler Noise Generator (Model 901 A) was used to generate white noise (87 DB as measured by a General Radio Sound Level Meter, Type #1551-B, set at Weighting C—Meter "slow". Ambient room noise was approximately 57 DB, and the noise level when the Block Tape Reader was operating was approximately 67 DB.) through a set of Lafayette Stereo Headphones (F-767) which were worn by the subject on test trials to mask the noise of the Block Tape Reader. A closed-circuit television system was operating so that the experimenter was able to see the visual displays.

Procedure

There were three central tasks and one peripheral task. The subject was always performing one of the three central tasks and the peripheral task during each testing session. Task A required the subject to watch the fixation light (the central display module was turned off) and turn it on again when it went off by pushing a button located near his right hand. Task B required the subject to monitor the central display channel (the fixation light was turned off) and press a button (the same one for re-activation of the lamp) when a "Z" appeared on the display module. The third central task (Task C) required the subject to "shadow" the central display channel; that is, to read aloud each character as it appeared.

While doing one of the above described central tasks, the subject was also performing a peripheral task. The peripheral task was the same regardless of the central task, and required the subject to identify the last character which appeared in the peripheral channel when all displays stopped. The experimenter could stop the block reader by means of a foot switch and thus extinguish all display modules which were operating. The subject's task was to perform a central task and at the same time monitor a peripheral channel, identifying the last seen element in the peripheral channel when the sequential presentation stopped.

Three peripheral channels were used (10°, 20° and 30° of visual angle from the fixation lamp) but only one peripheral channel was operating at any given time. This channel was programmed similar to the central channel (six random orders recycling). Usually different characters appeared in the peripheral channel and the central channel, but it was possible that at any given time both channels could be presenting the same visual character.

Three different sets of instructions were used. Instructions I emphasized that the peripheral task was the more important task, and although the subject would be performing both tasks, he was to try and perform as best he could on the peripheral task. Instructions II emphasized that both tasks were of equal importance. Instructions III stressed the importance of the central task.

Each subject was given two hours of practice to completely familiarize himself with the apparatus, the different tasks, and especially the shadowing. The subjects were told exactly what tasks they were to be tested on and shown how they would be scored for both the central and peripheral tasks. Every subject performed all three central tasks (and the peripheral task) under each set of instructions. The order of instructions was counterbalanced and a testing session under each set of instructions was performed over a three-day period (one hour each day). The order of central tasks performed under each set of instructions was partially counterbalanced (Appendix B).

For Task A (monitoring the fixation light), the light was programmed to go off at the same time that a "Z" would appear if the central channel were lit. Thus, Task A and Task B required the same number of responses at exactly the same time intervals. Reaction times for Task A and Task B were recorded on polygraph paper and scored later by the experimenter. For Task C, a tape recorder was turned on and the subject's shadowing was recorded and scored later by the experimenter. (Scoring was in terms of the number of mistakes made.)

The peripheral task was scored by the experimenter during the testing session. For each test stop, both the correct visual character and the subject's response were recorded.

Testing Sessions

After two hours of training, each subject received three testing sessions on three separate days. The subject was seated with his forehead held firmly against a headrest. He was instructed to always look at the central display or central light. Eye movement recording electrodes were placed on the outer sides of each eye, and the subject was told that these electrodes were sensitive to changes in eye muscle potential and any eye movements would cause a pen to deflect on the dynagraph recorder. The experimenter monitored the eye movement recording to insure that the subject kept his eyes on the central channel. The subject wore a headphone delivering white noise throughout the testing session (except during brief rest periods).

On any given day, the subject performed all three central tasks and the peripheral task under one set of instructions. The amount of time spent performing each central task was exactly the same for all the subjects under all instructions. This time interval was determined by having 30 test stops on the peripheral task for each central task (10 stops at each visual angle). A list of 10 random time intervals (Appendix A) for each of the three visual angles (30 items) was used to determine when each test stop occurred. This same list was used for all the subjects and for all central tasks but was randomly rearranged each time. Thus, for each testing session, the subject received 90 peripheral test stops, 30 each while performing each central task.

Results

An analysis of variance was performed on the peripheral detection data (number of correct identifications of the visual character) and the results are summarized in Table 1. These results are presented graphically in Figure 1.

Performance on the central tasks was also analyzed. For Tasks A and B, the mean reaction time for each subject under each set of Instructions was computed (summing across all visual angles). These data were subjected to an analysis of variance using Task as a factor (two Tasks x three Instructions) and the results are summarized in Table 2 and Figure 2.

Performance on Task C (shadowing the central channel) was measured by making a tape recording while the subject shadowed. This tape was later played by the experimenter (who had a list of the correct responses) and scored in terms of the number of errors made. An error was any omission of a visual character, or a misnaming of a visual character (e.g., calling a "P" a "9"). An analysis of variance was performed on the errors made while shadowing under the three Sets of Instructions. The results were not significant, $\underline{F}(2,10) < 1$. (The raw data for peripheral performance and central task performance are presented in Appendix C and D, respectively.)

Even though all subjects received two hours of training, performance as a function of days (three testing days) for both the peripheral task and the central tasks was analyzed (summing across Instructions). For the peripheral performance, an analysis of variance showed a significant Day effect, $\underline{F}(2,10) = 5.24$, $\underline{p} < .01$, while performance on the Central Tasks showed no significant differences as a function of Days (for Tasks A and B, $\underline{F}(2,10) = 1.10$, $\underline{p} > .05$; for Task C, $\underline{F}(2,10) = 3.01$, $\underline{p} > .05$).

Table 1. Analysis of variance of peripheral detection

Source	df	MS	F
Subjects	5	15.12	
Angle	2	240.04	96.79**
A X S	10	2.48	
Instructions	2	.49	.05
I X S	10	8.28	
Central Task	2	68.62	18.25**
C X S	10	3.76	
A X I	4	1.56	.48
A X I X S	20	3.22	
A X C	4	9.39	3.86*
A X C X S	20	2.43	
I X C	4	1.56	.47
I X C X S	20	3.31	
A X I X C	8	1.02	.53
A X I X C X S	40	1.92	
Total	161		

* $p < .05$
**$p < .01$

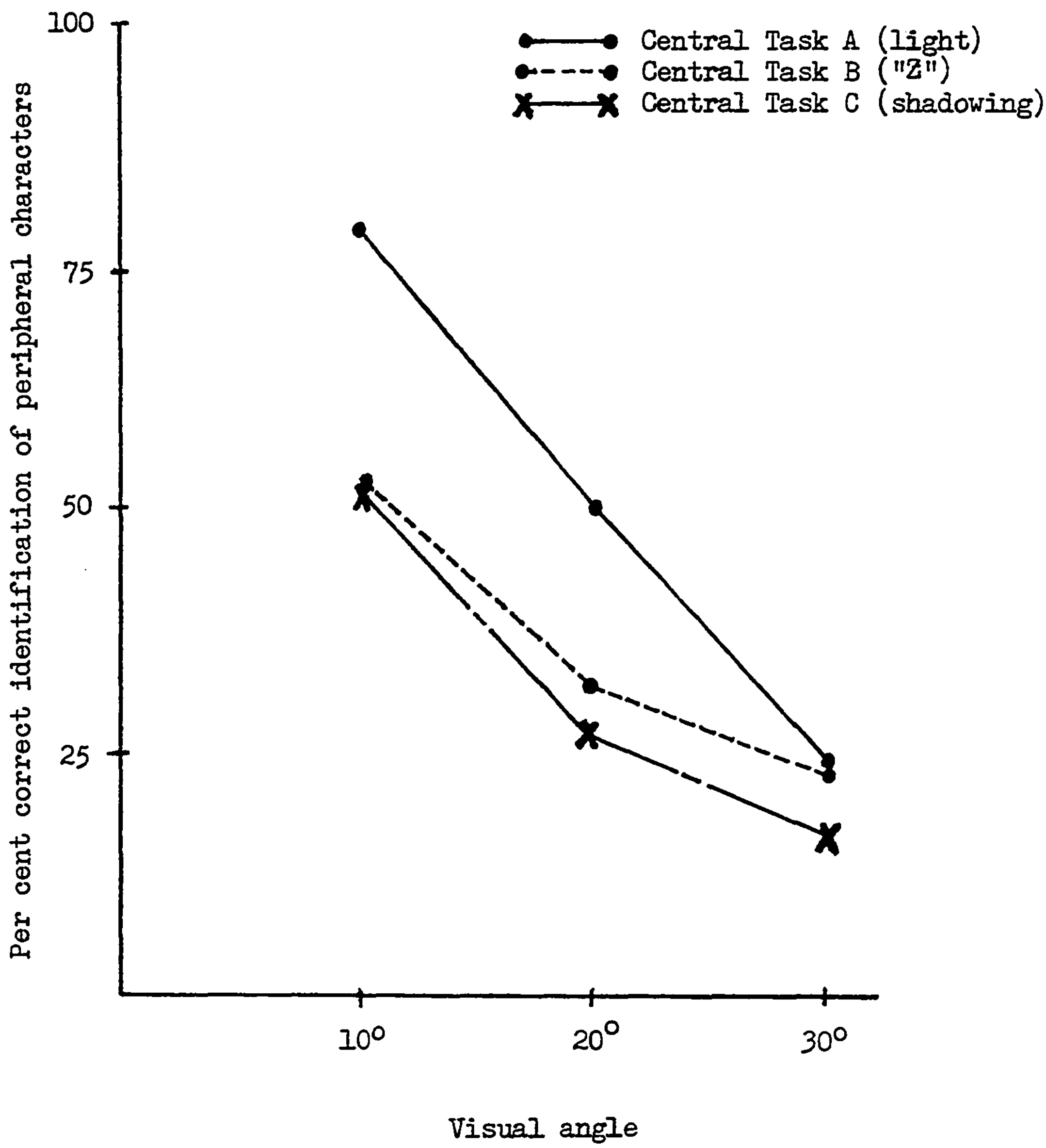

Figure 1. Peripheral detection performance

Table 2. Analysis of variance of performance on central tasks A and B

Source	df	MS	F
Subjects	5	58547.86	
Task	1	17336.10	1.32
T X S	5	13039.51	
Instructions	2	13770.23	6.37*
I X S	10	2161.75	
T X I	2	2153.54	2.21
T X I X S	10	974.63	
Total	35		

* $p < .05$

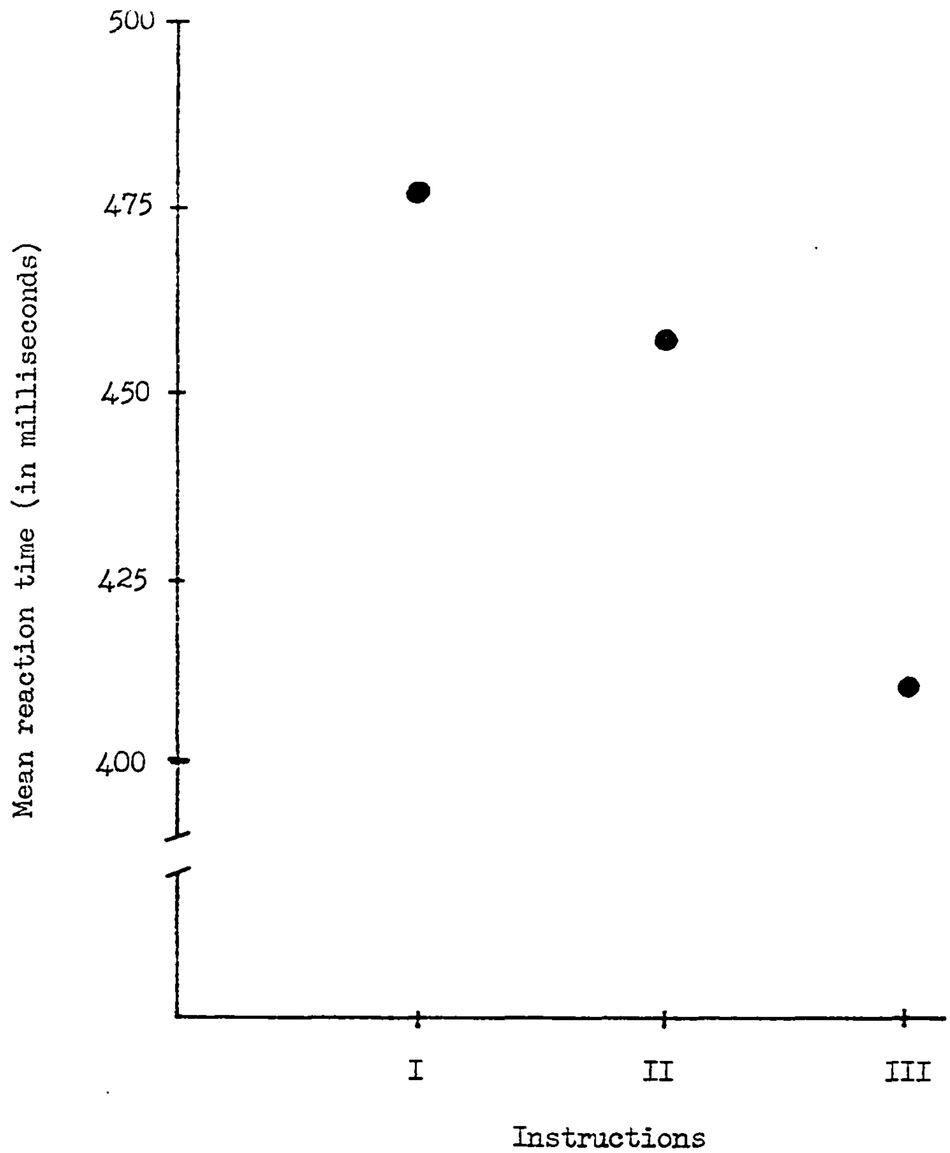

Figure 2. Performance on central tasks A and B

Since test stops on the peripheral channel were determined by a random order of time intervals, a Chi-square test was performed on the number of times each visual character was present at a test stop. The results were not significant for any single day or for the total over all three days, $\chi^2(14) = 19.2$, $p > .05$; $\chi^2(14) = 14.4$, $p > .05$; $\chi^2(14) = 17.4$, $p > .05$; $\chi^2(14) = 11.7$, $p > .05$, for Days 1, 2, 3, and total, respectively (see Appendix E for data). The proportion of correct responses for each visual character (summed across Visual Angle, Instructions, and Central Tasks) was computed, and the results are presented in Figure 3.

Discussion

The performance on the peripheral task showed a significant effect due to Visual Angle, Central Task, and an Angle x Central Task interaction. This interaction may be due to a "floor effect". At 10° of visual angle there were no instances of a subject being incorrect on all ten test stops for any given Instruction x Central Task "block" (54 such "blocks"). At 20° of visual angle, one subject was incorrect on all ten test stops, while at 30° of visual angle there were 15 instances of a subject being incorrect on all ten test stops. Since in many cases subjects were missing all characters at 30° of visual angle, their performance was approaching a "floor" of zero.

The significant effect of Visual Angle on peripheral detection was predicted and confirmed the well known finding that visual acuity decreases in the peripheral retina as one moves farther and farther away from the fovea. This gradient of visual acuity appears to be a monotonically decreasing function which is almost linear for at least a small part of the peripheral retina (less than 30° of visual angle).

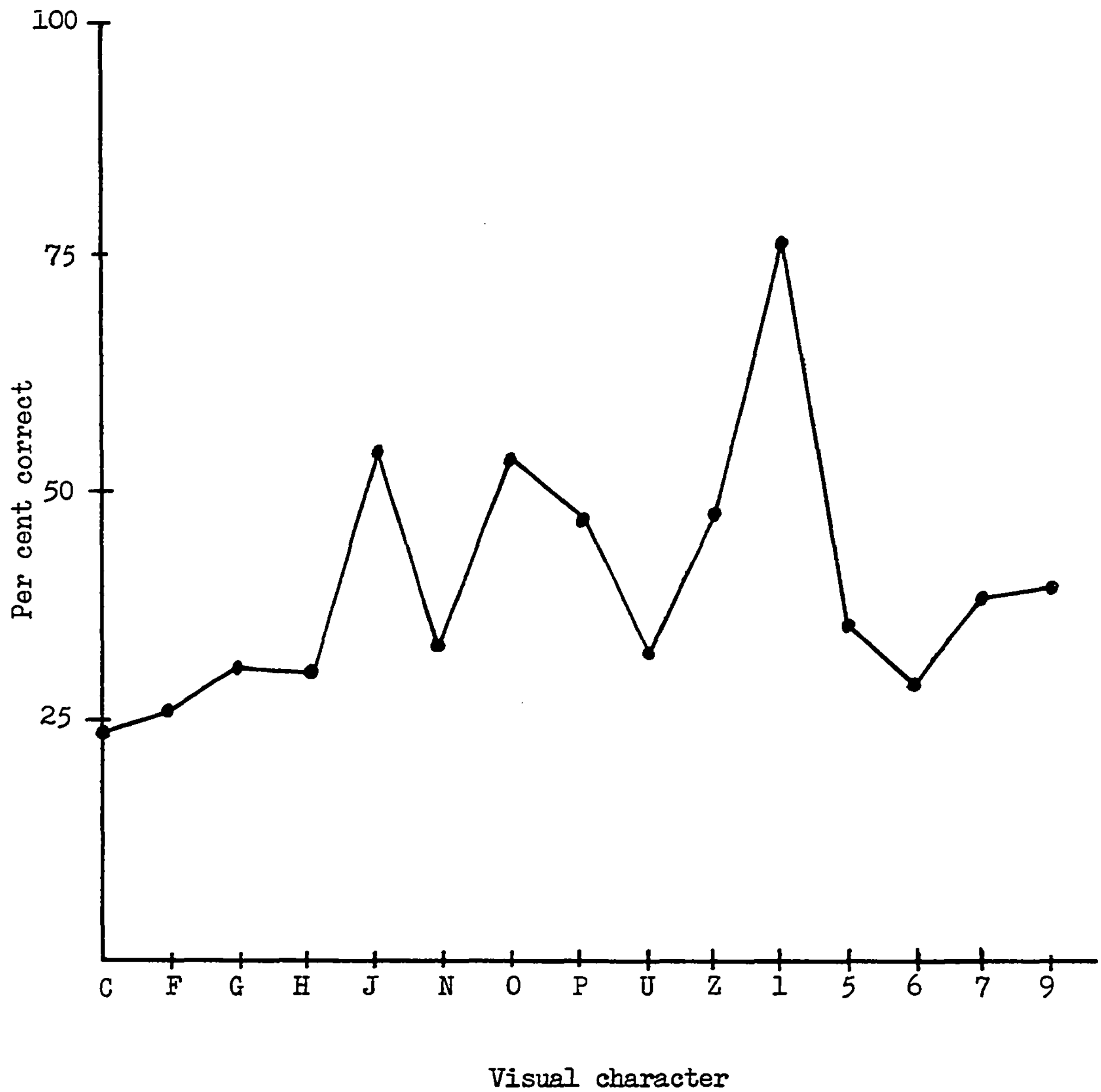

Figure 3. Correct detection of each visual character on peripheral task

Performance on the peripheral task was best in all cases if the Central Task the subject was performing was Task A (turning the fixation lamp back on each time it went off). If the subject was required to monitor the central channel for a given character (Task B) or "shadow" the central channel (Task C), his performance on the peripheral task declined significantly. It appeared that Central Tasks B and C produced about the same decrement in peripheral performance, with peripheral performance being slightly better while performing Task B than while performing Task C.

These results support the earlier findings that as a central task increases in difficulty or "amount of attention needed", performance on a peripheral task declines. Monitoring a central channel for a given character certainly requires more "attention" (information processing, decision making) than does monitoring a light (a simple on or off decision). The Central Task of "shadowing" adds a number of responses to the monitoring for a character task, since each character not only has to be identified but also has to be named aloud. (Also the subject hears his own responses.) However, since the response (naming letters and numbers) is so familiar or overlearned, the task of "shadowing" may not be too much more attention demanding than the monitoring for a character task.

"Shadowing" was chosen as a central task because it was thought to be one which would necessitate a great deal of "attention". As Norman (1969) suggests (referring to shadowing of an auditory message), "Shadowing, then, is a powerful but complicated task. It has many problems as a laboratory tool in the study of attention because it is difficult to measure just how much effort the subject uses in performing the shadowing. ...a simple tabulation of how accurately the subject's spoken words agree with the presented material does not even begin to tell us how much attention is diverted to the task", (p. 20). Although the shadowing task caused a decrement in peripheral performance, it did not demand all of the subject's attention since the subjects got an average of approximately 50% correct on peripheral detection at 10^{o} of visual angle. A human subject is evidently capable of processing a large amount of information at a rapid rate (perhaps more than is commonly believed possible). Reading a random presentation of visual characters aloud, at the rate of two per second, while still watching for visual characters in the peripheral field of vision is indeed a remarkable task, and suggests that the limits of information processing from simultaneous inputs may be very high.

A difficult peripheral task was required of the subjects and one noteworthy result is the relatively large amount of information processed by the peripheral retina. Although the exact functioning and capabilities of the peripheral retina are relatively unknown, this study suggests that the peripheral retina is capable of processing a large amount of information. While, in everyday situations, the peripheral retina may indeed play a secondary role to the fovea, as far as processing of visual information, the peripheral retina is certainly capable of extracting more than "crude" information about visual stimuli. Correct identification of visual characters (presented at a rate of two per second) at 30^{o} of visual angle requires a great deal of information processing.

Subjects performed the peripheral task under three sets of instructions, and it was hypothesized that the different instructions would affect peripheral performance. The effect of Instructions was not significant for peripheral performance. The results of this study do not clarify whether the decrement on the peripheral task as the central task varied was due to an attentional factor or to a perceptual factor, because if subjects were told that the peripheral task was the primary task their performance was no different than if they were told that the central task was the primary task. When subjects were questioned by the experimenter after the testing sessions, they indicated that they understood the instructions and tried to follow them.

The Instructions did have a significant effect on performance of two of the Central Tasks (A and B). Mean reaction time was highest for the two Central Tasks when the subjects were told that the peripheral task was the primary task, and lowest when they were told that the central task was the primary task. If instructed that both tasks were of equal importance, mean reaction time was between the other two (Figure 2). These results suggest that the Instructions were understood and that instructions designating which was the primary task effected performance on Central Task A and B (however, there was no effect on the peripheral task). Thus it appears that subjects were understanding the instructions and following them, but their performance on the peripheral task was unaffected.

The Instructions did not effect performance on Central Task C (shadowing). Shadowing demands a high level of performance on the part of the subject, and he probably performs at the best level he can. Telling him that the peripheral channel is more important, but still requiring him to shadow, may not effect his shadowing accuracy much since the task demands a certain amount of attention regardless of which task is designated as the primary task. In other words, shadowing appears to demand a certain amount of attention regardless of instructions.

The data were also analyzed in order to investigate whether there was a training effect occurring over the three day testing sessions. The results showed no training effect for the Central Tasks, but a significant training effect for the peripheral task. Thus, it appears that the subjects' performance on the peripheral task was improving over time, and that the two hours of training were not sufficient to reach the maximum ability of the subjects to detect visual characters in the peripheral retina. Since such a use of the peripheral retina (processing complex stimuli without eye movements) is a relatively rare occurrence, and not a situation which occurs often in the everyday situation, it is understandable that the subjects' use of the peripheral retina would continue to improve with practice. This training effect suggests further research in the topic of training peripheral vision. It also suggests that Instructions didn't affect peripheral performance perhaps because the subjects were still learning the peripheral task. On the two Central Tasks which required pushing a button (not a difficult response), no such training effect occurred nor did it occur for the shadowing task. Perhaps the two hours of training were sufficient for the Central Tasks, but not for the peripheral task.

Two other results seem to be of interest. One is the detectability of the different visual characters and the other is the errors made by the subjects on the peripheral task (errors on the Central Tasks were very rare). As can be seen in Figure 3, certain visual characters were identified correctly more often than others. The "J", "O", and "1" seemed to be detected with a greater ease than the other characters. The ease of detectability for the "O" and "1" could perhaps be explained in terms of a "good

Gestalt" but why the "J" was so easily detected is not clear. More research is certainly needed in the area of detectability of various stimuli by the peripheral retina.

The most common error in the peripheral detection of visual characters was simply naming the wrong character. Since subjects had to make a response at each test stop, there was a great deal of guessing (subjects knew the population of visual characters which were possible). Most subjects reported that when they were unsure of a peripheral character they tried to guess as best they could from what they thought they had seen. An inspection of the errors showed no trends, except that some subjects adopted a somewhat specific pattern of guessing if they were unsure of the character. These subjects would choose one character, and if unsure of what they saw, would always report the same thing (e.g., always responding "l" when unsure).

STUDY II

In Study I the different instructions had no significant effect on peripheral detection, but had a significant effect on two of the three central tasks. Study II was performed to further investigate the effect of instructions in a two-task situation, using a peripheral task which was not as complex as identification of visual characters. Two tasks were chosen for Study II, one requiring the subjects to monitor a light (Peripheral Task), and the other requiring the subjects to monitor a sequence of visual characters for a given character (Central Task). Only one location for the peripheral task was used (30° of visual angle) since the effect of visual angle on peripheral detection had already been demonstrated. Two sets of instructions were used (the instructions stressing that both tasks were of equal importance were omitted) and only one central task was required of the subject. Thus, Study II required subjects to perform two tasks, a central and a peripheral task, under two different sets of instructions. It was hypothesized that the instructions would effect performance on both tasks. If the peripheral task is named as the primary task, performance on the peripheral task should be better than if the central task is named the primary task. Performance on the central task should be reversed, being best if the central task is the primary task and showing a decrement in performance if the peripheral task is the primary task.

Method

Subjects

Five male undergraduates from the General Psychology class were used as subjects. They were given extra credit toward their course grade for participating in the experiment. All subjects had normal vision without glasses or contacts and no history of visual abnormalities.

Apparatus

The apparatus used in this study was the same as that in Study I with some minor changes. Only one display module was used for the peripheral task, and it was located at 30° of visual angle. This module was programmed so that only one element at any given time was lit, a small disc in the lower right corner (diameter approximately 14 minutes of visual angle). The block tape reader read the same programmed paper tape (at the same rate) as in Study I, and the disc on the peripheral display was lit at the same time that a "Z" would have appeared on that display if it had been programmed for visual characters. The disc remained lit for one-half sec.

The central display was exactly the same as in Study I and located in the same position. There was a restriction imposed that at no time would a "Z" appear in the central channel at the same time that the disc was lit in the peripheral channel. The onset of a "Z" in the central channel and the onset of the disc in the peripheral channel caused a pen to deflect on the polygraph and the subject's response to either stimuli (pushing a button) caused another pen deflection. Thus, reaction times to both stimuli were recorded on the same channel of the polygraph and scored later by the experimenter.

Procedure

Subjects were required to perform two tasks. The Central Task required the subject to watch the central display and push a button whenever the character "Z" appeared. The Peripheral Task required the subject to push the same button whenever the disc appeared on the peripheral channel. The subject always kept his eyes fixated on the central channel, and eye movements were recorded and monitored exactly the same as in Study I.

Two sets of instructions were used. Peripheral Instructions named the Peripheral Task as the primary task and the subject was told to try to react as quickly as he could to the disc on the peripheral channel while performing both tasks. Central Instructions named the Central Task as the primary task. The experimenter emphasized that the subject was to always keep his eyes on the central channel regardless of instructions.

Testing Session

After the experimenter explained exactly what was required of the subject, each subject was given five minutes of practice on the two tasks. The subject was seated as in Study I and wore the headphones delivering the white noise to mask the sound of the block reader. The testing session was divided into four test periods of six minutes each with a short break in between each period. For two of the test periods, the subject was told that the Peripheral Task was the primary task. For the other two test periods, the subject was told that the Central Task was the primary task. The order of instructions for three of the subjects was: Central; Peripheral; Central; Peripheral. The order of instructions for the other two subjects was: Peripheral; Central; Peripheral; Central.

During each six minute period, a "Z" appeared on the central channel approximately 48 times and the disc on the peripheral channel appeared approximately 48 times. Since reaction time to both stimuli were recorded on the same channel of the polygraph, the experimenter labeled each reaction time as it occurred (the experimenter was able to see the visual stimuli on the closed circuit television).

Results

The data were analyzed as follows. The mean reaction time of each subject was computed for each test period for both the Peripheral and Central Task. The first test period for <u>each</u> set of Instructions was called Block 1. The second test period for <u>each</u> set of Instructions was called Block 2. Thus, for each subject, there were eight scores: mean reaction time for the Peripheral Task for Block 1 and 2 under Peripheral Instructions; mean reaction time for the Peripheral Task for Block 1 and 2 under Central Instructions; mean reaction time for the Central Task for Block 1 and 2 under Peripheral Instructions; and mean reaction time for the Central Task for Block 1 and 2 under Central Instructions. An analysis of variance was performed on the mean reaction times, and the results are summarized in Table 3 and Figures 4 and 5. Blocks was considered as a factor in this analysis in order to assess any changes in performance on the two tasks as a function of practice within each testing session. The raw data for Study II are presented in Appendix F. Errors (not responding to a signal) were very rare and were not analyzed.

Discussion

The results showed a significant Block effect, a significant Task effect, and a significant Task X Instructions interaction. The Block effect indicates that the subjects' performance on both tasks improved over time within each testing session. This practice effect appears to have affected both Tasks equally, as can be seen in Figure 4.

There was a significant difference in mean reaction times for the two tasks. Mean reaction time for the Peripheral Task (responding to the onset of the disc) was always less than mean reaction time for the Central

Table 3. Analysis of variance of mean reaction time

Source	df	MS	F
Subjects	4	6790.82	
Blocks	1	1729.20	16.06*
B X S	4	107.67	
Task	1	21762.20	28.45**
T X S	4	764.80	
Instructions	1	65.00	.40
I X S	4	160.47	
B X T	1	75.70	.33
B X T X S	4	229.42	
B X I	1	330.70	.40
B X I X S	4	828.54	
I X T	1	731.10	46.96**
I X T X S	4	15.57	
B X I X T	1	99.10	2.37
B X I X T X S	4	41.82	
Total	39		

* $p < .05$
**$p < .01$

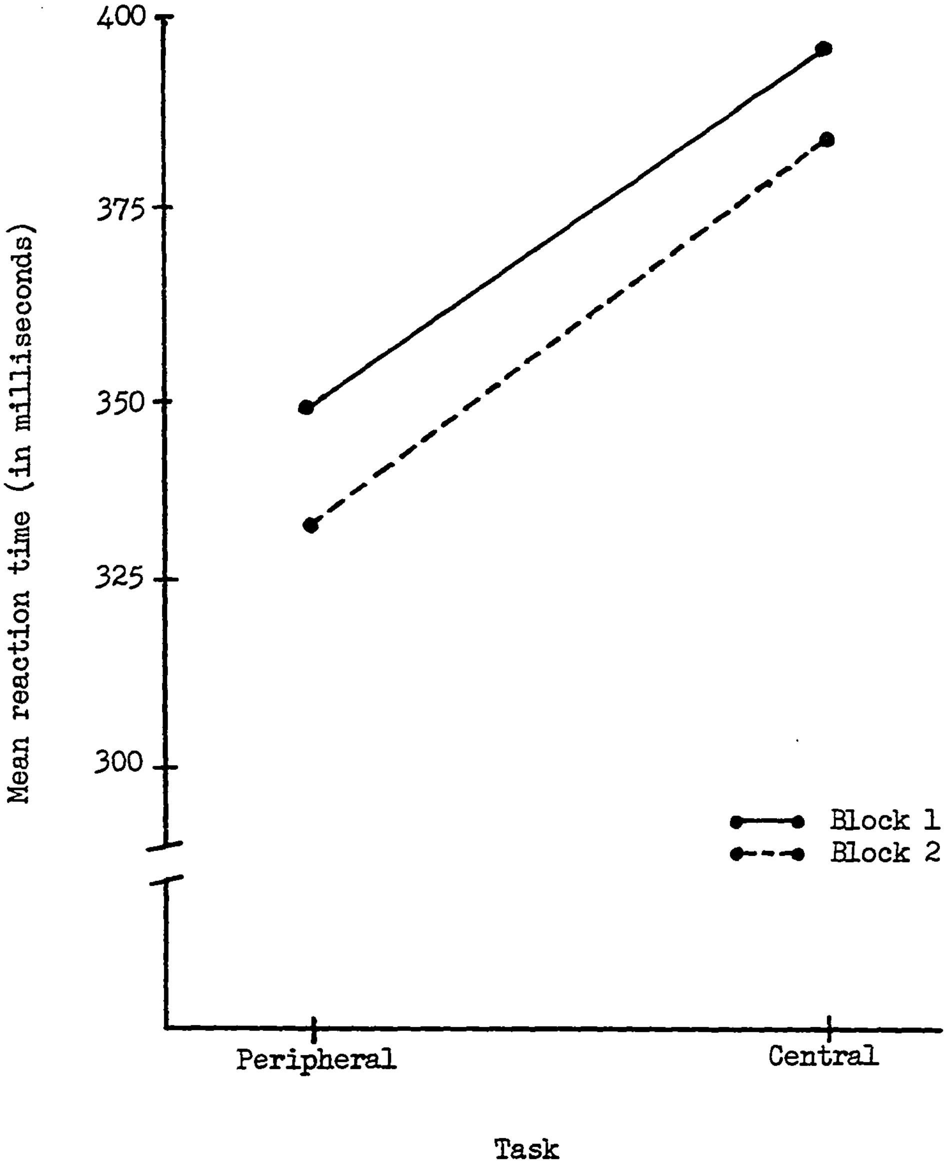

Figure 4. Mean reaction time for peripheral and central tasks as a function of blocks

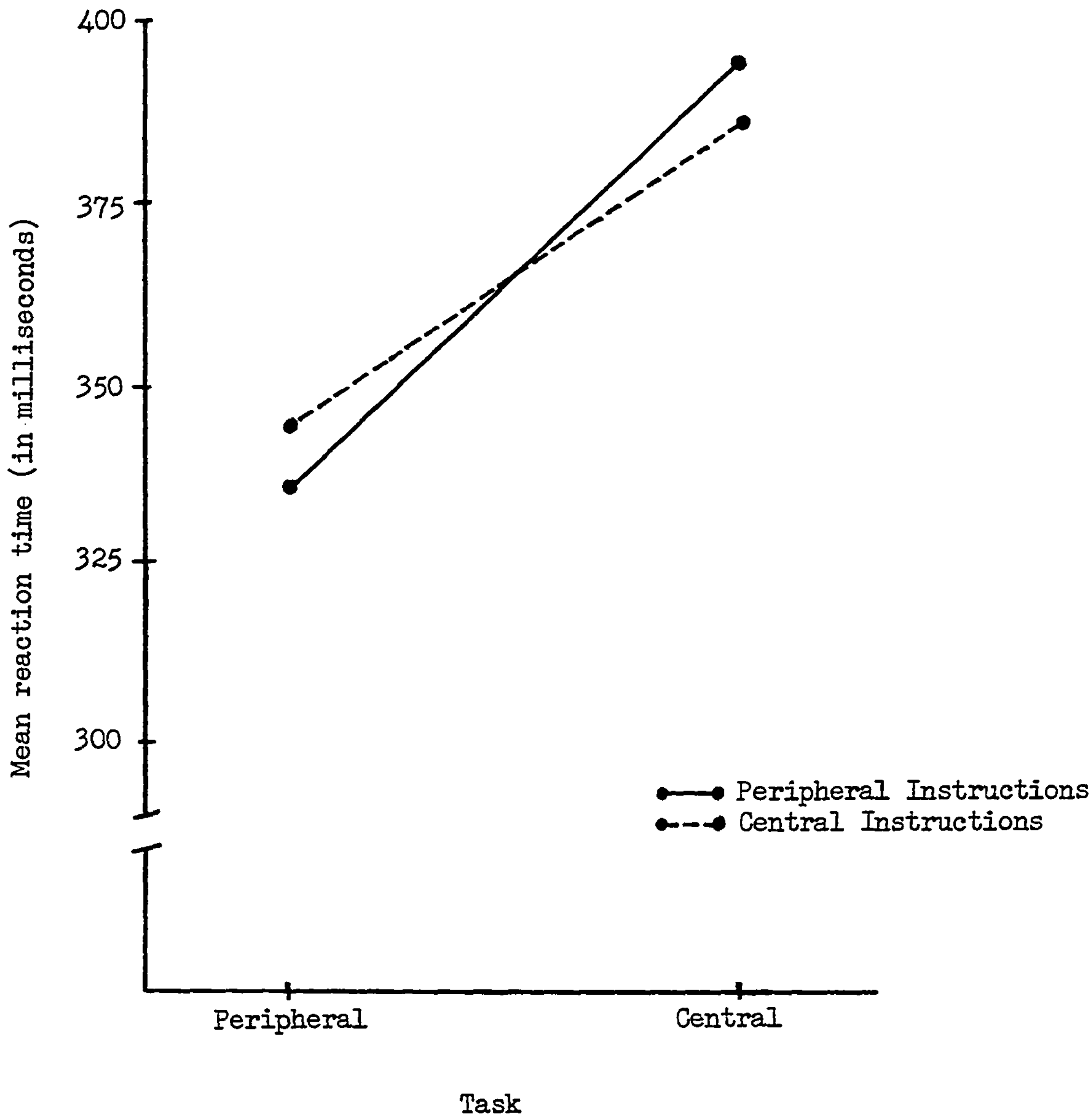

Figure 5. Mean reaction time for peripheral and central tasks as a function of instructions

Task (responding to the onset of a "Z"). In both cases, the same response was made by the subject and this difference in reaction time is interpreted to mean that the Peripheral Task required less decision making (information processing) than the Central Task. (The fact that there was no difference in mean reaction time to Central Task A and Central Task B in Study I is discussed in the General Discussion.)

The finding of greatest interest in this study is the Task X Instruction interaction. Mean reaction time for the Peripheral Task was faster under Peripheral Instructions and slower under Central Instructions. Mean reaction time for the Central Task was exactly the opposite. The subjects evidently understood the Instructions and were able to follow them. Since subjects made no eye or head movements, the change in performance on the two tasks as a function of Instructions cannot be attributed to any changes in scanning or search processes, but must be attributed to a change in the attentional processes. If the parameters of peripheral performance are due to perceptual changes caused by the performance of a central task, then the different instructions should have had no effect on peripheral performance, since the central task was the same under both sets of instructions. The concepts of a "perceptual narrowing" or "tunnelling of vision" are rejected as an explanation for the changes in peripheral performance while simultaneously performing a central task in favor of an explanation in terms of an "attentional shift" or "change in strategy" on the subject's part.

Obviously, which central task is chosen is of great importance, since some tasks, by their very design, require a great deal of attention (e.g., a pursuit rotor task). When such a task is used, peripheral performance may show a great decrement because the subject <u>has</u> to attend the central task in order to perform it adequately.

Instructions to the subject, in a two-task situation, are also important in determining how a central task affects performance on a peripheral task. If a subject is told to perform two visual tasks without moving his eyes, and instructions are either not given as to the relative importance of each task, or are ambiguous (which appears to be the case in many two-task experiments), then it is reasonable for the subject to assume that the task he is told to look at (fixate) is the primary task and he may perform accordingly. While there are limits as to the speed and ease with which a subject can shift his attention in a two-task situation, these limits appear to be not entirely determined by the difficulty of the central task. The limits may also be a function of the subject's evaluation of the relative importance of each task.

GENERAL DISCUSSION

In Study I it was demonstrated that the peripheral retina is capable of processing quite complex visual stimuli. Visual characters were presented at the rate of two per second at either 10°, 20° or 30° of visual angle, and were stopped according to a random order of time intervals, the subject's task being to identify the last character seen in his peripheral field of view. Since subjects did not know when the stops would occur, in order to perform well on this task they would have to monitor each visual character as it occurred. No studies reported in the literature have used a task such as this. The majority of studies concerned with peripheral detection require either a response as to whether a signal occurred or not, or an identification of geometric forms at various visual angles. It was concluded that the peripheral task used in Study I required a great deal of attention on the part of the subject. The verbal reports of subjects in that experiment indicated that it was a very difficult task.

Possibly the capabilities of the peripheral retina have been greatly underestimated. While it is generally known that the peripheral retina is capable of processing some information, and may be the mechanism which guides eye movements (eye movements are <u>not</u> random), little research has been done on the information processing ability of the peripheral retina. Some early studies have attempted to "map out" the detection limits of the peripheral retina in terms of color and form discrimination, but were largely unsuccessful. Perhaps, with better techniques and modern equipment, research in the area of peripheral detection may be more fruitful in the future.

Study I clearly demonstrated the gradient of visual acuity as a function of visual angle. It is well known that visual stimuli are more difficult to identify as one moves farther into the peripheral field of vision. But often vision is divided into a strict dichotomy--foveal and peripheral. Such a dichotomy greatly oversimplifies the information processing ability of the retina. A great number of visual stimuli are processed by the peripheral retina in most situations, and a large part of this information is processed <u>entirely</u> by the peripheral retina without foveal vision (driving a car or walking are good examples). The retina is extremely complex and the variations in thickness, number of receptors, number of ganglia, and number of associative cells demand a more detailed description of vision than a simple foveal/peripheral dichotomy. Study I demonstrated that the peripheral retina is capable of complex visual discrimination at as great as 30° of visual angle, which is well into the middle periphery (as described by Polyak, 1941).

The retina is capable of detecting a wide range (in terms of spatial location) of stimuli, but obviously a person cannot respond to all of the stimuli he is capable of perceiving at any given time. Thus, the concept of attention is often employed to explain why one stimulus is responded to instead of a different stimulus. If one accepts the definition of attention as the selective component of behavior (or as Neisser says, an "allotment of analyzing mechanisms to a limited region of the field Neisser, 1967, p. 88"), then visual perception becomes largely a matter of attention. When a subject is exposed to a visual array containing many visual stimuli, he must "select" some components to attend, and "ignore" or "attenuate" others if there are time limits imposed on him. (If he were given as much time as he wanted to view the array, he may fixate and process each element.)

In most two-task experiments, subjects are given two tasks to perform and performance on both tasks is measured. In the case of two visual tasks, arranged as central and peripheral as a function of visual angle from the fixation point, the subject often has to refrain from making eye movements while responding to various visual stimuli. The fact that responses to a visual stimulus located in the peripheral field of view often show a decrement if a central task is required of the subject, or if the central task becomes more "difficult" is often reported in the literature, and Study I supports this finding. The different central tasks showed a significant effect on the performance of the peripheral task. As the central task required more attention on the part of the subject, peripheral performance declined.

The results of Study II suggest that the subject's performance in a two-task situation is not due to any perceptual changes but to an attentional change. Peripheral performance was better if the peripheral task was named the primary task than if the peripheral task was named the secondary task. The nature of both the central task and the peripheral task are important in investigating performance in a two-task situation. Requiring a subject to make any response to a stimulus demands a certain amount of attention on the part of the subject. Different tasks require different amounts of attention if the subject is to perform the tasks successfully. Thus, in a two-task situation, the attentional demands of each task must be considered in assessing performance on either task.

The task of monitoring a visual display for a given character was assumed to be more attention demanding than monitoring for either the onset or offset of a light because greater information processing is required by the subject (some "test" or decision must be made for each visual character which appears). The results of Study II support this assumption as there was a significantly longer mean reaction time to the onset of the "Z" than to the onset of the disc. However, in Study I there were no differences in mean reaction times for the onset of the "Z" or the offset of the light. The light used was powered by a six volt, wet cell battery, and when extinguished the filament had a slow decay rate (in terms of milliseconds). This slow decay rate, added to the subject's reaction time, is believed to be the factor which caused both reaction times to not differ significantly.

There were significant changes in mean reaction times for both tasks in Study II as a function of instructions. In Study I there was a significant effect due to instructions for two of the central tasks, but no significant differences for the other central task (shadowing) or for the peripheral task. This lack of an instruction effect for these two tasks may have been due to the high attentional demands of the tasks. Both tasks required a great deal of information processing, and instructions as to primary and secondary tasks were not able to affect significantly the amount of attention already needed.

In Study I it was suggested that since the subjects were still improving on the peripheral task (but not the central tasks), this learning factor may have been an explanation for the lack of instructions to affect peripheral performance significantly. However, Study II showed a similar learning effect and also a significant instruction effect. It appears more reasonable to suggest that in some cases performance in a two-task situation is affected by both instructions and attentional demands. However, with tasks of very high attentional demands, the attention required by the subject to perform the task may be determined by the nature of the task regardless of instructions.

In Study I the decrement in performance of the peripheral task as a function of the nature of the central task could possibly be interpreted as a perceptual change in the peripheral retina because the subjects may have reported less characters correct as they saw either fewer stimuli or stimuli which were not as clearly defined. However, in Study II the subjects were able to improve performance on one task at the expense of a decrement in performance on the other task under different sets of instructions for both the peripheral and central task. When a given task was designated as the primary task, the subjects did not miss signals in the other task but showed a longer reaction time to them. Signals in the secondary task were seen as well as signals in the primary task. Thus, the interpretation of a perceptual change in the retina is rejected in favor of an attention change by the subject.

Although different subjects were used in each experiment, the differences in mean reaction time to the onset of a "Z" between Study I and Study II are of interest. The task of monitoring the central channel and responding to the onset of a "Z" was used in both studies. The mean reaction time for this task was 425 milliseconds for Study I and 387 milliseconds for Study II although the task was identical in both studies. While performing this task in Study I, the subject was also performing a difficult peripheral task. In Study II, the peripheral task was simplified. Although an appropriate statistical test cannot be performed on these data, another study is immediately suggested; that is, testing performance on a central task as a function of the difficulty of a peripheral task. If the explanation is true that performance in a two-task situation is due to attentional factors, then performance of a peripheral task which requires a great deal of attention should impair performance of a central task.

The present studies have provided several results of interest and, as is usually the case, they have provided even more questions to be investigated through future research. The peripheral retina—its functions and capabilities—is an interesting challenge to future researchers. The importance of the visual system in many organisms is obvious, and the relative lack of understanding of how this system functions is painfully evident. The topic of attention (especially visual and auditory attention) is, of course, a persistent problem for the psychologist.

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APPENDIX A. VISUAL CHARACTERS AND TIME INTERVALS USED FOR PERIPHERAL TASK (STUDY I)

Visual characters

C	N	1**
F	0*	5
G	P	6
H	U	7
J	Z	9

Time intervals for each visual angle (in sec.)

7	14
9	17
11	18
11	19
12	22

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* This character was correct if called either "o" or "zero".

** This character was correct if called either "i" or "one".

APPENDIX B. ORDER OF INSTRUCTIONS AND CENTRAL TASKS FOR EACH SUBJECT (STUDY I)

Subject	Day	Instructions	Order of Central Tasks
	1	III	A - B - C
1	2	II	B - C - A
	3	I	C - A - B
	1	I	B - C - A
2	2	III	C - A - B
	3	II	A - B - C
	1	II	C - A - B
3	2	I	A - B - C
	3	III	B - C - A
	1	II	A - B - C
4	2	III	C - B - A
	3	I	B - A - C
	1	I	C - B - A
5	2	II	B - A - C
	3	III	A - C - B
	1	III	B - A - C
6	2	I	A - C - B
	3	II	C - B - A

APPENDIX C. PERIPHERAL DETECTION FOR EACH SUBJECT (STUDY I)

Day 1 - Central Task A

Visual Angle	Subject	Visual character (no. times presented/no. times correct) C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
10°	1				2/2		1/1			2/0		2/1	1/1	1/0		1/1
	2		1/1	2/0		1/1		1/0	1/0					1/0	2/2	1/1
	3		2/2	2/2	1/0		1/1	1/1				1/1	1/1		1/0	
	4		2/1	2/0	1/0	1/1		1/0					1/0		2/2	
	5	2/2			1/1		1/1	1/1		1/1	1/1	1/1	1/0			1/0
	6	1/0				2/2		1/1			1/1	1/1	1/1			3/2
20°	1	2/1		1/1			1/0	2/2				2/2			1/1	1/1
	2	2/0	1/1		1/0			1/1				1/1	4/0			
	3	1/1			1/0			3/2		1/1			1/1	3/3		
	4		2/0	2/1		1/1	1/0		2/0					2/1		
	5			1/1		1/1	1/0	3/1		1/1		1/1	1/0			1/1
	6	1/0	2/0	2/2	1/0	1/0			1/0				1/0			
30°	1	1/1	1/0	1/1	1/0	1/0				1/1	1/1		1/0		1/0	1/0
	2	1/0			1/0		1/0	1/0					1/0	3/0		2/0
	3		1/1	1/0		1/0	2/0	2/0	2/0						1/0	
	4		2/0						1/0	1/0	1/1	1/0	2/0		2/0	
	5				2/0		1/0	1/0	1/0			1/1		1/0	1/0	2/0
	6	3/0		1/1	1/1	1/1	2/0	2/0								

Day 1 - Central Task B

Visual Angle	Subject	C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
		Visual character (no. times presented/no. times correct)														
10°	1		1/1			1/1		1/1	3/0			2/1	1/1	1/0		
	2	1/0	1/1	2/0							1/0	2/2		2/1	1/1	
	3	1/0	2/0		1/0	1/0		1/1					2/1	1/0		1/1
	4	1/1	2/1	2/0						1/0		1/0	1/0	1/1		1/1
	5	1/0	1/1	1/0	1/0	1/1	1/0				1/0			2/2	1/0	
	6	2/0	1/0	1/0	1/0	1/0	1/0			1/0	1/1			1/0		
20°	1		1/0	1/0	1/1		1/1	2/2	1/0		1/1		1/0	1/0		
	2			1/0	1/0			3/1	1/0		1/1	1/1		1/0		1/0
	3			1/0	1/1		1/0	1/0	2/0	1/0	1/0	1/0			1/0	
	4	1/0		1/0	1/0	1/1	1/0	1/0			2/0				1/0	1/0
	5			1/0	4/0			1/1	2/0	1/1			1/0			
	6	1/0	1/1			1/0	2/0	2/0		1/0			1/1		1/0	
30°	1	1/0	2/0	2/0	2/0	1/1					1/0					1/0
	2		1/0	1/0	2/0					1/0			2/0	2/0	1/0	
	3						1/0			3/1	1/0	2/2			2/0	1/1
	4		1/0		2/0	1/1		1/0	1/1	1/0			1/0	1/0		1/0
	5		1/0			2/1	1/0		1/0	1/0	1/0	1/1	1/0			1/0
	6		3/0		2/0	1/1					1/0			1/0	1/0	1/0

Day 1 - Central Task C

Visual Angle	Subject	C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
		Visual character (no. times presented/no. times correct)														
10°	1	1/0		1/0		1/1		4/4	1/0					1/0		1/1
	2	1/0			1/1				1/1	2/1		1/0		3/0	1/0	
	3			1/1	2/2	1/1		1/1				2/2	1/0	2/1		
	4	1/0		1/0					1/1	1/0	2/0		1/0	1/0	1/1	1/0
	5		1/0					3/3	1/1		1/0	1/1	2/2	1/0		
	6		3/1	1/0	1/0				1/1				1/1	1/1	1/0	1/1
20°	1							1/0		1/0	3/0	3/3		1/0	1/0	
	2	1/0	1/0					1/1			1/0	3/2		3/0		
	3	1/0		1/0		2/0			1/0	1/0					1/0	3/1
	4	3/0				2/1		2/3		1/0			1/0			
	5		1/0		2/0		2/0				1/1	1/1	2/0	1/0		
	6	2/0	2/0	1/0	1/1	2/1				2/0						
30°	1	1/0			2/0	1/1			1/0		2/0	1/0	1/1			1/1
	2		1/0	1/0		1/0	1/0	1/0				1/0		2/0	1/0	1/0
	3	2/0	1/0		2/1				2/1				1/0	1/0		1/1
	4		1/0	2/0					3/1		1/0			2/0	1/0	
	5	2/0				1/0	2/0			1/0	1/0			3/0		
	6					3/0	1/0	1/0				2/0	1/0		2/0	

Day 2 - Central Task A

Visual Angle	Subject	C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
		Visual character (no. times presented/no. times correct)														
10°	1	1/1	1/1		1/1		1/1			1/0	2/2	2/2				1/1
	2	1/1	1/0	1/1	2/2	2/2	1/1							1/0	1/1	
	3	1/1		1/1			3/3		2/2				1/1	1/1	1/1	
	4	2/2		1/1			1/1		1/0				1/0	2/1	1/1	1/1
	5		1/0		1/1			1/1	3/3	2/2		2/2				
	6	2/1	1/1	1/1						1/1	2/2		1/0		1/1	1/0
20°	1				1/0			1/1	1/1		1/1	3/2		2/0	1/0	
	2	2/0	1/1	2/0	1/0			1/1	1/0				1/0	1/0		
	3				2/1	1/1	2/0		1/0			1/1			2/2	1/1
	4	2/2	3/1		1/1	1/1	1/0			1/0		1/1				
	5		1/0	1/0			1/0	1/1	2/0		2/2			1/1		1/1
	6		3/1				1/1	2/1	1/1	1/1		1/1		1/0		
30°	1		1/0	1/0	1/0		1/0					1/1	1/0	1/0		3/0
	2		2/0	1/0			3/1	1/0				1/0		1/0	1/0	
	3					1/1		1/1	1/1		2/0	1/1		3/1		1/1
	4	1/0			1/0		1/0		3/0	2/0					1/0	1/0
	5					1/0	1/1			1/1		2/1		4/1	1/0	
	6	1/1	2/0		1/0	2/1				1/0		2/1				1/0

Day 2 - Central Task B

Visual Angle	Subject	C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
		Visual character (no. times presented/no. times correct)														
10°	1	1/0	1/0		1/1	1/1	1/1		2/2		1/0	1/1	1/1			
	2				1/1	2/2		1/1		1/1	2/0	2/2	1/1			
	3		2/0	2/2	1/0			1/1			2/1		1/1			1/1
	4	4/2				2/2								1/1	3/0	
	5			1/0	1/1	2/1	1/0	1/1				2/2				2/2
	6		3/2	1/1					2/1	1/0			1/1			2/1
20°	1		1/0	1/0	1/1	1/1	1/1	1/1					1/0	1/0		2/1
	2		3/0	2/0			1/0			1/0			2/0	1/0		
	3	1/0		1/1	2/1	1/0					2/0	1/1		2/0		
	4	2/0	2/0		2/0				1/0			1/1		1/0	1/1	
	5		1/0			2/2	1/0	1/0	1/1		2/1	1/1	1/1			
	6		2/0	2/1	1/0	1/1				2/0	1/1		1/1			
30°	1	1/0					2/1	1/1		1/0	2/1				1/0	2/0
	2	1/0		1/1				1/0	1/0	1/0	1/0	2/1	1/0		1/0	
	3		1/0						1/0	2/0	1/0	1/0	1/0	1/1	2/1	
	4			2/0		2/2				1/0	1/0	2/1			1/0	1/0
	5			2/2	1/0		2/0			1/0	2/2			1/0	1/0	
	6		1/0	2/0		2/2	1/1	1/0				1/0			1/0	1/0

Day 2 - Central Task C

Visual Angle	Subject	Visual character (no. times presented/no. times correct) C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
10°	1				1/0				5/5		1/0			1/0	1/1	1/0
	2			1/0	2/0		1/0	1/0	2/1	1/0	1/0		1/0			
	3	1/0				1/1	1/0	1/1		1/0		2/2		1/0		2/0
	4			1/0	1/0		1/1		2/1	1/1	1/1		1/0	1/1	1/0	
	5		2/0			2/2	1/1	1/1		1/0	1/0			1/0		1/0
	6						3/1			1/0	1/1	1/1	1/0	1/1	2/1	
20°	1		1/0		1/0		1/0		2/0	1/1	1/1			1/0	2/1	
	2							1/0	1/0	2/0	2/0	2/1	1/0			1/1
	3	1/0	2/0			2/0	1/0		1/0		1/0		1/0			1/0
	4			2/0				1/0	1/0		2/1			2/1		2/0
	5			1/0		1/0	3/0		1/1		1/1		1/0	1/0		1/0
	6	1/0			1/0		1/1	1/1	1/1	1/0				1/0	2/2	1/0
30°	1		1/0		1/0	1/0	1/0	3/0	1/0	1/0						1/0
	2				3/0		1/0						2/0	3/0		1/0
	3		1/0				1/0		2/0	1/0			1/0	2/0	2/0	
	4	1/0	2/0				1/0			3/0	2/0		1/0			
	5	1/0						1/0	1/0		1/0		1/0	1/0	2/0	2/0
	6			3/0						1/0		1/0	1/0	1/0	2/0	1/0

Day 3 - Central Task A

Visual Angle	Subject	C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
		Visual character (no. times presented/no. times correct)														
10°	1	1/1					1/1	2/2	2/2		1/1	1/1		1/0	1/1	
	2	1/0					1/1	2/1		2/2	1/1	1/1		1/1		1/1
	3		2/2			1/1					3/3		1/1	1/1	1/1	1/0
	4	1/1		1/1	1/1	1/1					2/2		3/1	1/1		
	5	1/1	1/1		1/0				1/1	4/3	1/1	1/1				
	6		1/1		1/1		1/1	2/2	3/3	1/1		1/1				
20°	1		1/0	2/1	2/1	1/1				2/0		1/1			1/1	
	2	1/0		1/0	1/0		2/2				1/0	3/2		1/1		
	3	1/1		1/1	3/2			1/1	2/2		1/1		1/0			
	4	2/1	1/1	1/1	1/0	1/0		1/1		1/0	1/1		1/1			
	5	1/0	2/2				1/0		1/1				4/4	1/1		
	6	1/0		3/3		1/0				1/1		2/2		1/0	1/0	
30°	1	3/0					1/0	1/0	1/0		2/0		1/0		1/0	
	2			1/0	1/0	1/0		2/0		1/0	1/0			2/0		1/0
	3	1/0				1/0	1/1	1/0	1/1	1/0		4/2				
	4	1/1		2/1		1/1	2/0			1/0		1/1	1/1		1/0	
	5		3/1		1/1		1/0				1/1	1/1	1/0	2/2		
	6	2/0	1/0			1/0	1/0	2/0				1/1		2/0		

Day 3 - Central Task B

Visual Angle	Subject	C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
		Visual character (no. times presented/no. times correct)														
10°	1			1/1	1/1		1/1	1/1		1/1	1/0	1/0			2/2	1/0
	2	2/0	1/0	2/0		2/0				2/2					1/1	
	3							2/0	2/1	2/2		2/2		2/1		
	4			4/1	1/0		1/1				1/1	2/2			1/0	
	5	1/1		1/0	2/1	1/0			2/2		1/1		1/0	1/1		
	6			1/0		1/1		1/0		2/1	1/1	2/2	1/1			1/1
20°	1	2/1		2/0				1/0			1/1		1/0	1/0	1/1	1/1
	2	1/0		1/0	1/0	1/0						1/0	2/0	1/0	2/1	
	3		1/0		1/0	1/0	3/1	2/2			1/1					1/0
	4				2/0	2/2		1/0	1/0	1/0	1/1		1/0	1/1		
	5	2/0	2/0					2/0	1/1	1/1					1/0	1/0
	6	1/0				1/1				3/1	2/2	1/1			1/1	1/0
30°	1			1/0	1/0			4/1		1/0		1/0		1/0	1/0	
	2	2/0	2/0					2/0						1/0	2/1	1/0
	3			1/0	2/0			1/1		1/1	1/0		1/0	2/0		1/1
	4	2/2	1/0	1/0	1/0	1/0				1/0	1/1	1/1			1/0	
	5		1/0		1/0				1/0	1/0	2/1	2/2			1/0	1/0
	6		1/0		2/0		1/1	1/0	1/0		2/0		1/0			1/0

Day 3 - Central Task C

Visual Angle	Subject	C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
		Visual character (no. times presented/no. times correct)														
10°	1					2/2	2/2	2/2	2/1			1/1				1/1
	2	2/0	1/0	1/0	1/0	1/0	1/0		1/1	2/1						
	3					1/0		1/1		1/0	1/0	2/2	1/1	2/1		1/1
	4		3/2		1/1		1/0			2/2			1/0	1/1		1/1
	5	1/0				1/1	2/0	2/1			2/2				2/0	
	6			1/1		2/2		1/1	1/1	1/1		1/1	1/1	1/1	1/1	
20°	1	5/0	1/1			1/1	1/0					1/1		1/0		
	2			1/0	1/0	1/0		1/0	1/1	1/0		1/1	1/0		2/0	
	3		1/0			1/0			1/0	1/0	3/1		1/0		2/1	
	4			1/1	2/1			1/0		3/0		3/1				
	5			2/1		3/1			1/0			1/1		1/0	2/0	
	6	1/0				1/0	3/2					1/1	2/2			2/1
30°	1	1/0		1/0	1/0			1/1	1/1	1/0	1/0			2/0		1/0
	2	1/0	1/0	2/0		3/0	1/0								1/0	1/0
	3	2/0				1/1			1/0	2/0	1/0	1/0	2/0			
	4		3/1	1/0		2/2					1/0	1/1			2/1	
	5	1/0	1/0		1/0	2/1			1/1			1/1	1/1	2/1		
	6		1/0	2/1	1/0					1/0	1/1			3/0	1/1	

APPENDIX D. PERFORMANCE ON CENTRAL TASKS FOR EACH SUBJECT (STUDY I)

Mean reaction time for tasks A and B (in milliseconds)

Subject	Task	Instructions I	Instructions II	Instructions III
1	A	481	492	484
	B	478	389	445
2	A	312	362	270
	B	334	316	320
3	A	804	731	635
	B	486	556	468
4	A	393	371	337
	B	411	424	392
5	A	524	441	314
	B	489	429	372
6	A	507	532	455
	B	476	450	420

Errors made while shadowing (Task C)

Subject	Instructions I	Instructions II	Instructions III
1	38	27	37
2	2	14	10
3	51	39	34
4	16	8	33
5	15	5	9
6	13	14	13

APPENDIX E. FREQUENCY OF OCCURRENCE OF EACH PERIPHERAL CHARACTER AT A TEST STOP (STUDY I)

	C	F	G	H	J	N	O	P	U	Z	1	5	6	7	9
Day 1	38	43	38	43	35	27	48	31	27	28	36	38	47	29	32
Day 2	28	43	34	33	31	44	26	44	36	41	37	28	43	35	37
Day 3	44	33	39	35	41	29	39	30	42	42	45	32	36	33	20
Total	110	119	111	111	107	100	113	105	105	111	118	98	126	97	89

APPENDIX F. MEAN REACTION TIME FOR EACH SUBJECT FOR PERIPHERAL AND CENTRAL TASKS, IN MILLISECONDS (STUDY II)

Subject	Task	Peripheral Instructions		Central Instructions	
		Block 1	Block 2	Block 1	Block 2
1	Peripheral	368	363	409	347
	Central	399	398	405	382
2	Peripheral	331	312	330	330
	Central	396	367	381	355
3	Peripheral	322	324	365	309
	Central	350	376	363	347
4	Peripheral	354	364	395	371
	Central	428	436	447	434
5	Peripheral	315	292	291	309
	Central	395	352	355	368