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The Role of Attentional Resources in Automatic Detection

Report No. 8101 ✓

James E. Hoffman and Billie Nelson
Department of Psychology
University of Delaware • Newark, Delaware 19711

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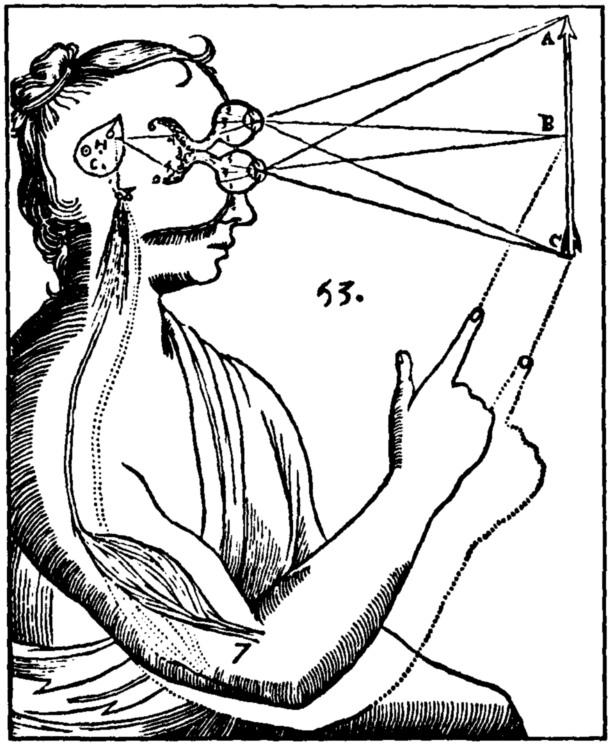

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A series of experiments investigated the question of whether automatic detection of visual targets requires the investment of attentional resources. Subjects were required to perform an automatic target detection task in conjunction with three different concurrent visual discriminations. Subjects were only able to increase their accuracy on the concurrent task at the expense of decreasing performance on the automatic task, indicating that automatic detection requires the voluntary investment of a limited resource.

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20. One component of the limited resource required by the automatic detection process is the spatial attention system. When attention was in a "distributed state", automatic targets were able to capture the spatial attention system resulting in decreased performance on the concurrent task (the intrusion effect) and increased acuity for forms occurring near the automatic target. In contrast, when attention was "focussed" on a display area removed from the automatic target, the intrusion effect was eliminated and automatic detection accuracy declined.

Automatic detection is a process that requires the use of limited mental resources. Its speed and apparent lack of flexibility reflect the ability of automatic targets to capture a share of those resources which are unused by other concurrent mental activities.

The role of attentional resources in automatic detection

James E. Hoffman and Billie Nelson
University of Delaware

Abstract

A series of experiments investigated the question of whether automatic detection of visual targets requires the investment of attentional resources. Subjects were required to perform an automatic target detection task in conjunction with three different concurrent visual discriminations. Subjects were only able to increase their accuracy on the concurrent task at the expense of decreasing performance on the automatic task, indicating that automatic detection requires the voluntary investment of a limited resource.

One component of the limited resource required by the automatic detection process is the _spatial attention system_. When attention was in a "distributed state", automatic targets were able to capture the spatial attention system resulting in decreased performance on the concurrent task (the intrusion effect) and increased acuity for forms occurring near the automatic target. In contrast, when attention was "focussed" on a display area removed from the automatic target, the intrusion effect was eliminated and automatic detection accuracy declined.

Automatic detection is a process that requires the use of limited mental resources. Its speed and apparent lack of flexibility reflect the ability of automatic targets to capture a share of those resources which are unused by other concurrent mental activities.

This paper is concerned with the question of whether highly practiced and presumably automatic mental activities require the investment of attentional resources for their successful completion. We show that both the accuracy and speed of an automatic detection process can be severely impaired when the subject must make simultaneous visual discriminations. The degree of impairment depends, in part, on the extent to which both tasks allow for a sharing of "visual attention".

What are the limits to people's ability to process simultaneous sensory inputs? And given that a choice of signals must be made, at what level of sensory analysis does it occur? These are the questions that have motivated much of the research on attention over the past 25 years. We will not attempt to review the extensive literature dealing with these questions, especially since excellent reviews are already available (c.f., Kahneman, 1973; Schneider and Shiffrin, 1977; Duncan, 1980). Instead we will describe what is probably the currently accepted view of attention, critically examine the evidence that appears to support it, and finally describe an alternative approach. This alternative view has implications for the issue of whether attention affects "early" or "late" processing stages as well as the distinction between automatic and controlled modes of information processing (Schneider and Shiffrin, 1977). These implications are tested in a series of four experiments.

Capacity limitations in human information processing

Considerable evidence supports the following characterization of the perceptual processing system. The many simultaneous signals that are arriving at the receptors, for example, different visually presented forms, activate corresponding nodes in a long-term memory. This mapping process is a parallel, unlimited capacity, content-addressable matching operation that can be thought of as a resonance of the memory node with the signal (Ratcliff, 1978). This initial activation represents a variety of perceptual information about the presented signal such as its spatial location, color, size, etc.

The activity in memory nodes has two important properties. First, the activation spreads to neighboring nodes through associative links (Collins and Loftus, 1975) so that "semantic" information about the signal is automatically activated due to the mere presentation of a previously learned pattern. The second important characteristic of node activation is that it is transient and decays rapidly (perhaps less than a second). Information can be preserved and presumably enter into conscious awareness only if it is brought into working memory (Baddeley & Hitch, 1974). Working memory is so named because it is here that subjects may bring to bear a variety of control processes which are responsible for preserving information, integrating it into the long-term memory network, and making decisions. Working memory is inherently a slow, limited capacity, serial device that serves as a control center for the vast amounts of information arriving in parallel.

The coupling of an unlimited capacity pattern recognition stage with a limited capacity short-term memory is the "late"-selection model of attention. This model suggests that instructions to attend to one signal source and ignore another affects which of the already recognized messages gains the services provided by short-term memory. For example, suppose that one set of locations in visual space is designated to be more important than others. This is the situation in the partial report paradigm (Sperling, 1960) in which the observer receives a cue specifying a subset of visually presented forms to be retained for later report. This cue is usually spatial and designates a row or location of the display. The observer follows instructions by rapidly scanning through the set of activated long-term memory nodes checking each one for the presence of the desired "location tag". Only those passing this test are allowed into working memory where maintenance control processes ensure they will be retained for the several-second period before report. In this model, physical cues such as spatial location or color do not allow for a different kind of selection than other cues such as category differences (e.g., letters vs. numbers). It may only appear so because investigators have not attempted to match discriminability of semantic or category cues with the rather large physical discriminability differences usually employed in research on attention (Duncan, 1980).

Empirical support for late selection

There are two separate claims made by the late-selection model that merit examination. One claim is that processing of sensory information consists of two separable stages: a parallel activation of long-term memory representations followed by a distinctly serial process identified with short-term memory. The second claim is that voluntary attentional mechanisms can only influence second-stage processing. Our review of the evidence suggests that the first claim is supported but that there are good reasons to doubt the validity of the second claim. To anticipate our conclusions, it appears that the initial stage is a parallel activation of long-term memory nodes in which the strength of activation is determined by a combination of factors: the physical characteristics (energy, size, etc.) of the signal, the amount of attention allocated to the signal, and the degree to which the signal matches the expectations generated by the subject. These factors influence the clarity of representation of signals. This representation forms the basis for decisions and overt responses that are controlled by routines in short-term memory. According to this hybrid view, selective attention can operate at both the first and second processing stages and these effects can be observed separately with suitable experimental operations.

Consider first the evidence that is taken as supporting the traditional late-selection model. The most compelling evidence comes from experiments showing that material that subjects are told to ignore, in fact influences their behavior. Words in the to-be-ignored channel can intrude into the shadowed channel when they are "important" (Moray, 1959). They can also serve to aid in the interpretation of ambiguous words in the shadowed or attended channel (Mackay, 1973). In addition, unattended shock conditioned words can produce GSR's even when subjects report no awareness of their occurrence (Corteen & Dunn, 1974).

These findings clearly indicate that material that subjects are instructed to ignore is in fact processed to a fairly "deep" level. Since the subject's short-term memory is occupied by material from the attended message, effects of unattended material must arise from spreading activation in the memory network initiated by first-stage processing. A demonstration that unattended material is processed in a situation where one is reasonably confident that short-term memory is fully occupied with an attended message serves as a basic experimental separation of the two different processing stages.

Atkinson and Juola (1974) provided a very clear example of separation of processing stages. They reasoned that if a memory node had been recently activated, residual activity in that node could combine with activity evoked by presentation of the corresponding sensory input. The resultant activation level of the node itself could then serve as an indicator, for example, of the presence or absence of an item on a previously memorized list. Thus, a recognition decision could be made on the basis of activation level and the slower serial matching routines provided in working memory could be bypassed. A quantitative version of the model provided an excellent account of a variety of recognition memory experiments.

Hoffman (1978, 1979) extended this model to the case when more than one input signal is presented simultaneously, i.e., visual search. We will refer to this model as the similarity ordered search (SOS) model. Along with Atkinson and Juola (1974), he assumed that the initial activation of memory nodes could serve as the basis of recognition decisions; if activation levels were insufficient for a decision, information was passed to working memory for a slower but more accurate comparison process. The new assumption was that the order of entry to working memory was determined by the activation levels, the highest activity items being passed first. This assumption allowed the model to predict two interesting results. First, the model gave a quantitative description of the fact that subjects can accurately detect targets in fast sequential presentations under conditions in which the speed of comparisons in working memory would impose severe restrictions (Sternberg and Scarborough, 1969; Hoffman, 1978). Second, it predicted that if subjects were attempting to detect signals from two independent sources, the major interference would occur in processing simultaneous targets. This is in fact a very general finding. Duncan (1980) has recently reviewed these results and concluded that targets gain entry to working memory in preference to distractors.

Automatic vs. controlled processing

Hoffman (1978, 1979) assumed that extensive training with the same memory set would gradually result in all of the detection decisions being based on the results of the parallel activation stage. Since this stage is inherently parallel, search decisions would no longer require that each display form be examined in working memory. It should be noted that this assumption does not mean that search accuracy will be independent of the number of inputs. As Eriksen and Spencer (1969) and Kinchla (1974) have pointed out, increasing the number of inputs increases the "noise" in the decision process and lowers detection even if all inputs are processed in parallel and independently. A parallel analysis of signals does predict, however, that detection should be independent of the rate at which inputs are presented, assuming that masking, acuity, and other peripheral factors are held constant. This result was in fact reported by Eriksen and Spencer (1969) and Shiffrin and Gardner (1972).

Schneider and Shiffrin (1977) have recently shown that when a subject continually searches for the same set of targets in the same set of distractors (a training schedule they called consistent mapping or CM), search speed does become <u>relatively independent</u> of the number of inputs. By comparison, periodically exchanging the roles played by target and distractor items (known as varied mapping or VM) produces a slow serial search for the target. They suggested that CM training leads to automatic detection while VM training leads to controlled detection. Consistent with results reviewed previously, automatic detection reflects the operation of the initial parallel activation stage while controlled processing makes extensive use of the comparison operations available in working memory. Thus the distinction between controlled and automatic detection is taken as representing another experimental separation of the two different processing stages.

Empirical support for early selection

The evidence reviewed to this point suggests two conclusions. First, it appears that it is possible to experimentally separate effects occurring at two different processing stages: a parallel pattern recognition process and a decision process. Second, attended material appears to dominate short-term memory resources while unattended material maintains access to first-stage processing.

A further examination of the evidence, however, suggests that attention to a message source may also affect the quality of the representation produced by first-stage processing, contrary to the tenets of the traditional late-selection model. Recall that in our discussion of the role of selectivity in the late-selection model, we pointed out that instructions informing a subject that some spatial locations were more important than others determined which of the several available inputs were to be transferred to working memory. But suppose that only one input is presented. According to the late-selection model, knowing the spatial position in which this input is going to appear should not be advantageous because there is only one input to be transferred to working memory. Shaw and Shaw (1977) found that, to the contrary, knowing the likely position of a single letter improved recognition accuracy. Similar effects of attention on recognition and detection latency and accuracy have been reported by Bashinski and Bacharach (1980), Eriksen and Hoffman (1974), and Posner (1980). These results suggest that attending to a position in space may improve the initial representation of signals occurring in the attended location, contrary to the assumptions of the late-selection model.

A second class of experiments shows that interference produced by simultaneous messages can be decreased by increasing spatial separation of message sources. Consider two related paradigms: the Stroop effect (Stroop, 1935) and the spatial adjacency interference effect. In the Stroop effect, subjects required to name the color in which a word is printed are slow when the word itself spells a different color name. This may be due to automatic activation of the word's name code which provides interference at the response level with the naming of the ink color. In the spatial adjacency interference effect (Eriksen and Hoffman, 1973; Eriksen and Eriksen, 1974), subjects are required to make a speeded response indicating which of two target letters is present in a position in space. In general, if positions adjacent to the target position contain opposite-response targets, interference occurs.

These experiments present a problem for the late-selection model they demonstrate a reduction of interference with spatial separation: in the Stroop paradigm (Egeth, 1977), if the ink color and color word are spacially separated; and, in the spatial adjacency paradigm, if the interfering letters are separated in the display. It is not clear why spatial separation should matter if interference is due to an automatic activation of responses that is not under attentional control.

Suppose that we change our theory of the Stroop effect and move the source of interference to the working memory stage where selection is allowed to occur in the late-selection model. How can we explain the Stroop effect as well as spatial adjacency interference if selection takes place in working memory? Perhaps, in the color task the subject brings the wrong feature of the stimulus into working memory to produce a response. In the case of adjacent letters, this interpretation would suggest that on some proportion of trials, the subject fails to bring into working memory the attended letter but instead transfers an adjacent letter. This interpretation was effectively ruled out by a recent experiment (Eriksen and Eriksen, Note 1) in which the subject was given memory sets of different sizes and made a speeded recognition response to a centrally fixated letter (a probe). Reaction time (RT) is generally a linear function of set sizes with equivalent slopes for both matching (positive) and nonmatching (negative) probes (Sternberg, 1969). If a negative probe is surrounded by letters from the positive set, interference occurs, i.e., correct negative responses are slower when they are surrounded by conflicting letters than when they are flanked by same set letters or when they appear alone. Suppose this interference was due to the subject occasionally entering an adjacent letter into working memory for comparison and, after completion of the comparison process, repeating the operation on the correct letters. This model is, in fact, an appropriate description when all of the letters are potential targets (Schneider and Shiffrin, 1977). It predicts that the slope of the RT vs. memory set size function should be greater when a target is flanked by other letters than when it occurs alone. Eriksen and Eriksen (Note 1), however, found a large interference effect that was the same for all set sizes; i.e., the intercept but not the slope of the RT vs. memory set size function was increased by conflicting letters.

The Eriksen and Eriksen results suggest that to-be-ignored letters in the spatial adjacency interference paradigm exert their interfering effects "outside" working memory. It seems likely that interference arises because an unattended form activates its corresponding long-term memory node which in turn produces the response tendencies appropriate for that letter (Eriksen and Schultz, 1979). Since moving the interfering letters more than a degree of visual angle from the attended form eliminates their interfering effects, it must be concluded that a letter falling outside the field of attention produces a weaker initial activation in stage one processing.

We should note that the Eriksen and Eriksen (Note 1) result has some generality. Hoffman (1980) presented subjects with large letters composed of small letters. When subjects were to base their recognition decision on one level of the form (e.g., "Is the large letter a member of the memory set?") conflicting information on the to-be-ignored level provided interference. As in the Eriksen and Eriksen study this interference produced an increase in the intercept of the RT vs. memory set size function. However, if the form on the to-be-ignored level was slightly distorted, the interference was eliminated. If interference occurred because the subject sometimes brought the wrong form into working memory, we would expect a reduction in the speed of the comparison operation with distorted forms and consequently an increase in the latency of responding to the attended form. Distortion of forms did cause an increase in latency when both forms were relevant to the decision.

The effect of distortion on response latency provides another experimental separation of effects due to operations at the parallel activation stage and comparison operations occurring in working memory. Distortion of a to-be-ignored form speeds responses to attended information while slowing the comparison operation in working memory when it is relevant to decisions. These results, together with the results of the Eriksen and Eriksen (Note 1) study, suggest that interference provided by conflicting information in the to-be-ignored display areas arises at the parallel activation stage. The magnitude of interference is affected by the allocation of attention and the clarity of the form. We conclude that the parallel activation stage can itself be influenced by attention.

A reexamination of the conditioned GSR literature leads to much the same conclusion. An implicit assumption in the GSR experiments is that the magnitude of the GSR reflects the degree of activation of the memory node representing the conditioned word. That is, the GSR reflects the operation of the parallel activation stage and not the operations in working memory. This is supported by the finding that when the subject is searching for a previously conditioned word, a GSR is evoked even on trials when the subject fails to detect its presence (Corteen and Dunn, 1974). The general finding of these studies is that although conditioned words in a "nonattended" message evoke GSR's, the magnitude of the GSR is less than when the word appears in the "attended" message (Forster and Govier, 1978; Von Wright, Anderson, and Stenman, 1975). These results once again implicate the role of attention in the degree of activation of memory nodes produced by the initial encoding process.

Automatic and controlled processing

Finally, consider once again the distinction between controlled and automatic processes. Shiffrin and Schneider (1977) explicitly take this distinction as reflecting the separation of the parallel activation stage and working memory. They suggest that presentation of a CM target automatically and without any capacity limitation, activates its corresponding node in long-term memory. This activation can in turn trigger other nodes leading to the production of an overt response. Thus the entire sequence of processing operations from presentation of the stimulus to production of the overt response may occur automatically and without any use of working memory. One consequence of this assumption is that automatic processes may be conducted in conjunction with other tasks that rely on control processes without mutual interference.

A slightly different perspective is offered by Hoffman's (1978, 1979) account of automaticity. In the SOS model it was assumed that automatic detection responses can be based on the evidence gathered at the parallel activation stage. This evidence, however, might still have to be examined in working memory for the purposes of making a decision and producing a response. Two findings suggest that, in fact, automatic detection does require use of working memory. Hoffman, Nelson, and Laubach (Note 2) found that production of both VM and CM search responses was delayed when the subject was required to make a difficult visual discrimination at the moment the search array was presented. At the very least then, the production of overt responses in automatic detection can be interfered with when the subject's working memory is engaged in making concurrent decisions.

A second source of evidence indicating that automatic detection responses require the use of decision processes in working memory is some preliminary results we have obtained using averaged cortical evoked potentials (AEPs) (Hoffman, Simons, and Houck, Note 3). The P300 component of the AEP appears to be related to conscious decision processes in a wide variety of information processing tasks (Donchin, Ritter, & McCallum, 1978). We have observed virtually identical P300's for both automatic and controlled detection. To the extent that P300 is a measure of decision processes in working memory, this result indicates that both controlled and automatic detection require the use of this resource.

These results together suggest that even if the parallel activation stage is responsible for producing the evidence on which automatic detection is based, this evidence must still be examined in working memory for the purpose of making a detection decision and producing a response. This characterization of automatic detection is compatible with Hoffman's (1978, 1979) description of automatic detection, but another aspect of automatic detection is in conflict with this model. Shiffrin and Schneider (1977) found that when CM trained targets occurred in areas of the display that subjects were to ignore, these targets produced disruption of ongoing controlled search. It is clear from their description of this phenomenon as well as our own observations that the disruption is due to attention being involuntarily drawn to the <u>position of the CM target</u>. Recall that according to the SOS model of search, information about targets provided by the first stage determined the order of entry of display letters into the second stage of working memory.

The SOS model is capable of predicting that VM targets occurring in unattended positions sometimes gain access to short-term memory ahead of attended items. Such effects should not occur for CM targets, however, because automatic detection need not rely on short-term memory.

The "automatic attention response" described by Shiffrin and Schneider (1977) suggests that controlled and automatic detection may have more in common than their reliance on working memory. Shiffrin and Schneider (1977) describe a weaker form of the automatic attention response that is produced when VM targets occur in areas of the display that are to be ignored. Specifically, interference occurs when a member of the memory set occurs in a to-be-ignored part of the display prior to onset of the display having a VM target in a valid display position. In the CM version of this automatic attention response, interference occurs when the CM distractor occurs in either the same frame or the frame following that containing the VM target. These observations provide the key to understanding the role of spatial attention in the distinction between automatic and controlled detection.

The role of spatial attention in automatic detection

The foregoing discussion suggested that it is useful to assume that there are two levels of processing: a parallel activation of long-term memory nodes by sensory patterns and a limited capacity working memory. We described several paradigms that attempt to separate effects occurring at these two different levels and concluded that a critical reading of this evidence indicates that voluntary attention to positions in space can affect the degree of activation produced by forms occurring in attended areas. That is, attention can affect "early" processing of signals. We are now ready to consider how the last paradigm that provides separation of levels, the distinction between automatic and controlled detection, also leads to this conclusion. We will attempt to show that the allocation of spatial attention affects automatic detection, a process that presumably reflects the operation of the parallel activation stage.

We will take the SOS model and attempt to modify it in line with the implications of the preceding discussion. Assume that there is a parallel activation stage in which the degree of activation produced by an input is a function of the attention allocated to the spatial position of that input. In the visual search situation, the subject starts with attention "distributed" over the visual field because there is uncertainty as to the location of the target. Presentation of the display causes parallel activation of long-term memory nodes corresponding to each form in the display. If at some point, the buildup of activation exceeds some threshold, visual attention is shifted to the location of high activity, further improving the representation of information in that area. Following this activation stage, the accumulated information in each position is transferred to working memory where a decision is made as to the presence of a target. As in the SOS model, we assume that forms producing the highest activation level are transferred first.

The principal difference between automatic and controlled detection is that consistent mapping training produces a high activation level in those memory nodes corresponding to targets. This means that presentation of a CM target will cause a rapid allocation of attention to the target's position producing fast and accurate detections. This also provides the mechanism by which to-be-ignored CM targets may interrupt controlled search even when they are presented after the VM display.

We assume a similar process operates in VM search. Rehearsal of the memory set items produces temporary activation of memory nodes and a relatively weak and slow attention response. In this case, VM targets in invalid display positions can cause interference only when they precede presentation of the valid display items. There is additional experimental evidence to support this claim. Hoffman and Nelson (Note 4) found that discriminability of an acuity target occurring next to a VM target was better than when the acuity target occurred adjacent to distractor positions. This is precisely what would be expected if the VM target triggered a shift of attention which, in turn, improved the perceptual processing of signals within the "attentional field".

In this view, both automatic and controlled detection utilize switching of spatial attention to improve perceptual processing of targets and both rely on the comparison and decision making processes in working memory. The principal difference between the two processing modes is that automatic detection quickly and reliably triggers attention shifts while VM training results in a slower and less reliable shifting of attention.

Measuring resource utilization in automatic detection

We have suggested that automatic detection requires the use of two different resources: visual attention and working memory. One way to evaluate the resources required by a task is to examine the pattern of interference that results when this task must be performed in combination with another task. The dual task situation used in the first experiment is shown in Figure 1 and is similar to one used by Hoffman, Nelson, and Laubach (Note 2).

Insert Figure 1 About Here

The search task is similar to that employed by Schneider and Shiffrin (1977) in their initial demonstration of automatic detection. The subject is required to determine whether or not a digit target is present in a display of letter distractors. The frame that may contain the target is preceded and followed by masking frames. The other task is flicker location in which the subject is required to determine the location at which one of four light points is briefly interrupted.

In different conditions, the subject is instructed to emphasize one or the other task (e.g., "give 90% of your attention to the search task and 10% to the flicker task"). The resulting trade-off in performance of the two tasks as instructions are varied defines a performance operating characteristic (Sperling and Melchner, 1979; Navon and Gopher, 1979) or POC. If these two tasks do not require any common resource, then dual dask performance should be equal to the respective single task performances. The degree of departure of the POC from this "independence point" indexes the degree of interference

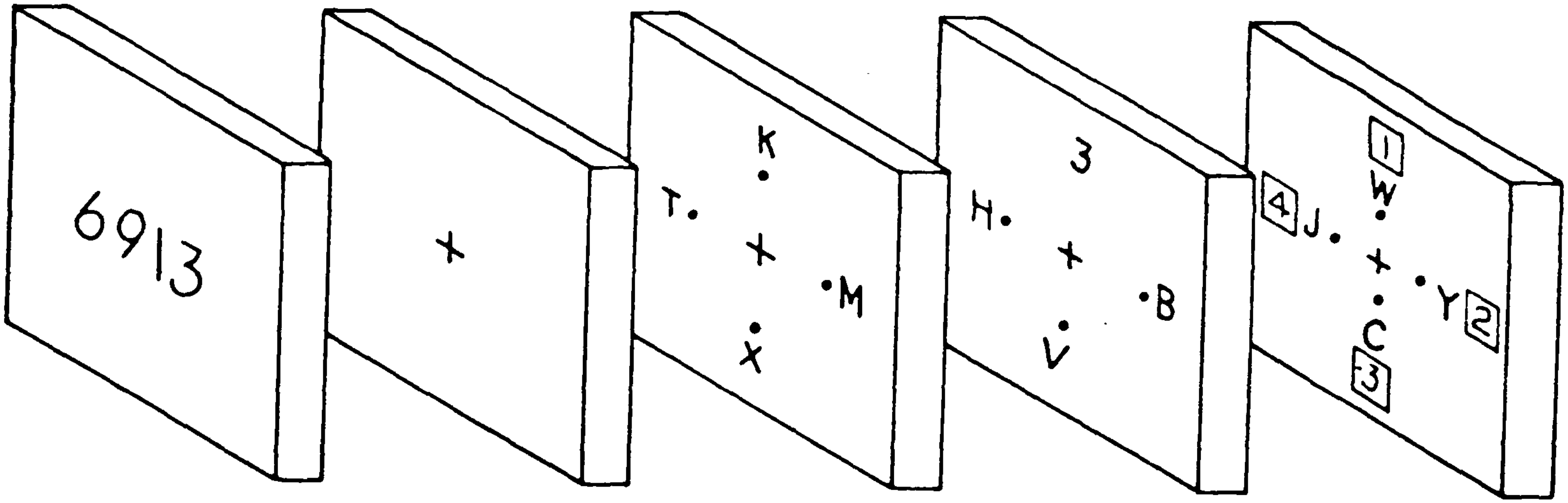

Figure 1: Sequence of events occurring on each trial of Experiment 1. Following presentation of the memory set the subject viewed three arrays: a premask, a target array, and a postmask. In dual task conditions subjects were required to determine whether a digit was present and which of four light points was briefly extinguished.

between the two tasks. We hypothesized that these two tasks compete for working memory and therefore we expect that the POC will depart from the independence point.

The degree to which the two tasks are competing for a spatial attention mechanism can be assessed by looking at *spatial adjacency effects*. The flicker task should have the ability to automatically trigger an attention shift to the spatial area of the flicker. If the location of spatial attention plays a role in automatic detection of the digits, we should find superior performance on the digit detection task when its target is adjacent to the flicker location. When the flicker and digit target occur in different spatial positions, a conflict in allocation of attention occurs and both tasks should suffer.

Criteria for automaticity

In attempting to measure the resource demands of automatic tasks, it is obviously important to have a definition of "automaticity." Unfortunately, even in the case of visual search tasks there is no *single* unambiguous criterion defining automaticity (Schneider and Shiffrin, 1977). We will look for the following features in our data as evidence that search has become automatic. Search should show relatively small effects of load. As pointed out earlier, even automatic tasks should continue to show effects of the number of possible target/display letter comparisons for purely statistical reasons. In most studies of automaticity, the RT vs. load function has a slope of about 10 msec/item (Schneider and Shiffrin, 1977). Also, significantly above chance performance can be obtained with short display durations, in the neighborhood of 100 msec, with a 4 item display and a a 4 item memory set.

A second feature of automaticity is what we will call the intrusion effect which is the decrement in performance of a controlled task when a CM target is present. The intrusion effect occurs even when the subject is told to ignore CM targets and is further evidence of the automaticity of the search task.

A third feature of the data indicative of automaticity is stability in RT over sessions. We assume that if load effects and absolute RT are not changing over sessions despite continued CM training then the task is automatic or as automatic as it is likely to become.

A final criterion of automaticity proposed by Logan (1978, 1979) is that one of two tasks is automatic if the effects of load on the RT of one task remain the same when the task is performed under dual task conditions.

Experiment 1

Method

Subjects. Subjects were 3 males and 3 females with normal or corrected to normal vision who were paid for their participation. The same subjects served in all the experiments to be reported.

Apparatus and Stimuli. Presentation of visual displays and timing were provided by a Plato V terminal which has a plasma panel screen. Timing was provided by the terminal's micro-processor, and had a period of approximately 7 msec. Letters and masks were .35° x .27° of visual angle in height and width respectively and were defined on a 9 x 7 dot matrix. Digits were slightly smaller, defined on an 8 x 5 dot matrix subtending .32° x .20° visual angle. Four letters appeared in a circular display with a diameter of 4.27° of visual angle. The light points used for the "flicker" task were defined on 2 x 2 dot matrices with visual angles of .08° x .08° and were always plotted .17° toward the center of the circle from each letter/digit. Subjects responded by pressing keys on a typewriter style keyboard.

The luminance of a blank screen was .2 ft-L while a fully illuminated screen produced a luminance of 6.5 ft-L.

Procedure. Each subject served in 8 sessions. Each session consisted of 5 blocks of 64 trials. The display sequence was similar in each block, and the blocks differed only in instructional condition. Before each trial, subjects were shown either 1 digit or 4 digits to remember. Each trial display then contained either four letters, or three letters and one of the digits. At the onset of the digit search display, one of the light points used for the "flicker" task was extinguished briefly. Subjects were first required to indicate whether the digit was present or not present in the trial display, and then to locate the light point that flickered. Both responses were made by means of the keyboard.

In one of the blocks, subjects performed only the digit search task; in another block only the flicker detection was required. In the remaining three blocks, subjects were asked to divide their attention between the two tasks in one of three ways: 90% digit search/10% flicker detection; 50% search/50% flicker; 10% search/90% flicker. Subjects were told to perform the search task as quickly and accurately as possible, with accuracy stressed over speed. The order of blocks within a session was random, with the constraint that across sessions each block be represented as equally as possible in the ordering.

On each trial, the subject was first presented with the memory set which remained on view until a key press initiated the following sequence. A fixation cross appeared in the center of the screen for 1 second followed by a sequence of 3 arrays. A typical sequence is shown in Figure 1. A set of 4 pre-masks appeared for 500 msec, and then were replaced by the target array of letters/digit. The duration of the target array was dependent on each subject's digit search performance in preliminary tracking trials. The postmask letter array then replaced the target array and remained in view until a response occurred. Coinciding with the target array onset, one of the light points was extinguished for a brief time determined by a second set of preliminary tracking trials performed on this flicker location task. The tracking manipulated the display or flicker duration so that a subject's performance would approximate 75% accuracy on each single task. Each subject was required to do 24 trials of each task to satisfy this preliminary tracking procedure each session. The digit display duration averaged across subjects and sessions, was 156 msec with a range for individual subjects of 111 to 225 msec. The flicker duration was 67 msec with a range of 40 to 103 msec for individual subjects. At the end of every trial the subject received feedback concerning the accuracy of response on each task. No RT feedback was provided.

Subjects initiated each trial with the left hand and indicated whether the digit was present or not present in the display by pressing the appropriate key with the right hand. In blocks devoted only to the flicker location task, the subject was similarly required to execute a motor response with the right hand. In this instance the right hand key press only brought to the screen a displav of numbered boxes adjacent to display positions. The subject indicated the flicker position by pressing the appropriately numbered key.

A consistent mapping procedure was used for the search task. The memory set was taken randomly from the digits 1-9, and the distractor letters from the set [B, D, F, H, N, P, R, V]. Pre- and postmask letters were selected randomly without replacement from the remaining letters of the alphabet.

Within each memory set condition, there were equal numbers of trials in which the digit was present or absent in the display. When present, the digit was assigned randomly but equally to each of the four positions. Flicker position was also randomly and equally selected; and, for those trials with the digit present, an additional constraint was made that the flicker occur equally in all positions relative to the digit. Within each block then, the spatial positions of the digit and the flicker were independent.

Results

Performance operating characteristics

The hit rate/false alarm rate combinations for search performance were used to compute d' measures assuming equal variance, normal distributions of signal and signal plus noise[1]. Figure 2 shows the performance operating characteristic (POC) relating discriminabilities on the search and flicker location tasks. Control performance for each task is indicated by points on the axes. The independence point is defined as the intersection of a horizontal line through a point on the ordinate with a vertical line through the point on the abscissa. The main conclusion to

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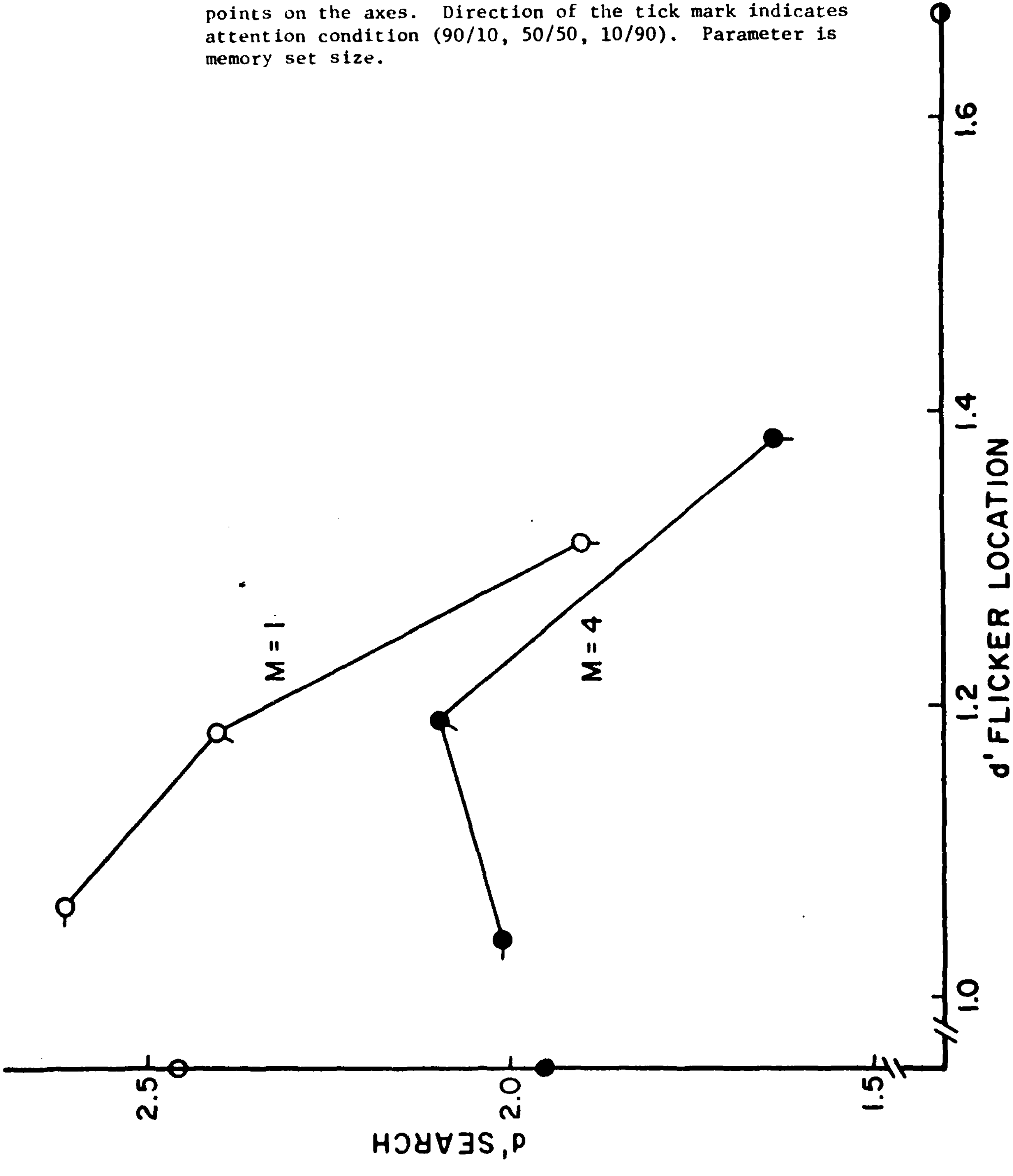
Insert Figure 2 About Here

Figure 2: Performance operating characteristics showing the relations between accuracy on the search task and accuracy on the flicker location task for Experiment 1. 100% attention performance is shown by points on the axes. Direction of the tick mark indicates attention condition (90/10, 50/50, 10/90). Parameter is memory set size.



be drawn from Figure 2 is that the POC's for both memory set sizes are substantially below the independence point indicating that these two tasks are engaged in competition for a limited resource.

Analysis of variance on the search data revealed significant effects of instructions, F(3,15)=5.4, p<.01 and memory set size, F(1,5)=20.4, p<.01. The interaction was not significant, F(3,15)=2.3, p>.05. An analysis of the flicker data revealed significant effects of instructions, F(3,15)=12.8, p<.01. The effect of search memory set size on flicker performance was not significant in the three dual task conditions, F(1,5)<1.

Figure 3 shows a POC using correct reaction time as a measure of search performance. The POC is approximately linear for both set sizes. In addition, the effect of memory set size on search RT is about the same at each instructional condition. This pattern of additivity has been proposed by Logan (1978) as evidence that one or both tasks are automatic in the sense that they are not sharing the same limited resource simultaneously. We will apply a different interpretation in the discussion. It is interesting to note that the data from the Hoffman, Nelson and Laubach (Note 2) study can be located on this POC. They found that dual task conditions produced a decrement in flicker accuracy of about .78 d' units accompanied by an increase in search RT of 185 msec. This is quite close to the 90% search, 10% flicker point in the present study which produced corresponding values of .62 d' units and 180 msec. In the previous study, secondary task instructions were used in which subjects were told to "protect" their search performance and use spare capacity for the

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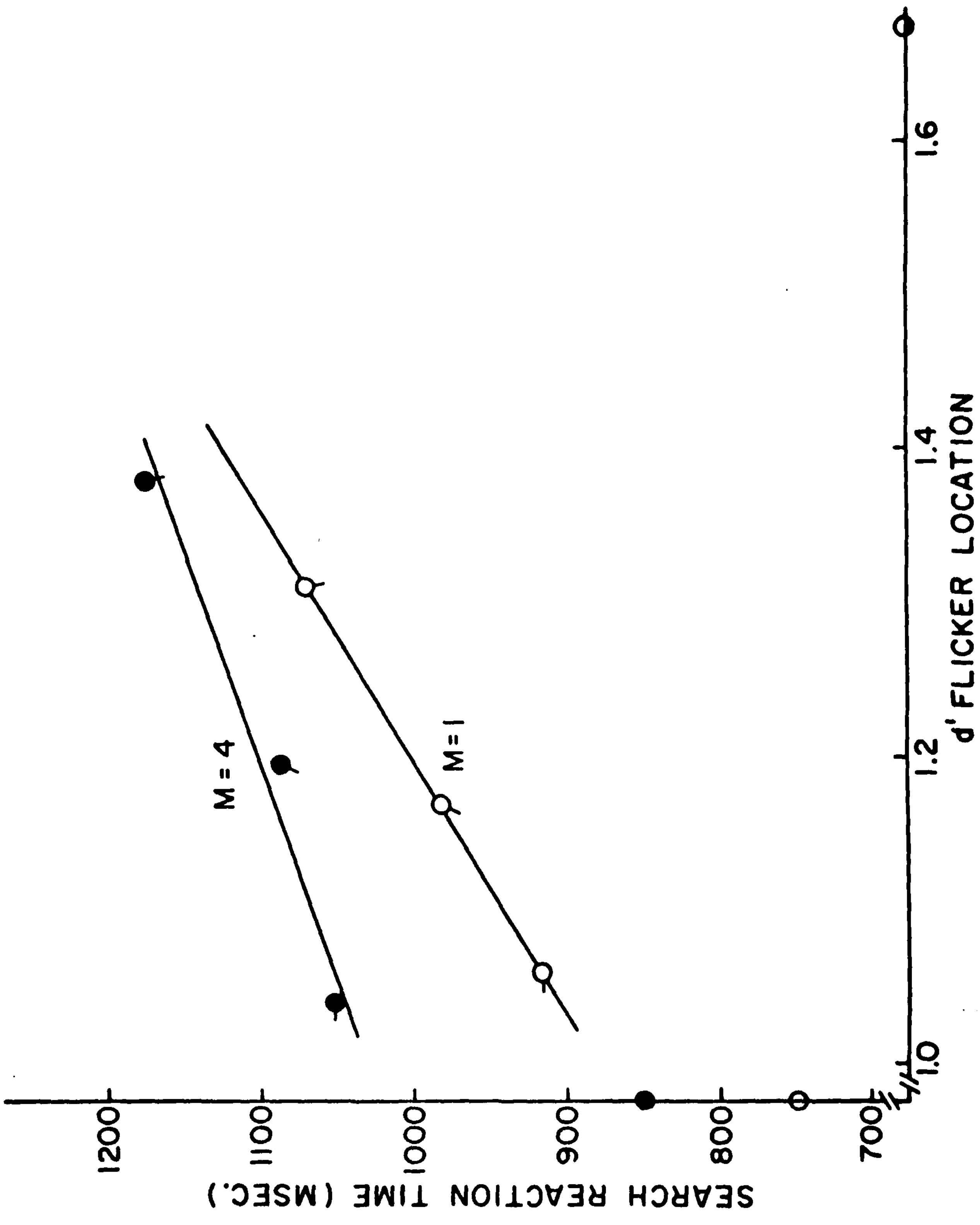
Insert Figure 3 About Here

Figure 3: Performance operating characteristic showing the relation between correct search reaction time and flicker location accuracy for Experiment 1.



flicker task. As is often found in secondary task experiments, the primary task could not be protected. These results suggest that there is a "concurrence cost" (Navon and Gopher, 1979) involved in performing these two tasks. That is, a certain amount of processing resources are consumed in simply coordinating the two tasks.

An analysis of variance confirmed that instructions significantly affected search RT, $F(3,15)=21.5$, $p<.01$ as did memory set size, $F(1,5)=15.3$, $p<.05$. The interaction did not approach significance, $F(3,15)<1.0$. The effect of increasing memory set size from one to four is about 110 msec. Dividing this value by the change in load of 12 items gives an estimated slope of about 9 msec/comparison.

The intrusion effect.

Table 1 shows flicker accuracy contingent on the presence or absence of a digit in the display. Flicker accuracy is clearly worse in the presence of a digit, $F(1,5)=18.5$, $p<.01$ and this holds true for all instructional conditions even when the subject is attempting to ignore the digit task, $F(3,15)=1.3$, $p>.10$. Our results replicate those of Schneider and Shiffrin (1977) in showing that targets that have received consistent mapping training generate an "automatic attention response" that disrupts the processing of other simultaneously presented material.

Insert Table 1 About Here

TABLE 1

d' on the Flicker Task Contingent on the
Presence or Absence of the Target Digit

	Percent Attention Devoted to Flicker Task			
Target Digit	10	50	90	100
Present	.92	1.08	1.14	1.38
Absent	1.05	1.42	1.59	1.71

Spatial adjacency effects

Recall that we hypothesized that an aspect of automatic detection is attending to the target's spatial position and that this possibility could be evaluated by examining how performance on the two tasks was influenced by the spatial separation of the CM target and flicker position. We classified the four possible separations as follows. The position of the flicker was coded as adjacent (A), clockwise (CW), opposite (O) or counterclockwise (CCW) from the target letter. This coding preserves relative position (in an admittedly arbitrary fashion) while ignoring absolute display positions. Table 2 shows hit rate as a function of relative position and instructions.

Insert Table 2 About Here

It is clear that targets were detected about 8% more often when they occurred adjacent to the flicker positions than when they occurred in other positions, F(3,15)=16.8, p<.001. This location advantage did not interact with instructions F(9,45)<1.0. It appears that the flicker, like the CM target, has some ability to call attention to itself independent of whether the subject is trying to locate it.

Consider now the question of whether the position of the target digit influenced the ability to perceive the location of the flicker. Both the position of the flicker and the subject's judgment of its position may be coded in terms of their locations relative to the target as in the previous analysis. The data then form a 4x4 stimulus-response confusion matrix. An examination of these matrices for each subject x memory set size combination revealed a clear bias to report the position of the target digit as the position of the flicker.

TABLE 2

Percentage of Hits on Search Task as a Function of the Relative Position of the Target Digit and Flicker and the Percentage of *Attention to be Devoted* to the Search Task

	Location[a]			
Percent Attention Devoted to Search Task	Adj	CW	Opp	CCW
100	88	78	78	81
90	82	77	76	75
50	85	76	77	78
10	75	66	66	66

[a] Location refers to location of flicker relative to location of the target digit. Adj = adjacent, CW = clockwise, Opp = opposite CCW = counterclockwise.

In an attempt to separate bias and sensitivity parameters, we fit a simple guessing model to the data. We assumed that the subject either detected the flicker in position j with probability x_j or guessed position i with probability g_i. Formally, the probability of giving response i (R_i) given flicker in position j (S_j) is

$$\begin{aligned} R_i/S_j &= x_j + (1 - x_j)g_i \text{ for } i = j \\ &= (1 - x_j)g_i \text{ for } i \neq j \end{aligned}$$

The sum of the four guessing probabilities (g_i) are constrained to sum to 1 so the model has 4 sensitivity parameters (x_j) and 3 guessing parameters (g_i) to account for a data matrix with 12 degrees of freedom. Not surprisingly, a least squares fit of the model gave a good account of the data producing an average standard error of 2.3%

Table 3 shows the estimated guessing probabilities for each position as a function of memory set size. The first three parameters were entered as separate dependent variables into a multivariate analysis of variance to test the null hypothesis that each variable was equal to .25. This hypothesis was rejected, F(2,30)=60.7, p<.001. The interaction of location with memory set size did not approach significance, F(2,30)<1.0. There was clearly a bias to guess the target position as also having been the location of flicker. In fact, the subject was about twice as likely to guess the target position as any other position.

Insert Table 3 About Here

TABLE 3

Bias and Sensitivity[a] Measures

for Flicker Task

		Location[b]			
Memory Set Size		Adj	CW	Opp	CCW
M=1	Bias	.41	.21	.20	.18
	Sensitivity	.50	.39	.39	.47
M=4	Bias	.38	.22	.21	.19
	Sensitivity	.37	.46	.44	.44

[a] Bias is the probability of guessing that location when the signal failed to exceed threshold. Sensitivity is the probability that the signal exceeds threshold.

[b] Location refers to location of flicker relative to the location of the target digit: Adj = adjacent, CW = clockwise, Opp = opposite, CCW = counterclockwise.

Why should the subject have a bias to guess the target position as having been the location of the flicker? Interestingly we noticed similar effects when the experimenters served as subjects even though we were convinced that the positions of target and flicker really were independent. It was clear that the calling of attention produced by both flicker and the occurrence of CM targets was very similar. In both cases, one was aware that "something" had occurred in a particular area of the display but this initial attention response could have been produced by either one of two very different events. This suggests that the system responsible for producing shifts of spatial attention may be separate from the system responsible for fine analysis of form or pattern, a suggestion we shall consider in detail later in this paper.

The bottom portion of Table 3 shows the estimated sensitivity parameters (probabilities of entering a "detect" state). Separate analyses of variance revealed no effect of location for memory set four, $F(3,15)=1.2$, $p>.10$. The apparent loss in sensitivity at the target position was produced primarily by two subjects. For a memory set size of one, the effect of location was significant, $F(3,15)=3.7$, $p<.05$. Five of the six subjects showed maximum sensitivity in detecting the flicker position when it occurred adjacent to the target. A least significant difference test (Keppel, 1973) showed that the position adjacent to the target was superior to the CW and OPP positions but not to the CCW position. It would be nice to dismiss the intermediate performance for the CCW position as an accident but we are convinced that spatial adjacency effects often reveal patterns that do not simply correspond to the notion of attention as a single field which can be moved through visual space. For example, Skelton and Eriksen (1976) found that subjects could match a letter in a cued position with the diametrically opposite letter much faster than letters in other positions. Considerable work will be required to investigate the parameters influencing the "geometry" of visual attention. We tentatively conclude that CM targets trigger a shift of spatial attention which increases the ability to process information in adjacent spatial areas and, to a lesser extent, information in counter-clockwise positions. This adjacency effect will be examined in Experiment 3 using a technique that is free of guessing bias.

Practice effects

Certain results discussed to this point were relatively independent of the degree of practice. For example, the accuracy POC shown in Figure 2 changed very little over sessions. An analysis of variance showed that the interaction between instructions and sessions was not significant for either search accuracy, $F(21,105)<1.0$ or flicker accuracy, $F(21,105)=1.77$, $p>.05$. A similar analysis of the effects of sessions on the intrusion effect showed that it was constant over sessions, $F(7,35)<1.0$. It is interesting to note the decrement caused by the presence of a digit was .14 d' units in the first session in the 100% flicker condition so the intrusion effect occurs very early, at least when there is a categorical difference between targets and distractors.

The ability of flicker to improve the detection of adjacent targets was evaluated as follows. The location factor was reduced to two levels (adjacent vs nonadjacent) and entered into an analysis of variance. The interaction of sessions and location was significant, $F(7,35)=2.94$, $p<.025$. This was due to an attenuation of the effect in some of the intermediate sessions. The advantage of the target when it was adjacent to the flicker position was 11% in the first session and 12% in the last session.

Other aspects of our data did change over sessions. In particular, aspects of the RT data changed dramatically over the first few sessions. These data will be considered in more detail in the final results section.

Individual Differences

One subject (S2) was able to perform both tasks together at levels close to those he achieved in the corresponding single task conditions. A second subject (S5) showed a relatively small drop in search accuracy (.27 d' units) as emphasis on the search task varied from 100 to 10%. A similar variation in emphasis on the flicker task yielded a drop in flicker accuracy corresponding to 1.0 d' units. These subjects were unremarkable in other respects showing average effects of memory set size and increments in search RT in dual task conditions.

Discussion

The results of the preceding experiment show that automatic detection relies on several control processes for effective performance. First, consider those factors that affected _search accuracy_. One factor that influenced search accuracy was the location of spatial attention. Automatic targets were detected more often when they occurred in a position adjacent to the flicker. Similarly, flicker was detected more often when it occurred near the automatic target. These _spatial adjacency effects_ suggest that automatic targets produce a shift in spatial attention to their area which enhances the ability to process nearby forms. If this shift is inhibited, for example because attention has been allocated to a different display position by another event, detection of automatic targets suffers. The ability of automatic targets to "call" the spatial attention system may be the basis of the intrusion effect in which performance of the flicker location task declined in the presence of an automatic target even when such targets were to be ignored.

Competition for a spatial attention system cannot be the only basis for trade-offs between the two tasks in Experiment 1. In fact, both the intrusion effect and the spatial adjacency effect appeared to have effects on search accuracy that were largely additive with the effect of instruction to attend to one or the other task. Clearly the subject uses the emphasis instructions before each trial to differentially prepare to process information for each task. Introspectively, it seems that one can "image" the kind of visual event corresponding to the emphasized task and that it is difficult to simultaneously maintain activation of images for both tasks. For example, if subjects are searching for the digit "5", and emphasizing the search task, they maintain a corresponding visual image which produces an accurate representation of the actual presentation of a "5" and in turn interferes with the representation of the flicker information. We assume that preparation is modality specific because there is other information to suggest that maintenance of an image may interfere with detection of signals in the same modality as that of the image (Segal and Fusella, 1970).

The assumption that search accuracy is dependent on the quality of an internal visual representation forms the basis for the following general conclusions. There appear to be at least three factors which influence the quality of the representation formed by a visual display: the physical characteristics of the display (energy, size, etc.), the location of the spatial attention system, and the degree to which appropriate recognition units have been preactivated by the subject prior to display onset.

The quality of the representation formed in the first stage of analysis must be translated into decisions and actions appropriate for the experimental task. We assume that control processes in working memory must be employed for this purpose. The reaction time data of the present study show that the execution of the search task response is delayed by even partial attention to the flicker task. This delay is approximately additive with the effects of memory set size. In a previous study (Hoffman, Nelson, and Laubach, Note 2) this additivity held over a range of search reaction times greater than 1500 msec. This pattern of additivity would be obtained if the two tasks had to access working memory in a strictly serial fashion. We assume that in dual task conditions, the subject first converts the visual representation for the flicker task into a more permanent abstract code. Next, working memory is loaded with routines necessary for discrimination of the search information and the execution of the motor response. Thus the delay of responding to the search task in dual task conditions is composed of two parts: the time to discriminate the flicker information plus the time to load working memory with routines required by the search task. The increase in reaction time to the search task with increasing emphasis on the flicker task may reflect greater time spent in working memory in discriminating flicker information. The hypothesis that both tasks must use a common mechanism (working memory) in a serial fashion would account for the additive effect of instructions and memory set size on search reaction time shown in Figure 3.

To summarize, the accuracy and reaction time POC's together with the spatial adjacency effects and intrusion effect suggest that automatic detection is a process that utilizes several different control processes: preactivation of recognition units, spatial selective attention, and control processes in working memory that make decisions about the presence/absence of automatic targets and execute appropriate motor responses.

Experiment 2 was designed to investigate in more detail the role of spatial attention in automatic detection. In Experiment 1, subjects were unable to ignore automatic targets even when instructed to do so (the intrusion effect). We suggested that the intrusion effect is due to the automatic target calling the spatial attention system to its location which, in turn, increases the quality of the representation of automatic targets. Suppose that the spatial attention system was already focussed on a position removed from the automatic target at the time of target onset. If the spatial attention system can only be reallocated if it is in a distributed mode, then the intrusion effect should be eliminated and detection of automatic targets should suffer.

The task shown in Figure 4 attempts to achieve the above condition

Insert Figure 4 About Here

by requiring the subject to make a difficult visual discrimination at the point of fixation. Compare the task shown in Figure 4 with that used in Experiment 1. There are four "context dots" in the center of the display. At the moment the search array is presented, a single dot occurs displaced toward one of the four context dots and the subject is required to determine the direction of displacement. This task bears at least superficial similarity to the task employed in Experiment 1. It is a four-alternative forced choice discrimination of location and the level of performance is adjusted to be comparable to that obtained in the first experiment. It differs in that the

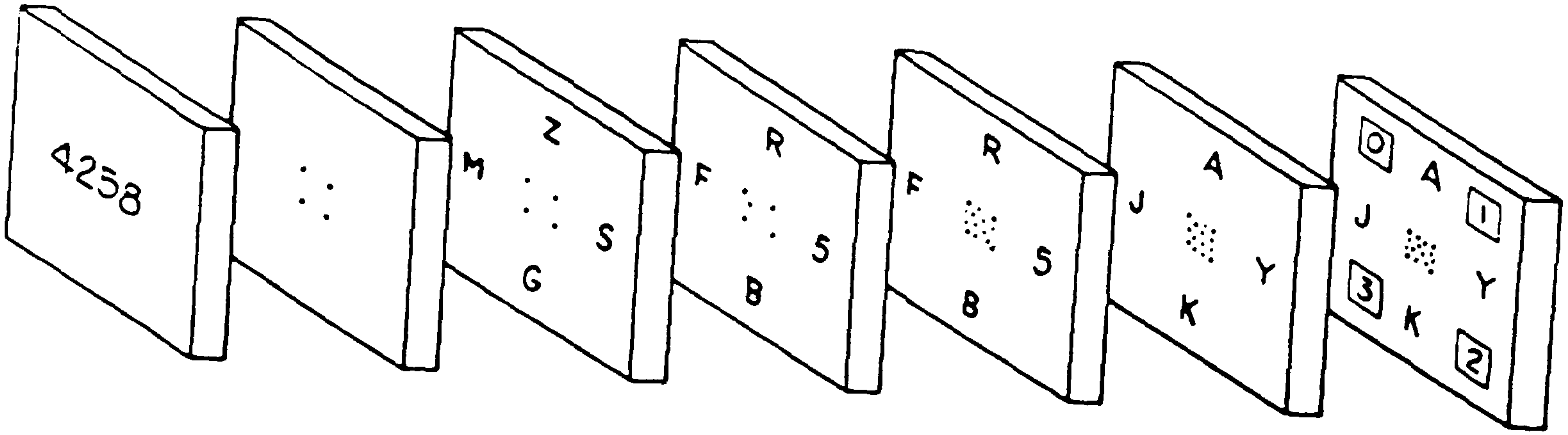


Figure 4: Sequence of events occurring on each trial of Experiment 2. The subject was required to determine whether a digit was present and to judge the direction of displacement of a centrally located dot. The occurrence of the dot was followed by a random field of masking dots.

relevant information occurs within a small region about the fixation point. We assumed that subjects would "focus" their attention on this region resulting in reduced activation produced by the more peripherally located display characters. As evidence of this reduced activation, we expect large trade-offs in terms of the performance operating characteristic and elimination of the intrusion effect.

Experiment 2

Method

Subjects. The same subjects that served in Experiment 1 served in the present experiment.

Apparatus and Stimuli. The same Plato V terminals were used as in the previous experiment. The target display was also the same as in Experiment 1. Instead of the flicker task, a central dot detection task was used. The fixation cross was replaced by a fixation "square" defined by 4 light points. This central area of .5° x .5° visual angle was the location for the second task. The fifth light point (size described in Experiment 1) appeared .22° visual angle toward the center of the square from the corner points. This central location area was masked by a random dot pattern that filled in approximately 50 percent of the area.

Procedure. Each subject served in 4 sessions. The procedure was the same as in Experiment 1 except that the flicker location task was replaced by a central probe dot location task. At the onset of the digit search display, a dot appeared briefly in one corner of the central fixation area. After indicating presence/absence of the digit, subjects then located the corner containing the dot by means of the keyboard.

Figure 4 illustrates a typical sequence. The probe dot in the center square was presented in the same frame as the digit search array. This probe dot was extinguished in 7 msec and was followed by the center square mask. The interval between the probe dot onset and mask depended again on a separate set of preliminary tracking trails. The digit display duration averaged across subjects and sessions, was 126 msec with a range for individual subjects of 91 to 165 msec. The central dot onset-to-mask duration was 48 msec with a range of 32 to 79 msec for individual subjects.

The right hand key press in this series brought to the screen a display of numbered boxes adjacent to the corners of the center square. The probe dot was located by pressing the key number corresponding to the box number.

Results

The intrusion effect

The principal question that Experiment 2 sought to answer was whether the intrusion effect of CM targets could be eliminated when the subject's attention was focussed on the center of the display. Table 4 shows that indeed this was the case. In contrast to the results of Experiment 1, performance on the centrally located displacement task was independent of the presence or absence of the target digit despite the increased practice subjects obtained on the automatic detection task. Statistical analyses of these results will be deferred until the results section of Experiment 4.

Insert Table 4 About Here

TABLE 4

d' on the Displacement Task Contingent on
the Presence or Absence of the Target Digit

	Percent Attention Devoted to Displacement Task			
Target Digit	10	50	90	100
Present	.76	1.13	1.46	2.08
Absent	.81	1.22	1.52	1.99

Performance operating characteristics

The withdrawal of attention from the periphery not only eliminated the intrusion effect but produced a large decrement in automatic detection performance as well, as shown in Figure 5. For both memory set sizes, increasing emphasis on the displacement task improves its level of performance at a cost of decreasing performance on the search task. Unlike Experiment 1, there is an apparent concurrence cost associated with performing the displacement task. For the M4 condition, even partial attention to the displacement task causes a drop of .8 d' units in accuracy.

Insert Figure 5 About Here

The RT POC shown in Figure 6 is quite similar to that found in the first experiment. Partial attention to the displacement task produced a large increment in search RT followed by a small and roughly linear increase in RT with increasing emphasis on the search task. This linear increase in RT probably grossly underestimates the "true effect" of increasing attention to the displacement task because the overall accuracy of search responses is decreasing. Nonetheless the RT results suggest that the decision regarding the presence of the CM target is delayed while the subject is encoding the displacement task information.

Insert Figure 6 About Here

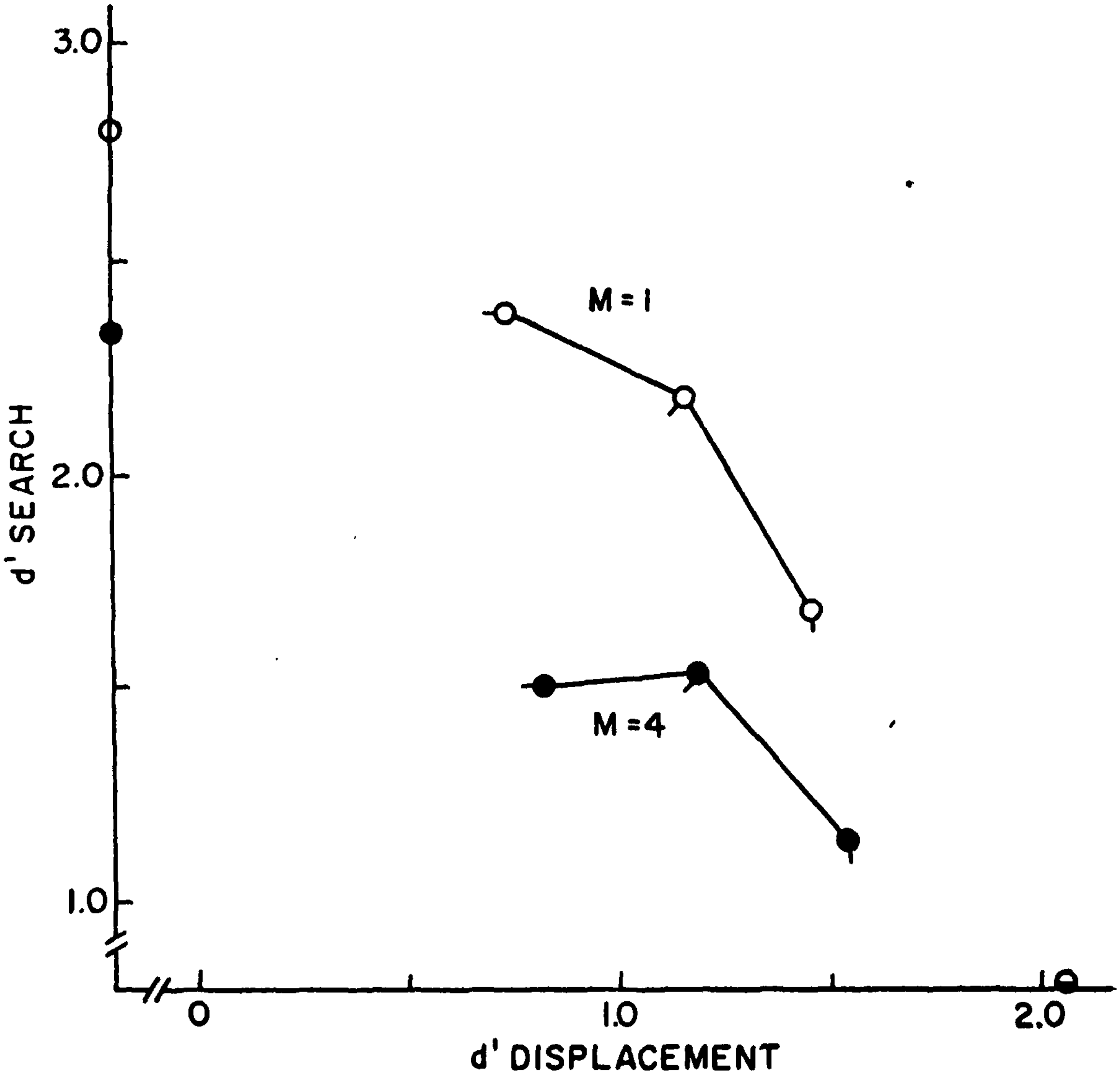


Figure 5: Performance operating characteristic showing the relation between search accuracy and accuracy on the dot displacement task in Experiment 2.

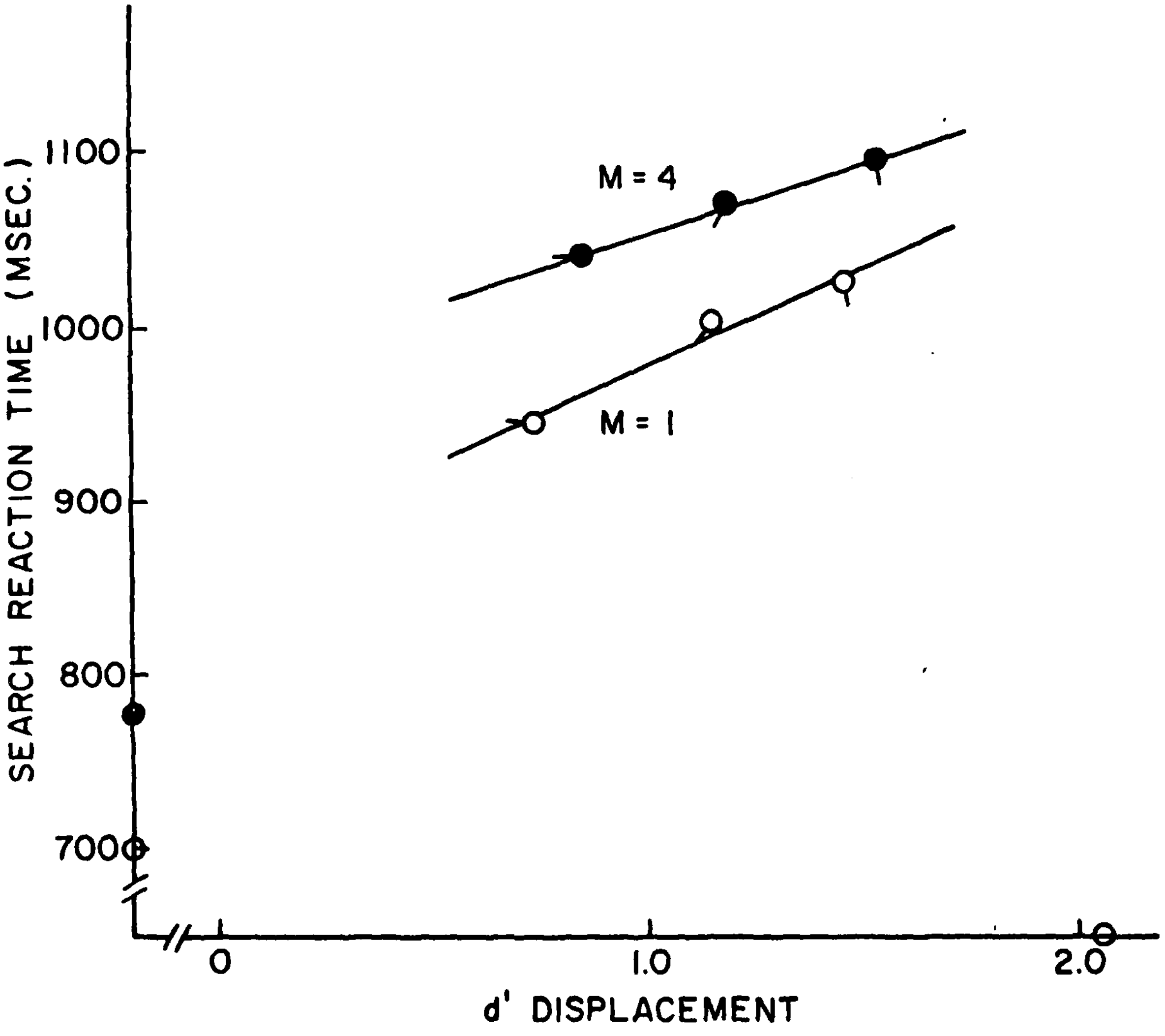


Figure 6: Performance operating characteristic showing the relation between correct search reaction time and accuracy on the dot displacement task in Experiment 2.

Individual differences

All six subject's POC's showed large departures from the independence point including the subject (S2) in Experiment 1 who could apparently perform both tasks without mutual interference. Our tentative hypothesis is that some subjects can effectively time share when attention is in "distributed" mode but all subjects suffer the effects of withdrawing attention from the periphery.

Discussion

The results of Experiment 2 confirmed the dependence of automatic detection on the spatial attention system. We suggested that the ability of CM targets to interfere with other concurrent tasks was due to their ability to rapidly capture the spatial attention system when it was in a "distributed" state. This intrusion effect was eliminated in Experiment 2 presumably because the subject's attention was focussed on information occurring in the center of the display at the moment the CM target appeared. The withdrawal of attention from the area in which the CM target occurred not only eliminated the intrusion effect but was accompanied by large decreases in search accuracy.

Are the striking differences between the results of Experiments 1 and 2 really due to the different states of the spatial attention system in these experiments or could they be due to differences between the flicker and displacement tasks that have nothing to do with attention? Experiment 3 addresses this question by introducing a third task: orientation discrimination. As shown in Figure 7, the subject is once again required to perform two tasks: detection of a digit in letters and discrimination of the orientation of a briefly flashed U-shaped figure. The orientation form can occur adjacent to any of the four display forms and the subject's attention should be in the distributed state. We should therefore observe a reinstatement of the

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Insert Figure 7 About Here

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intrusion effect.

This task should provide additional information on the role of spatial selectivity in automatic detection. In Experiment 1, interpretation of the effect of an adjacent automatic detection target on flicker detection was complicated by response bias. In the present experiment we should find that discrimination of the orientation of the U-figure is better when it occurs adjacent to the target than when it occurs in other positions. The use of a forced choice form discrimination task should eliminate any response bias effects.

We also presented the U figure during the same frame as the CM target or in the successive frame. The successive frame condition should allow sufficient time for the allocation of spatial attention to the region of the CM target before the U-figure is presented. Note, however, that the total time of presentation even in the successive presentation condition is too short to allow the occurrence of saccadic eye movements.

Experiment 3

Method

Subjects. The same subjects served as in the previous experiments.

Apparatus and Stimuli. The same Plato V terminals were used as in the preceding experiments. The target display was as described in Experiment 1. A task requiring symbol orientation discrimination was used instead of the

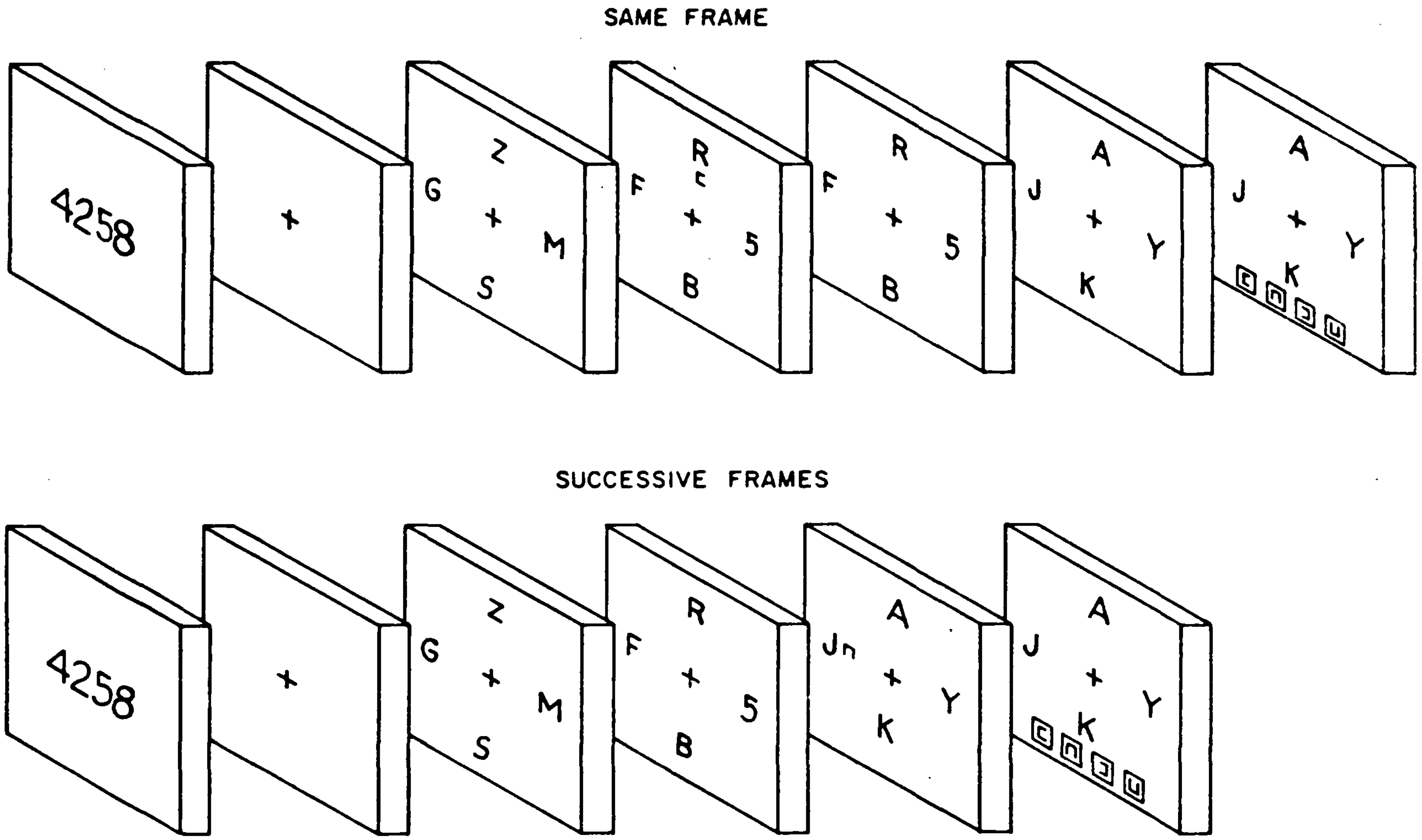

Figure 7: Sequence of events occurring on each of two kinds of traisl in Experiment 3. In the "same frame" condition, the subject was required to determine whether a digit was present as well as to judge the orientation of a simultaneously presented U-shaped figure. In the "successive frame" condition, the U-shaped figure occurred with the onset of the postmasks.

flicker task. The symbol used for this orientation task was defined on a 5 x 5 dot matrix, subtending a visual angle of $.2^\circ \times .2^\circ$ and was always plotted $.17^\circ$ toward the center of the circle from the letter display.

Procedure. Each subject served in 4 sessions. General procedure was the same as in Experiment 1. Before each trial subjects were shown only 1 digit to remember. In this experiment an orientation discrimination task was paired with the digit search. The orientation forms appeared with either the onset of the letter search display (same frame) or onset of the postmasks (successive frames). By means of the keyboard, subjects indicated the symbol's orientation after making the digit search response.

Figure 7 illustrates a typical sequence. The symbol remained on for a duration dependent on a set of preliminary tracking trials performed on the orientation task. The digit display duration, averaged across subjects and sessions, was 116 msec with a range of 100 to 138 for individual subjects. The orientation symbol duration was 67 msec with a range for individual subjects of 21 to 128 msec.

The right hand key press in this experiment brought the display of symbol orientations (with key numbers) to the screen so that an appropriate key could be selected.

Within each orientation symbol onset condition, there were equal numbers of trials in which the digit was present or absent in the display. When present, the digit was assigned randomly but equally to each of the four positions. The orientation symbol was presented randomly and equally next to the four display positions, with the additional constraint that this probe occur equally in all positions relative to the digit.

Results

Performance operating characteristics

Table 5 shows the variation in accuracy on the search and orientation discrimination tasks across the different attentional conditions. Notice that in the 100% orientation condition, the successive frame condition enjoys a large advantage over the same frame condition. This same advantage holds across all of the attention conditions. This difference is certainly due to masking effects. When the orientation form occurs in the same frame as the target, its onset is accompanied by a change of display characters in an adjacent position and its offset is temporally close to the offset of a display character. Moving the orientation form to the following frame removes the second transient and reduces masking. This masking effect is evidently additive with any effect of instructions. This effect is not due to the orientation form being "released" from attentional effects of the CM target since the magnitude of improvement was the same regardless of whether the CM target was present or absent.

Insert Table 5 About Here

To facilitate comparison across the two onset conditions we corrected the accuracy scores by subtracting a constant from each score corresponding to the difference between accuracy obtained in the 100% condition across the two onset conditions. Geometrically, we are simply sliding the POC for the successive frames conditions so the 100% points are aligned with the 100% points in the same frame condition for both search and orientation discrimination.

TABLE 5

d' on the Search and Orientation Tasks

		Percent Attention Devoted to Search Task				
		100	90	50	10	0
Same Frame	d' search	2.62	2.38	1.94	1.96	----
	d' orientation	----	1.33	1.33	1.46	2.03
Successive Frame	d' search	2.42	2.37	2.36	2.28	----
	d' orientation	----	1.96	2.02	2.26	2.67

These corrected POC's are shown in Figure 8. As we found in the previous two experiments, subjects were unable to perform automatic search in conjunction with another simultaneous discrimination without mutual interference. Moving the orientation form to the succeeding frame however, evidently allowed the CM target to "capture" its required resources, and search performance is close to the level achieved in the 100% search condition.

Insert Figure 8 About Here

Separate analyses were conducted on the two different frame conditions. The effect of instructions on search performance in the same frame condition was significant, $F(3,15)=5.23$, $p<.025$. The effect of instructions for the successive frame condition did not approach significance, $F(3,15)<1$. The effect of instructions on orientation discrimination was significant, $F(3,15)=35.8$, $p<.001$ and did not interact with onset, $F(3,15)<1$.

<u>The intrusion effect</u>

Table 6 shows that, as expected, the use of a task requiring distributed attention reinstated the intrusion effect. The main effect of the presence or absence of the target digit was highly significant, $F(1,5)=109.4$, $p<.001$. Table 6 also reveals a three way interaction between instruction, onset, and target present/absent that was significant, $F(3,15)=3.9$, $p<.05$. It is clear that, in general, the intrusion effect is greater when the orientation

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Insert Table 6 About Here

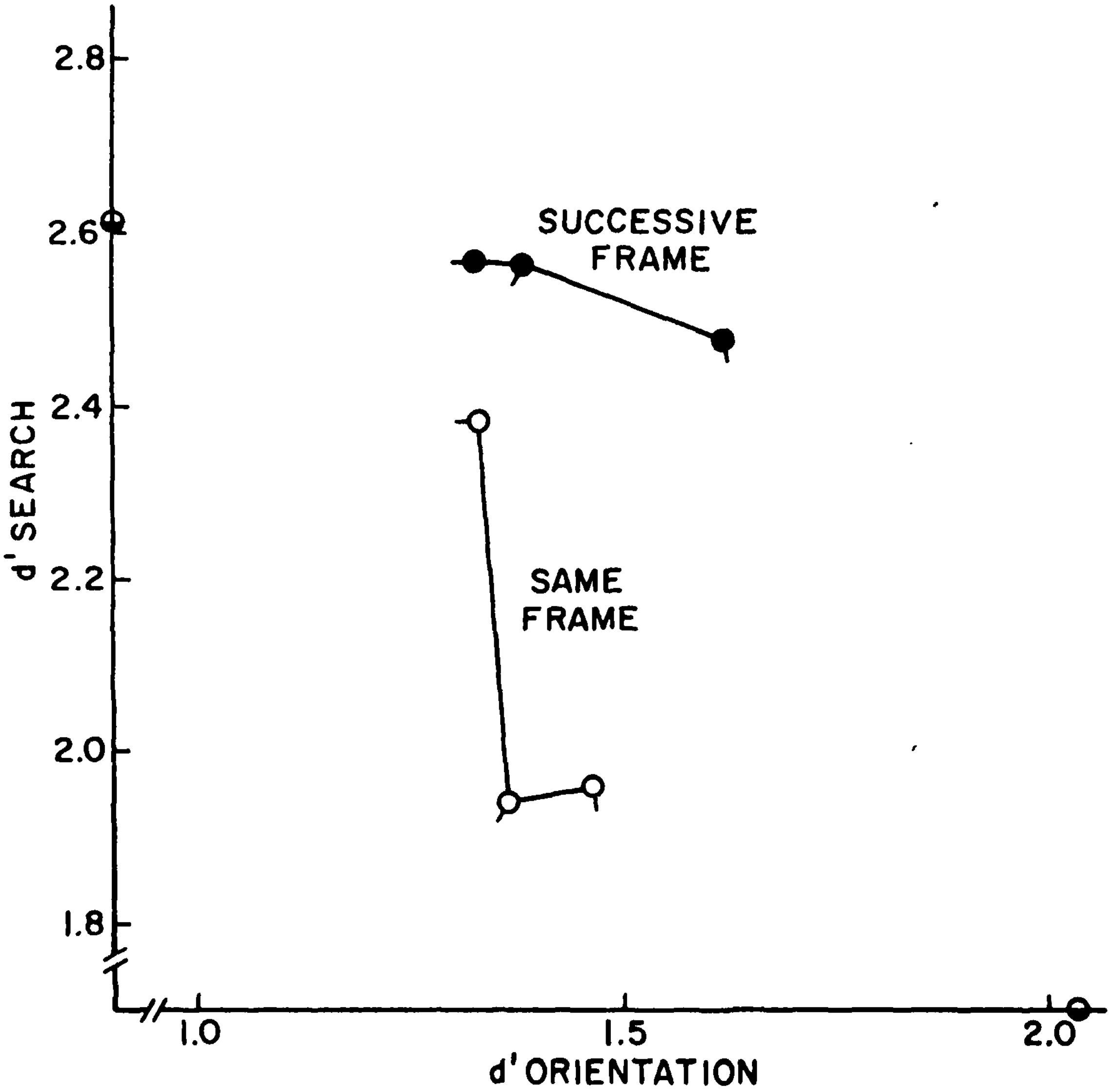

Figure 8: Performance operating characteristic showing the relation between search accuracy and orientation accuracy in Experiment 3. The orientation form either occurred in the same frame as the target digit or in the succeeding frame.

TABLE 6

d' on Orientation Task Contingent on Presence or Absence of Target Digit

		Percent Attention Devoted to Orientation Task			
Frame	Target Digit	10	50	90	100
Same	Present	1.15	1.15	1.36	1.94
	Absent	1.51	1.57	1.57	2.12
Successive	Present	1.67	1.81	1.83	2.43
	Absent	2.26	2.24	2.69	2.91

form occurs in the frame following the target digit. This suggests that the target digit is more effective in capturing the spatial attention system when there are no competing inputs, as we suggested for Experiment 1. Similarly, increasing emphasis on the orientation task should be more effective when the target digit is not present since the spatial attention system can be allocated to the orientation form without the competition provided by CM targets. To some extent this is what occurred in the successive frame condition as subjects were able to improve their orientation performance across the three dual task conditions. It is not clear why a similar effect did not occur for the same frame condition.

To what extent does the intrusion effect depend on the subject correctly detecting the target digit? To answer this question, we looked at orientation discrimination contingent on the subject being incorrect on the search task. This analysis has very low power because of the small number of trials involved, and the effect of target present vs. not present failed to reach significance, $F(1,5)=3.48$, $p>.10$. It is of interest to note, however, that the target not-present condition held a .6 d' advantage over the present condition. In addition, 5 of the 6 subjects showed this effect. This finding is at least suggestive that the process in which the target digit captures spatial attention is not a conscious one since the intrusion effect is independent of target detection. The findings of Experiment 1 in which subjects seemed to be uncertain as to whether their attention was drawn by the target digit or the flicker suggest a similar conclusion.

Spatial adjacency effects

If CM targets produce a shift of spatial attention to their area, we should find that the orientation form is better discriminated when it occurs within this attentional field than when it occurs in other areas. Table 7 shows that this was the case. Orientation discrimination was reliably better when the U-form occurred adjacent to the CM target and in the following frame, F(3,15)=3.45, p<.05. This effect did not occur when both targets shared the same frame, F<1.

Insert Table 7 About Here

Table 8 shows the probability of correctly detecting a CM target as a function of onset and relative location of the orientation form.

Insert Table 8 About Here

A significant onset x location interaction, F(3,15)=3.3, p<.05, was due to the position opposite from the orientation form showing little improvement as the orientation form is delayed. Why should the subject be most effective in correctly performing concurrent discrimination when targets are in opposite positions? It may be that both the adjacent and opposite positions are improved but the advantage of the adjacent position is offset by the masking produced by the orientation form. It is interesting to note that Skelton and Eriksen (1976) found that two letters could be compared for similarity faster when they were in opposite display positions than any other arrangement. In addition Singer, Zihl, and Poppel (1977) found that habituation produced by

TABLE 7

d' Orientation Task Contingent on Correct Detection of Digit Target

Frame	Location[a] Adj	CW	Opp	CCW
Same	1.08	1.07	1.15	1.20
Successive	2.11	1.56	1.71	1.58

[a] Location refers to location of the orientation form relative to the location of the target digit.
Adj = adjacent; CW = clockwise; Opp = Opposite;
CCW = counterclockwise.

TABLE 8

Probability of a Hit Contingent on Correct Orientation Discrimination

	Location[a]			
Frame	Adj	CW	Opp	CCW
Same	.62	.59	.72	.60
Successive	.79	.76	.75	.71

[a] Location refers to location of orientation form relative to location of target digit: adj = adjacent; CW = clockwise, Opp = opposite; CCW = counterclockwise.

repeated stimulation in one area of the visual field could be eliminated by allowing the subject to make a saccade to a diametrically opposite position.

Reaction Time POC

Figure 9 shows the POC relating correct search RT to orientation accuracy. The now familiar concurrence cost is present in which even partial attention to another task produces large increase in search RT. This is accompanied by much smaller increments in RT as further attention is allocated to the orientation task.

Insert Figure 9 About Here

An analysis of variance indicated that the effect of instructions was significant, F(3,15)=15.1, p<.001. None of the other main effects or interactions approached significance.

Individual Differences

All six subjects showed large decrements in the orientation task when it had to be performed in conjunction with the search task. Two subjects, however, could perform the search task in dual task conditions at levels close to what they achieved in the 100% search condition. These two subjects (S2 and S5) were the same ones that showed relatively small decrements in search performance under dual task conditions in Experiment 1. These subjects were unexceptional in other aspects of their data; they showed the increase in search latency in dual task conditions, the intrusion effect, and spatial adjacency effects. We can only speculate that there are individual differences in time-sharing ability that especially manifest themselves when attention is in the distributed mode.

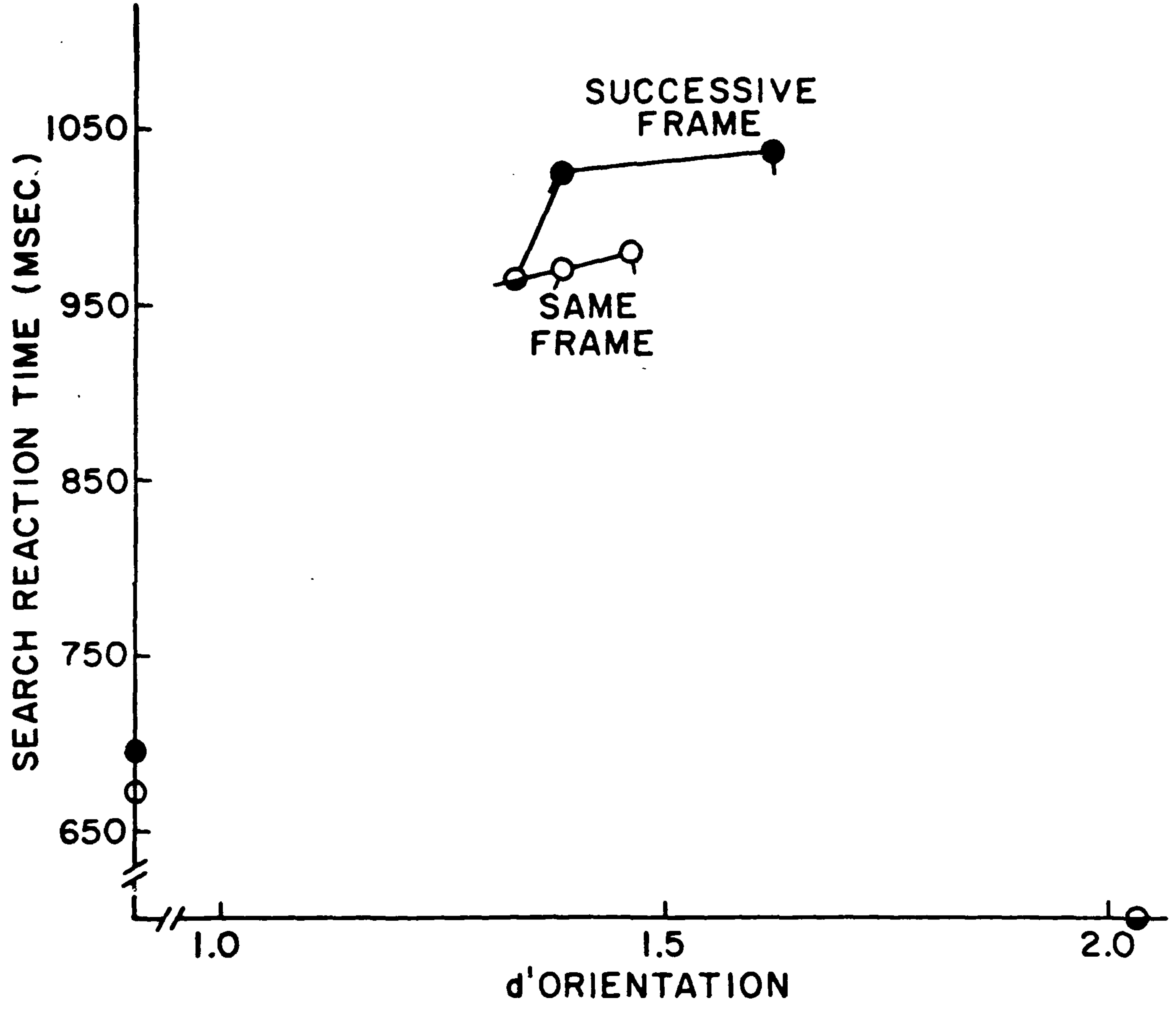

Figure 9: Performance operating characteristic showing the relation between correct search reaction time and accuracy on the orientation task in Experiment 3.

Discussion

The results of Experiment 3 show that when a subject's attention is in a "distributed" state because of uncertainty as to the spatial location of targets, the intrusion effect is obtained in which the occurrence of an automatic detection target decreases performance on another concurrent activity. This intrusion effect is accompanied by relatively modest trade-offs in the performance operating characteristics relating search accuracy to accuracy on a concurrent task. Both of these findings are similar to those obtained in Experiment 1 which also used a task producing distributed attention. These findings stand in marked contrast to the results of Experiment 2 in which the spatial attention system was focussed on the center of the display. Here the intrusion effect was eliminated and large decreases in search accuracy were obtained with even partial attention to the information in the center of the display.

These results strongly imply that a critical component of automatic detection is the ability of consistently mapped (CM) targets to trigger a shift of spatial attention. This is further supported by the finding in Experiment 3 that correct detections of CM targets were accompanied by a general increase in the ability to process other information in a spatial region surrounding the target. When attention is withdrawn from the periphery of the display and focussed in the center, automatic detection of peripheral targets may suffer for two reasons. First the withdrawal of attention may result in only weak activation of long-term memory nodes by CM targets. Second, because attention is already "locked" into a position it cannot shift to the position of the target even if its activation level were strong enough to trigger an attention shift.

Given the strong dependence of automatic detection on the spatial attention system, it is possible to at least outline the conditions under which automatic detection accuracy will suffer when combined with an additional task. If a task is to interfere with automatic detection it must allow for a rapid shift of spatial attention to its own target area which must be spatially remote from the location of the CM target. Experiments 1 and 3 meet this criterion. The position of the flicker and the orientation symbol did not require a search process and could offer immediate competition to the CM target for a spatial attention shift. When this competition is weakened, for example in Experiment 3 by slightly delaying the onset of the orientation symbol, the location of attention is dominated by the CM target resulting in a large intrusion effect and high accuracy on the automatic detection task. Experiment 2 is, of course, an extreme example of the effects of competition for spatial attention on automatic detection.

In order to insure that the reinstatement of the intrusion effect in Experiment 3 was due to the nature of the task and not to increased levels of practice we returned our subjects to the procedure of Experiment 2. All details of this experiment are identical to those of Experiment 2.

Experiment 4

Method

This experiment was a repetition of Experiment 2. Digit display duration determined by the preliminary tracking trials averaged 107 msec, with a range of 68 to 179 msec overall. Center area pre-mask duration was 35 msec with a range of 18 to 49 msec for individuals.

Results

Figure 10 shows the accuracy performance operating characteristic for Experiment 4. The results are similar to those of Experiment 2 but somewhat less dramatic. We still see a "concurrence" cost for the memory set size one condition in which partial attention to the displacement task causes a sharp drop in accuracy on the search task.

Insert Figure 10 About Here

In performing statistical analysis of these data, we included data from Experiments 2 and 4 and used experiments as a factor. We will note any effects or interactions of this factor. For search accuracy, the effects of instructions F(3,15)=29.8, p<.001 and memory set size, F(1,5)=26.5, p<.01, were significant. For accuracy on the displacement task, the effect of instructions, F(3,15)=32.4, p<.001 and its interaction with experiment was significant, F(3,15)=6.3, p<.01.

Table 9 shows that accuracy on the displacement task was independent of the presence or absence of the target digit, F(1,5)=1.28, p>.10. This result is in agreement with results obtained in Experiment 2 with the identical task and confirms our supposition that the spatial attention system must be in a distributed mode to obtain the intrusion effect.

Insert Table 9 About Here

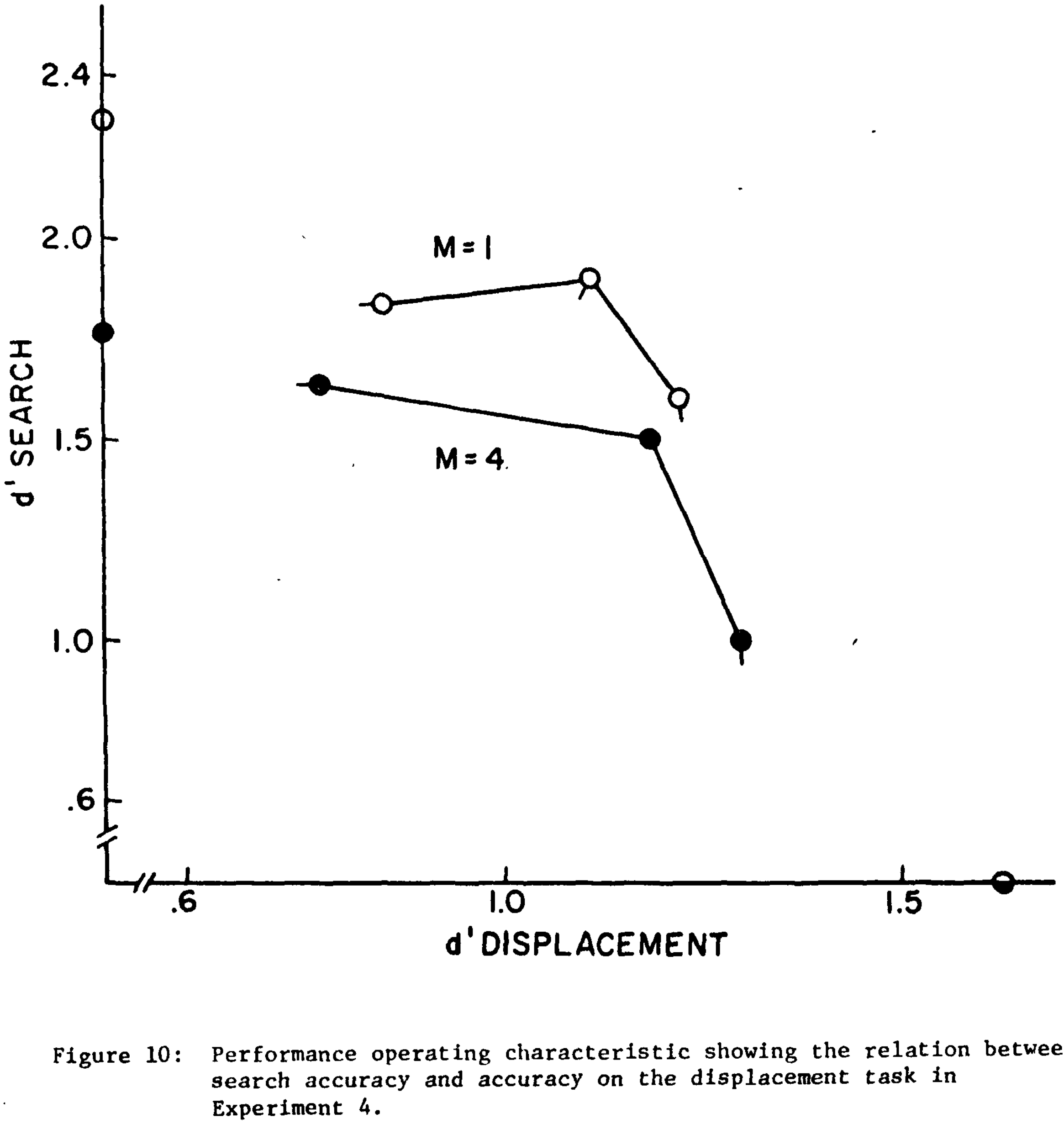

Figure 10: Performance operating characteristic showing the relation between search accuracy and accuracy on the displacement task in Experiment 4.

TABLE 9

d' on Displacement Task Contingent on

Presence or Absence of Target Digit

	Percent Attention Devoted to Displacement Task			
Target Digit	10	50	90	100
Present	.70	1.10	1.28	1.65
Absent	.90	1.21	1.25	1.61

a suggestion of a small intrusion effect in the 90% search condition but the interaction of instructions and target present/absent was not significant, $F(3,15)=1.12$, $p>.10$.

Reaction Time POC

Figure 11 shows the POC relating mean correct reaction time to accuracy on the displacement task. Once again there is an apparent concurrence cost as partial attention to the displacement task produces large increments in search RT. In this case, further emphasis on the displacement task produces virtually no further changes in RT. The effect of instructions, $F(3,15)=22.8$, $p<.001$ and memory set size, $F(1,5)=8.9$, $p<.05$, were both significant while the interaction was not, $F(3,15)=1.06$, $p>.10$.

Insert Figure 11 About Here

There is a remarkable constancy evident in the RT POC's across these four experiments. Consider the memory set size equal one condition in which information occurs in the same frame. This condition is common to all four experiments. Despite the variation in tasks employed, the range of performance trade-offs observed, and different degrees of practice they represent, RT in all four experiments invariably increases from about 700 msec in the 100% search condition to about 950 msec in the 90% search condition. Any further changes in attention produce only modest increases in RT. This constancy suggests that the concurrence cost has little to do with the actual events occurring within the trial. Instead it appears that the subject cannot both be prepared to execute the search response and encode the information presented by the other task.

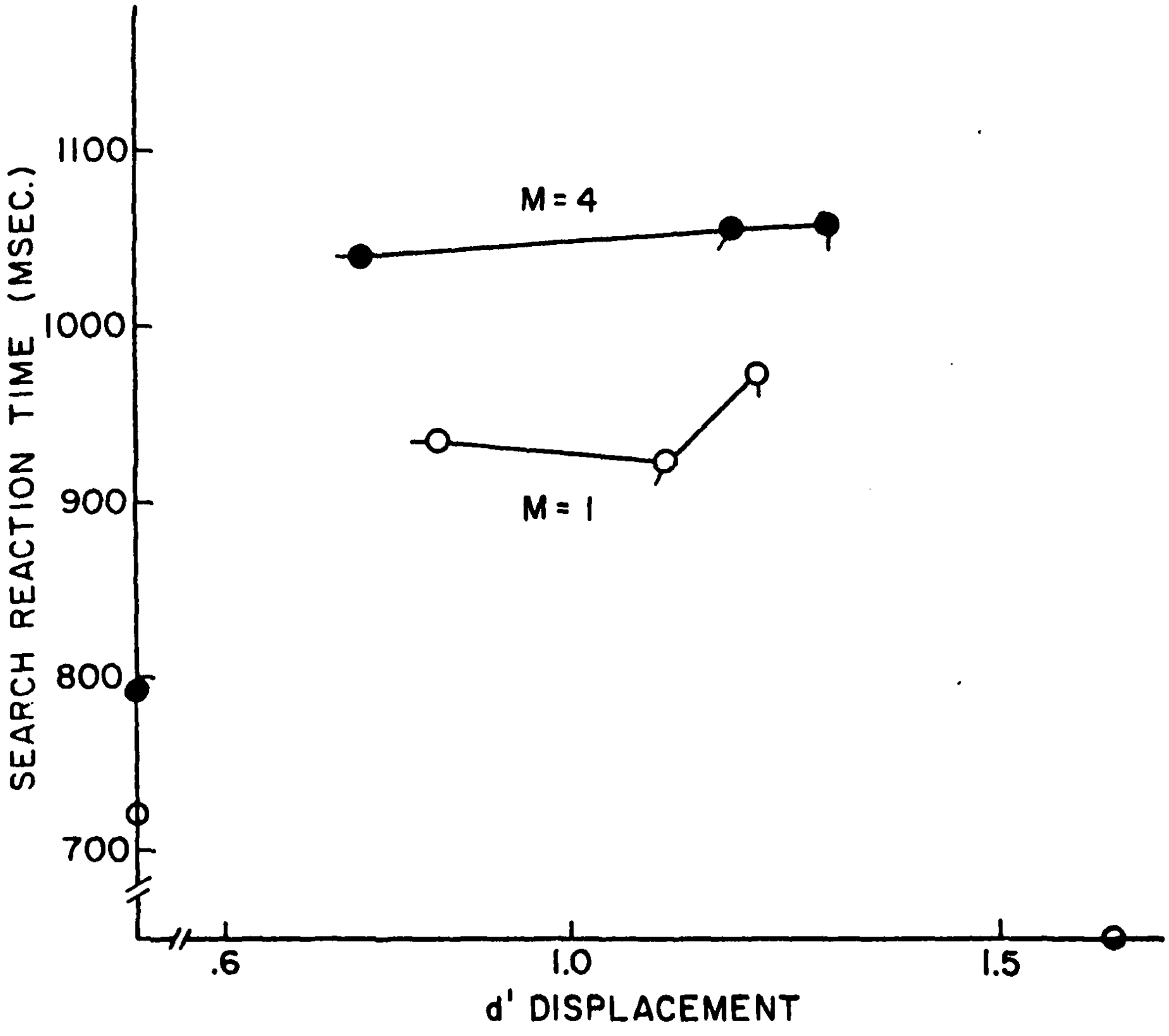

Figure 11: Performance operating characteristic showing the relation between correct search reaction time and accuracy on the displacement task in Experiment 4.

Individual differences

All subjects showed large departures from the independence point in their POC's with the exception of S5 working with a 1-digit memory set. S5 showed a total decrease in search accuracy of only .22 d' units in moving from 100% search to 10% search. The displacement task showed a .4 d' unit decrease in accuracy as its emphasis changed from 100 to 10%. The corresponding figures for the 4-digit set were 1 d' unit on the search task and .27 d' units on the displacement task.

S5's performance with a 1-digit memory set is unusually good relative to the other subjects. For example, her closest competitor (S2) achieved values of .4 and .77 on the search and displacement task respectively while the corresponding values for the "worst" subject were 1.30 and 1.38. These individual differences occurred despite large amounts of practice and our attempts to match all subjects in terms of performance in 100% attention conditions.

S5 did not appear unusual in any other way. She showed a .6 d' unit advantage for a 1-digit memory set relative to a 4-digit set and showed large increments in RT in dual task conditions. Thus, her superior dual task performance does not appear to be due to greater "automaticity" than other subjects.

General Results

This section describes results from all four experiments that bear on the question of whether our subjects had achieved automatic detection.

Were subjects automatic?

Most of the features of our data are in reasonably close correspondence with Schneider and Shiffrin's (1977) original demonstration of automatic processing. Table 10 summarizes the correct RT data in the 100% search condition over the entire 20 sessions grouped into sets of 4 sessions each. Several aspects of these data are notable.

Insert Table 10 About Here

First, after the first 4 sessions, RT was relatively stable and there is no indication that further training would result in any further improvements in performance. Second, the average slope for positive RT (excluding session set 4) is about 6.9 msec/comparison and for negative RT is about 8.1 msec/comparison. The corresponding data for the identical load conditions in Schneider and Shiffrin are 5.8 (+) and 6.6 (-). Although caution must be used in interpreting our RT data because of the relatively high error rates, they do not appear to correspond to the slope relationships predicted by a controlled search process in which the negative slope is twice the size of the positive slope.

All four experiments show a 1/2 d' unit advantage in accuracy for the memory set size one condition relative to the four element set condition. In conditions in which hit rates are comparable (their frame time = 80 msec), Schneider and Shiffrin show an approximately .8 d' unit difference for comparable load conditions.

TABLE 10

Average Correct RT (msec) Across Experiments 1-4

		Session Sets[a]				
Memory Set Size	Response	1	2	3	4	5
M=1	positive	760	678	661	650	666
	negative	862	729	740	703	771
M=4	positive	899	776	663	---	755
	negative	1028	802	823	---	840

a. Sets are averages of 4 sessions. Sets 1 and 2 correspond to Experiment 1 and sets 3-5 correspond to experiments 2-4 respectively.

These results together suggest that our subjects were employing the same search mechanisms utilized by subjects in Schneider and Shiffrin's experiments. This close correspondence between experiments, together with the demonstration of the intrusion effect in Experiments 1 and 3 clearly indicate that our subjects were utilizing "automatic detection".

Discussion

The role of spatial attention in automatic detection

The principal conclusion to be drawn from the preceding experiments is that automatic detection of visual targets requires a set of resources to operate effectively. One resource that automatic targets require is the spatial attention system. When spatial attention is drawn to a display region removed from the automatic target, detection suffers (Experiment 1) and conversely, when attention is "captured" by an automatic target, discrimination of other adjacent visual information is improved (Experiment 3). This ability of automatic targets to trigger shifts of spatial attention is evidently the basis of the intrusion effect in which the presence of automatic targets disturbs the performance of other concurrent visual discriminations. This intrusion effect can be eliminated if, at the time of presentation of the automatic target, the subject's spatial attention system has been allocated to a region removed from the automatic target (Experiments 2 and 4). In these circumstances, the ability to detect automatic targets suffers large losses.

The role of priming and decision processes in automatic detection

Although the spatial attention system clearly plays a role in the trade-off between concurrent visual discriminations, it cannot be the only basis of intertask interference. Trade-offs occurred even when relevant information from the two tasks was in adjacent spatial positions. In addition, trade-offs occurred on trials in which the automatic target was not present and could not trigger a shift in spatial attention.

What is the basis of intertask trade-offs that cannot be attributed to the spatial attention system? Our subjects' introspective reports are suggestive of a mechanism. When the instructions favor, for example, the flicker location task (90% flicker task--10% search task) subjects, prior to each trial, concentrate on "seeing" the flicker. Similarly, if instructions favor the search task, subjects concentrate on "seeing" digits. As a working hypothesis, we assume that this preparatory set consists of a preactivation of the recognition units that the subject uses to encode or recognize the visually presented material. In other words, two factors act in concert to determine the activation level achieved by a form: the amount of spatial attention devoted to the region of the form as well as the degree of preactivation.

There is good evidence that preparatory set for a form affects its representation or encoding. For example, Seamon (1976) controlled the rehearsal of the memory set items in a Sternberg (1969) type recognition task and found that probes were responded to very quickly when they had just been rehearsed or "primed". Similar priming effects occur for a wide variety of recognition tasks (see Posner, 1980 for a summary).

Trade-offs between concurrent tasks occur partly because there is an incompatibility in maintaining maximum activation of recognition units for two different tasks. This sort of control over processing is nicely illustrated by an experiment conducted by Neisser and Becklen (1975). They showed that observers could selectively attend to either one of two spatially superimposed event sequences. As they point out, selection on the basis of spatial position was impossible and instead appeared to be based on a continuous interaction between the input and subject-generated schemas for representing that input.

We assume then that the intertask trade-offs we have observed may be attributed partially to changes in the initial activation levels achieved by forms. These variations in activation level are determined by spatial attention as well as preparatory priming processes conducted prior to each trial.

The interaction between these two different sources of activation is highlighted by the results of Experiment 3 in which the automatic detection task was paired with a task requiring the subject to discriminate the orientation of a form appearing in the <u>same</u> frame as the automatic target or in the <u>successive</u> frame. In the same-frame condition, increasing emphasis on the orientation task produced a decrease in automatic detection performance. Evidently, a loss in priming due to instructions coupled with a loss in activation due to spatial attention being controlled by the location of the orientation form resulted in a loss in detection. When the orientation form occurred in the frame following the automatic target, automatic detection was essentially independent of instructions to emphasize one or the other task. This cannot be due to any changes in pretrial preparation since the same and successive frame conditions occurred randomly. The successive frame condition allows automatic targets to "capture" the spatial attention system without competition resulting in activation levels close to those obtained in control conditions. These results suggest that automatic detection accuracy can only be reduced by pairing the automatic task with a concurrent task that allows for a rapid allocation of attention to a spatial position.

The RT data, however, point to additional processes involved in these pairs of tasks. Following the formation of a representation for visual information, the subject must execute control processes that determine what decisions and actions will be taken on the basis of the information provided by the input. In the case of the flicker task, the subject must store the location of the event. In the case of the search task, the subject must make a decision as to the presence or absence of the target and execute a motor response. These control functions are presumably within the purview of working memory. There is good evidence that these control processes are mutually exclusive. Both the present study, as well as that of Hoffman, Nelson, and Laubach (Note 2), show that even partial attention to a concurrent task produces large delays in the execution of the search task response. These delays occur regardless of whether or not the accuracy of the search task is affected (Experiment 1 vs. 2 of the present paper).

Evidently, although the input representations for each task are formed in parallel, the interpretation and subsequent actions based on those representations are carried out serially. We assume that the interpretation of the flicker, dot displacement, and form orientation were carried out prior to the search decision. This imposes a delay before the representation of the search array is examined. A serial use of working memory by the two tasks would account for the additivity of memory set size and instructions that are consistently observed across the four experiments. We are currently attempting to obtain converging evidence for this view by examining whether the P300 component of the evoked potential associated with the automatic search decision is also delayed in dual task conditions. If it is, it would support our conclusion that it is the actual decision and not just the overt response associated with automatic detection that is delayed in dual task conditions.

What is automaticity?

Our characterization of automatic detection includes a large role for "control processes". What then are the differences between controlled and automatic detection that account for their different characteristics revealed by the studies of Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977)? We believe the same processes are involved in both kinds of detection and that rather than representing two qualitatively distinct processing modes, they are two points on a continuum. Consistent mapping training produces a variety of perceptual learning that results in increasing ability to discriminate targets and distractors. This increase in discriminability has two major effects. First, it allows for a rapid allocation of spatial attention to the region of the automatic target, which improves its detectability at short display durations. Second, there is less "noise" in the decision process which means relatively small effects of "processing load" (in terms of memory set size or display size). It appears, however, that spatial attention, priming, decision making, and response execution are all control processes that play a role in the detection of consistently mapped targets.

The improving discriminability between targets and distractors that results from consistent mapping training may have a counterpart in "real world" examples of automaticity. The ability of chess masters to quickly encode visual representations of standard chess configurations (Chase and Simon, 1973) is an example of perceptual learning. Similarly, expert typists learn to encode groups of letters into response commands (Shaffer, 1976). The chunking of input information into larger units may represent the principal hallmark of automatic processes. Our results suggest that maintenance of these high order representations as well as the attendant decisions and responses that are to be based on the input representation are control processes that require the active investment of attentional resources. Shaffer's (1975) observation that even highly skilled copy typists may suffer dual task interference is consistent with this view.

Conclusion

A series of studies demonstrated that even highly practiced and presumably automatic processes require the investment of "attention" to operate effectively. The detection of consistently mapped visual target digits was interfered with by requiring the subject to make a concurrent visual discrimination. The pattern of interference between different pairs of tasks suggested that automatic targets produce a rapid allocation of visual spatial attention to the region of the target. The allocation of attention affects the activation level achieved by the target. Further control processes are required to interpret the resulting activations and execute an appropriate motor response. The principal conclusions are that spatial attention can affect "early" processing of visual information and plays a significant role in automatic target detection.

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Footnotes

1. It would have been preferable to have avoided the equal variance gaussian assumptions in computing a detectability measure but attempts to collect confidence ratings for the purpose of computing A' in the task have been unsuccessful. It should be noted that in all cases in which we obtained a drop in d', it was produced by both a decrease in hit rate and increase in false alarm rate.

We have chosen not to present β measures for the search task primarily because they showed little variation across different instructional conditions. For example, the β measures for the 100% and 10% conditions were between .9 and 1.78 across all 4 experiments with one exception. In Experiment 3, β declined from 4 to 1.9 as search emphasis changed from 100 to 10%. The large changes in d' coupled with the stability of β measures precludes the possibility that the drop in search accuracy obtained in these studies is due to variation in criteria. The complete hit rate/false alarm rate tables are available from the authors on request.

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University of Kansas
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Univ. of So. California
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