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In Partial fulfillment if the Requirement,

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THE CATHOLIC UNIVERSITY OF AMERICA

Orienting of Attention and Vigilance

A DISSERTATION
Submitted to the faculty of the
School of Arts and Sciences
of The Catholic University of America
In Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy

Toufik Bahri

Washington, D.0
1990

Dedications

To all those who are fighting for freedom
anywhere in the world
....

To the children of "El Intifadha"
....Stones.... Tears.... and...

This dissertation was approved by Dr. Raja Parasuraman, as Director, by Dr. James H. Howard, Jr and Dr. John Convey as readers.

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Aknowledgement

There are many people to be thanked for their generous assistance, guidance and support which made the completion of this dissertation possible. I wish to thank in particular my advisor and supervisor of my dissertation Dr. Raja Parasuraman for the semingly tremendous amount of time, support and encouragement which he has given. Your guidance will be remembered and deeply appreciated throughout my career. Thanks also to the other two members of my committee, Dr. James H Howard Jr and Dr. John Convey. I could not have asked for for finer teachers.

Special thanks are also extended to my friends and colleagues in the Cognitive Science Laboratories whose friendship, enthusiasm and team work gave me the best academic environment any student can dream of. Similarly I am indebted to all staff of the Psychology department and all students who participated in the study. I would like to extend my appreciation to my friend and colleague Dr. John E Deaton for his encouragement and assistance with the editing of an early draft of this work.

My warm and sincere appreciation also goes to a special friend of mine, Maria Kirsch who assisted with the editing and for her encouragement and priceless friendship during the achievement of this work. It is really appreciated. This research could not have been done without my friends whose help and moral support were always there when needed. A thounsand thanks.

Not least of all my evaluating gratitude goes to my parents for all these years of love and support which made this work possible.

Abstract

Attention is an important area in cognitive psychology. There are several varieties of attention which have been defined and described. Two important aspects of attention are orienting of attention and sustained attention or vigilance. The study of the orienting of attention deals with the ability of people to detect critical signals while their attention is guided to a specific location in the visual field over a short period of time. Such orienting is usually achieved through the use of visual cues. The spatial cues help shift the person's attention to the target's location (valid cues) or towards the opposite side of its occurence (invalid cues) respectively. On the other hand, research in the domain of vigilance concerns of the ability of people to sustain attention to low-probability critical signals for prolonged periods of time. Historically these two areas of research have proceeded independently of one another. However, there are theoretical reasons to investigate the relationship between these two attentional phenomena. For example, Posner's inhibition theory states that the inhibition generated during the orienting of attention may be responsible for the decrement over time in vigilance tasks.

The present study examined the relationship between orienting of attention and sustained attention by combining the covert orienting and vigilance paradigms. Two major issues were explored: (1) as a result of orienting attention in a visual field, is detection of a signal facilitated or inhibited? (2) Does the phenomenon of facilitation or inhibition change over time? These are questions dealing with selective and sustained attention respectively.

Two experiments were carried out. Forty subjects participated in the first experiment while the second experiment involved 45 volunteers. Subjects in both experiments performed a cued visual detection task for a sustained period of time (30 min). In Experiment 1, stimulus events were presented at fast (30 events/min) or slow (15 events/min) event rate with a 350 msec cue-target interval. The second experiment was a replication of Experiment 1 with the exception that only the slow event rate was used, and there were three different cue-target intervals.

Visual cues facilitated performance (increased sensitivity; d') in the 30-min vigilance task. Furthermore, sensitivity remained stable over time for validly cued targets but increased for invalidly cued targets. However, both these effects were found only at the low event rate condition. No cue validity effects were found at the high event rate condition. In Experiment 2, no significant difference was found between valid and invalid cues at the short interval (150 msec), but greater sensitivity decrement over time was found with valid than with invalid cues at the average interval (350 msec). Surprisingly, there was more decrement with invalid than with valid cues at the long interval (550 msec).

The results of both experiments point to a close relationship between orienting of attention and vigilance. However, the nature of this relatioship is dependent on the event rate experienced during the vigilance task. At the low event rate both facilitatory and inhibitory effects of orienting are found. Furthermore the vigilance decrement is related to the accumulation of inhibition over time supporting the Posner et al (1984) theory. At the high event rate, however, neither facilitation nor inhibition effects are observed reliably and vigilance decrement is related to limitations of the allocation of attentional capacity, supporting Parasuraman's (1985) theory.

Overall the results suggest that facilitation and inhibition are important opposing mechanisms in visual attention. These opposing mechanisms permit control of the distribution of attention both over visual space and over time. The results of this study are important both theoretically and practically since they suggest that standard vigilance tasks show decrement over time because they do not allow dissipation of accumulated inhibition. Such inhibition is dissipated by the use of some visual cues which provide a practical means for enhancing vigilance performance.

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OVERVIEW

The ability of human beings to focus their attention on a specific location in a visual field, in order to detect or select a critical signal, has been the subject of many studies in the domain of human performance. Although this capacity to move attention to detect a signal may be regarded as a rather simple operation, the cognitive processes involved are quite complex. This research will address two fundamental issues concerning these cognitive processes: (1) Once attention is oriented to a location in the visual field, is detection of a signal facilitated or inhibited? and (2) Does the pattern of facilitation or inhibition vary over time? These are issues concerned with selective and sustained attention respectively.

In the domain of attention, research efforts have attempted to account for complex cognitive phenomena in terms of basic mental operations that can, in turn, be related to neural systems. This can be done through the investigation of "component processes" that play a role in the identification of sensory events (Posner and Cohen, 1982). In studying these processes, the concept of attention has been defined in various ways depending on the method(s) and approach(es) used by different investigators and theorists (Parasuraman and Davies, 1984b). Attention has been defined as a "mental faculty that selects one or more external stimuli or internal mental events or traces" (Mackworth, 1970, p 13). Posner, on the other hand, defined attention as a "name of a field that consists of the study of internal mechanisms relating to our awareness of events" (Posner, 1978, p 123). This is obviously a general definition encompassing all aspects and processes of this phenomenon. Parasuraman (1984a) proposed that the ability of a person to accomplish an attentional task is affected by "arousal", which can be considered as a "general state of the organism" (Parasuraman, 1984b ,p 243). Parasuraman's view included two major characteristics of the concept of attention: the state of the organism and the external event. The former represents the subjective side of attention while the latter deals with the objective physical events controlling attention.

Each of these different views agree that in general three aspects of attention predominate. These include selective attention (the ability of a subject to select a target stimulus among many other competing stimuli), divided attention (the ability to share attentional efforts between two tasks or sources of stimuli), and finally sustained attention (the capacity of a subject to stay alert for a specific target event for a prolonged period of time). All of these aspects should be considered not as independent of one another, but as closely related to the point of affecting each other, as discussed further in this chapter. The inter-relationship between two aspects of attention, selective attention and sustained attention, forms the focus of the present investigation.

The relationship is examined in the context of two specific experimental paradigms that have been studied extensively, but so far independently-covert attention tasks and vigilance tasks. Covert orienting studies investigate how cues that direct a person's attention to a particular spatial location affect performance at that location. These tasks are labelled "covert" because overt orienting, or eye movements, are not permitted. Vigilance studies examine how the ability to maintain attention is affected by elapsed time and by features of the to-be-attended stimulus. These tasks demand vigilance because the critical stimuli occur unpredictably and with a low probability. Historically these two paradigms have defined different domains of research, as discussed in the following two sections of this chapter.

COVERT ORIENTING OF ATTENTION

Covert orienting of attention refers to the guidance of attention toward a specific site in the visual field by information provided by cues about the likely location of the visual event to be responded to. In general, it has been found that such cues enhance a person's performance in responding to an event at that location (decreases in reaction time (RT) or increases in detection accuracy).

The easiest and most commonly used technique to select a visual target is to move one's eyes. Thus, eye movements to a target are generally associated with selective attention. However, as a number of studies have shown, people can also shift visual attention without necessarily moving their eyes (Colegate, Hoffman and Eriksen, 1973; Eriksen and Hoffman, 1972,1973; Posner, 1980; Posner and Cohen, 1982). Probably the best natural example of this is the ability of a predator to be attentive to the entire visual field while focussing at a particular spot.

Covert orienting and eye movements

A number of studies have found that orienting of attention may be independent of eye movements (Eriksen and Hoffman, 1973; Posner, Nissen and Ogden, 1978; Shaw, 1978). For example, if subjects are given the choice to move their eyes in a covert orienting task, they usually discontinue doing so once they discover that it does not help their performance (Posner, 1980). Various other experimental techniques have been used to examine the relationship between eye movements and orienting of attention. In many experiments (Posner, 1980; Prinzemetal, Presti and Posner, 1987; Tassinari, Aglioti, Chelazzi, Marzi and Berluchi, 1987) subjects were asked to fixate the center of a visual display while stimuli were presented in the periphery. In other cases eye movements were recorded (Kosnik, Fikre and Sekuler, 1985). It was found that subjects detected the critical signals, displayed in the periphery, while they were fixating the center of the visual field.

Additional evidence of the independence of attention shifts and eye movements was provided by studies showing that subjects do not need to track a moving target in order to make a discrimination. This conclusion was confirmed by the fact that subjects' eye movements while tracking a moving target progressively resemble their eye movements while fixating a target. Such a finding is better explained by Kosnik et al (1985) who gave their subjects a discrimination task over repeated sessions of practice. Using Signal Detection Theory (SDT) measures (based on hits and false alarms) they found that discrimination of direction of movements (movements of dots) improved over practice. By recording eye movements, they found that the subjects' eye movements while tracking the stimulus were very similar to their eye movements while fixating a centered target. They concluded that improvement in discrimination is independent from eye movements. This finding suggested that subjects did not need to learn how to move their eyes because such tasks (orienting of attention) are perceptual rather than sensorimotor in nature.

The independence of attention and eye movements has also been demonstrated in other studies (Eriksen and Hoffman, 1973; Shaw and Shaw, 1977; Van Voonhis and Hillyard, 1977; Posner, Nissen and Ogden, 1978). These studies gave evidence that although humans usually focus their eyes and their attention on the same location, movements of attention can occur independently of eye movements. In other words, when subjects expect an event to occur (such as illumination of a light) in a specific location, they can detect the event faster when it is in the expected (cued) location than when they have no prior information about its location. This effect occurs even when subjects are asked to fixate on a central location.

These results indicate that a person may fixate one location but attend another. Hence, if attention facilitates the processing of sensory stimuli, a signal will be detected more efficiently at the attended location than at the fixated location. Usually the two are at the same location, but occasionally they may be dissociated. In some cases, attention may be diverted sufficiently away from the fixated location so that a target presented there is not detected at all. This phenomenon of "looking but not seeing" has been reported in the domain of vigilance research. Vigilance studies focus on performance decrement over time, that is, a decrease in the detection of critical targets over time, the so-called "vigilance decrement". Mackworth, Kaplan and Metlay (1964) found that the occurrence of eye movements in a vigilance task was not correlated with detection performance. In other words, missed targets were not necessarily associated with eye movements away from the target location. Conversely, targets that were fixated were equally likely to be detected or misssed. The results showed that an eye movement to a target does not indicate unequivocally that the target has been attended. Similar findings were reported later by Coates, Loeb and

Alluisi (1972). Thus, the independence of eye movements and attention shifts has been demonstrated in both selective and sustained attention studies.

In sum, most studies conclude that covert orienting and eye movement are independent phenomena. That is, a person's performance in shifting attention is not affected by moving or not moving his/her eyes. Eye movements are thus only one aspect of the study of orienting of attention. Early work on orienting of attention examined different variables that may be involved in the constitution of this phenomenon. This research is discussed in the next section.

Orienting of attention and detection performance

Many scientists agree that the phenomenon of orienting of attention goes back as far as Helmholtz, (1886) and to James (1890), and was explored more extensively with the dawn of the experimental psychology age beginning with the work of Wundt in 1912 (Downing, 1988; Tsal, 1983). As already mentioned, there are two types of orienting, covert orienting (the movement of attention through the visual field) and overt orienting (the movement of eyes and head).

Previous investigations in this field (Eriksen and Hoffman, 1972; Posner, 1980; Posner, Snyder and Davidson, 1980; Posner and Cohen, 1982) have shown improvements in detection performance when attention is oriented to a specific location in visual space. Eriksen and Hoffman (1972) showed that a subject's RT to detect a target letter decreased as the time interval of the cue preceding the target increased. Based on this experiment, Eriksen and Hoffman (1972) investigated the involvement of focused attention in detection tasks. In their experiment, the task consisted of detecting letters used as targets. The number of non-targets was limited to four, but the spacing (distance) between the target and non-target was manipulated as follows: the closest spacing (no blank space was left between the target and noise), a larger spacing (one blank) and finally the largest spacing (two blanks). The nontargets, were of two types; letters and disks. Another new variable in the design of this experiment was that the cue did not precede the target but was displayed at the same time, followed by the noise. The experiment was designed in this manner to test the role of focused attention, if any, in the detection of targets (Eriksen and Hoffman (1972). Their hypothesis was that if gradual concentration of attention had a role in the selection of the critical item, then the larger the spacing (between the target and the noise), the more interference (of the noise) will occur.

A spacing effect was found to have occurred only as a result of the difference between the various spacing conditions. If the difference in separation between the target and the non-target was 1 degree or more, then, "further separation seems to be immaterial" (Eriksen and Hoffman, 1972, p 203). This area of 1 degree of angle was considered to be the high resolution area where more details are processed (the fovea). However, Eriksen and Hoffman claimed that attention is not so closely tied to foveation. That is, one can focus his attention on a specific visual field even if that area is not foveated. In this research, Eriksen and his colleague used the concept of "energy" to express the focus or the concentration of attention on a specific area in the visual field. Divided attention was explained by the fact that this energy was shared among many items or stimuli.

Following this pioneering work, a series of experiments were conducted in the early 1980s to investigate in more detail the phenomenon of orienting of attention. The most extensive experiments were carried out by Posner and his colleagues.

Posner (1980) defined orienting of attention as "the aligning of attention with a source of sensory input or internal semantic structure stored in memory" (p 4). Most selective attention studies have used search tasks where a spatially distributed display (under different forms and locations) is presented to individuals who are asked to decide on the presence or absence of a specific target. Usually the target is presented for a very short time, so that target detection requires attentional focus (i.e. there is no time for an eye movement). The use of cueing for longer tasks (e.g., vigilance tasks) is almost absent from the literature. Using visual cues was shown to have some effect on detection performance in general. But does cueing help subjects perform better in their detection task? This issue was the main concern of many covert orienting studies.

To examine this issue, Posner (1980) used a simple and a complex task in which subjects were asked to orient their attention to a specific visual location other than the center of fixation. Each trial started with a plus sign, an arrow pointing to the right or an arrow pointing to the left. The plus sign meant that the target could equally occur in the right or the left side. Each of the left and the right arrows indicated that there was a high probability (0.8) that the target would occur in the left or the right side respectively. In the simple task subjects were asked to press a key irrespective of the location of the target. Posner found that this instruction can be executed by a covert attentional mechanism which is "time locked" to outside stimuli. This mechanism varies according to the efficiency of discriminating targets from non-targets in the visual field. In the complex task condition subjects were asked to report whether the target was a letter or a digit. Posner (1980) concluded from his experiments that information about the stimulus does not help the performance of a simple task but has a facilitation effect in complex tasks.

In order to investigate the time course of the performance benefit, Posner used different time intervals between the cue and the target (100 msec, 200 msec, 300 msec, 400 msec and 500 msec). Posner found that the relationship between reaction time (RT) and cue-target intervals was a U-shaped function. RTs were high at very short and very long intervals and low at intermediate intervals. According to Posner, the U-shaped function reflected _facilitation_ in responding to the target at short to moderate intervals following the cue, and _inhibition_ at moderate to long intervals. RTs were found to be delayed after about 300 msec or more following the cue. The important concepts of facilitation and inhibition will be defined and discussed in detail in the following section.

Facilitation and _inhibition_

Previous studies have shown that visual cues enhance detection performance at short cue-target intervals, but a delay in RT occurs at longer intervals. Such effects were called facilitation and inhibition respectively. Facilitation refers to an enhancement in detection accuracy and/or decrease in RTs. Inhibition is characterized by a slowing in the response latency (Posner, 1978; 1980; Maylor, 1985; Posner and Cohen, 1982; Prinzemetal, Presti and Posner, 1986). The concepts of facilitation and inhibition in orienting of attention and their role in visual attention have been developed further in more recent studies.

Facilitation is conceived of as a natural outcome of the use of valid cues. That is, if the critical signal occurs at the cued location then an advantage in RT is observed (Eriksen, 1972; Posner, 1980; Posner and Cohen, 1982). However, if the target does not occur after 300 msec or more from the display of the visual cue, the facilitation effect is then changed to an inhibitory one. This inhibition is said to last about 1 to 1.5 sec (Posner and Cohen, 1982). Given the existence of facilitatory and inhibitory processes one can ask whether they have different or similar effects on information processing during various attention tasks.

Such a question was the focus of an early attempt by Posner and Snyder (1975). They found that low validity cues produce facilitation but not inhibition (cost). They also observed that in the case of high validity cues facilitation starts to accumulate more rapidly than inhibition. More specifically, Posner and Cohen (1980) have shown that the use of peripheral visual cues speeds the RT to the critical target if the target is displayed in the cued location and within 100 msec of the cue. This facilitation effect was attributed to the summoning of attention to a specific visual location as a consequence of the occurrence of an external visual stimulus. However, if the target is displayed more than 300 msec after the cue, then the RT to the target occurring in the same location is delayed. Posner and Cohen concluded that inhibition is an automatic process which occurs inevitably in response to any visual stimulus presented in the periphery and without any deliberate behavior on the part of the subject. They claimed that inhibition is sensory rather than attentional in origin. This claim led to other investigations to verify Posner's theory.

Among other attempts to define the origins of the phenomenon of inhibition, was a study by Maylor (1985). Based on the assumption of Posner, Choate, Hockey and Maylor (1984) which states that facilitation is attentional whereas inhibition is sensory in origin, so that overloading subjects with a secondary task would disturb the facilitation effect only, Maylor (1985) gave subjects a detection task plus another secondary task (which was a discontinuity in a central tracking task that demanded overt attention). The introduction of a secondary task was supposed to disrupt facilitation since it is attentional, but not inhibition, since it is sensory. Maylor found that the use of a secondary task eliminated the facilitation effect as well as the inhibition effect. The finding argued against the theory that facilitation is an attentional process whereas inhibition is an automatic process which is sensory rather than attentional in nature. Maylor (1985) stated that "the facilitatory and inhibitory components of externally controlled orienting appear to act together to direct the eye-movement system and to maintain selectivity in visual space" (p 189) .

Using cues is not the only factor affecting subjects' performance in covert orienting tasks. Other sensory and attentional variables also play a role in determining the efficiency and the strategy by which a signal is detected. A need to investigate such factors leads to more research and experiments. Using the detection of signals as a model task, another study by Posner et al, (1980), examined the effect of sensory and attentional factors in controlling subject's awareness of the environmental events. They found that subjects performed better when they were cued regarding the location of the critical signal in the visual field. They explained this finding by claiming that subjects showed greater expectancy effects when cued on a trial by trial basis, than when a probable position is held constant for a block. While information about the signal location was very helpful, they found that information about the nature of the stimulus did not help the subjects in their detection tasks.

The general rule emerging from these studies seems to be that cueing improves subjects' detection performance. Furthermore, cues have facilitatory and inhibitory effects depending on temporal factors. But can people learn how to locate targets and improve their detection performance in orienting tasks? This forms another focus in the study of orienting of attention.

Practice and orienting of attention

Basic evidence from previous studies and experiments demonstrates that people can rapidly learn to inspect spatial locations on a display in an optimal order to detect targets that may be present (Rabbitt, 1984). Rabbitt cited an experiment he conducted in 1979 where subjects were asked to detect letter targets on displays that contained other background letters (noise). Targets were displayed with different probabilities at various locations. He found that young subjects (18-30 years) were very fast in identifying the constraints and used the information to guide their search to detect targets rapidly when they occurred at the most frequent locations. While old subjects (70 years and older) were as accurate as young subjects in the description of relative target probabilities at different display locations, they were unable to use this information to guide their search (since their detection was not faster for frequent than for infrequent locations). Rabbitt (1984) concluded that people know both where to look (spatial location) and what to look for (targets) and both of these tasks can be improved with practice.

Muller and Findlay (1987) conducted two experiments using a signal detection plus localization task. They used SDT measures to analyse their data. They found that there were benefits of cueing on perceptual sensitivity. They also found that subjects were liberal (in terms of the decision criterion) in making decisions with cued locations and conservative with uncued ones. They concluded that subjects shifted their decision criterion according to probabilities they assigned to particular locations. That is, subjects learned where most probably targets occurred, after watching some trials.

Facilitation: Sensitivity enhancement or response bias?

Most of the studies conducted to explore the phenomenon of orienting of attention have used RTs as their indices for any performance change that occurs as a result of a shifting of attention. For a given error rate, a change in RT may reflect either a change in sensitivity or in response bias, in terms of SDT. Within this context an important methodological question arises: Does the use of RTs reflect the existence of a facilitatory effect at the level of sensitivity? In other words, are these RTs significantly different because of a sensory change that occurs during the detection task or because of a bias change in the subject's performance?

To answer these questions, a study by Bashinski and Bacharach (1980) was conducted to examine the effects of selective attention on perceptual sensitivity. A visual signal-detection task was used. The subjects in this study were instructed to move their attention to a specific cued location. The targets occur at the location indicated by the arrow (cue) 80%, 50% or 20% of the time. These conditions were referred to as of high, neutral and low validity, respectively. Data for hit and false alarm rates were calculated for each subject under the three conditions. Bashinski and Bacharach (1980) found a positive relationship between the hit rates and the three validity conditions. A higher rate of false alarms was also found with the low than with the high validity condition. That is, high validity cues enhanced the subject's perceptual sensitivity. This sensitivity improvement occurred without any significant shift of response bias (Beta) across the three conditions. Subjects also showed more sensitivity to the right than to the left side of the visual space. This was explained simply as the result of the way people read (from left to right).

One of the most recent studies focusing on different factors affecting orienting of attention was conducted by Downing (1988) to investigate the effect of cueing and stimulus type on perceptual sensitivity. Subjects were given one of four tasks (luminance detection, brightness discrimination, orientation discrimination or discrimination of form) to perform at four different locations. Using SDT measures, Downing found that both distance and type of task to be performed had major effects on subjects' sensitivity. Overall sensitivity improved at expected locations and decreased as the distance increased from the expected location. Interaction of type of task by spatial distribution of stimuli showed that distance affected sensitivity more (greater decrement) with orientation discrimination and form discrimination than with brightness and luminance detection. Downing concluded that spatial expectancy affects perceptual processing. She argued against the idea that changes in detection performance are fully due to variations in response bias. Downing supported Posner's (1978) and Bashinski and Bacharach's (1980) findings that cueing affects perceptual pathways. Another finding of Downing's research is that spatial resolution and limitations of the amount of information to be processed affect attentional processes.

The nature of visual attention

Using RTs or SDT measures, researchers have demonstrated the effect of visual cues on subjects' attention performance. Being able to produce a quantitative translation of the shifting of attention led to investigations about the structure and the nature of visual attention, that is, the way visual attention operates and the manner by which different stimuli are represented within the attentional structure. Many scientists argue about whether attention works as a "spotlight" or in a different way such as the concept of a "zoom lens".

Posner et al (1980) concluded that detection is an interaction between the framework of the visual system and the structure of the attentional system. They defined attention as "a spotlight that enhances the efficiency of detection of events within its beam" (Posner et al, 1980, p 172). The investigators distinguished between two different aspects of attention; orienting (the location to which attention is directed) and detection (the discrimination of the critical signal from the noise). According to their findings, orienting may be a completely "central phenomenon" without change in eye position and it may include the selection of a modality. They hypothesized that if the orienting of attention can be "time locked" to an external stimulus, then it would be possible to determine the speed of the orienting of attention, the nature of the relationship between the distance and the RT in switching attention, and the manner in which the orienting of attention is related to eye movements. While Posner et al (1980) seem to explain orienting of attention on the basis that attention operates as a "spotlight", other researchers disagree with such interpretations. Eriksen and James (1986) are among those who represent the second view

In their study, Eriksen and James (1986) questioned the possibility of modifying the spatial extent of the attentional focus as a result of precueing. They also investigated the question of whether the extension of the attentional focus causes deficiency for the processed stimuli. The last point they explored was the question of whether the boundary of the concentration was totally separate from the processed field or whether it merely demonstrated a gradual processing deficiency in resources. In order to clarify this point, two experiments were conducted. The subjects were required to search eight letters distributed in a circular pattern. Up to four stimuli were precued at different intervals of time. Other targets were used as noise for both cued and non-cued spaces. They found that RT to noise targets was disrupted no matter whether they were inside or outside the precued zone. There was a linear relationship between an increase in RT to target letters and the increase of cued positions. They attributed part of this finding (increase in RT) to a confusion in discriminating the targets because of an increase in the cued positions. But within the attentional focus, their results suggested that subjects use additional resources to process such a difficult task (increase in the focus area). The RT to noise letters was less disrupted as the target locations decreased in distance (from 5 degrees to 1.5 degrees). They found a 100 msec stimulus onset asynchrony (SOA) was optimal to avoid the disruptive effect of noise letters. The disruptive effect occurred at less than 100 msec SOA regardless of the degree of location.

Eriksen and James (1986) concluded that the extent of focused attention can be varied by using cues, and that within this attentional focus size, resources cues are processed evenly. They concluded that this mechanism of attentional concentration was better explained by a zoom lens model. That is, subjects at a first stage distribute their attention over all possible visual locations and search for the target in parallel. At a second level, subjects narrow their area of attentional distribution by focusing on precued locations. So attention is sometimes largely distributed (like an open lens) or narrowly concentrated in a smaller area for better detection of details (like focusing with a zoom lens). In Eriksen and James' words "As the power of the lens increases, the field of the view constricts, with a concomitant increase in the resolving power for detail of the objects still remaining within the field" (p 227).

How does attention move?

Exploring different structures that define the nature of visual attention leads to the question of the nature of the shifting of attention. For example, if one accepts the metaphor of visual attention as a spotlight, then it is natural to ask how the spotlight moves. The most crucial question seems to deal with whether attention moves proportionally to distance or independently from it. Experiments have been conducted to examine this issue.

Collecting RTs to precued targets at three different locations (4 degrees, 8 degrees and 12 degrees) and using five different SOAs, Tsal (1983) found that as SOA increased RT decreased and that was the case with each simple location until it reached a stage of asymptote. Tsal concluded that attention traversed the visual field at a constant velocity of approximately 8 msec per degree along the horizontal meridian. Tsal's study has been criticized for his not being able to verify some of his assumptions and particularly his calculation of the velocity. Eriksen and Murphy (1987) criticized Tsal mainly for his assumptions that attentional resources are distributed in the visual field, that the attentional focus travels along the the visual field, and that attention is concentrated at the fixation point at the start of the trials.

Investigating the shifting of attention from one location to another, Remington and Pierce (1984) designed two experiments which measured the time to shift attention to different objects located at different locations (10 degrees or 20 degrees) from the central fixation (where the cue, a directional arrow, was located). They tested attentional shifts at 10° and 20° in separate sessions. The precue validity was 80%. They found that the distance had no effect on the time course of the attentional set. That is, the attentional focus was time invariant with the distance to be traversed. They therefore concluded that attentional velocity was proportional to distance (and not fixed) resulting in RTs that were invariant over the distance traversed by the focus of attention. They also found a selective attentional effect that was translated by an increase in RT to probes at unexpected locations at 150 msec and 200 msec after the cue. The question of whether there was facilitation for attended locations and cost for unattended ones was explored in a second experiment in which a neutral cue was added. They found that facilitation for cued positions develops earlier than cost for uncued locations. There was longer RT for neutral and uncued positions than for cued ones. Remington and Pierce concluded that shifting of attention is tied to hand and saccadic eye movements. The shifting time across the visual field was found to remain invariant by adjusting velocity in proportion to distance.

Shulman, Wilson and Sheehy (1985) investigated the distribution of attention at different points of eccentricity. Cues were used to indicate to the subjects the location of the target (target light). The cues they used were not always valid. Subjects were required to detect the target from one specific location. They did not have to discriminate between a target and a non-target since only one stimulus was used. Shulman et al (1985), found that the longer the distance between the target light and the area of the attentional focus, the slower the RT. A difference was found between peripheral focus of attention, which produced a very small increase in RT to noncued events, and foveal focus in which the increase in RT to noncued targets was longer. This finding is consistent with that of Eriksen and Hoffman (1972) who claimed that the focus of attention corresponds to the fovea and that the farther the target from the foveal location, the longer the RT. Another major finding was that regardless of the location (peripheral or foveal) the same effect of selective attention (increase in RT) occurred in the peripheral location if the distance was long enough. They concluded that the distribution of spatial attention is determined by two factors, the location of the representation and the change in its amplitude.

Other factors affecting detection and orienting of attention

It appears that detection performance is also affected by some organizational and structural features of processed visual input. The problem is in locating this organizational effect. In this context, Batram (1978) suggested that one can not attribute the change in performance to a single factor such as processing only, or visual input alone, since this merely clarifies one side of the effect and does not fully explain the performance change. He therefore suggested that there is a need to consider some processing operations that correlate between the structural effects.

Much research has come up with striking effects of different factors on detection, identification and orienting of attention. Some of these factors are external, physical elements that are involved mainly in the presentation of the external stimulus, its physical constitution and its environment (such as color, brightness, noise, etc). Another set of factors are those internal, subjective factors that are involved in the internal state of the human subject (such as memory, eye movements, visual acuity, etc). Both types of factors work together in an interactive system, thus, affecting various aspects of attention.

Configural and contextual effects are often found, even when the task to perform requires information about a single feature of the visual input (such as the orienting of a line segment) (Cooper, 1980). Additionally, in a study by Williams and Weisstein (1974) which looked into the effect of structure on recognition, they found that a line segment is better recognized when it is a part of a bigger shape (a unitary three-dimensional drawing), that is a "coherent context", than when it is displayed by itself alone. Williams and Weisstein (1974) argued that stimulus characteristics are not perceived independently of the whole picture in which they are presented.

Exploring the same phenomenon, another experiment concerning the configural effects in visual processing was reported by Prinzemetal and Banks (1977). They gave evidence that "the principle of good continuation can predict forced choice detection of an item" in a very brief visual presentation. They criticized the theory that claims that detection in a visual field is an outcome of simple interactions among the detectors of the present attribute. They suggested that the analysis of configuration precedes the analysis of features. Basing their experimental design on the Gestalt principles, Prinzemetal and Banks (1977) pointed out the importance of organizational principles in a theory of visual detection.

In addition to these configural effects, another aspect affecting orienting of attention seems to reside within the factors of stimulus size and visual quality. To explore these factors, Pashler and Badgio (1985) tested the hypothesis that detecting critical signals might be achieved without actually identifying targets and/or distractors.Pashler and Badgio (1985) manipulated size and visual quality to test predictions of serial versus parallel encoding models. The task used in these experiments required exhaustive identification (subjects named the highest digit in an array). They found that the effect of display size was additive with the effect of visual quality in the highest digit task, according to Sternberg's (1975) additive factors logic. This finding is an argument against the theory which claims that character recognition is a serial process, specifically against any other model in which stages delayed by quality reduction are executed in series (Pashler et al, 1985). They also found that visual quality affected the rate of feature identification, not just feature extraction.

Other explored variables include elements such as interstimulus interval (ISI) and target duration. This was the focus of a study by Laberge and Brown (1986) who verified the claim of two general classes of theories: (1) shifting-focus theories which stated that the attentional focus changes during a brief target display but does not change during the interstimulus interval (ISI) and (2) gradient theories which state that the attentional gradient does not change during a display but between displays. They found an attentional range effect which was inconsistent with both categories but which confirmed the theory that attentional factors dominate in processing visual targets, and that retinal sensitivity factors have a minor role, if any.

On their side, Prinzemetal, Presti and Posner (1986) investigated the effect of moving attention on the integration (combination) of color and shape information. Colored letters were displayed before the subjects. Subjects were informed about the location of most targets. They found that subjects were most of the time successful in integrating the color and shape of letters. Facilitation affected both the combination and registration of the characteristics. Therefore, the orienting of attention affected the sensory registration (representation) of the "features" and their combination.

Active and passive orienting

While the role of various physical and cognitive factors in covert orienting has been investigated in many studies, the connection between orienting of attention and other types of attention, namely sustained attention, needs to be clarified further. In this context, Posner et al, (1984) hypothesized that some of the same primary processes that permit people to focus on one source of sensory information (to make a selection), are also involved in the phenomenon of sustained "concentration", and if so, then research on the detection of sensory signals may be useful (informative) regarding people's capacity to sustain their attention during thinking. Posner and his colleagues examined the concepts of "active" and "passive" processes in selective attention to explain the phenomenon of sustained concentration. They considered two approaches to the phenomenon of sustained attention. According to the first approach, information outside the attended channel is filtered at an early stage (passive filtering), while the attended information is unfiltered. The other approach (active selection) suggests an active filtering of the attended source.

Posner et al (1984) used two paradigms to approach the problem of sustained concentration. One involved both divided and focused attention and the second concerned vigilance. Based on their own results, Posner et al (1984), showed that focused attention is better than divided attention only when events in the attended source must be actively processed. They gave an example of a subject who is checking a non-attended source when a target is actively selected on an attended channel. Concerning the second paradigm (vigilance), Posner et al (1984) pointed out that the research of Parasuraman (1979) established that there is a decrement in vigilance over time with only one channel of input. That is, performance declines as if there is a need for selection between the sensory channel and an internal channel, rather than between two different sensory channels. According to this then, sustained attention requires selective attention, particularly at high event rates. (For further details on the connection see the section on " The orienting of attention and sustained attention").

Posner and his associates concluded that active orienting processes would be best maintained with a continuous processing of events and might increase with the difficulty of the task (difficult discriminability between targets and noise). This study was an attempt to explain sustained concentration through basic studies of the characteristics of visual orienting. As Posner and his colleagues concluded, active orienting improves as the discrimination task becomes easier. That is, as the physical factors improve, subjects perform better.

Summary of covert orienting findings

Orienting of attention has been the focus of many studies in order to break down this phenomenon into its primary components and understand better its features and functions (Posner, 1978; Posner, 1980; Posner et al, 1980; Posner et al, 1982; Eriksen and Hoffman, 1972; 1972;1974). For this purpose many aspects and variables, involved in orienting of attention, have been explored:

(1) Eye movements have been shown to be independent of the movement of attention.

(2) Subjects detect targets better when targets appear in a cued than in an uncued location, independent of the location where the eyes are fixated.

(3) This performance benefit seems to be the result of an increase in sensitivity (d') rather than a change in bias (Beta).

(4) The concepts of facilitation and inhibition have been proposed as a function of cue-target intervals and performance change with cues. Attention moves following a cue and has facilitatory effects but has inhibitory effects at long cue-target intervals.

(5) The nature of the movement of attention and its function have been studied and evidence for either a "spotlight" or "zoom lens" metaphor has been put forward.

(6) Organizational features of the stimulus also affect target detection performance in covert orienting tasks.

(7) Finally, covert orienting seems to be an active attentional process rather than one of passive filtering. This active process may be similar to active filtering processes occuring in vigilance tasks although this has not been demonstrated empirically yet.

Even though the effect of spatial cues has been shown to alter attention (producing facilitation or inhibition), it has not been shown, for instance, whether such a cueing effect is applicable to all types of attentional tasks. That is, do such effects occur with the use of a different attention task such as sustained attention or vigilance? Before examining the relationship of covert orienting to vigilance, prior research on vigilance is briefly reviewed in the next section.

VIGILANCE OR SUSTAINED ATTENTION

Historical Background and practical relevance

The word vigilance was used by the British neurologist Sir Henry Head (1926) to describe a state of physiological energy (readiness or preparation). Mackworth (1950) used the term to refer to the ability of detecting infrequently presented signals over a prolonged period of time (Davies and Parasuraman, 1982). Other scientists agree that the origin of work on sustained attention goes back as early as 1932 to the research conducted by Wyatt and Langdon (Mackie, 1977).

The study of the human ability to sustain his attention for a prolonged period of time (vigilance) has been a very relevant issue in the domain of human performance since the early work of Mackworth in 1948. At the request of the British Royal Air Force, Mackworth (1948) conducted some experiments to determine the causes of the failure by anti-submarine radar operators to detect targets on the radar screen after a prolonged period of watch. Mackworth later referred to this problem as the vigilance decrement. The work done by Mackworth (1948) is considered as the first real laboratory setting of a vigilance task. Since then many other studies have been conducted in experimental (laboratory) settings. Most vigilance studies focus on the nature of the deterioration of sustained attention over time, referred to as the vigilance decrement.

A major criticism of experimental settings in vigilance is the degree of similarity between the laboratory settings and the real world situations. Experimental settings seem to be more monotonous and more controlled than the unexpected and various events of the everyday worla As early as 1965, Kibler mentioned that due to rapid technological developments, laboratory studies were no longer able to simulate real world situations. Vigilance decrement has been found to be rare if not absent in real monitoring situations (Teichner, 1972).

Despite these criticisms, operational problems found in early studies of vigilance using less complex equipment may still persist in new human-machine systems. The major change that has occurred in these systems is in the role of the human operator which has been transformed from a direct controller to a passive monitor. Even in the most sophisticated automated systems where humans have a very small role to play, the problems arising from a vigilance task such as the ability to make inferences and generate judgements regarding a signal's source, interpretation of complex information, and other monitoring functions still remain (Parasuraman, 1986).

Warm (1984) has pointed out that the importance of vigilance is seen more clearly in automated systems where missing signals can have fatal consequences. He claimed that the decrement occurs because of the allocation of complex tasks such as monitoring to the human operator.

Moreover, according to Warm, the solution to this problem will be the assignment of such tasks to machines. But automation has its consequent complications as well (costs, difficulty of the task, requirement for sophisticated decision making, etc)(Warm, 1984).

The above considerations suggest that vigilance research has important practical implications. What about theoretical implications? A number of theories have attempted to explain the phenomenon of the vigilance decrement. The main theories are discussed in the following section.

Theories of vigilance

One of the earliest views in the field was the inhibitory theory introduced by Mackworth (1950). Mackworth attributed the vigilance decrement to a conditioned inhibitory effect (the fact that the monitor is not responding for long periods of time results in decreased readiness for the signal to be responded to) due to a lack of reinforcement or negative conditioning (lack of signals). The main criticism of Mackworth's theory is that he did not distinguish between an inhibitory effect caused by distractive factors of attention from one generated by a response to a detected target (Loeb and Alluisi, 1977). Another problem in supporting this theory is the fact that an increase in the frequency of signals would reduce the decrement and not increase it (Davies and Parasuraman, 1982).

Broadbent (1958) proposed the filter theory. He attributed vigilance decrement to the rejection of repetitive information. This theory claims that a filter selects the information which reaches the organism. This filter rejects some frequent information while permitting new information to enter the processing sequence. This filter theory is not observed and therefore there is no evidence of attributing such vigilance decrement to this non-observed rejection of information. This theory has also been criticized for not being able to cope with the vigilance events. (Loeb and Alluisi, 1977). As discussed earlier, Posner et al (1984) also obtained evidence indicating that selective attention involves active orienting rather than the passive orienting implied by a filter concept.

Similar view suggested that the observing responses necessary for attention and observation such as head and eye movements, etc (Holland, 1958) are considered as distracting and cause a decrement in vigilance performance. An extended version of this theory was represented by Jerison and Pickett (1964) who focused on other observing responses such as the subject's observing (eg. concentrated, distracted, or mixed observing of the display) strategies and his/her decision making rules while performing a vigilance task. This theory was criticized on the ground that decrement can still occur even if these observing responses are eliminated (Broadbent, 1963). Moreover, many other distractors are internal and are not observable or measurable (Loeb and Alluisi, 1977). However, Jerison's theory is important because it suggested a link between vigilance and selection of stimulus sources, or selective attention. This link is explored and made more explicit in this thesis.

A purely psychological theory (if one can use this term to describe the expectancy theory) was proposed by Baker (1963). The essence of this view is that operators in vigilance situations expect more signals than what actually occur during the task. The matching of such expectancy with the reality generates the decrement. Colquhoun and Baddeley (1964) found that the decrement increases if people are initially given high signal probability tasks, and are then introduced to low signal probability tasks. The effects generated from the previous tasks might have a sensory shifting role since such expectancies reinforce the subject's state of readiness, which might affect the criterion shift of the monitor (Loeb and Alluisi, 1977).

J. F Mackworth (1969) suggested that vigilance decrement occurs because of neural habituation due to stimulus repetition. That is, no neural responses are generated as a result of this habituation. This habituation theory reasons that responses to signal stimuli disappear gradually until there is no response. This theory was criticized on the basis that vigilance tasks are too short to allow such habituation and that research on dishabituation argued against such theory (Davies and Parasuraman, 1982). Jerison (1977) criticized this theory, claiming that habituation of basic physiological systems is more rapid. Also at longer interstimulus intervals (ISI) of 5 seconds or more there is no habituation at all (Jerison, 1977).

Vigilance decrement is a complex phenomenon resulting from involvement and interaction of more than one factor. It is evident that each theory tried to explain the vigilance decrement from its proper theoretical background. Nevertheless, no single theory can give a complete explanation of this phenomenon. A better understanding of vigilance decrement is to consider all evidence provided by each of these theories and others as well. The above theories do not take into account differences between perceptual effects and response bias in vigilance. Separation of these two is provided by Signal Detection Theory (SDT).

Signal Detection Theory

Signal detection theory (SDT) provides a means for differentiating between an observer's perceptual sensitivity and his or her decision criterion. According to Swets and Green (1978), the theory not only helps to discriminate between these two aspects of performance, but it also offers two measures of analyzing and evaluating the effectiveness of the observer's choices in making a decision.

The original application of SDT to vigilance was made possible by Broadbent and Gregory (1963). They showed that the vigilance decrement in hit rate is due to a change in the criterion shift (Beta) rather than the observer's sensitivity (d').

In most cases of vigilance decrement, a drop in false alarm rates was seen to accompany the hit rate decline. This was perceived as a result of a shift in the observer's decision criterion and not in sensitivity (d'). This finding was general with the exception of few studies which used a relatively high event rate and visual displays, and which required an almost continuous attentional effort, where a decline in the observer's sensitivity was observed. Even in those experiments, the decision criterion became stricter with time (Swets, 1977).

Using SDT measures, Swets (1977) reviewed twelve studies to answer the question of whether a decline in hit rate is caused by a decrease in the observer's sensitivity (d') or by a stricter Beta. He concluded that a sensitivity decrement occurs under high event rate, in tasks requiring continuous attention and in the presence of other factors such as fatigue, boredom, stress etc. Parasuraman (1979) has demonstrated that sensitivity (d') declines under high event rate with successive tasks (where the subjects base their discrimination decision on critical change(s) between the successively and randomly displayed targets and non-targets).

SDT has been both criticized and supported by many researchers. The theory was first accepted because it enables quantification of some behavioral aspects that had been ambiguous for a lengthy period of time (Jerison, 1977). It has also been credited for providing an efficient way of describing the tools of any detection task (Warm, 1984). In addition SDT offers a simple graph termed Receiver Operating Characteristic (ROC) which uniquely represents performance in detection tasks. This graph separates the two major aspects of performance: sensitivity and decision criterion (Swets and Green, 1978). The distinction offered by the ROC curve is important in evaluating the performance of any system. This graph also enables observers to select the appropriate decision criterion using the appropriate approach. The shape of the ROC curve can demonstrate whether the two measurement tools used by SDT (d' and Beta) are appropriate or whether others are preferred (Swets, 1977).

Craig (1977) studied and reviewed about 200 individual ROC's obtained from four vigilance experiments. He found that about 50% of the ROC curves were in a form which corresponds to the equal variance SDT prediction. But 30% of the individual ROC's were difficult to explain using SDT. He warned against the uncautious use of d' and Beta as two mesures in vigilance performance. Craig pointed out that SDT may not be appropriate to analyze individual behavior and concluded that SDT assumptions are not met in a typical vigilance task. Warm (1984) joined Craig by stating that "vigilance tasks are not normal psychophysical settings, not settings that SDT was designed to explain" (Warm, 1984 p 41).

In defending SDT, Swets (1977) believes that the assumptions of normal distribution and equal variance are not necessary to use SDT but are only important to calculate d'. Despite this conclusion it is still clear that a cautious use of both d' and Beta is in order.

Despite the critique of the use of SDT, this theory has found its way to many areas of application such as medical diagnosis (Parasuraman, 1980), different studies of memory and detection tasks (Lockhart and Murdock, 1970; Banks, 1970) and more complicated domains such as combat training in military air forces (Eubanks and Killeen, 1983). The theory can be very useful in deciding on the use of appropriate (effective) human engineering principles, such as, training or selection in a specific situation (Parasuraman, 1980). SDT offers many means to analyze performance data which can be summarized as follows: (1) SDT assists in understanding different cognitive mechanisms and other processes of signal detection, discrimination and recognition; (2) it offers a means of measurement and analysis of human performance across a variety of tasks; and (3) describes theoretically how a perfect or ideal detection and discrimination system behaves.

Distinguishing between the two main effects of vigilance performance (perceptual and reponse bias) was indeed a great contribution to the study of sustained attention. Despite the difficulties in applying SDT, use of SDT measures brought much-needed order to the diversity of results in vigilance research. However, in recent years another type of separation was found to be needed--between different components, stimuli and physical attributes that constitute different vigilance tasks. Such a need was the motive behind the creation of classifications of vigilance tasks.

Taxonomy of Sustained Attention

The difficulties encountered by many vigilance researchers in generalizing their findings and results (due to the diversity between the tasks) made the development of a taxonomy of vigilance tasks a necessity. Such a taxonomy would be able to classify different factors affecting vigilance performance in a systematic way that would facilitate the attribution of specific factors to specific effects and consequences in the sustained attention tasks.

A taxonomic analysis is seen to offer at least four important advantages: (1) a better organization of the experimental data into well-defined categories, (2) very systematic comparisons between different variables and therefore different experiments, (3) improvement of the generalization of the results and (4) as a heuristic device for generating hypotheses for further research studies.

Early work on a vigilance taxonomy was carried out by Levine, Romashko and Fleishman (1973). They classified vigilance tasks into two main categories: perceptual speed and flexibility of closure. In perceptual speed, the subject must make a rapid discrimination between a stimulus and a preceding one based on changes made to one of them. In tasks requiring flexibility of closure, the observer must identify a stimulus in a more complex sensory field. These two categories were referred to by Davies and Parasuraman (1982) as successive and simultaneous discrimination, respectively.

A very significant and recent contribution to the study of vigilance is the taxonomic analysis of vigilance tasks by Parasuraman and Davies (1977). They criticized earlier efforts at taxonomies based on ambiguous, broad variables that can not be measured or evaluated, such as the concept of "total stimulation value" (Bergum, 1966) or human performance abilities (Levine et al, 1973). Their main concern was to build a taxonomy that involves well defined, measurable, and objective factors that are constants. They came up with their own taxonomy based on different information processing factors.

After reviewing and comparing many studies and running their own experiments, (Parasuraman and Davies, 1976; 1977; Parasuraman, 1979; Davies and Parasuraman (1982) classified the vigilance task on the basis of five categories: (1) discrimination type (simultaneous or successive) , (2) event rate (high or low), (3) task type (sensory or cognitive), (4) source complexity (single source or multi-source) and, (5) modality type (visual or auditory).

In their taxonomy, Parasuraman and Davies (1977) proposed a classification of the sustained attention task into successive' and simultaneous discrimination. The successive discrimination is specified as the task where the target is detected by comparing it to a change of some characteristics in a stable repetitive non-target which is absent when the target is present. In the simultaneous discrimination, the target is detected in one event, that is in an event that contains noise as well as the signal (Parasuraman, 1984). In the former type of task there is a memory load involved, since the targets and the non-targets are displayed successively. The subject must retain a standard picture of the signal in his/her memory as a reference to make a decision by comparing displayed stimuli to the stored image of the target. In the latter condition (simultaneous), the decision making is based on what is perceived on the display.

Using the different criteria in the taxonomy, Parasuraman (1979) found that vigilance decrement can be due to either a decrement in the observer's perceptual sensitivity or to a change in the response criterion. He reported that the observer's perceptual sensitivity declines under memory load requirements (successive discrimination) and high event rate conditions. The criterion shift causes the vigilance decrement when no memory load is imposed on the observer (as in the simultaneous discrimination task) and when the events are displayed at a slow rate.

As previously mentioned, the classification of vigilance tasks was based on five categories. Parasuraman (1985) suggested that such categorization and discrimination between event rate and target discrimination type, for instance, helps to determine whether the effect on the vigilance task is due to sensitivity (d') or criterion shift (Beta). Parasuraman (1979) found that sensitivity decrement occurs only with successive discrimination at high event rate regardless of the sensory modality used.

Parasuraman, Warm and Dember (1987) discussed and evaluated the utility of the vigilance taxonomy. They demonstrated its importance in narrowing the major gap that exists between different vigilance tasks. For example, in previous research vigilance performance was considered task specific. Using the vigilance taxonomy, it was demonstrated that there is a low but positive correlation between different vigilance tasks. Moreover, that correlation becomes higher when different tasks using the same target discrimination type are compared. Furthermore, Parasuraman et al (1987) showed the importance of this taxonomy in differentiating between a vigilance decrement caused by a decline in the perceptual sensitivity and one resulting from a change in the criterion. Using the taxonomic approach, they also explained the concept of resource demand in vigilance which does not consider vigilance as a simple task, but distinguishes those difficult and resource demanding tasks involving successive discrimination, high event rate, and memory load. Such a taxonomy shows, for instance, that successive tasks are more capacity demanding than simultaneous ones. In summary, the taxonomy analysis has helped to clarify more precisely the effects of different variables on vigilance performance (Parasuraman et al, 1987). It is hoped that a viable theory of vigilance will incorporate features of the taxonomic analysis with the best features of the "traditional" theories discussed earlier.

THE ORIENTING OF ATTENTION AND SUSTAINED ATTENTION

Are Covert Orienting and Vigilance Related?

In this section the focus will be on the new trend of a possible link between the orienting of attention and sustained attention. Concerning this topic, the spotlight will be on two major points of view; Posner et al (1984), and Parasuraman (1985). First, both theories will be discussed and new possibilities will be proposed to explain the possible relation that may exist between the shifting of attention and vigilance.

As discussed previously, Posner et al (1984) tried to explain the role of passive and active processes in selective attention, as an attempt to come up with a framework for investigating sustained attention. Two sets of experiments were used. In the first, a selective attention task was used (a central cue with targets occurring in the periphery). The goal behind this design was to test whether the selectivity to the cued position can be sustained by a passive process. The same type of task and design was used in the second set of experiments. This time both processes (passive and active) were tested (subjects were asked to orient their attention to the cued side and return to the central fixation point, after detection). The critical signal followed either the peripheral cue or the summoning of the subject's attention to the fixation point.

Posner et al concluded that inhibition is caused by repeating the display of the same target in the same location which made it impossible to give good evidence about selectivity. They suggested that sustained attention in which stimuli and responses are presented in blocks was inhibited and facilitated under the same conditions that were involved in the inhibition and facilitation of performance in tasks in which trial-by-trial cues are used.

On the other side, Parasuraman (1985) claimed that the sensitivity decrement over time during sustained attention under a high event rate may be a consequence of time-sharing the vigilance task with other internal or external processes. In other words, sustained attention efficiency decreases as a result of sharing "primary vigilance" with other sources of activating events which arise over time while performing the task. Such other events include distracting extraneous stimuli or internal (covert) processes. Such a time sharing process is not required at low event rates, when the observer can easily process both sources. Parasuraman suggested a close relationship between selective and sustained attention, based on the Posner et al, (1984) findings that gave evidence that sustained attention was changing (in terms of facilitation and inhibition) under the same conditions that facilitate selectivity in the divided attention tasks. This suggestion needs further research and studies to explore that nature of this link between these two aspects of attention.

According to these two points of view, the relation between sustained attention and selective attention is like two different sides of the same phenomenon. A cue that facilitates and inhibits sustained attention actually improves selective attention. The conclusion drawn from the previous comments is that the human subject cannot select the critical signal without being vigilant (sustained attention).

Conversely, one cannot say he is vigilant if he is not aware (selective attention) of the multiple external stimuli that surround him.

If so, would there be any vigilance decrement (followed by selection deficiency) over a relatively long period of time, if the sustained attention task is cued? Does the vigilance decrement function differ for uncued and cued tasks? Does the facilitation or the inhibition of sustained attention improve selective attention? The present study investigated these issues specifically by combining the covert orienting and vigilance paradigms.

Rationale for present study

Paying attention to environmental events is a prerequisite for effective visual functioning. The orienting of attention, or the selection of specific locations in order to detect targets, has been the focus of much recent research (Eriksen and Hoffman, 1972; Posner, 1978; Posner et al, 1980; Posner, 1982). Both benefits (facilitation) and costs (inhibition) of such orienting of attention have been found in these studies (Posner, 1978; 1980). Facilitation occurs when subjects detect more targets with fewer errors and with speeded reaction times (RTs) when attention is directed to a spatial location by a cue (valid cue) (Maylor and Hockey, 1985). However when an invalid cue is presented (i.e. the cue points to location other than where stimulus occurs), subjects make more errors and have delayed RTs. Posner (1980) pointed out that the inhibitory effect occurs when the time interval between the cue and the target event (stimulus-onset asynchrony:SOA) is long, resulting in the subjects' attention being summoned to the opposite side of the cued area. The inhibitory effect was defined as the failure of subjects to respond quickly to a stimulus occurring in the position indicated by the orienting cue (Maylor et al, 1985). Other studies confirm the fact that this inhibition does not occur until at least 200-300 msec after the display of the cue (Posner, 1980; Tsal, 1983; Posner and Cohen, 1982; Maylor, 1985).

Previous studies of the orienting of attention have investigated facilitatory and inhibitory effects over relatively short periods of time, namely 1-2 seconds. It would be of interest to examine such effects for longer time periods, and more specifically investigate the relationship of orienting of attention to detection performance in long-term tasks, such as vigilance or sustained attention tasks. It has been concluded that the most rapid decrements over time in sustained attention occur under the same conditions that facilitate selectivity in short-term divided attention tasks (Parasuraman, 1985), namely under a high event rate (short interstimulus interval). Moreover, the deallocation of attention (which is the effect caused by the invalid cues) has been found to have an arousing effect (stimulation of attention) on the subjects' performance because of unexpected movements of attention to the uncued area (Tsal, 1983). The taxonomy of vigilance (Parasuraman, 1985) offered evidence that an increase in the number of events that are displayed causes sensitivity decrement over time in vigilance tasks. On the other hand, Posner (1978) attributed such decrement to an inhibitory effect. One major goal of the present study was to test these competing claims by combining the vigilance and covert-orienting paradigms in which they had been previously proposed.

Another important finding in the study of orienting of attention is that subjects become faster in responding to the target as the Stimulus Onset Asynchrony (SOA) increases (Tsal, 1983; Remington and Pierce, 1984). As the time interval (SOA) between the visual cue and the target increases, subjects will have more time to concentrate on the target location and therefore more time to focus on the target for a better detection. The facilitation and inhibition caused by different conditions of precueing have been discussed in terms of RT to the stimulus. A close look at the effect of these two aspects of attention task (inhibition and facilitation) on detection sensitivity in a vigilance situation formed another goal of the present study.

Hypotheses and predictions

Four major hypotheses were proposed. First, it was hypothesized that valid cues would enhance sensitivity and invalid cues would decrease sensitivity. This follows from the large number of orienting studies previously reviewed, all of which, however, examined short-duration (selective attention) tasks. The present study investigated whether the facilitatory and inhibitory effects of cues are also found in long-duration vigilance tasks.

The second hypothesis tested appears at first sight counter-intuitive, but follows directly from the inhibition theory proposed by Posner et al, (1984). This theory proposes that an inhibitory process develops at a cued location if a target does not appear at that location within a certain period of time (300 msec). Such inhibition is dissipated by an invalid cue that moves attention to another location. Posner suggested that the accumulation of inhibition over long periods of time in a vigilance task may be responsible for the decrement. This leads to the interesting prediction that in a cued vigilance task, greater decrement over time should occur for validly cued targets than for invalidly cued targets (even though overall detection performance is higher for validly cued targets). The proposal that invalid cues have an arousing effect because they involve re-summoning of attention (Tsal, 1983) is also consistent with this prediction. On the other hand, the taxonomic analysis of Parasuraman (1985) predicts a vigilance decrement at high event rates only, irrespective of whether targets are cued or not. The present study tested these competing predictions by comparing vigilance decrement (in sensitivity) for valid and invalid cues at low and high event rates.

The third hypothesis tested concerned the effects of SOA on the above predictions. Detection performance was predicted to be greater as SOA increases from short (150 msec) to medium (350 msec) to long (550 msec). This follows from the previous studies on selective attention, and the present study thus investigated whether it extends to long-duration sustained attention tasks.

Finally, it was predicted that the vigilance decrement would be greater for validly cued than for invalidly cued targets at the medium and long SOAs (for which inhibition develops) but not at the short SOA (for which there is insufficient time for inhibition to develop). This prediction follows from Posner et al, (1984) as discussed above. The null hypothesis, that vigilance decrement is unaffected by cue-target SOA, is consistent with Parasuraman, (1985).

Two experiments using a cued vigilance task were carried out to test these hypotheses.

CHAPTER II

METHOD

Subjects

Subjects consisted of forty students from The Catholic University of America who participated to fulfill a requirement for their introductory psychology course. The forty subjects were randomly assigned to two groups of 20 persons in each event rate condition (high and low event rates). There were 10 males and 30 females. Their ages varied between 18 to 29 years. All subjects had normal (20/20) or corrected-to-normal vision. To avoid any previous learning effect, all participants had never been subjects in similar experiments before. All subjects indicated that they were not taking medications that might affect their level of arousal.

Design

A 2 X 2 X 3 (event rate X cue validity X time period) factorial design was employed with repeated measures on the last two factors. Two different event rates were employed: 30 and 15 events per minute for high and low event rate respectively. Cues were of two types: valid (representing 80% of the overall cues) and invalid cues (representing the remaining 20%). The time periods factor consisted of the three 10-minute blocks within each 30-minute vigilance session.

Apparatus

The stimuli in this study were of two kinds: the signal and the non-signal (which were both squares differing in size) and the cue (which was an arrow oriented to the left or the right side). These stimuli were displayed on an IBM XT computer monitor. One square at a time was displayed either on the right or the left side of the center. Each square measured 3 cm2 for non-targets and measured 2.98 cm2 for targets. Thus, the subject's task was to discriminate a decrease in the size (area) of a square stimulus. The arrow was displayed centrally.

The main vigilance task lasted 30 minutes and consisted of three blocks of trials of 300 events at the high event rate or 150 at the low event rate for each 10-minute block. Subjects were instructed to fixate the center of the computer screen. The trials began with a 150 msec display of the cue in the center of the monitor. A stimulus (a square) was presented 6 degrees to the right or the left side of the monitor 350 msec after the arrow display. The subjects were asked to respond as quickly as possible by pressing the space bar whenever they detected a target. Targets occurred randomly with a probability of 0.2 (20%). The distance between each square and the arrow was 5 cm. The arrow pointed to either the left or the right side of the screen.

The trial began by displaying the cue. The cue indicated that the stimulus, if it occurred, would be displayed in the direction of the arrow 80% of the time. Using these cues (right and left), detection rate data (hits and false alarms rates) were obtained at two levels of the validity factor, valid and invalid. The probability of the occurrence of a target was held constant at 0.2 (20%). The factors that were manipulated were event rate and validity of the cue.

Procedure

After being introduced to the lab, the subjects had their vision checked by using a Snellen eye chart. After that, subjects read a brief description of the study and its purposes (see appendix A), after which they were required to read a consent form (see appendix B) and sign it if they agreed to be part of the experiment. They were also asked to fill out the Cognitive Science Laboratories of the Catholic University of America Biographical Questionnaire (see appendix C). Subjects then entered the experiment room where they sat in front of an IBM PC monitor. Written instructions on the screen reinforced by verbal clarifications from the experimenter explained in detail the different sessions of the experiment and described the general procedure to be followed while completing the task. Subjects were given time to ask any further questions about the experiment and they were assured that at no point would any type of discomfort or deception be part of the experiment.

Each subject participated in two sessions of which the first was a practice session. The practice session consisted of one block of 75 trials for low event rate and 150 trials for the high event rate. When finished with the practice task, the subjects were shown their results and were given feedback regarding their performance. The subjects were then introduced to the main task which consisted of 150 trials in each 10-minute block for the low event rate and 300 events in each 10-minute block for the high event rate.

Subjects were instructed to attempt to maximize their hit rate and to minimize their false alarm rate. Before participating in the main task, subjects had to reach a minimal score of at least 80% detection rate and less than 40% false alarm rate in their practice sessions. Subjects who could not meet this criterion (they were two) were not included in the experiment.

Measures

Percentages of correct and incorrect responses were collected to calculate hits and false alarms for each 10-minute block for each subject. The performance measures hits, false alarms, the sensitivity index d' and the criterion index C were used. The criterion measure Beta was not used because of its variability in low-probability vigilance tasks (Davies and Parasuraman, 1982). The index C is defined as the distance of the criterion cut-off from the equal-bias point in the signal detection model. Snodgrass and Corwin (1988) have shown that C is superior to Beta in that it is orthogonal to d', whereas Beta is not.

CHAPTER III

EXPERIMENT I

Results

Hit rates

The hit rate means for both event rate groups are shown in Table (1) as a function of cue validity and time period. A 2x2x3 (event rate x cue validity x time period) analysis of variance (Anova) was applied to the hit rate data with repeated measures on the two last factors. The Anova showed a main effect of event rate significant at $F(1,38)=10.89$, $p <.005$. This effect was due to the higher hit rate scores at low event rate than at the high event rate. The main effect for time period was also significant at $F(2,76)=10.45$, $p <.0001$, indicating that the hit rate decreased over blocks under all conditions. No other sources of variance were significant. The Anova results are shown in Table 2.

Figure 1 shows the mean hit rate as a function of time period at the high event rate for valid and invalid cues. Figure 2 shows the corresponding functions at the low event rate. This figure (2) shows that hit rate was somewhat higher for the valid cues than for the invalid cues. However, the main effect of cue validity was not significant (see Table 2). Furthermore, although there was a greater decline in hits over blocks (greater vigilance decrement) for valid cues than for invalid cues, particularly at the low event rate (see Figure 2), these differential trends were not significant. Moreover, the two figures show that overall detection scores were higher at low than at high event rate. But as can be seen, a detection decrement occurred at both event rates for valid and invalid cues.

Table (1)
Mean hit rates for successive 10-minute blocks for high and low event rates (valid and invalid cues).

	Valid Blocks				Invalid Blocks			
ER	1	2	3	Mean	1	2	3	Mean
High	90.75	85.37	81.62	85.91	90.00	84.25	83.50	85.91
Low	97.75	96.00	93.50	97.75	97.00	92.50	93.50	95.04

Table 2

Summary of Analysis of Variance
for hit rate.

Source	SS	df	MS	F	
Between Subjects		38			
Event Rate (ER)	4995.94	1	4995.94	10.89	*
Error	17428.13	38	458.63		
Within Subjects		76			
Cue Validity (CV)	30.10	1	30.10	.83	
ER X CV	30.10	1	30.10	.83	
Error	1377.29	38	36.24		
Time Period (TP)	1473.80	2	736.90	10.45	**
ER X TP	157.97	2	78.98	01.12	
Error	5357.81	76	70.50		
CV X TP	105.68	2	52.84	01.76	
ER X CV X TP	15.68	2	7.84	.26	
Error	2284.90	76	30.06		
TOTAL		114			

* P< .005

** P< .0001

FIG 1: HIT RATES AS A FUNCTION OF CUES AND TIME PERIOD AT THE HIGH EVENT RATE

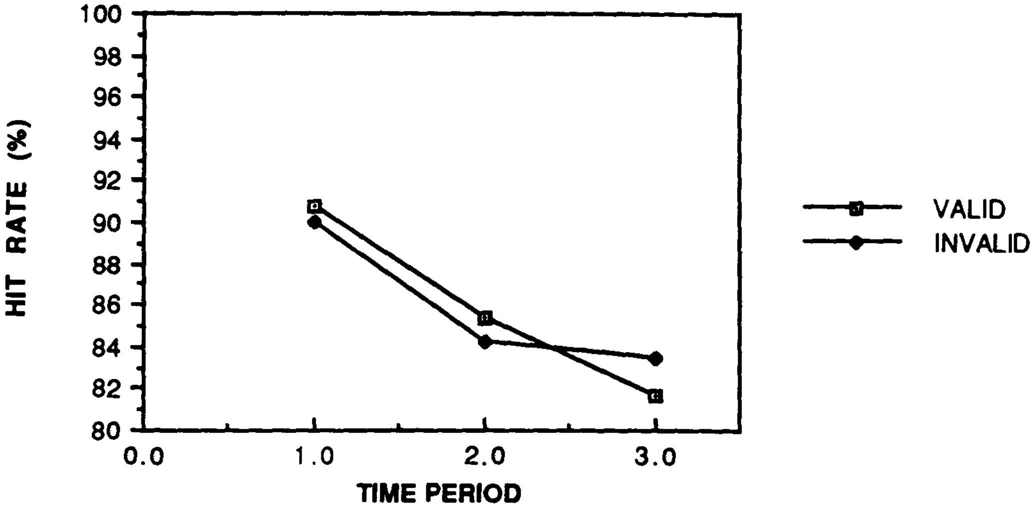
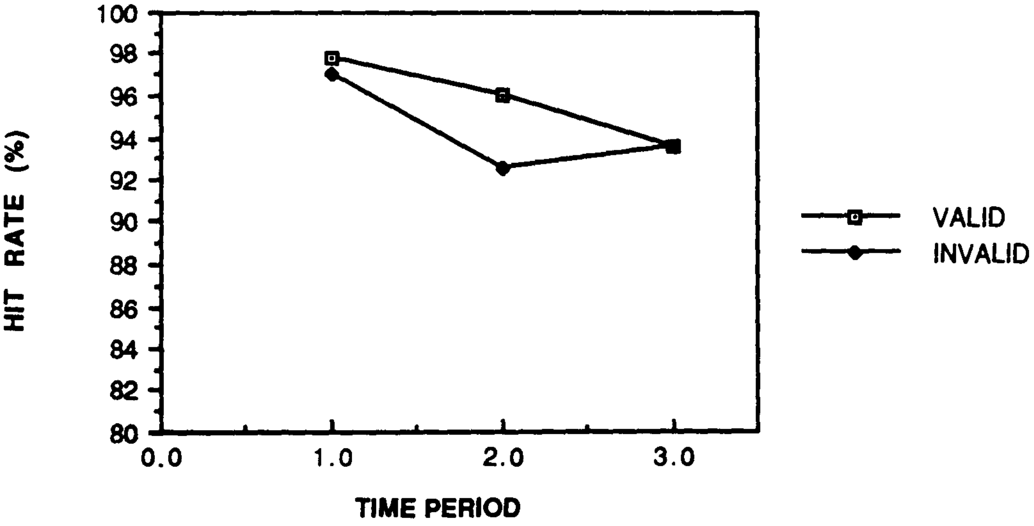


FIG 2: HIT RATES AS A FUNCTION OF CUES AND TIME PERIOD AT THE LOW EVENT RATE.



False alarm rates

The mean false alarm rates are shown in Table 3. A 2x2x3 (event rate x cue validity x time period) analysis of variance was applied to these scores. The interaction of event rate x cue validity x time period was significant at F(2,76)=4.19, p <.05. All other sources of variance were not significant (see Table 4). The interaction probably reflects two facts: First, there was a larger decrease in false alarm rate over time at the low event rate than at the high event rate. Second, there were fewer false alarms over time with invalid cues than with valid cues in the low event rate condition (see figure 4), but not in the high event rate condition (see Figure 3).

Simple effect analyses of cue validity and of time period for each event rate separately confirmed these impressions. No significant effect of cue validity or time period was found for the high event rate condition. In other words, there was no significant difference in false alarm rates between valid and invalid cues, and the false alarm rate did not change significantly over time. On the other hand, a significant effect of time period at F(2,38)=3.53, p< .05 was found at the low event rate, indicating a significant decrease in false alarm rate over time. A significant interaction of cue validity x time period was also found for the low event rate at F(2,38)=3.27, p < .05. This interaction indicates that there was a greater decrement of false alarms over time with invalid cues than with valid cues in the low event rate condition.

The event rate x cue validity x time period interaction is presented in Figures 3 and 4. False alarm rates are plotted as a function of event rate, cue validity and time period. It is apparent from Figure 4 that invalid cues under the low event rate showed the greatest decline of false alarms over time, while figure 3 shows that

Table (3)

Mean False alarms for successive 10-minute blocks for high and low event rate (valid vs invalid).

	Valid				Invalid			
	Blocks				Blocks			
ER	1	2	3	Mean	1	2	3	Mean
High	9.14	8.42	8.63	8.73	8.52	7.90	9.39	8.60
Low	11.77	9.33	9.52	10.20	12.75	11.62	7.00	10.45

Table 4
Summary of Analysis of Variance
for false alarm rate.

Source	SS	df	MS	F
Between Subjects		38		
Event Rate (ER)	166.40	1	166.40	.28
Error	22199.52	38	584.20	
Within Subjects		76		
Cue Validity (CV)	.23	1	.23	.01
ER X CV	2.08	1	2.08	.12
Error	673.33	38	17.72	
Time Period (TP)	149.94	2	74.97	1.65
ER X TP	187.78	2	93.89	2.07
Error	3450.33	76	45.40	
CV X TP	31.54	2	15.77	1.27
ER X CV X TP	103.98	2	51.99	4.19 *
Error	942.80	76	12.41	
TOTAL		114		

* $P < .025$

FIG 3: FALSE ALARMS AS A FUNCTION OF CUES AND TIME PERIOD AT THE HIGH EVENT RATE.

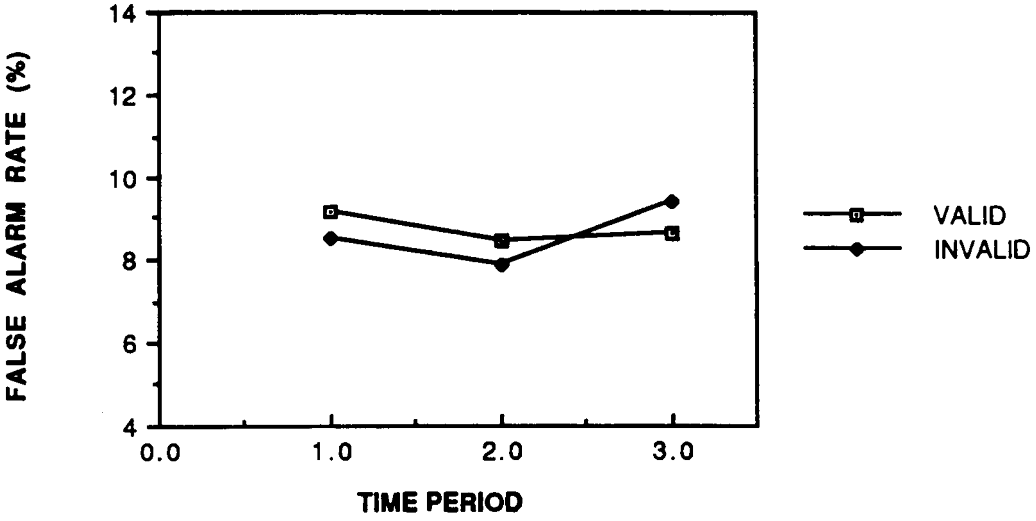
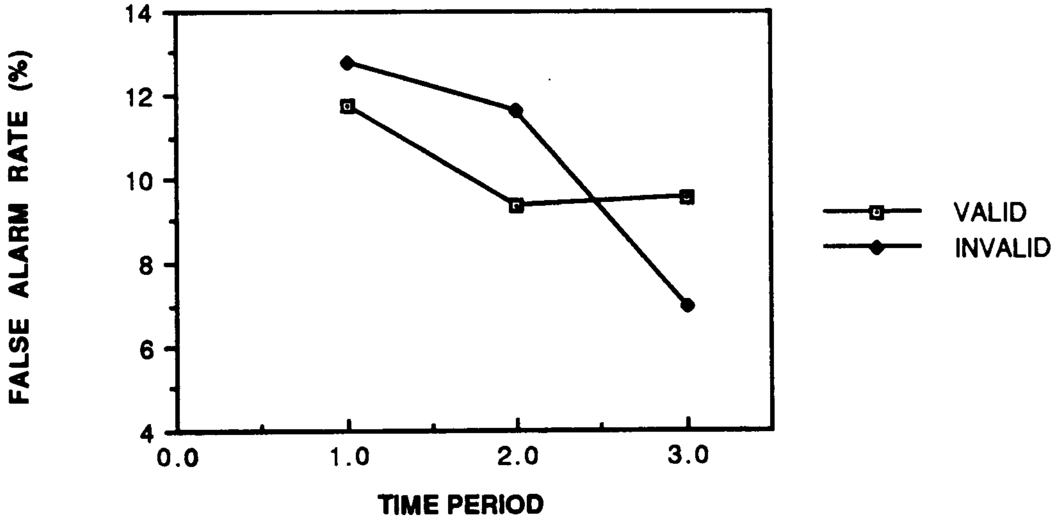


FIG 4: FALSE ALARMS AS A FUNCTION OF CUES AND TIME PERIOD AT THE LOW EVENT RATE



there was an increment over time for false alarms for invalid cues for the high event rate. All valid cues showed decrement over time, but there was more decrement of invalid cues at low event rate than at high event rate. Given that a decrement in false alarm rate over time is indicative of improved performance, the results indicated that targets preceeded by invalid cues showed greater performance improvement over time than validly-cued targets.

Sensitivity (d')

The same 2 X 2 X 3 (Event rate X Cue validity X Time period) ANOVA was applied to d' scores. The d' means for both event rates are shown in Table 8 as function of cue validity and time period. The ANOVA of the d' scores revealed a significant main effect of cue validity at F(1,38)=16.31, p <.0001. This main effect was due to the fact that there were higher sensitivity scores with valid than with invalid cues. The ANOVA also showed a significant interaction of event rate by cue validity at F(1,38)=5.53, p <.05. This finding indicated that there were higher sensitivity scores for valid than for invalid cues at the low event rate, while there was almost no difference between valid and invalid conditions at the high event rate. A marginally significant interaction of event rate by time period was found at F(2,76)=2.75, p <. 070. This result reflected the presence of a larger decrement over time at the high event rate than at the low event rate. Finally, the interaction of cue validity by time period was significant at F(2,76)=3.21, p <.05. This finding indicated the presence of greater decrement over time with valid than with invalid cues. No other effect was significant. The ANOVA summary results for d' is presented in Table (9).

Figure 5 shows sensitivity scores as a function of cue validity and time period in the high event rate condition. Sensitivity was

Table (8)

Sensitivity (d') means for successive 10-minute blocks for high and low event rate (valid vs invalid).

	Valid				Invalid			
	Blocks				Blocks			
ER	1	2	3	Mean	1	2	3	Mean
High	3.10	2.88	2.71	2.89	2.95	2.77	2.71	2.81
Low	3.16	3.13	3.07	3.12	2.75	2.67	2.95	2.79
				3.00				2.80

Table 9

Summary of Analysis of Variance for d' scores (Sensitivity).

Source	SS	df	MS	F	
Between Subjects		38			
Event Rate (ER)	.62	1	0.62	0.21	
Error	110.68	38	2.91		
Within Subjects		76			
Cue Validity (CV)	2.65	1	2.65	16.31	*
ER X CV	.90	1	0.90	5.53	**
Error	6.17	38	16		
Time Period (TP)	.91	2	0.46	1.85	
ER X TP	1.36	2	0.68	2.75	***
Error	18.74	76	.25		
CV X TP	.63	2	0.31	3.21	**
ER X CV X TP	.15	2	0.08	0.77	
Error	7.46	76	.10		
TOTAL		114			

* P< .0001

** P< .05

*** p< .070

FIG 5: d' SCORES AS A FUNCTION OF CUES AND TIME PERIOD AT THE HIGH EVENT RATE.

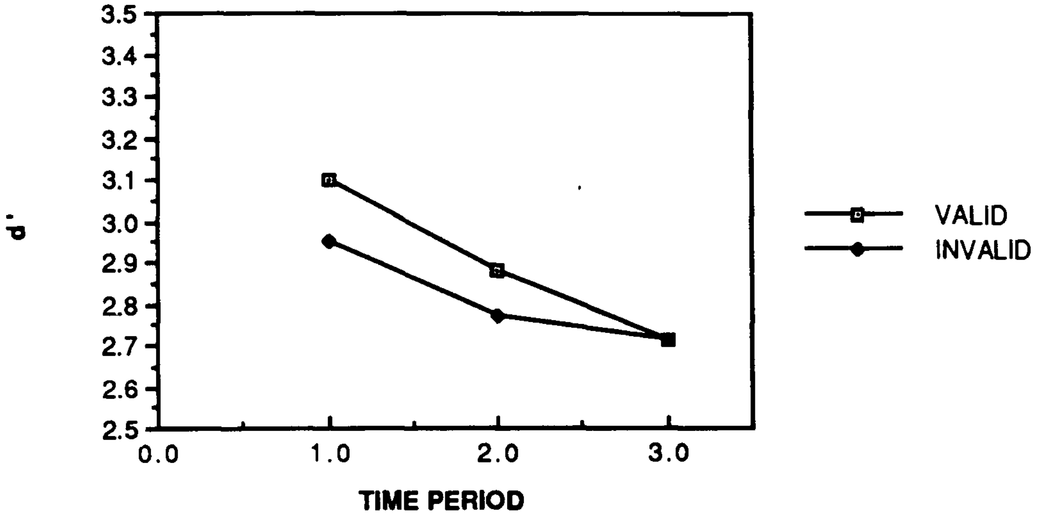


FIG 6: d' SCORES AS A FUNCTION OF CUES AND TIME PERIOD AT THE LOW EVENT RATE.

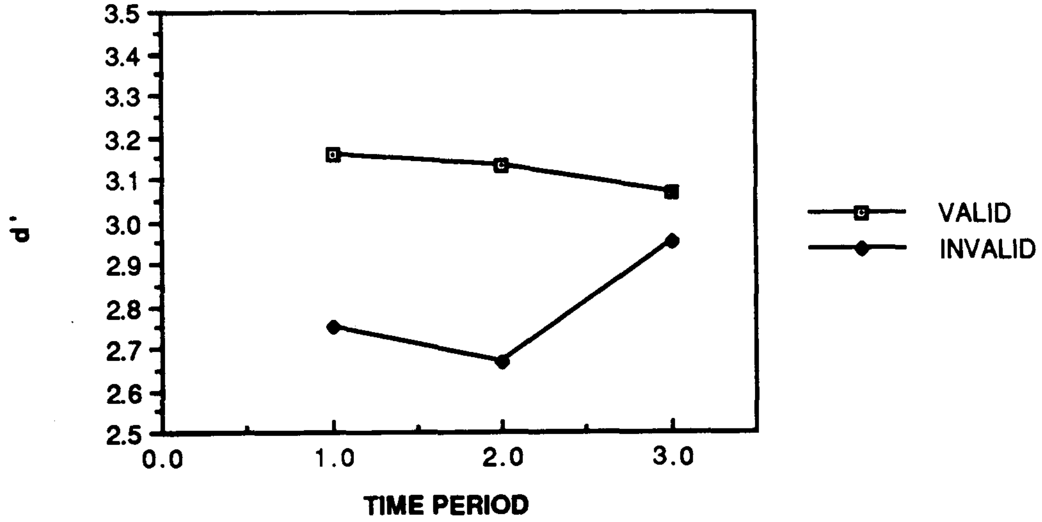


FIG 7: d' SCORES AS A FUNCTION OF EVENT RATE AND CUE VALIDITY.

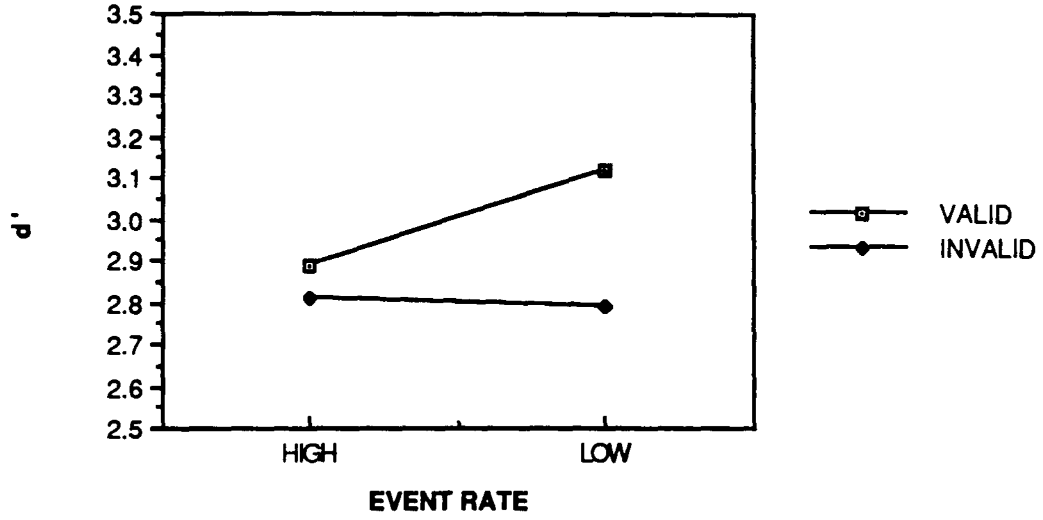
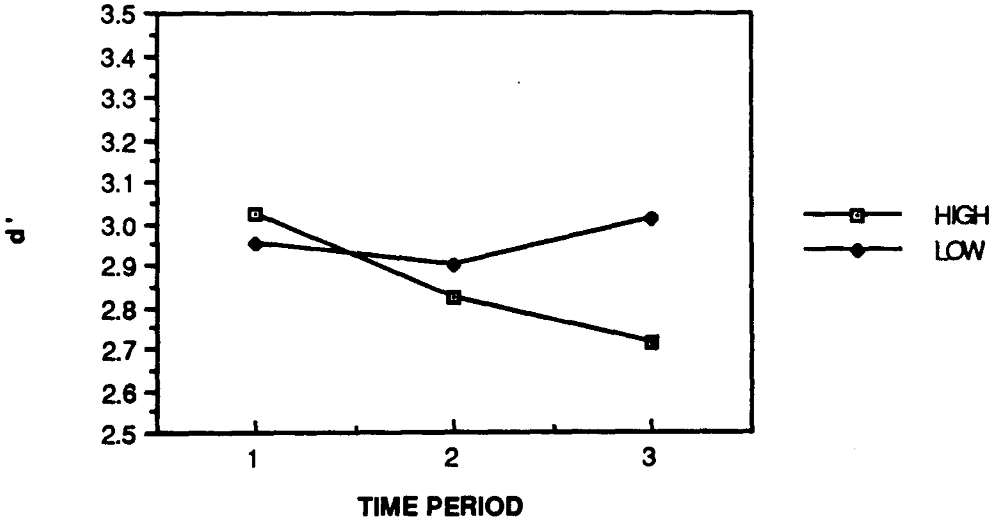


FIG 8: d' SCORES AS A FUNCTION OF TIME PERIOD AND EVENT RATE.



approximately equivalent for valid and invalid cues. Furthermore, sensitivity decreased over blocks for both valid and invalid cues. Figure 6 displays d' scores as a function of cue validity and time period in the low event rate condition. In this case sensitivity was higher for valid than for invalid cues. However, whereas sensitivity decreased slightly for valid cues, it increased over blocks for the invalid cues.

The event rate by cue validity interaction is displayed in Figure 7. Mean d' scores are plotted as a function of event rate and cue validity. Figure 7 clearly shows that under valid cue conditions performance was higher at the low than at the high event rate, whereas under invalid cues performance remained relatively the same at both event rates. Figure 7 also shows that d' values with valid cues were higher than those with invalid cues, but the cue validity effect was greater for the low than for the high event rate.

Figure 8 shows the event rate by time period interaction. The d' scores are plotted as a function of event rate and time period. The figure indicates that there was a sensitivity decrement over time at high event rate, whereas sensitivity remained stable at the low event rate.

Criterion (C)

The C scores were analyzed using a 2X2X3 (event rate X cue validityX time period). The analysis showed that there was main effect of time period which was significant at $F(2,76)=12.92$, $p< .0001$. This finding indicated that C increased over time for all groups. Other sources of variance were not significant. Hence the effects of cues on performance were indicated by changes in sensitivity and not in criterion. The C scores and the summary of the analysis of variance are shown in Tables 12 and 13 respectively.

Table (12)
Criterion measure (C) means for successive 10-minute blocks for high and low event rate (valid vs invalid).

	Valid				Invalid			
	Blocks				Blocks			
ER	1	2	3	Mean	1	2	3	Mean
High	0.04	0.19	0.29	0.17	0.15	0.26	0.26	0.23
Low	-0.13	-0.03	0.06	-0.03	-0.05	0.05	0.15	0.51

Table (13)

Summary of Analysis of Variance for C scores (Criterion).

Source	SS	df	MS	F
Between Subjects		38		
Event Rate (ER)	2.30	1	2.30	3.53
Error	24.78	38	0.65	
Within Subjects		76		
Cue Validity (CV)	0.30	1	0.30	4.84
ER X CV	0.02	1	0.02	0.58
Error	2.35	38	0.06	
Time Period (TP)	1.51	2	0.76	12.92 *
ER X TP	0.02	2	0.01	0.21
Error	4.44	76	0.06	
CV X TP	0.05	2	0.03	0.66
ER X CV X TP	0.06	2	0.03	0.78
Error	2.99	76	0.04	
TOTAL		114		

* $P < .0001$

Additional Analyses

Decrement Analyses

A hit rate, false alarm and d' decrement analysis was used to obtain a more detailed picture of the vigilance decrement (C was not analyzed because of the lack of significant effects for this measure. Table 6 shows means of hit rate decrement scores for both event rates as function of cue validity. A negative score indicates a vigilance decrement over time, while positive scores indicate the presence of an increment in the vigilance performance over time. These scores were obtained by subtracting the hit rate score of the first time block from the hit rate score of the last time block. A 2x2 (event rate x cue validity) Anova was conducted with repeated measures on the last factor. The analysis of hit rate decrement data revealed no significant effect or interaction.

Table 5 shows the means of the false alarm decrement scores. The same decrement analysis as the one applied to hit rate was applied to false alarm rate. The analysis showed a marginal main effect of event rate which was significant at $F(1,38)=2.41$, $p<.097$. That is, there was more false alarm decrement at the low than at the high event rate. The analysis also revealed a significant interaction of event rate by cue validity, which was significant at $F(1,38)=3.92$, $P< .05$. This interaction is explained by the fact that there was more decrement in false alarm rate over time with invalid cues than with valid cues at low event rate, while there was more false alarms decrement over time with valid than invalid cues at high event rate. The ANOVA summary results of false alarm decrement means are shown in Table 7.

The d' decrement scores were also submitted to the same

Table (6)

Mean hit rates decrement for successive 10-minute blocks for high and low event rate (valid vs invalid).

Event Rate	Valid	Invalid	Mean
High	- 09.12	- 06.50	- 07.81
Low	- 04.25	- 03.50	- 03.87
Mean	- 06.68	- 05.00	

Table (5)

Mean false alarm rates decrement for successive 10-minute blocks for high and low event rate (valid vs invalid).

Event Rate	Valid	Invalid	Mean
High	- 00.51	00.87	00.18
Low	- 02.21	- 05.75	- 03.98
Mean	- 01.36	- 02.43	

Table (7)

Summary of Analysis of Variance for false alarm decrement scores.

Source	SS	df	MS	F
Between Subjects		38		
Event Rate (ER)	346.69	1	346.69	2.89 *
Error	4551.39	38	119.77	
Within Subjects		38		
Cue Validity (CV)	23.05	1	23.05	0.75
ER X CV	121.18	1	121.18	3.92 **
Error	1174.72	38	30.91	
TOTAL		76		

* P< .097

** P< .050

analyses. Table 10 presents the d' decrement scores. Analyzing the d' decrement scores, a main effect of event rate was significant at $F(1,38)=1.87$, $p < .05$. This finding indicated that there was more sensitivity decrement at the high than at the low event rate. The analysis of the d' decrement scores revealed a significant main effect of cue validity at $F(1,38)=3.91$, $p < .05$. This result reflected the greater sensitivity decrement that was found with valid than with invalid cues. The ANOVA summary results for d' decrement scores are presented in Table 11.

Table (10)
Means of d' decrement scores for successive 10-minute blocks for high and low event rate (valid vs invalid).

Event Rate	Valid	Invalid	Mean
High	-0.39	-0.24	-0.31
Low	-0.08	0.19	0.11
Mean	-0.23	-0.05	

Table (11)
Summary of Analysis of Variance
for d' decrement means.

Source	SS	df	MS	F
Between Subjects		38		
Event Rate (ER)	2.81	1	2.81	3.79 *
Error	28.13	38	.74	
Within Subjects		38		
Cue Validity (CV)	.89	1	0.89	3.91 *
ER X CV	.09	1	0.09	0.37
Error	8.66	38	.23	
TOTAL		76		

* P< .050

The results of these decrement analyses are generally in agreement with the interpretations of the interactions involving time period in the ANOVAS presented previously.

Data transformation analysis

After reviewing performance scores, it was suggested that using transformed data may help to stabilize large variances within groups. For this purpose an arcsine transformation was applied to hit rates, false alarm rates, d', and C scores. The Same factorial design (i.e event rate X cue validity X time period) was used to analyze this transformed data. The analyses of variance of the transformed data revealed the same significant effects and interactions that were found previously with hit rates, false alarms, d', and C scores.

Practice data analyses

To analyze the practice data, a 2x2 (cue validity x event rate) analysis of variance was applied to hit rate scores. The factor of cue validity was repeated within subjects. The analysis showed a main effect of cue validity that was significant at $F(2,38)=5.17$, $p < .05$. This effect was due to higher hit rates with valid cues than with invalid cues. Submitting the false alarm data of the practice session to a 2x2 (cue validity x event rate) analysis of variance, a main effect of event rate was significant at $F(2,38)=5.07$, $p < .05$. This main effect indicated the presence of higher false alarm rate in low event rate than in high event rate. Another main effect of cue validity was found significant at $F(2,38)=4.37$, $p < .05$. This result showed greater false alarm rate with valid than with invalid cues. Applying the 2 X 2 (cue validity X event rate) analysis of variance to d' practice scores, a significant main effect of event rate was found at $F(1,38)= 7.64$, $p <.0010$. This showed the presence of higher sensitivity scores at high event rate than at low event rate. The d' ANOVA revealed a significant main effect of cue validity at $F(1,38)=4.50$, $p <.05$. This finding reflected higher d' scores with valid than with invalid cues. The event rate X cue validity two way interaction approached but did not achieve significance ($p < .105$). Other findings were not significant.

Summary of Major Results of Experiment 1

Applying ANOVA to different vigilance performance measures (hit rates, false alarms, d' and C), a number of effects, main and interactive, were found. Analyzing hit rate scores, a main effect of event rate was found significant. This effect revealed the fact of higher detection performance at low than at high event rate. Another main effect of time period was also significant indicating a decrement over time under all conditions. Although there was a trend for the hit rate decrement to differ for valid and invalid cues the cue validity by time period interaction was not significant.

Processing false alarm scores, a three-way interaction of event rate by cue validity by time period was observed. This interaction was caused by greater decrement of false alarms over time at low than at high event rate. The interaction also indicated the occurrence of fewer false alarms over time with invalid than with valid cues at the low event rate only.

The d' analyses showed two significant interactions, event rate by cue validity, and cue validity by time period, while a third interaction was marginally significant (event rate by time period). The event rate by cue validity interaction indicated that there were higher sensitivity scores with valid than with invalid cues at low event rate, but almost no difference was observed between the two cue types at high event rate. The cue by time period interaction resulted from greater decrement over time with valid than with invalid cues. Finally, the marginally significant event rate by time period interaction reflected the larger sensitivity decrement over time that occurred at high than at low event rate. No other sources of variance were significant.

The data analysis of the Criterion (C) showed a main effect of time period indicating an increase for C values in all conditions.

The findings of Experiment 1 provide partial support for the first and the second hypotheses made at the beginning of this study. First it was shown that valid cues enhanced sensitivity (d') and that invalid cues lowered sensitivity (hypothesis 1). Also greater sensitivity decrement was found with validly cued targets than with invalidly cued ones (hypothesis 2), where in fact, an increment in d' was found in the low event rate condition. The occurrence of an increment in sensitivity with invalid cues at low event rate is a highly interesting and unusual finding in vigilance and hence needs to be replicated. However, hypotheses 1 and 2 were only partially supported in the sense that these findings were restricted to the low event rate condition. Thus the dissipation of inhibition theory following from Posner et al (1984) was supported at the low event rate. At the high event rate, no cue validity effects were found, and sensitivity declined over time for both validly and invalidly cued targets, supporting Parasuraman (1985). The third and the fourth hypotheses were the focus of a second experiment.

CHAPTER IV

EXPERIMENT 2

A second experiment was conducted to determine the effect of stimulus onset asynchrony (SOA), the time interval between the cue and the stimulus, on cued and uncued detection performance in a vigilance situation. Experiment 2 was a replication of Experiment 1, with two exceptions: (1) only the low event rate was used, since Experiment 1 showed that cue validity effects were maximized at low event rate; and (2) three different SOAs were used in different groups.

Method

Forty five subjects, 15 males and 30 females, participated in this experiment to fulfill a requirement for their introductory psychology course at the Catholic University of America. The forty five subjects were randomly assigned to three different SOA groups: long SOA (550 msec), average SOA (350 msec) and short SOA (150 msec). Subjects in this experiment did not participate in the first experiment or any prior study of a similar nature. The procedure and the apparatus were exactly the same as in Experiment 1 with the exception of the variation across groups in time interval between the cue and the stimulus. The design in Experiment 2 was a 3 X 2 X 3 (SOA X cue validity X time period) with repeated measures on the last two factors.

Results

Hit <u>rates</u>

Table 14 shows hit rate means for each SOA group. Hit rate means for each group were submitted to 3 X 2 X 3 (SOA X cue validity X time

Table (14)

Mean hit rates for successive 10-minute blocks for short, average and long SOA (valid and invalid cues).

	Valid				Invalid			
	Blocks				Blocks			
	1	2	3	Mean	1	2	3	Mean
SOA								
150 msec	97.33	91.00	86.33	91.55	97.33	87.33	86.66	90.44
350 msec	98.00	98.00	95.33	97.11	98.00	95.33	95.33	96.22
550 msec	95.66	91.33	90.00	92.33	96.66	94.00	84.00	91.55

period) analysis of variance. The analysis revealed a significant main effect of time period at F(2,84)=13.92, $p < .0001$. The main effect was an indication of performance decrement over time for all SOA groups under both cue validity conditions. Other results were not significant. **ANOVA** results are shown in Table 15. Figures 9, 10 and 11 show hit rate scores as a function of time period and **SOA** intervals at 150, 350 and 550 msec **SOA** respectively. It is clear from the figures that the hit rate decreased over time regardless of different **SOA** intervals or cue validity types. **As** in Experiment 1, the hit rate for valid cues was slightly but not significantly greater than for invalid cues.

False alarm rates

The false alarm data was also submitted to the same 3 X 2 X 3 **ANOVA.** The analysis showed a significant main effect of time period at F(2,84)=5.01 $p <.001$. This finding indicates a false alarm decrement over time that occurred in all three groups under all cue conditions. Mean false alarm rates are displayed for each condition and time period in Table 16. Other sources of variance were not significant. The ANOVA results are shown in Table 17.

Sensitivity (d')

The same 3 X 2 X 3 **(SOA X** cue validity X time period) analysis of variance was used for sensitivity scores. The analysis showed a significant main effect of cue validity at F(1,42)=36.59, $P < .0001$ showing higher scores with valid than invalid cues under all conditions. The sensitivity means are showed in Table 18. **A** more interesting finding was the three-way interaction of **SOA** by cue validity by time period which was marginally significant at F(4,84)=2.40, $p < .057$. This interaction indicated that there was more decrement over time with short **SOA** than with long **SOA** under invalid cues. There was a slight increment with average **SOA.** The interaction also revealed that there was

Table (15)

Summary of Analysis of Variance
for hit rates.

Source	SS	df	MS	F
Between Subjects		42		
SOA	1659.07	2	829.54	1.77
Error	19698.89	42	469.02	
Within Subjects		84		
Cue Validity (CV)	57.87	1	57.87	1.55
SOA X CV	1.30	2	.65	.02
Error	1570.00	42	37.38	
Time Period (TP)	2587.41	2	1293.70	13.92 *
SOA X TP	714.81	4	178.70	1.92
Error	7806.11	84	92.93	
CV X TP	58.52	2	29.26	0.51
SOA X CV X TP	368.15	4	92.04	1.62
Error	4781.67	84	56.92	
TOTAL		126		

* P< .0001

FIG 9: HIT RATES AS A FUNCTION OF TIME PERIOD AT 150 msec SOA.

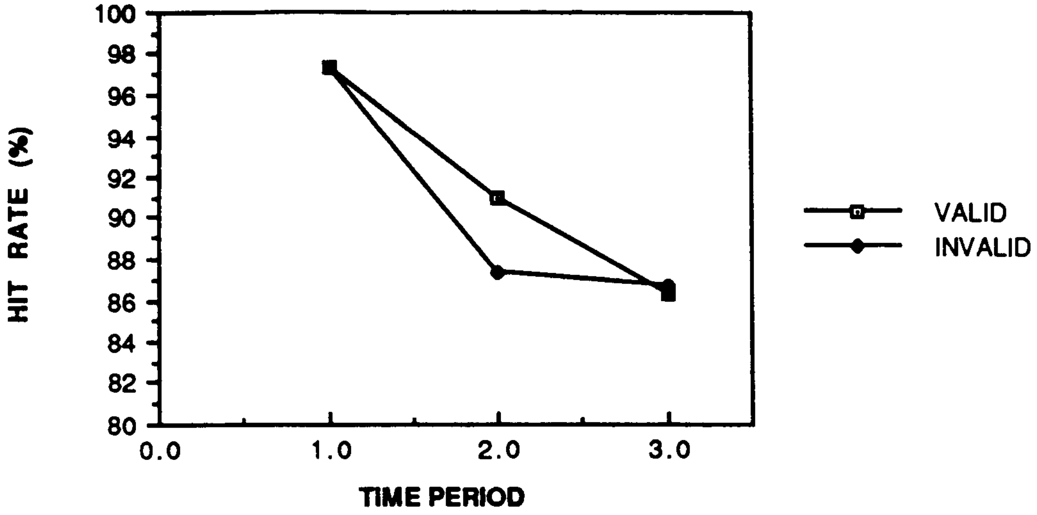


FIG 10: HIT RATES AS A FUNCTION OF CUES AND TIME PERIOD AT 350 msec SOA.

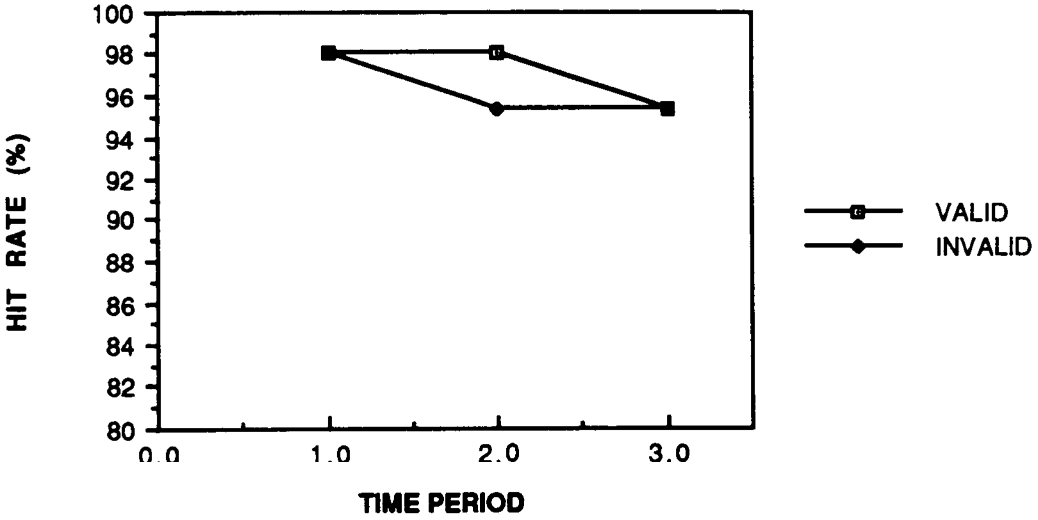


FIG 11: HIT RATES AS A FUNCTION OF CUES AND TIME PERIOD AT 550 msec SOA.

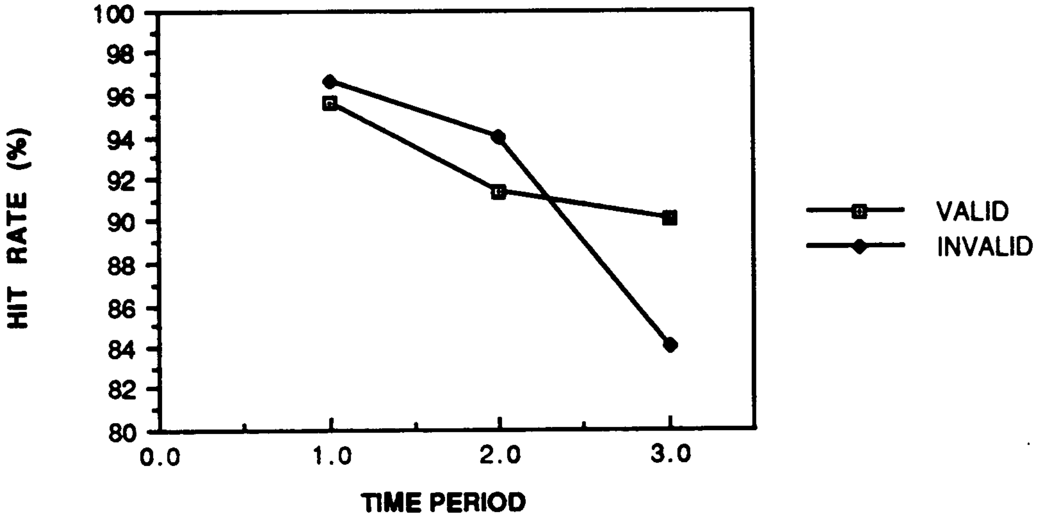


Table (16)

Mean false alarms for successive 10-minute blocks for short, average and long SOA (valid and invalid cues).

	Valid				Invalid			
	Blocks				Blocks			
	1	2	3	Mean	1	2	3	Mean
SOA								
150 msec	10.61	9.44	9.35	9.80	10.83	7.50	8.50	8.94
350 msec	11.19	10.44	10.68	10.77	11.66	13.00	7.16	10.60
550 msec	7.51	4.52	4.51	05.51	8.50	4.00	4.33	5.61

Table (17)
Summary of Analysis of Variance
for false alarm rate.

Source	SS	df	MS	F
Between Subjects		42		
SOA		2	638.33	1.15
Error				
Within Subjects		84		
Cue Validity (CV)		1	6.47	0.37
SOA X CV		1	5.44	0.31
Error				
Time Period (TP)		2	165.71	5.01 *
SOA X TP		4	41.06	1.24
CV X TP		2	26.22	1.84
SOA X CV X TP		4	29.35	2.06
Error				
TOTAL		126		

* P< .001

Table (18)

Sensitivity (d') means for successive 10-minute blocks for short, average and long SOA valid and invalid cues).

	Valid				Invalid			
	Blocks				Blocks			
	1	2	3	Mean	1	2	3	Mean
SOA								
150 msec	3.20	3.00	2.89	3.03	2.83	2.69	2.65	2.72
350 msec	3.22	3.17	3.07	3.15	2.87	2.73	3.02	2.87
550 msec	3.26	3.27	3.23	3.25	2.89	3.17	2.79	2.95

more decrement over time with short SOA than with long or average under valid cues. Anova results are displayed in Table 19.

A simple effect analysis of cue validity and time period for each SOA showed that no effect of cue validity or time period was found with short SOA. This indicates that there was no significant difference in sensitivity between valid and invalid cues at the short SOA and that sensitivity did not decrease significantly over time. The simple effect analysis demonstrated that there was a significant main effect of cue validity at p <.0001 for both average (F(1,13)=21.75) and long SOAs (F(1, 13)=23.52). This finding reflected higher scores with valid than with invalid cues. Another significant finding was the cue x time period interaction which was significant at p <.05 for both average (F(2,26)=3.66) and long SOA (F(2,26)=3.21). This interaction showed that sensitivity remained stable over time with invalid or with valid cues at the long SOA. The opposite effect took place at the average SOA, where an increment in sensitivity occurred with invalid cues and a decrement with valid cues. This confirms the d' findings in Experiment 1, that there was no significant decrement with invalid cues at both event rates. The anomalous result is that for the 550 msec SOA where d' increased at first, but then decreased in the third time period, rather than increase consistently as predicted (see Table 14). The cue by time period by SOA interaction is presented in Figures 12, 13 and 14 for 150, 350 and 550 msec SOA respectively. d' scores are plotted for each 10-minute block by SOA intervals and cue validity types. The figures show clearly a greater decrement at short SOA with invalid and valid cues, more than at the average or long SOAs. It also shows that there was higher sensitivity scores with valid than invalid cues in general.

Criterion (C)

By applying the same 3X2X3 (SOA X cue validity X time period) Anova to C

Table (19)
Summary of Analysis of Variance for
d' scores (Sensitivity).

Source	SS	df	MS	F	
Between Subjects		42			
SOA	2.28	2	1.14	0.62	
Error	77.67	42	1.85		
Within Subjects		84			
Cue Validity (CV)	6.01	1	6.01	36.59	*
SOA X CV	.01	2	0.00	0.02	
Error	6.90	42	0.16		
Time Period (TP)	.50	2	0.25	1.23	
SOA X TP	1.31	4	1.62	0.17	
Error	16.99	84	.20		
CV X TP	0.16	2	0.08	0.77	
SOA X CV X TP	1.02	4	0.26	2.40	**
Error	8.94	84	.11		
TOTAL		126			

* P< .0001

** P< .05

FIG 12: d' SCORES AS A FUNCTION OF CUES AND TIME PERIOD AT 150 msec SOA

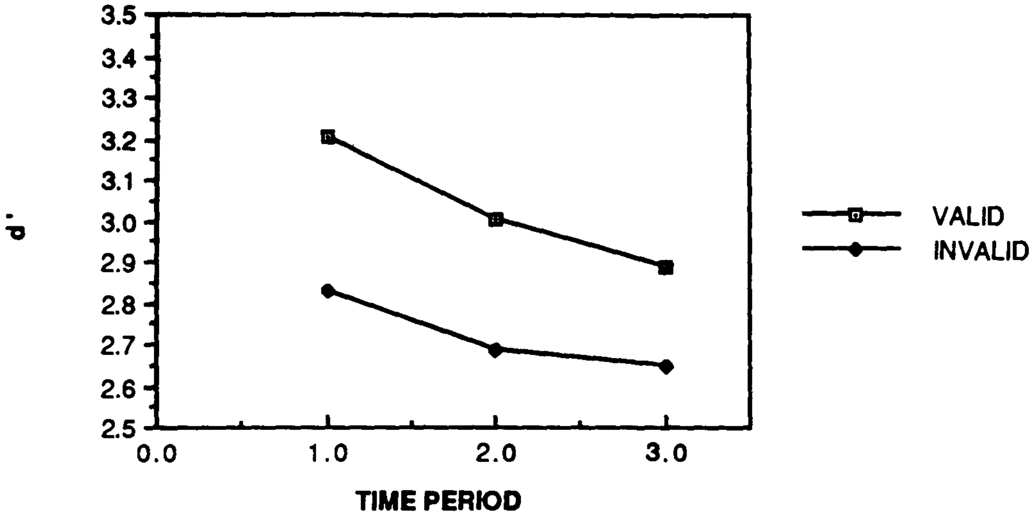


FIG 3: FALSE ALARMS AS A FUNCTION OF CUES AND TIME PERIOD AT THE HIGH EVENT RATE.

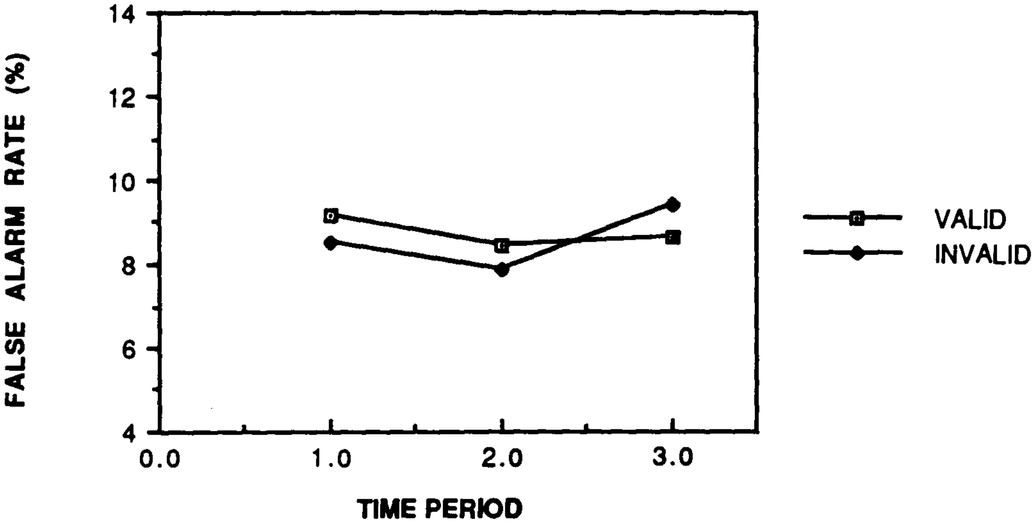
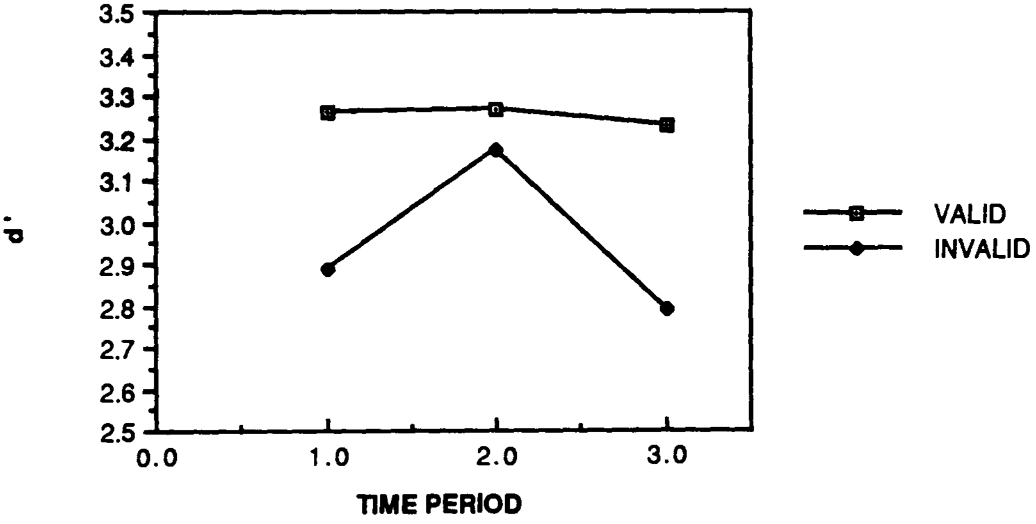


FIG 14: d' SCORES AS A FUNCTION OF CUES AND TIME PERIOD AT 550 msec SOA



scores (see Table 20), two main effects of cue validity and time period were found. Cue validity main effect was significant at F(1,39)=7.85, P< .010. This result reflected higher C scores with invalid than with valid cues. The time period main effect was significant at F(2,78)=17.23 P< .0001, indicating an increment over time in the C scores for all conditions. Other sources of variance were not significant. The ANOVA summary is presented in Table 21.

Additional Analyses

Decrement Analysis

As in the first experiment data analyses, a decrement analysis of hit rate, false alarm rate and sensitivity scores (d') was used to investigate any significant effect of vigilance decrement. 3 X 2 (SOA X Cue validity) was conducted on hit rate decrement scores with repeated measure on the last factor. The analysis revealed no significant findings. False alarm decrement means were submitted to the same 2 X 2 Anova. This analysis also showed no significant effects. The analysis of d' decrement scores revealed a main effect of cue validity which was marginally significant at F(1,42)=3.36 P <.074, indicating higher decrement over time valid than with invalid cues. In general then, two results are consistent with the previous ANOVAs.

Data Transformation

Using the Aresine transformation on the data to stabilize large variances within-group, a 3 X 2 X 3 (SOA X Cue validity X Time period) Anova was applied to hit rate, false alarm rate and d' scores. The analysis of transformed data revealed the same significant effects and interaction found with hit rate, false alarm rate, d', and C scores with non-transformed data.

Practice data analyses

Table (20)
Criterion measure (C) means for successive 10-minute blocks for short, average and long SOA valid and invalid cues).

	Valid				Invalid			
	Blocks				Blocks			
SOA	1	2	3	Mean	1	2	3	Mean
150 msec	-0.14	0.86	0.23		0.01	0.23	0.20	
350 msec	-0.16	-0.14	-0.28		-0.01	-0.01	0.13	
550 msec	-0.02	0.21	0.26		0.56	0.23	0.41	

Table (21)

Summary of Analysis of Variance for
C scores (Criterion).

Source	SS	df	MS	F
Between Subjects		42		
SOA	1.68	2	1.20	1.62
Error	28.76	39	0.74	
Within Subjects		84		
Cue Validity (CV)	0.63	1	0.63	7.85 *
SOA X CV	0.05	2	0.02	0.31
Error	3.15	39	0.08	
Time Period (TP)	2.33	2	1.17	17.23 **
SOA X TP	0.44	4	0.11	1.63
Error	5.28	78	0.07	
CV X TP	0.01	2	0.01	0.17
SOA X CV X TP	0.16	4	0.04	0.89
Error	3.51	78	0.04	
TOTAL		126		

* P< .010

** P< .0001

The practice data was submitted to a 3 X 2 (SOA X cue validity) analysis of variance. Analysis of the hit rate scores revealed a significant main effect of cue validity at F(1,42)=23.19, p <.0001, indicating Higher hit rate scores with valid than with invalid cues. A marginally significant main effect of SOA was found at F(2,42)=2.85, p <.069 indicating that the highest hit rate score was found with average SOA rather than long or short one. Actually the lowest hit rate score was found with short SOA. Submitting false alarm data to the same analysis of variance, a main effect of SOA was found significant at F(2, 42)=4.07, p <.025, indicating lower false alarm rates with long SOA than with the average and short intervals. The highest false alarm rate was found with average SOA under both cue conditions. Another significant finding (but marginal) for false alarm data was a main effect of cue validity at F(1,42)=3.68, p <.062 showing higher false alarm rates with valid than invalid cues. Analyzing the sensitivity scores (d') a main effect of cue validity was found significant at F(1, 42)=18.10, p <.0001 showing higher sensitivity scores with valid than with invalid cues.

Summary of Major Results of Experiment 2

The data analyses of Experiment 2 showed three main effects and one three-way interaction. The first main effect was time period effect found in the hit rate analysis. The effect reflected a general decrement in detection rate which was observed with all cue types and SOAs. Another main effect of time period was found while analyzing false alarm rates, indicating a false alarms decrement over time in all conditions. The third effect was a significant effect of cue validity found with d' scores. The main effect was an outcome of higher d' scores under valid than under invalid cues.

The d' analyses also revealed a significant three-way interaction of SOA by cue validity by time period, reflecting a greater sensitivity decrement over time at the 150 msec SOA than at the 550 msec SOA. Another outcome of this interaction was the occurrence of more decrement over time at the 150 msec SOA than at the 350 msec or 550 msec SOA under valid cues. No other effects or interactions were significant.

Analyzing the criterion C, two main effects of cue validity and time period were found. The main effects reflected higher C scores with invalid than with valid cues and an increment over time for all groups respectively.

Experiment 2 supported the third hypothesis since the highest sensitivity scores were found at 550 msec SOA than at 350 msec or 150 msec SOA. The fourth hypothesis was partially supported by showing that there was no significant difference between valid and invalid cues at 150 msec. Also greater vigilance decrement over time was found with valid than with invalid cues at 350 msec SOA replicating the results of Experiment 1. The surprising result was that there was no significant sensitivity decrement under the 550 msec SOA condition for both valid and invalid cues. These results and those of Experiment 1 will be discussed in detail in the Discussion chapter.

CHAPTER V

DISCUSSION

Predicted and Obtained Results

The present study investigated the effects of attentional cueing on perceptual sensitivity during the performance of a long-duration (30 minutes) vigilance task. It was designed to show sensitivity changes in attentional allocation across the visual field in a vigilance task using the signal detection theory (SDT) paradigm. The general finding in studies of orienting of attention is that following a visual cue, subjects move their attention to the cued location and generate an expectation (focused attention). If the stimulus appears at the cued location, this produces an advantage in discriminating between the target and the non-target as a result of the concentration of attention in that location. If the stimulus appears at the uncued location, then the subject has to disengage attention and shift to the target location, which results in slowing and/or inaccuracy in discriminating between the target and the non-target (Posner et al, 1978; Bashinski and Bacharach, 1980; Posner, 1980)

The above finding has been reported in a number of studies but has not been examined for long-duration vigilance tasks. It was thus predicted that valid cues would enhance sensitivity in a vigilance task (increase in hit rate and decrease in false alarm rate) (hypothesis 1). Furthermore it was predicted that vigilance decrement over time would be <u>greater</u> with <u>valid</u> cues than with invalid cues, based on the inhibition theory of Posner et al, (1984) (hypothesis 2). Additionally, it was predicted that detection performance would increase as a monotonic function of cue-target Stimulus Onset Asynchrony (SOA) (hypothesis 3). Finally it was predicted that the greater vigilance decrement for invalidly cued targets would be found only for medium and long SOAs and not for short SOAs (hypothesis 4), for which inhibition cannot develop sufficiently. Two experiments with low and high event rate vigilance tasks were carried out to test the hypotheses.

The results of the present study provided qualified support for each of these hypotheses. Valid cues enhanced sensitivity compared to invalid cues (hypothesis 1) and validly cued targets showed greater sensitivity decrement over time than invalidly cued targets (hypothesis 2). However, both these findings of experiment 1, which follows from the Posner et al (1984) inhibition theory, occurred only for the low event rate condition, so that hypotheses 1 and 2 were only partially supported. The results of the high event condition rate were consistent with the predictions of Parasuraman (1985), in that a sensitivity decrement occurred for both validly and invalidly cued targets. In general, the results of experiment 1 supported the Posner et al (1984) theory for the low event rate condition and the Parasuraman (1985) theory for the high event rate condition.

In Experiment 2, overall detection performance did not increase monotonically with SOA, since best performance was found at the 350 msec SOA while the lowest detection rate resulted from the use of the 150 msec SOA. Detection rate at the 550 msec was slightly better than at the 150 msec SOA. Thus hypothesis 3 was partially supported. Finally, hypothesis 4 predicted greater sensitivity decrement over time for validly cued targets than for invalidly cued targets at medium and long SOAs but not at short SOA. This hypothesis was also partially supported. While the results conformed to the predictions for the medium and short SOAs, invalidly cued targets did not show a sensitivity increment decrement at the long SOA, and valid and invalid cues did not differ in terms of decrement.

Two unexpected results were the increment in sensitivity over time for invalidly cued targets at the low event rate (as opposed to reduced decrement), found in both experiment 1 and 2, and the absence of an inhibition effect at the 550 mesc SOA in Experiment 2. These findings are explained further below.

Implications for mechanisms of the vigilance decrement

Many arguments were built to account for the phenomenon of the vigilance decrement. Most of the theories discussed earlier, could explain a small part of the results of vigilance studies. Parasuraman and Davies' (1977) taxonomy of vigilance tasks came as a response to this state of affairs in order to classify different tasks according to their underlying processing meachanisms. A fundamental distinction was made between low event rate and high event rate tasks, and Parasuraman (1985) proposed a multifactorial theory in which different concepts accounted for performance decrements in the two kinds of tasks. The results of the present study provide further corroboration for this taxonomic view, but show additionally that the concept of inhibition, following the orienting of attention, introduced by Posner et al (1984), can account for the vigilance decrement in one class of vigilance tasks.

As discussed earlier, several studies have shown that a visual cue directing attention to a location has a facilitating effect on detection or discrimination of a target presented at that location (Posner, 1980; Posner and Cohen, 1982; Bashinski and Bacharach, 1980). Thus facilitatory effect lasts about 200-300 msec. If the target does not appear for this time, an inhibitory process develops, resulting in a delay in RT to the target (Posner, 1980; Posner and Cohen, 1982). Inhibition also develops for a location following the presentation of a target at the location. That is, if a target is presented at the same location a short time later (1-1.5 seconds) it is responded to less efficiently (Posner, Rafal, Choate and Vaughan, 1985) referred to this as inhibition of return. It is as if the attention orienting system is such that it is unwilling to return to a position it has recently visited, but would rather sample another location. If it is forced to return immediately to the same spot, there is a temporary inhibition. It is precisely this inhibition, or rather the "accumulation" of inhibition over long periods of time, that Posner et al (1984) speculated might lead to the vigilance decrement. The results of the present study support this view for low event rate vigilance tasks. It was proposed that with valid cues there would be greater accumulation of inhibition than with invalid cues, which divert attention away from the current location and hence may dissipate inhibition. Thus less vigilance decrement over time would be expected for invalidly cued targets than for validly cued targets. The results supported this prediction for the d' measure of sensitivity, as a greater sensitivity decrement was found for valid than for invalid cues. Such a finding could be explained by the fact that invalid cues have, in fact, an arousing effect, as stated by Tsal (1983). This effect is an outcome of the negative information produced by invalid cues which breaks the monotony of observing valid cues for most of the trials.

However, performance differences between valid and invalid cues were not significant at the high event rate. Thus orienting of attention did not affect vigilance performance under high event rate conditions. At the high event rate, sensitivity declined for both validly and invalidly cued targets. Furthermore, there was no overall performance advantage for valid cues over invalid cues like at the low event rate. These findings indicate that the inhibitory effect cannot account for vigilance decrements at the high event rate. This does not deny the occurrence of inhibition at the high event rate but it suggests that inhibition may exist but is "over-ridden" by the mechanism causing sensitivity decrement at the high event rate. That mechanism is the "time sharing" process identified by Parasuraman (1985) as necessary in tasks with high information-processing rates. Parasuraman (1985) stated that vigilance decrement over time at the high event rate could be a consequence of sharing primary vigilance with other activating events (display of cues in the present research). Such a time-sharing demand does not arise at low event rates.

Sensitivity decrement over time at high event rates is thus a result of different demands on processing compared to low event rates. The cue-target SOA between the high and the low event rates was kept the same (350 msec), which excludes the possibility that the absence of an inhibitory effect at the high event rate is caused by the change in SOA. Another alternative explanation for the present findings is Parasuraman's (1979) theory that sensitivity decrement occurs only with successive vigilance tasks at a high event rate (more than 24 events per minute). The inter-stimulus interval (ISI) was different between the high (2000 msec) and the low (4000 msec) event rate. Such a difference may have made it easier for subjects in the low event rate group to have enough time to process their stimuli and consequently make a decision. Also, despite using a block design and a constant ISI (within each event rate group), the inhibitory effect was still observed at the low event rate. Therefore, the absence of inhibition at the high event rate cannot be attributed to an artifact of the design but due to the nature of the vigilance task (successive) and the attentional demands of the high event rate.

According to a capacity model of attention (Kahneman, 1973; Norman and Bobrow, 1975), attentional resources are limited in terms of the amount available at any one instance of time. Attentional deterioration (according to this theory) may result from either a non-optimal spread of attentional resources or greater attentional demand than the available resources (Lanzetta, 1984; Lanzette, Dember, Warm and Berch, 1987). By using valid visual cues, attentional demands increase since the subject has to follow the visual cue (attentional effort to shift attention), and then locate and identify the target (focused attention). In the case of invalid cues, the demand for attentional resources may also arise because deallocation causes shifting of attention from a previously cued location (at this point subject starts concentrating on that visual spot) to where the target is actually occurring (subject starts focusing attention on the new location). Due to the nature of the vigilance task (successive) and the event rate (high) used in this study, the attentional demand becomes higher (memory requirements of the successive task in vigilance necessitates more attentional resources) which causes sensitivity decrement (Parasuraman, 1979). In this study, subjects had not only to hold a standard representation of the target in memory (to make a decision by comparing different stimuli to the stored standard), but also to remember the type of visual cue (direction of the arrow) presented (at the fast rate) prior to the target. These results suggest that inhibition occurred, but it was over-ridden by demands from the high event rate.

From what was discussed earlier, it seems that invalid cues dissipate inhibition in a visual field. Such a finding corresponds to what must be termed -"natural ecology"- a notion which offers an important evolutionary argument for animal survival. That is, attending to _different_ locations for long periods of time is of survival value for animals. Being alert to various parts of the environment is a natural required law for the survival and safety of animals. This necessitates a mechanism by which the nervous system operates in a distributed attention mode rather than a focused mode. Such dissipation of inhibition is not found in traditional vigilance tasks because targets occur in only one location. It seems that the unexpectedness factor is very much involved in the dissipation of inhibition in the visual field.

In summary, the results of Experiment 1 support the idea of a multifactorial theory of vigilance decrement in which inhibition (Posner et al, 1984) seems to be implicated in low event rate vigilance tasks but not in high event rate tasks, in which the underlying mechanism is represented as limitations in allocation of processing capacity (Parasuraman, 1985).

Temporal factors in the _orienting_ of _attention_

After conducting Experiment 1, the findings clearly showed that the cueing effect on vigilance performance resided within the low event rate condition only. Experiment 2 was designed to explore the effect of SOA on vigilance performance at the low event rate only. Three different SOA of 150 msec, 350 msec and 550 msec were used in a between-subjects design.

The results of Experiment 2 for the 350 msec SOA closely replicated those of Experiment 1. Overall detection performance was higher with valid than with invalid cues, but there was greater vigilance decrement with valid than with invalid cues. The finding that there was in fact an _increment_ for invalidly cued targets was also replicated. Therefore, the main results of Experiment 1 were replicated in the 350 msec SOA condition of Experiment 2. Such findings indicate that the facilitation and inhibition phenomena are relatively robust. Sensitivity scores in the 350 msec SOA in both experiments are presented in Table 22. The sensitivity scores in both experiments closely matched each other.

As predicted earlier, the results of Experiment 2 indicated that there was no inhibitory effect at the 150 msec SOA, under which inhibition does not develop. However, the results concerning the 550 msec SOA did not support the inhibition theory since there were no

Table (22)
Comparison of d' scores between experiment 1 and 2 with 350 msec SOA at low event rate for both valid valid and invalid cues.

	Valid				Invalid			
	Blocks				Blocks			
	1	2	3	Mean	1	2	3	Mean
Exp 1	3.16	3.13	3.07	3.12	2.75	2.67	2.95	2.79
Exp 2	3.22	3.17	3.07	3.15	2.87	2.73	3.02	2.87
Mean	3.19	3.15	3.07		2.81	2.70	2.98	

differences in vigilance decrement between both valid and invalid cues. Two possible explanations for this anomalous finding.

Attentional velocity interpretation

The first possible explanation makes use of findings concerning the velocity of attention shifts, and related temporal factors. According to Tsal (1983), attention moves in an analog manner at a constant speed of 8 msec per degree. While trying to orient to a location, the subject's attention traverses the distance between the cue and the designated location. In the valid condition, the subject moves attention from the center to the cued location. When the cue is invalid, attention travels the same distance as in the valid condition, but then an additional shift to the opposite side is necessary. At this point and according to Tsal's (1983) theory, will subjects be able to detect the target given that attentional velocity is 8 msec per degree? To test this theory, the following questions arise: 1) Is it too late to reach the cued location using one of the three different SOAs utilized in this study? and 2) Is there any difference between valid and invalid cues in crossing the visual field?

The design of the present experiment seems to be a good one to test Tsal's (1983) theory. If the movement of attention is constant at 8 msec per degree (as Tsal claimed), and if the eccentricity of the target location used in this study (6 degrees) does not give enough time for the subject to focus attention on the target, then detection would be less accurate at short than at long SOAs.

Experiment 2 revealed that there was no difference between valid and invalid cues at the 150 msec SOA. That is there was no effect of cueing at the short SOA. This finding was expected since inhibition does not have enough time to develop at 150 msec SOA. Sensitivity decrement was greater with valid than with invalid cues at the 350 msec SOA as in Experiment 1. However, the opposite effect to that proved to be true at the 550 msec SOA, since the decrement was greater with invalid than valid cues. It may be that after waiting for a long interval (550 msec) subjects lose some of their state of attentional readiness for the upcoming stimulus. When the target occurs at the opposite side of the cued location (invalid cue), it becomes more difficult for subjects to switch their attention to that location. If the SOA is long enough, attentional focus occurs before the target is displayed. In this case detection will be faster and more accurate. This happens when the visual cue is valid. More time will be spent (RT) and the detection will not be as accurate when the cue is invalid, since after focusing on the cued visual spot, subjects will have to move their attention to the opposite location of the cued field (attentional readiness).

According to previous investigations (Posner, 1980; Posner et al, 1984; Maylor, 1985; Maylor and Hockey, 1985) inhibition is observed by summoning attention to the opposite side of the cued location. In other words Posner and Cohen (1984) stated that in order to observe inhibition, attention must be withrawn from the cued location. This inhibitory effect does not develop until about 300 msec from the display of the cue. Based on these conclusions and according to Tsal's (1983) theory of analog movement of attention, it is reasonable to assume that inhibition does not occur at 150 msec SOA. Such short interval does not allow inhibiton to develop yet. At 350 msec, inhibition develops after about 300 msec, and if nothing happens then subjects move their attention to the opposite side. In shifting their attention to the opposite side, the subjects' attention must travel the distance (12 degrees) in 96 msec (8x12) to reach the target location. If the target occurs (as in the case of invalid cues), subjects will catch it after 46 msec of its display with 254 msec display time remaining. In the case of valid cues, subjects shift their attention back to the originally cued location, after reaching the opposite side and finding no stimulus. By moving their attention to the opposite side and returning back to the originally cued location, subjects spend 192 msec. That is, they will "catch" the target with 158 msec of display time. Therefore, more processing time is provided in the case of deallocation (invalid cues) which may explain the finding of less decrement over time with invalid than with valid cues at the 350 msec SOA. At the 550 msec SOA things are quite different. After about 300 msec from the cue display, subjects move their attention to the opposite side and reach that location 104 msec before the target occurs. During that time, they might shift their attention again to the originally cued location reaching the occurrence of the target in time or may be 8 msec earlier (this is in the case of valid cues). Such timing gives them the opportunity to watch the stimulus for its complete 300 msec display time and consequently enough time to make a decision. In case nothing happens at the cued location (invalid cues), subjects will move their attention again to the opposite side to reach the the stimulus after 100 msec of display time (i.e 200 msec of display time left). The alternate shifting of attention from one peripheral side to the other is in accordance with Posner et al's (1984) statement that "Failing to find a target at the cued position shortly after the cue, the subject may guess that the target is more likely to occur at the other position" (P 537). Such calculations of time intervals lead to the assumption that subjects have more time processing a stimulus under valid cues than under invalid cues at 550 msec SOA. Such reasoning may explain the vigilance decrement over time observed with invalid cues at 550 msec.

Memory load interpretation

Another alternative explanation of the results of Experiment 2 resides within the length of each SOA and is based on the taxonomic analysis of vigilance of Parasuraman (1985). It is expected that inhibition does not develop at the 150 msec SOA. This assumption has been supported by the present findings. The 350 msec is to be a perfect interval for such an inhibitory effect to develop. The 550 msec SOA is to be a long interval and due to the nature of the vigilance task used (successive), working memory is involved in target discrimination (Parasuraman, 1979). Subjects not only have to remember the target size as opposed to the non-target, but also to keep in working memory the directional information provided by symbolic cue (arrow). First, subjects hold in their memory a standard image of the target during the whole session to be able to compare different events to that optimal standard. The cue appears after the subjects have already memorized the image of the target. It is possible that the additional memory load imposed by the cue may have a negative impact on performance at long SOAs. After 550 msec subjects might not remember clearly the direction of the arrow (cue) and focus more on remembering the signal size, since this critical evidence allows them discriminate against non-targets and therefore make a decision. Thus at this SOA vigilance decrement is primarily affected by memory load and an equivalent decrement occurs for valid and invalid cues.

This interpretation is obviously post-hoc and requires further test. If true, however, it would represent an important extension to Parasuraman's (1985) taxonomy because it would show that in some specific cases, changes in memory load affect vigilance decrement in both low and high event rate tasks.

Additional findings

Inhibition and event rate

While the present results support the degrading effect of high event rates on vigilance performance, they do not support Posner's (1978) theory that a faster build up of pathway inhibition occurs at high event rates than at low event rates. Surprisingly, the opposite effect occurred, since an effect of spatial cues was found at the low event rate but not at the high event rate. Bowers (1982) also found that a slow event rate facilitated detection RTs instead of high event rate as stated by Posner (1978). Bowers (1982) argued that the discrepant findings arose from the use of different stimuli (white bars) than those used by Posner (1978) (letters). Letters are very familiar stimuli and are probably encoded automatically which makes them less demanding, in terms of attentional capacity. In the present study, more abstract and less familiar stimuli (squares) were used. These stimuli can not be encoded automatically, since the only evidence for a subject to detect a signal was the slight difference in size between two squares (the target and the non-target). Such a display does seem to require the allocation of attentional capacity, and the association of these stimuli with the high event rate leads to a predicted (and obtained) sensitivity decrement. In addition, such capacity-demanding stimuli may have made it difficult for subjects to process spatial cues at a high event rate. On the other hand, the use of these stimuli would be very convenient at the low event rate since the ISI used gave subjects enough time to perceive spatial cues (no distracting effect) and therefore make a judgement. In addition to the difference in the stimuli used, the difference in inter-stimulus intervals (ISI) between those in previous studies and those used in the present experiment makes it impossible to process any stimulus during ISI used at the high event rate (which was 2000 msec). Longer ISI provides more time to process a stimulus (i.e comparing it to a standard picture of the signal stored in short term memory). Therefore, the longer the ISI, the better the detection. Moreover, Posner et al (1984) stated that inhibition lasts up to 1.5 sec or more which makes it quite impossible to occur and develop at the high event rate.

One more important factor to mention and which might have made the difference in performance and especially at the high event rate and that is the task used in the present study (discrimination) is much more complicated than the ones used in previous studies (detection). Such a task (discimination) not only requires the subject to locate the target at the right location but also to discriminate between a target and a non-target. This factor makes the task more complicated (demanding) at the high event rate. Such finding supports Lanzetta et al's, (1987) view that event rate and task type are interactive rather than independent and additive. So the capacity demanding factor is also a contributing one behind the absence of cueing effects at the high event rate.

These results along with those of Bowers (1982) lead to the conclusion that Posner's (1978) theory is task specific. Even though the low event rate used in Bowers (1982) study was different (5 events/min) from the one used in the present experiment (15 events/min), the high event rate was the same (30 events/mn). Two major differences between Bowers' (1982) work and the present investigation are: 1) Bowers used visual probes which were not used in the present study. 2) His data analyses was based on response times while in this experiment vigilance performance scores (hit rates, false alarms, d' and C) were used.

Despite these differences, the evidence from both studies are consistent in indicating that inhibition does not accumulate faster at high event rates.

The attentional metaphor

The evidence showed that there was higher sensitivity scores with valid than with invalid cues for both the 350 msec and the 550 msec SOA conditions. No significant difference between cues was found at 150 mesc SOA. This finding suggests that 150 msec SOA contributes more to sensitivity decrement than 550 msec or 350 msec SOAs. This finding supports the results of Eriksen and Murphy (1987) that if the SOA is very short then the target occurs before the attentional focus. The results also favor a spotlight theory of attention since the subject will not have adequate time to focus on the target if the display duration is short. Once the target disappeared from the visual field, it is presumed that the attentional focus is applied on an image or persisting trace of the stimulus. In this case the RT increases and detection performance decreases because the focus depends on the fidelity of the icon in representing the target. While the present study was not designed to differentiate between various attentional metaphors, such as the spotlight, gradient or zoom-lens, the results are most consistent with the view of visual attention as a moving spotlight.

Central versus peripheral cueing

The present findings support Maylor and Hockey's (1985) results that inhibition can occur with central cues as well as with peripheral cues, and argue against Posner's et al (1984) claim that inhibition occurs only with peripheral cues. Furthermore, Maylor and Hockey, (1985) found a larger inhibition at the fovea than in the periphery. Moreover, these conclusions also support the results of Bashinski and Bacharach (1980) which reflected the occurence of inhibition using central cues with peripheral target locations which is, in fact, the same design of cueing as in the present study. The results also support those of Muller and Findlay (1988), who found that central cues did not cause any decrease in accuracy for valid trials at a longer SOA and that inhibition occurred but was less stronger than with peripheral cues.

It should be noted however, that the definition of central cueing in previous studies (Posner et al, 1984; Maylor, 1985; Maylor and Hockey, 1985) is quite different from the one used in the present investigation. Their use of central cueing was characterized by the display of a central box in the center of the visual field with valid trials being displayed inside the central box and invalid trials in any other box in the periphery. In the present study, the cue appeared in the center of the visual field followed by targets in the periphery. No stimulus occurred at the center. When Posner et al (1984) argued that central cues cannot produce inhibition, they based their evidence on an experiment they conducted, where the cue (arrow) was central with three probable locations: one central (just under the arrow) and two peripherals. In the present study the target locations were peripheral only. Another difference is their use of a higher probability of target occurence (.6) in the central than in the two peripheral locations (.2) giving an advantage in focusing attention on the central location. On the other hand, the present investigation used an equal probability of target occurence (.5) between the two peripheral target locations. In their late SOA conditions (950 msec and 1250 msec), Posner and Cohen (1984), brightened the central box 600 msec after the cue display, thus reinforcing the summoning of attention to the foveal location. Hence it is no surprise that an inhibitory effect was not found, since the fovea remains the fastest of all visual locations. It seems that their evidence for the absence of an inhibitory effect is not due to the central cue per se but to a central location of the target which makes the RT to that location (fovea) the fastest.

Finally, the cueing used in most previous studies (Maylor, 1985; Maylor and Hockey, 1985; Posner and Cohen, 1984 (Experiment 1)) is represented by a change in light energy (appearance of small squared light) in the cued location, and which is very similar to the target. In the present investigation however, the cue was a directional arrow and was dissimilar to the target. Therefore, these findings argue against the possibility mentioned by Posner and Cohen (1984) that one probable source of inhibition may reside in the change of light energy in the cued location. In the present experiment, no light or energy change of any form occurs at the cued location before the stimulus display. Actually, Posner and his colleague (1984) admitted that they do not have enough "convincing evidence that light energy itself is sufficient for the inhibition effect" (p 542, footnote 3).

Sensitivity versus criterion

From the previously mentioned findings in both experiments 1 and 2, it seems clear that changes in vigilance performance are due to sensitivity effects and not to criterion shifts. Calculation of the bias measure C did not reveal any significant interaction that could account for any of the changes in the vigilance performance. These findings argue against the Muller and Findlay (1987) theory in which they claimed that "subjects are more liberal for more likely and more conservative for less likely locations" (p, 390), and also against Kinchla's (1977) weighted integration model which implies that subjects assign preferential weight to repeated input in higher order forms (valid cues in the present study). No such bias for cued locations was found.

It seems that knowledge of target location enhances sensitivity. The results obtained in these two experiments clearly indicate the advantage (gain) and the deficit (cost) in vigilance performance using valid and invalid cues, respectively. Such findings support the Posner's (1980) conclusion that cognitive factors provide some logical criteria that assist in the selection and therefore detection of the sensory evidence. These cognitive factors (central factors) help sensory processes which suggests an interactive relationship between the two processes.

Conclusion

The application of the concept of orienting of attention to the study of vigilance is of great theoretical importance. This application enabled us to look at the orienting of sustained attention. The precueing methodology helps locate attention in the visual field and therefore controls its movements.

The results of the studies broaden knowledge about the role of precueing in vigilance. The design also allowed us to explore two major issues, which are most relevant to the study of orienting of attention. The first is that in terms of selective attention, the present research showed that once attention is oriented to the target location (allocation) detection of signals was enhanced (facilitated). However, an inhibitory effect was created when subjects were cued to the opposite side of target location (deallocation), resulting in decreased detection rate and increased false alarms. This finding supports the Bashinski and Bacharah (1980) statement that "a deallocation of attention resulted in an inhibition of sensitivity in unattended spatial locations" (p 241). This result favors the theory of early attentional effects prior to short-term memory.

The second issue is that in the context of sustained attention, the findings provided evidence for greater decrement under facilitation than under inhibition. The two patterns (facilitation and inhibition) seem to change over time, but with more decrement observed under the facilitation effect. Facilitation generally favors detection performance under short-term visual attention conditions, whereas inhibition appears to boost performance changes over time, at least for low event rate tasks. Thus there are complementary effects of facilitation and inhibition that favor selective and sustained attention respectively. Such a balanced system seems quite compatible with other cognitive and neural systems, many of which involve opposing influences of facilitation and inhibition.

The present study offers evidence that supports Posner's et al, (1984) and Parasuraman's, (1985) claim suggesting a close relationship between selective and sustained attention. Sustained attention changes (in terms of facilitation and inhibition) under the same conditions that facilitate selectivity in a divided attention task (use of a central cue with targets occurring in the periphery) such as the one used in this study. This claim was ,however, confirmed only at the low event rate.

In conclusion, one hopes that the present research has contributed to the enrichment of different theories of attention in general and sustained attention in particular. The theoretical benefits offered by the present investigation have been discussed. The present study has shed light on two important issues of attention namely, the orienting of sustained attention and the effects of facilitation and inhibition on vigilance performance. The phenomenon of attention is still a wide-open field. Many questions remained to be more fully answered, such as the nature of orienting of attention, its movements and the precise nature of the relationship between facilitation and inhibition. Other unanswered questions involve the role of individual factors such as age. A learning approach will question the effect of practice in demolishing the inhibitory effect and improving vigilance performance. The existence of so many questions does not reflect a lack of efforts on the part of the researchers, as much as it shows the richness of the phenomenon of attention and the complexity of the different cognitive operations involved.

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APPENDIX A

INSTRUCTIONS

Welcome to the Cognitive Science Lab and thank you for being part of this study. We are interested in searching factors which may affect sustained attention. In this study. we are interested in how well people sustain their attention over time when they are informed about the probable location of the stimilus to be presented to them and how well they can detect targets.

You will have a brief training, a brief practice session and a longer main task session. The entire session will not exceed one hour. During these sessions you will see an arrow in the center of your video screen. The arrow will be displayed repeatedly followed by a square which will be displayed in the right or left side of the screen.

80% of the time the arrow will indicate exactly where the square will appear. In the 20% remaining trials the arrow will not be valid. You should fixate the center of your screen and detect changes in the size of squares. When you see the target square (which is smaller than the non-target square) you are to press the space bar on the keyboard as quickly as you can.You are encouraged to press the space bar if you think there is the slightest chance you saw a target. Do not press indiscriminately though.since this will lower your score.

Try to be accurate. Remember the target square will appear infrequently and the arrow is not always indicating the right position of the target. Do not forget to fixate the center of the screen. You are not encouraged to move you eyes to the right or the left side of the screen.

NOTE: If you should hear a beep from the computer that means you are resting your hand on the space bar. Please be careful to press the bar only when you intend to respond. If you are wearing a watch please remove it and give it to the experimenter. You will know that the session is over when you see a message that says: 'Please call your experimenter' Now you will see examples of the non-target and the target.

APPENDIX B

CONSENT FORM

Title of the investigation: Orienting of attention and vigilance.

Investigator: Toufik Bahri

Supervisor: Dr. Raja Parasuraman

Date: Fall, 1988

This is to certify that I,......................herebey agree to participate as a volunteer subject in a scientific experiment as an authorized part of the educational and research program at the Catholic University of America.

The experiment has been defined and fully explained to me by Toufik Bahri and I understand his explanation. I have read a description of the procedures to be followed and the potential risks, discomfort and benefits.

I have been given an opportunity to ask whatever questions I may have and all such questions and inquiries have been answered to my satisfaction.

I understand that I am free to deny to answer specific items or questions in interviews or questionnaires.

I UNDERSTAND THAT I AM FREE TO WITHDRAW MY CONSENT AND TERMINATE MY PARTICIPATION WITHOUT PENALTY. I UNDERSTAND I WILL RECEIVE CERDIT FOR THE PORTION OF THE EXPERIMENT I SERVED IN PRIOR TO WITHDRAWAL.

Subject's signature:______________________Date: _______________

Experimenter's signature _________________Date: _______________

APPENDIX C

THE CATHOLIC UNIVERSITY OF AMERICA

COGNITIVE SCIENCE LABORATORIES

BIOGRAPHICAL QUESTIONNAIRE

INSTRUCTIONS: Answer the following questions.

Date: / / (Mo Dy Yr) Age: Date of birth: / / (Mo Dy Yr)

Name: ____________________

Address: ____________________________

____

____

Telephone: ___________________

Sex: ____

Occupation: (If retired indicate that fact and give former occupation):

____

Ethnic Background:

Caucasian Hispanic Black

___ Asian ___ American Indian ___ Other (specify) ________

Marital Status:

___ Single Married Divorced Widowed

Are you a student? No ___ Yes

In what socio-economic class do you place yourself?

___ Lower ___ Upper-Lower Lower-Middle ___ Middle

___ Upper-Middle Lower-Upper Upper

What is your yearly income? (If married, give combined income):

* If you are a student and are not self-supporting answer this question as if it were about you parents:

___ $0 - $2,499

___ $2,500 - $4,999

___ $5,000 - $9,999

___ $10,000 - $14,999

$15,000 - $19,999

$20,000 - $29,999

--- $30,000 - $50,000

Over $50,000

Education (Check one):

Elementary or Junior High

High School Diploma

AA or Other Community College Degree

Business School

Trade School

BA, BS, or Equivalent

MA, MS, or Equivalent

PhD, JD, or Equivalent

MD, DDS, LLD, or Equivalent

___ Other (specify) ___________

Which hand do you generally prefer to use?

___ Left Right Both

Specify <u>Current</u> Medical Problem Only:

	Yes	No
High Blood Pressure	___	
Stroke	___	___
Heart Disease	___	
Kidney Disease		
Neurological Disease	___	

Other (specify) ________________________

If you have been hospitalized in the last 2 years, specify why and for how long:

Do you wear glasses? Yes No

Visual acuity:

___ Left eye ___/___ Right eye

Medications:

Please list all medications tha you are currently taking. Include vitamins, aspirin, antaids, etc, as well as perscription drugs, recreational drugs, and alcoholic beverages. This information will be kept confidential.

	USE
NAME OF MEDECINE	REG or OCC

Do you smoke cigarettes? ___ Yes ___ No

If you answer was "Yes", how many do you smoke per/day?

1 to 10

11 to 20

21 to 40

___ Greater than 40

Indicate how often you engaged in exercise?

___ Frequently ___ Occasionally ___ Never

Data Collection

Practice

HR	FA	d'	A'
______			______

Main task

First Session:

HR	FA	d'	A'
______	______	______	______

Second Session:

HR	FA	d'	A'
______	______	______	______

Remarks:

APPENDIX D

BASIC PROGRAM USED FOR PRACTICE SESSION

```
10 KEY OFF

20 REM

30 DIM BUFFER(1700),RDATA(2000,4)

40 DIM TCUES(1700), SRMAT%(2,2,10)

50 DEF FNTODEC(X)=(X\16)*10 + X MOD 16

60 REM

70 NBL = 1

100 REM

110 REM

120 INPUT "Which clock does this computer use: AST [1] or TECMAR [2]

130 IF COMP.NUM=2 THEN CADDR=637: DADDR=CADDR+2

140 IF COMP.NUM=1 THEN CADDR=893: DADDR=CADDR+2

150 SCREEN 2

160 REM

170 REM read in stimulus code file for this subject

180 INPUT "Low (L), High (H) or Normal (N) Event Rate Task?";G$

190 IF (G$="1") OR (G$="L") THEN NTR=75 ELSE NTR=150

200 IF (G$="1") OR (G$="L") THEN ISI=4000 ELSE ISI=2000

210 IF (G$."1") OR (G$="L") THEN SIG=15 ELSE SIG=30

230 INPUT "Subject stimulus file name:";SUBFILE$

240 OPEN SUBFILE$ FOR INPUT AS #1

250 FOR I = 1 TO NTR

260  INPUT #1,BUFFER(I)

270 NEXT I

280 CLOSE #1

290 REM cues files

300 OPEN SUBFILE$ FOR INPUT AS #1
```

```
310 FOR I=1 TO NTR
320 INPUT #1,TCUES(I)
330 NEXT I
340 CLOSE #1
350 INPUT"Enter subject initials, age group and session #";SUBNAMS
360 DATAFILES=SUBNAMW.res"
370 OPEN DATAFILE$ FOR OUTPUT AS #2
380 DS=SUBNAMW.sum"
390 OPEN D$ FOR OUTPUT AS #3
400 REM now make identical stimulus codes for successive blocks
410 REM
420 IB=1
430 XX=NTR*(IB-1)
440 FOR I=XX+1 TO IB*NTR
450 BUFFER(I)=BUFFER(I-XX)
460 TCUES(I)=TCUES(I-XX)
470 NEXT I
480 REM
490 INPUT "SIZE CONSTANT";SC
500 CLS
510 SCREEN 1
520 LOCATE 12,40:PRINT "VIGILANCE PRACTICE TASK"
530 LOCATE 15,40:PRINT "PRESS SPACE BAR TO START"
540 X$=INKEYS:IF X$="" THEN GOTO 540
550 CLS
560 REM INSTRUCTIONS
570 LOCATE, 1:PRINT "You will now begin the practice task"
580 LOCATE, 1:PRINT "session. Remember you are to detect"
590 LOCATE ,1:PRINT " as many smaller squares as possible."
```

```
600 LOCATE, 1:PRINT "Once again you are to press the space"
610 LOCATE ,1:PRINT "bar as quickly as possible whenever you"
620 LOCATE, 1:PRINT "detect a smaller square. You will see"
630 LOCATE ,1:PRINT "a message instructing you to call your"
640 LOCATE, 1:PRINT "experimenter when the session is over."
650 PRINT
660 LOCATE ,10:PRINT "PRESS THE SPACE BAR TO CONTINUE..."
670 X$=INKEY$: IF X$="" THEN GOTO 670
680 CLS
690 REM
700 SCREEN 1
710 REM Task begins here
720 REM
730 LOCATE 10,40:PRINT "PRESS SPACE BAR WHEN READY TO START"
740 X$=INKEY$: IF X$="" THEN GOTO 740
750 SCREEN 2
760 CLS
770 REM
780 REM Trials begin here
790 REM
800 FOR TRIALS=1 TO NTR*NBL
810 REM
820 IB=INT((TRIALS-1)/NTR)+1
830 REM
860 Y=SC
870 X=CINT(2.55*Y)
880 OUT CADDR,21: OUT DADDR,1' clear clock
885 RESPTIME=O
890 IF TCUES(TRIALS)=1 THEN GOTO 980
```

```
900 IF TCUES(TRIALS)=2 THEN GOTO 1300
910 IF TCUES(TRIALS)=3 THEN GOTO 1620
920 IF TCUES(TRIALS)=4 THEN GOTO 1940
930 IF TCUES(TRIALS)=5 THEN GOTO 1140
940 IF TCUES(TRIALS)=6 THEN GOTO 1460
950 IF TCUES(TRIALS)=7 THEN GOTO 1780
960 IF TCUES(TRIALS)=8 THEN GOTO 2100
970 CLS
980 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
990 GOSUB 2870
1000 IF XTIME <=150 THEN 990
1010 CLS
1020 GOSUB 2870
1030 IF XTIME <=500 THEN 1020
1040 LINE (510+X,70+Y)-(610-X,110-Y)„B
1050 GOSUB 2870
1060 IF XTIME <=800 THEN 1050
1070 CLS
1080 GOSUB 2870
1090 IF XTIME >=ISI THEN 2350
1100 V$=INKEY$
1110 IF V$=”" THEN 1080
1112 RESPTIME=XTIME
1120 GOSUB 2870
1130 IF XTIME >=ISI THEN 2350 ELSE 1120
1140 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
1150 GOSUB 2870
1160 IF XTIME <=150 THEN 1150
1170 CLS
```

```
1180 GOSUB 2870

1190 IF XTIME <=500 THEN 1180

1200 LINE (510,70)-(610,110)„B

1210 GOSUB 2870

1220 IF XTIME <=800 THEN 1210

1230 CLS

1240 GOSUB 2870

1250 IF XTIME >=ISI THEN 2350

1260 V$=1NKEY$

1270 IF V$="" THEN 1240

1272 RESPTIME=XTIME

1280 GOSUB 2870

1290 IF XTIME >=ISI THEN 2350 ELSE 1280

1300 LOCATE 12,40:DRAW "al g15 u40 d40 al h15

1310 GOSUB 2870

1320 IF XTIME <=150 THEN 1310

1330 CLS

1340 GOSUB 2870

1350 IF XTIME <=500 THEN 1340

1360 LINE (50+X,70+Y)-(150-X,110-Y)„B

1370 GOSUB 2870

1380 IF XTIME <=800 THEN 1370

1390 CLS

1400 GOSUB 2870

1410 IF XTIME >=ISI THEN 2350

1420 V$=INKEY$

1430 IF V$="" THEN 1400

1432 RESPTIME=XTIME

1440 GOSUB 2870
```

```
1450 IF XTIME >=ISI THEN 2350 ELSE 1440
1460 LOCATE 12,40:DRAW "al g15 u40 d40 al h15
1470 GOSUB 2870
1480 IF XTIME <=150 THEN 1470
1490 CLS
1500 GOSUB 2870
1510 IF XTIME <=500 THEN 1500
1520 LINE(50,70)-(150,110)„B
1530 GOSUB 2870
1540 IF XTIME <=800 THEN 1530
1550 CLS
1560 GOSUB 2870
1570 IF XTIME >=ISI THEN 2350
1580 V$=INKEY$
1590 IF V$="" THEN 1560
1592 RESPTIME=XTIME
1600 GOSUB 2870
1610 IF XTIME >=ISI THEN 2350 ELSE 1600
1620 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
1630 GOSUB 2870
1640 IF XTIME <=150 THEN 1630
1650 CLS
1660 GOSUB 2870
1670 IF XTIME <=500 THEN 1660
1680 LINE (50+X,70+Y)-(150-X,110-Y)„B
1690 GOSUB 2870
1700 IF XTIME <=800 THEN 1690
1710 CLS
1720 GOSUB 2870
```

```
1730 IF XTIME >=ISI THEN 2350
1740 V$=INKEY$
1750 IF V$="" THEN 1720
1752 RESPTIME=XTIME
1760 GOSUB 2870
1770 IF XTIME >=ISI THEN 2350 ELSE 1760
1780 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
1790 GOSUB 2870
1800 IF XTIME <=150 THEN 1790
1810 CLS
1820 GOSUB 2870
1830 IF XTIME <=500 THEN 1820
1840 LINE (50,70)-(150,110)„B
1850 GOSUB 2870
1860 IF XTIME <=800 THEN 1850
1870 CLS
1880 GOSUB 2870
1890 IF XTIME >=ISI THEN 2350
1900 V$=INKEY$
1910 IF V$="" THEN 1880
1912 RESPTIME=XTIME
1920 GOSUB 2870
1930 IF XTIME >=ISI THEN 2350 ELSE 1920
1940 LOCATE 12,40:DRAW "al g15 u40 d40 al h15
1950 GOSUB 2870
1960 IF XTIME <=150 THEN 1950
1970 CLS
1980 GOSUB 2870
1990 IF XTIME <=500 THEN 1980
```

```
2000 LINE (510+X,70+Y)-(610-X,110-Y)„B
2010 GOSUB 2870
2020 IF XTIME <=800 THEN 2010
2030 CLS
2040 GOSUB 2870
2050 IF XTIME >=ISI THEN 2350
2060 V$=INKEY$
2070 IF V$."" THEN 2040
2072 RESPTIME=XTIME
2080 GOSUB 2870
2090 IF XTIME >=ISI THEN 2350 ELSE 2080
2100 LOCATE 12,40:DRAW "al g15 u40 d40 al h15
2110 GOSUB 2870
2120 IF XTIME <=150 THEN 2110
2130 CLS
2140 GOSUB 2870
2150 IF XTIME <=500 THEN 2140
2160 LINE (510,70)-(610,110)„B
2170 GOSUB 2870
2180 IF XTIME <=800 THEN 2170
2190 CLS
2200 GOSUB 2870
2210 IF XTIME >=ISI THEN 2350
2220 V$=INKEY$
2230 IF V$=”" THEN 2200
2240 RESPTIME=XTIME
2250 GOSUB 2870
2260 IF XTIME >=ISI THEN 2350 ELSE 2250
2350 IF (V$<>"") THEN C3=0 ELSE C3=1
```

```
2360 RDATA(TRIALS,0)=IB:RDATA(TRIALS,1)=TCUES(TRIALS):RDATA(TRIALS,2
      (TRIALS,3)=RESPTIME

2361 IF TCUES(TRIALS)=1 THEN BUFFER(TRIALS)=0

2362 IF TCUES(TRIALS)=2 THEN BUFFER(TRIALS)=0

2363 IF TCUES(TRIALS)=3 THEN BUFFER(TRIALS)=0

2364 IF TCUES(TRIALS)=4 THEN BUFFER(TRIALS)=0

2365 IF TCUES(TRIALS)=5 THEN BUFFER(TRIALS)=1

2366 IF TCUES(TRIALS)=6 THEN BUFFER(TRIALS)=1

2367 IF TCUES(TRIALS)=7 THEN BUFFER(TRIALS)=1

2368 IF TCUES(TRIALS)=8 THEN BUFFER(TRIALS)=1

2370 IF BUFFER(TRIALS)=1 THEN GOTO 2390

2380 BUFFER(TRIALS)=0

2390 SRMATUBUFFER(TRIALS),C3,IB)=SRMAMBUFFER(TRIALS),C3,IB)+1

2400 GOSUB 2870

2410 IF XTIME >=ISI THEN 2420 ELSE 2400

2420 NEXT TRIALS

2430 REM

2440 REM End of all blocks

2450 REM

2460 REM

2470 REM give performance feedback

2480 HIT!=0:FA!.0

2490 IB=1

2500 HIT!. HIT!+SRMAT%(0,0,IB)

2510 FA!.FA1+SRMAT%(1,0,IB)

2530 HIT!=HIT!/SIG

2540 FA!=FA!/(NBL*NTR - SIG)

2550 X!=HIT!-FA!

2560 IF HIT!=0 THEN 2580
```

```
2570 APR!=.5 +(.25*X!*(1+X!)/(HIT!*(1-FA!)))

2580 CLS

2590 PRINT "END OF SESSION"

2600 PRINT:PRINT:PRINT "YOUR CORRECT TARGET DETECTION RATE WAS";100*

2610 PRINT:PRINT "YOUR FALSE DETECTION RATE WAS";100*FA!;"%"

2620 PRINT:PRINT "YOUR OVERALL DETECTION SCORE WAS";100*APR!;"%"

2630 PRINT:PRINT:

2640 PRINT "THANK YOU. PLEASE CALL THE EXPERIMENTER"

2650 X$=INKEY$:IF X$="" THEN 2650

2660 FOR I=1 TO NBL*NTR

2670 PRINT #2,RDATA(I,0),RDATA(I,1),RDATA(I,2),RDATA(I,3)

2680 NEXT I

2690 REM close subject data files

2700 CLOSE #2

2710 IB=1

2720 PRINT #3,"Response":PRINT #3," NS S":PRINT #3," - -ft

2730 PRINT #3,"NS";SRMATZ(1,1,IB);SRMAT%(1,0,IB)

2740 PRINT #3,"S";SRMAT%(0,1,IB);SRMATUO,O,IB)

2750 PRINT

2770 CLOSE #3

2780 IB=1

2790 PRINT "Response":PRINT " NS S":PRINT " - - -

2800 PRINT "NS";SRMATZ(1,148);SRMAT%(1,0,IB)

2810 PRINT "S ";SRMATZ(0,148);SRMATZ(0,0,IB)

2820 PRINT

2830 X$=INKEY$: IF X$="" THEN GOTO 2830

2850 CLOSE #3

2860 END

2870 REM subroutine time
```

```
2880 OUT CADDR,0: MSEC=INP(DADDR)

2890 OUT CADDR,1: THSEC=INP(DADDR)

2900 OUT CADDR,2: SEC=INP(DADDR)

2910 XTIME=(FNTODEC(SEC)*1000) + (FNTODEC(THSEC)*10) + MSEC

2920 RETURN

2930 END
```

BASIC PROGRAM USED FOR TRAINING SESSION

```
10 KEY OFF
20 REM
30 DIM A1%(1700),A2M1700),BUFFER(1200),RDATA(1200,4)
40 DIM B%(1700), SRMATZ(2,2,10),SIGNAL(8)
50 DEF FNTODEC(X)=(X\16)*10 + X MOD 16
60 REM
70 NBL = 1
80 SD = 200
90 REM
100 REM
110 COMP.NUM = 1
120 IF COMP.NUM=2 THEN CADDR=637: DADDR=CADDR+2
130 IF COMP.NUM=1 THEN CADDR=893: DADDR=CADDR+2
140 INPUT "Size constant";SC
150 CLS
160 SCREEN 1
170 LOCATE 12,40:PRINT "VIGILANCE TRAINING TASK"
180 LOCATE 15,40:PRINT "PRESS THE SPACE BAR TO START"
190 X$=INKEY$:IF X$="" THEN GOTO 190
200 CLS
210 REM Instructions
220 LOCATE, 1:PRINT "Welcome to the Cognitive Science Lab"
230 PRINT
240 PRINT "and thank you for being part of this "
250 PRINT
260 PRINT "study. We are interested in searching "
270 PRINT
280 PRINT "factors which may affect sustained"
```

```
290 PRINT
300 PRINT "attention. In this study, we are "
310 PRINT
320 PRINT "interested in how well people sustain"
330 PRINT
340 PRINT "their attention over time when they are"
350 PRINT
360 PRINT "informed about the probable location of"
370 PRINT
380 PRINT "of the stimilus to be presented to them"
390 PRINT
400 PRINT
410 PRINT
420 LOCATE, 10:PRINT "PRESS SPACE BAR TO CONTINUE...."
430 X$=INKEY$: IF X$="" THEN GOTO 430
440 CLS
460 PRINT "and how well they can detect targets."
470 PRINT
480 PRINT "You will have a brief training, a brief"
490 PRINT
500 PRINT "practice session and a longer main task"
510 PRINT
520 PRINT "session. The entire session will not "
530 PRINT
540 PRINT "exceed one hour. During these sessions"
550 PRINT
560 PRINT "you will see an arrow in the center of"
570 PRINT
580 PRINT "your video screen. The arrow will be"
```

```
590 PRINT
600 PRINT "displayed repeatedly followed by"
610 PRINT
620 PRINT " a square which will be displayed in "
630 PRINT
640 PRINT
650 PRINT
660 LOCATE, 10:PRINT "PRESS SPACE BAR TO CONTINUE...."
670 X$=INKEY$: IF X$."" THEN GOTO 670
680 CLS
700 PRINT "the right or left side of the screen."
710 PRINT
720 PRINT "80% of the time the arrow will indicate"
730 PRINT
740 PRINT "exactly where the square will appear."
750 PRINT
760 PRINT "In the 20% remaining trials the arrow"
770 PRINT
780 PRINT "will not be valid. You should fixate"
790 PRINT
800 PRINT "the center of your screen and detect"
810 PRINT
820 PRINT "changes in the size of squares. When you"
830 PRINT
840 PRINT "see the target square (which is smaller"
850 PRINT
860 PRINT "than the non-target square) you are to"
861 PRINT
862 PRINT
```

```
863 PRINT
865 LOCATE, 10:PRINT "PRESS SPACE BAR TO CONTINUE...."
867 X$=INKEY$: IF X$="" THEN GOTO 867
869 CLS
880 PRINT "press the space bar on the keyboard as"
890 PRINT
900 PRINT "quickly as you can.You are encouraged"
910 PRINT
920 PRINT "to press the space bar if you think "
930 PRINT
940 PRINT "there is the slightest chance you saw"
950 PRINT
960 PRINT "a target. Do not press indiscriminately"
970 PRINT
980 PRINT "though,since this will lower your score"
990 PRINT
1000 PRINT "Try to be accurate. Remember the target"
1010 PRINT
1020 PRINT "square will appear infrequently and the"
1021 PRINT
1022 PRINT "arrow is not always indicating the right"
1031 PRINT
1032 PRINT
1033 PRINT
1035 LOCATE, 10:PRINT "PRESS SPACE BAR TO CONTINUE...."
1037 X$=INKEY$: IF X$="" THEN GOTO 1037
1039 CLS
1040 PRINT "position of the target. Do not forget to"
1041 PRINT
```

```
1042 PRINT "fixate the center of the screen. You are"
1043 PRINT
1044 PRINT "not encouraged to move you eyes to the"
1045 PRINT
1046 PRINT "right or the left side of the screen"
1047 PRINT
1048 PRINT
1049 PRINT
1050 LOCATE, 10:PRINT "PRESS SPACE BAR TO CONTINUE...."
1052 X$=INKEY$: IF X$="" THEN GOTO 1052
1053 CLS
1054 PRINT "NOTE: If you should hear a beep from the"
1055 PRINT
1056 PRINT "terminal it probably means that you are"
1057 PRINT
1058 PRINT "resting your hand on the space bar. "
1059 PRINT
1060 PRINT "Please be careful to press the bar only"
1061 PRINT
1062 PRINT "when you intend to respond. If you are"
1063 PRINT
1064 PRINT "wearing a watch please remove it and "
1065 PRINT
1066 PRINT "give it to the experimenter. You will"
1067 PRINT
1068 PRINT "know that the session is over when "
1069 PRINT
1070 PRINT "you see a message that says:"
1071 PRINT
```

```
1072 PRINT "'Please call your experimenter"
1073 PRINT
1100 LOCATE, 10:PRINT "PRESS BAR WHEN YOU ARE READY TO START"
1110 X$=INKEY$: IF X$="" THEN GOTO 1110
1120 IF KOUNT = 1 THEN 1140
1130 REM
1140 CLS
1150 LOCATE 12,40:PRINT "Now you will see examples of the"
1160 LOCATE 13,40:PRINT "non-target and the target"
1170 PRINT
1180 PRINT
2000 LOCATE 16,40:PRINT "PLEASE WAIT"
2020 FOR LOOP = 1 TO 4000:NEXT LOOP
2040 CLS
2060 SCREEN 2
2080 FOR Z=1 TO 3
2100 CLS
2120 LOCATE 5,30:PRINT "This is the right arrow"
2125 FOR LOOP=1 TO 1000:NEXT LOOP
2140 LOCATE 12,40:DRAW "Al G15 U40 D40 Al 815
2160 FOR LOOP=1 TO 1500:NEXT LOOP
2161 CLS
2162 LOCATE 5,30:PRINT "This is the left arrow"
2164 FOR LOOP=1 TO 1000:NEXT LOOP
2166 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
2168 FOR LOOP.1 TO 1500:NEXT LOOP
2169 CLS
2180 LOCATE 5,30:PRINT "This is the non-target"
2200 FOR LOOP =1 TO 1000:NEXT LOOP
```

```
2220 X=0
2240 Y=0
2260 LINE(50+X,70+Y)-(150-X,110-Y),,B
2280 FOR J=1 TO 1500:NEXT J
2300 CLS
2305 LOCATE 5,30:PRINT "This is the non-target"
2307 FOR LOOP =1 TO 1000:NEXT LOOP
2309 LINE(510+X,70+Y)-(610-X,110-Y),,B
2311 FOR J=1 TO 1500:NEXT J
2313 CLS
2320 LOCATE 5,30:PRINT "This is the target"
2340 FOR LOOP=1 TO 1000:NEXT LOOP
2360 Y=SC
2380 X=3.1*SC
2400 LINE(50+X,70+Y)-(150-X,110-Y),,B
2420 FOR J=1 TO 1500:NEXT J
2440 CLS
2480 CLS
2482 LOCATE 5,30:PRINT "This is the target"
2484 FOR LOOP=1 TO 1000:NEXT LOOP
2486 Y=SC
2488 X=3.1*SC
2490 LINE(510+X,70+Y)-(610-X,110-Y),,B
2492 FOR J=1 TO 1500:NEXT J
2494 CLS
2496 NEXT Z
2500 SCREEN 1
2520 LOCATE 10,40:PRINT "Do you wish to see the non-target"
2540 LOCATE 11,40:PRINT "and the target?"
```

```
2560 LOCATE 12,40:PRINT "Enter [y] or [n]"

2580 INPUT G$

2600 IF G$ "y" THEN GOTO 1140

2620 IF G$= "n" THEN GOTO 2760

2640 REM

2660 INPUT "Do you want to see other targets";G$

2680 IF G$   "y" THEN GOTO 140

2700 IF G$= "n" THEN GOTO 2640

2720 KOUNT=1:SCREEN 2:GOTO 380

2740 REM Now print out the results

2760 CLS

2780 PRINT "THANK YOU THAT WAS A BRIEF"

2800 PRINT"

2820 PRINT" DISPLAY OF THE STIMULI THAT"

2840 PRINT"

2860 PRINT"YOU WILL SEE IN THE PRACTICE

2880 PRINT"

2900 PRINT"SESSION AND THE MAIN TASK SESSION."

2920 X$=INKEY$:IF X$."" THEN 2920

2940 END

2960 REM subroutine time

2980 OUT CADDR,O: MSEC=INP(DADDR)

3000 OUT CADDR,1: THSEC=INP(DADDR)

3020 OUT CADDR,2: SEC=INP(DADDR)

3040 XTIME=(FNTODEC(SEC)*1000) + (FNTODEC(THSEC)*10) + MSEC

3060 RETURN

3080 END
```

BASIC PROGRAM USED FOR MAIN TASK SESSION

```
10 KEY OFF
20 REM
30 DIM BUFFER(1700),RDATA(2000,4)
40 DIM TCUES(1700), SRMAT%(2,2,10)
50 DEF FNTODEC(X).(X\16)*10 + X MOD 16
60 REM
70 NBL 3
100 REM
110 REM
120 INPUT "Which clock does this computer use: AST [1] or TECMAR [2]
130 IF COMP.NUM=2 THEN CADDR=637: DADDR=CADDR+2
140 IF COMP.NUM=1 THEN CADDR=893: DADDR=CADDR+2
150 SCREEN 2
160 REM
170 REM read in stimulus code file for this subject
180 INPUT "Low (L), High (H) or Normal (N) Event Rate Task?";G$
190 IF (G$="1") OR (G$="L") THEN NTR=150 ELSE NTR=300
200 IF (G$="1") OR (G$="L") THEN ISI=4000 ELSE ISI=2000
210 IF (G$="1") OR (G$="L") THEN SIG=90 ELSE SIG.180
230 INPUT "Subject stimulus file name:";SUBFILE$
240 OPEN SUBFILE$ FOR INPUT AS #1
250 FOR I = 1 TO NTR
260   INPUT #1,BUFFER(I)
270 NEXT I
280 CLOSE #1
290 REM cues files
300 OPEN SUBFILE$ FOR INPUT AS #1
310 FOR 1=1 TO NTR
```

```
320 INPUT #1,TCUES(I)
330 NEXT I
340 CLOSE #1
350 INPUT"Enter subject initials, age group and session #";SUBNAM$
360 DATAFILES=SUBNAM$+".res"
370 OPEN DATAFILE$ FOR OUTPUT AS #2
380 DS=SUBNAM$+".sum"
390 OPEN D$ FOR OUTPUT AS #3
400 REM now make identical stimulus codes for successive blocks
410 REM
420  FOR IB=2 TO 3
430 XX=NTR*(IB-1)
440 FOR I=XX+1 TO IB*NTR
450 BUFFER(I)=BUFFER(I-XX)
460 TCUES(I)=TCUES(I-XX)
470 NEXT I:NEXT IB
480 REM
490 INPUT "SIZE CONSTANT";SC
500 CLS
510 SCREEN 1
520 LOCATE 12,40:PRINT "VIGILANCE MAIN EXPERIMENT"
530 LOCATE 15,40:PRINT "PRESS SPACE BAR TO START"
540 X$=INKEY$:IF X$="" THEN GOTO 540
550 CLS
560 REM INSTRUCTIONS
570 LOCATE, 1:PRINT "You will now begin the main task"
580 LOCATE, 1:PRINT "session. Remember you are to detect"
590 LOCATE ,1:PRINT " as many smaller squares as possible."
600 LOCATE, 1:PRINT "Once again you are to press the space"
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610 LOCATE ,1:PRINT "bar as quickly as possible whenever you"
620 LOCATE, 1:PRINT "detect a smaller square. You will see"
630 LOCATE ,1:PRINT "a message instructing you to call your"
640 LOCATE, 1:PRINT "experimenter when the session is over."
650 PRINT
660 LOCATE ,10:PRINT "PRESS THE SPACE BAR TO CONTINUE..."
670 X$=INKEY$: IF X$="" THEN GOTO 670
680 CLS
690 REM
700 SCREEN 1
710 REM Task begins here
720 REM
730 LOCATE 10,40:PRINT "PRESS SPACE BAR WHEN READY TO START"
740 X$=INKEY$: IF X$="" THEN GOTO 740
750 SCREEN 2
760 CLS
770 REM
780 REM Trials begin here
790 REM
800 FOR TRIALS=1 TO NTR*NBL
810 REM
820 IB=INT((TRIALS-1)/NTR)+1
830 REM
860 Y=SC
870 X=CINT(2.55*Y)
880 OUT CADDR,21: OUT DADDR,1' clear clock
885 RESPTIME=O
890 IF TCUES(TRIALS)=1 THEN GOTO 980
900 IF TCUES(TRIALS)=2 THEN GOTO 1300
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910 IF TCUES(TRIALS)=3 THEN GOTO 1620
920 IF TCUES(TRIALS)=4 THEN GOTO 1940
930 IF TCUES(TRIALS)=5 THEN GOTO 1140
940 IF TCUES(TRIALS)=6 THEN GOTO 1460
950 IF TCUES(TRIALS)=7 THEN GOTO 1780
960 IF TCUES(TRIALS)=8 THEN GOTO 2100
970 CLS
980 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
990 GOSUB 2870
1000 IF XTIME <=150 THEN 990
1010 CLS
1020 GOSUB 2870
1030 IF XTIME <=500 THEN 1020
1040 LINE (510+X,70+Y)-(610-X,110-Y)„B
1050 GOSUB 2870
1060 IF XTIME <=800 THEN 1050
1070 CLS
1080 GOSUB 2870
1090 IF XTIME >=ISI THEN 2350
1100 V$=INKEY$
1110 IF V$=”" THEN 1080
1112 RESPTIME=XTIME
1120 GOSUB 2870
1130 IF XTIME >=ISI THEN 2350 ELSE 1120
1140 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
1150 GOSUB 2870
1160 IF XTIME <=150 THEN 1150
1170 CLS
1180 GOSUB 2870
```

```
1190 IF XTIME <=500 THEN 1180

1200 LINE (510,70)-(610,110),,B

1210 GOSUB 2870

1220 IF XTIME <=800 THEN 1210

1230 CLS

1240 GOSUB 2870

1250 IF XTIME >=ISI THEN 2350

1260 V$=INKEY$

1270 IF V$="" THEN 1240

1272 RESPTIME=XTIME

1280 GOSUB 2870

1290 IF XTIME >=ISI THEN 2350 ELSE 1280

1300 LOCATE 12,40:DRAW "al g15 u40 d40 al h15

1310 GOSUB 2870

1320 IF XTIME <=150 THEN 1310

1330 CLS

1340 GOSUB 2870

1350 IF XTIME <=500 THEN 1340

1360 LINE (50+X,70+Y)-(150-X,110-Y),,B

1370 GOSUB 2870

1380 IF XTIME <=800 THEN 1370

1390 CLS

1400 GOSUB 2870

1410 IP XTIME >=ISI THEN 2350

1420 V$=INKEY$

1430 IF V$="" THEN 1400

1432 RESPTIME=XTIME

1440 GOSUB 2870

1450 IF XTIME >=ISI THEN 2350 ELSE 1440
```

```
1460 LOCATE 12,40:DRAW "al g15 u40 d40 al h15
1470 GOSUB 2870
1480 IF XTIME <=150 THEN 1470
1490 CLS
1500 GOSUB 2870
1510 IF XTIME <=500 THEN 1500
1520 LINE(50,70)-(150,110),,B
1530 GOSUB 2870
1540 IF XTIME <=800 THEN 1530
1550 CLS
1560 GOSUB 2870
1570 IF XTIME >=ISI THEN 2350
1580 V$=INKEY$
1590 IF V$="" THEN 1560
1592 RESPTIME=XTIME
1600 GOSUB 2870
1610 IF XTIME >=ISI THEN 2350 ELSE 1600
1620 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
1630 GOSUB 2870
1640 IF XTIME <=150 THEN 1630
1650 CLS
1660 GOSUB 2870
1670 IF XTIME <=500 THEN 1660
16810 LINE (50+X,70+Y)-(150-X,110-Y),,B
1690 GOSUB 2870
1700 IF XTIME <=800 THEN 1690
1710 CLS
1720 GOSUB 2870
1730 IF XTIME >=ISI THEN 2350
```

```
1740 V$=INKEY$
1750 IF V$="" THEN 1720
1752 RESPTIME=XTIME
1760 GOSUB 2870
1770 IF XTIME >=ISI THEN 2350 ELSE 1760
1780 LOCATE 12,40:DRAW "al h15 d40 u40 al g15
1790 GOSUB 2870
1800 IF XTIME <=150 THEN 1790
1810 CLS
1820 GOSUB 2870
1830 IF XTIME <=500 THEN 1820
1840 LINE (50,70)-(150,110)„8
1850 GOSUB 2870
1860 IF XTIME <=800 THEN 1850
1870 CLS
1880 GOSUB 2870
1890 IF XTIME >=ISI THEN 2350
1900 V$=INKEY$
1910 IF V$="" THEN 1880
1912 RESPTIME=XTIME
1920 GOSUB 2870
1930 IF XTIME >=ISI THEN 2350 ELSE 1920
1940 LOCATE 12,40:DRAW "al g15 u40 d40 al h15
1950 GOSUB 2870
1960 IF XTIME <=150 THEN 1950
1970 CLS
1980 GOSUB 2870
1990 IF XTIME <=500 THEN 1980
2000 LINE (510+X,70+Y)-(610-X,110-Y)„B
```

```
2010 GOSUB 2870
2020 IF XTIME <=800 THEN 2010
2030 CLS
2040 GOSUB 2870
2050 IF XTIME >=ISI THEN 2350
2060 V$=INKEY$
2070 IF V$."" THEN 2040
2072 RESPTIME=XTIME
2080 GOSUB 2870
2090 IF XTIME >=ISI THEN 2350 ELSE 2080
2100 LOCATE 12,40:DRAW "al g15 u40 d40 al h15
2110 GOSUB 2870
2120 IF XTIME <=150 THEN 2110
2130 CLS
2140 GOSUB 2870
2150 IF XTIME <=500 THEN 2140
2160 LINE (510,70)-(610,110)„B
2170 GOSUB 2870
2180 IF XTIME <=800 THEN 2170
2190 CLS
2200 GOSUB 2870
2210 IF XTIME >=ISI THEN 2350
2220 V$=INKEY$
2230IF V$="" THEN 2200
2240 RESPTIME=XTIME
2250 GOSUB 2870
2260 IF XTIME >=ISI THEN 2350 ELSE 2250
2350 IF (V$<>"") THEN C3=0 ELSE C3=1
2360 RDATA(TRIALS,0)=IB:RDATA(TRIALS,1)=TCUES(TRIALS):RDATA(TRIALS,2
```

```
     (TRIALS,3)=RESPTIME
2361 IF TCUES(TRIALS)=1 THEN BUFFER(TRIALS)=0
2362 IF TCUES(TRIALS)=2 THEN BUFFER(TRIALS)=0
2363 IF TCUES(TRIALS)=3 THEN BUFFER(TRIALS)=0
2364 IF TCUES(TRIALS)=4 THEN BUFFER(TRIALS)=0
2365 IF TCUES(TRIALS)=5 THEN BUFFER(TRIALS)=1
2366 IF TCUES(TRIALS)=6 THEN BUFFER(TRIALS)=1
2367 IF TCUES(TRIALS)=7 THEN BUFFER(TRIALS)=1
2368 IF TCUES(TRIALS)=8 THEN BUFFER(TRIALS)=1
2370 IF BUFFER(TRIALS)=1 THEN GOTO 2390
2380 BUFFER(TRIALS)=0
2390 SRMATZ(BUFFER(TRIALS),C3,IB)=SRMATZ(BUFFER(TRIALS),C3,IB)+1
2400 GOSUB 2870
2410 IF XTIMB >=ISI THEN 2420 ELSE 2400
2420 NEXT TRIALS
2430 REM
2440 REM End of all blocks
2450 REM
2460 REM
2470 REM give performance feedback
2480 HIT!=0:FA!=0
2490 FOR IB=1 TO NBL
2500 HIT!= HIT!+SRMAT%(0,0,IB)
2510FA!=FAI+SRMAT%(1,0,IB)
2520 NEXT IB
2530  HIT!=HITUSIG
2540  FAI=FAMNBL*NTR - SIG)
2550 Xl=HIT!-FA!
2560 IF HIT!=0 THEN 2580
```

```
2570 APR!=.5 +(.25*X!*(1+X!)/(HIT!*(1-FA!)))
2580 CLS
2590 PRINT "END OF SESSION"
2600 PRINT:PRINT:PRINT "YOUR CORRECT TARGET DETECTION RATE WAS";100*
2610 PRINT:PRINT "YOUR FALSE DETECTION RATE WAS";100*FAl;"%"
2620 PRINT:PRINT "YOUR OVERALL DETECTION SCORE WAS";100*APR!;"%"
2630 PRINT:PRINT:
2640 PRINT "THANK YOU. PLEASE CALL THE EXPERIMENTER"
2650 X$=INKEY$:IF X$="" THEN 2650
2660 FOR I=1 TO NBL*NTR
2670 PRINT #2,RDATA(I,0),RDATA(I,1),RDATA(I,2),RDATA(I,3)
2680 NEXT I
2690 REM close subject data files
2700 CLOSE #2
2710 FOR IB=1 TO NBL
2720 PRINT #3,"Response":PRINT #3," NS S":PRINT #3," - -ft
2730 PRINT #3,"NS";SRMAT%(1,1,IB);SRMATU1,0,IB)
2740 PRINT #3,"S";SRMATU0,1,IB);SRMATUO,O,IB)
2750 PRINT
2760 NEXT IB
2770 CLOSE #3
2780 FOR IB=1 TO NBL
2790 PRINT "Response":PRINT " NS S":PRINT " - - -
2800 PRINT "NS";SRMATZ(1,1,IB);SRMATZ(1,0,IB)
2810 PRINT "S ";SRMATZ(0,1,IB);SRMATUO,O,IB)
2820 PRINT
2830 X$=INKEY$: IF X$="" THEN GOTO 2830
2840 NEXT IB
2850 CLOSE #3
```

```
2860 END
2870 REM subroutine time
2880 OUT CADDR,0: MSEC=INP(DADDR)
2890 OUT CADDR,1: THSEC=INP(DADDR)
2900 OUT CADDR,2: SEC=INP(DADDR)
2910 XTIME=(FNTODEC(SEC)*1000) + (FNTODEC(THSEC)*10) + MSEC
2920 RETURN
2930 END
```