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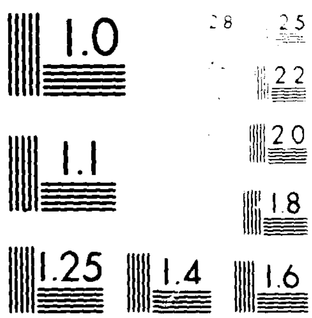
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AUTOMATIC/CONTROL PROCESSING AND ATTENTION

Walter Schneider, Sue T. Dumais, and Richard M. Shiffrin

(12)

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Automatic/controlled processing theory is reviewed with emphasis on applications to research on attention. Automatic/controlled processing theory assumes that human performance is the result of two qualitatively different processes; automatic and controlled processing. Automatic processing is a fast, parallel process not limited by short term memory. Automatic processing uses little subject effort, permits little direct

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subject control, but requires extensive and consistent training to develop. Controlled processing is a comparatively slow, serial process limited by short term memory. Controlled processing requires subject effort, permits a large degree of subject control, but needs little training to develop. Attention paradigms discussed include selective attention, focused attention, and attentional capacity. Conclusions from the application of automatic and controlled processing theory to research from attention paradigms suggest that: 1) performance differs to the degree that automatic or controlled processing determines performance; 2) performance improves with extensive consistent practice; 3) automatic processes are difficult to control; and 4) capacity reductions primarily harm controlled processing. The development of automatic processing is examined, and performance is seen to improve as a function of consistent executions. The functions, limitations, and interactions of automatic and controlled processing are discussed; it is suggested that automatic processing can be defined in terms of capacity limitations and control.

Automatic and Control Processing and Attention[1]

by Walter Schneider, Sue T. Dumais, & Richard M. Shiffrin

Human performance in almost any cognitive or motor skill shows profound changes with practice. Consider the changes that occur while learning to type, play a musical instrument, read, or play tennis. At first, effort and attention must be devoted to each movement or minor decision, and performance is slow and error prone. Eventually long sequences of movements or cognitive acts are carried out with little attention, and performance is quite rapid and accurate. For example, the beginning reader may need a few seconds to encode each new letter, and still may be error prone, whereas the expert can accurately encode 25 letters per second and still have sufficient capacity available to encode the material semantically as well. The striking changes that occur with practice have lead many researchers to propose that qualitative changes occur in the processing (e.g., James, 1890; LaBerge, 1975; Posner & Snyder, 1975; Shiffrin & Schneider, 1977).

The present report reviews evidence that human performance is the result of two qualitatively different processes referred to as automatic and control processing and describes many of the attentional phenomena in terms of this distinction. <u>Automatic processing</u> is a fast, parallel process, not limited by short term memory, requiring little subject effort, necessitating extensive and consistent training to develop, and providing little direct subject control. Manipulating a fork at dinner is an example of an automatic process. <u>Control processing</u> is a comparatively slow, serial process, limited by short term memory, requiring subject effort, providing a large degree of subject control, and necessitating little or no training to develop. In addition, control processing appears to be instrumental in causing substantial changes in long term memory. Trying to remember a telephone number long enough to dial it is an example of a control process.

The automatic/control processing approach suggests several generalizations about the attentional literature. First, performance in a given paradigm can be very different depending on whether a preponderance of controlled or automatic processing is involved. Second, performance should change due to the development of automatic processes when subjects are given extensive, consistent, practice. Consistent practice is assumed to occur when the stimuli and responses are <u>consistently mapped</u> (CM). That is, across training trials the subject makes the same response each time the stimulus occurs.[2] If the stimuli and responses have a <u>varied mapping</u> (VM) across trials no automatic processing should develop and performance should change little with practice. Such results were demonstrated by Schneider and Shiffrin (1977a) and Shiffrin and Schneider (1977). Third, as performance becomes more automatic subjects should have more difficulty controlling and modifying their ongoing processing. Fourth, since control processes are capacity limited, reductions in capacity (e.g., through drugs, fatigue, motivation, load) should much more severely harm control processes than automatic processes. Fifth, memory modification is a control process function suggesting one can serially process with long term memory via control processing or parallel process without memory modification via automatic processing.

This report will briefly review pertinent research in divided attention, focused attention, attentional capacity, and learning paradigms. These paradigms are dealt with from a variety of viewpoints throughout this book and have been extensively reviewed elsewhere (e.g., Broadbent, 1958, 1971; Kahneman, 1973; Moray, 1969a,b).

Even brief consideration of any complex task, such as tennis playing, makes it clear that such tasks are carried out with a mixture of automatic and control processes, possibly organized in a systematic network or hierarchy, with many of the automatic processes operating in parallel. It is our belief that this state of affairs holds true for far simpler tasks as well. In fact, it would be hard to find any task that is not accomplished through the use of both automatic and control processes. Because most selective attention paradigms involve very simple tasks, relatively few processes may be invoked, and it may be the case that most of the observed performance is due to some one process either automatic or controlled. Therefore, we may occasionally refer to the processes involved in carrying out a task as if they were wholly automatic or controlled. In all such cases the reader should understand that these statements are designed to simplify the discussion; the intended referent will always be some major component process. We assume as a working hypothesis that essentially all tasks are accomplished with a mixture of both types of processes.

Selective Attention

The process of selective attention is one in which "the organism selectively attends to some stimuli, or aspects of stimuli, in preference to others" (Kahneman, 1973, p. 3). This concept presupposes that there is some bottleneck or capacity limitation in the processing system and that subjects have the ability to give preference to certain stimuli so that they pass through this bottleneck easily and at the expense of other stimuli.

Divided Attention

Many studies show that subjects exhibit reduced performance when they try to accomplish simultaneously an increased number of tasks, or to attend simultaneously to an increased number of stimuli. These are studies of divided attention deficits and are discussed at length in the literature (e.g., Kahneman, 1973). From a theoretical point of view it is desirable to ascertain the locus of such deficits, their cause, and the conditions that allow these deficits to be bypassed. In this section we try to show that the automatic/control distinction goes a long way toward predicting the answers.

The simultaneous/successive paradigm provides a straightforward test of the ability of subjects to give preference to perceptual processing of simple stimuli presented at threshold. Subjects are presented a number of stimuli on independent channels (e.g., retinal locations). In the successive condition information is presented on only one channel at a time such that subjects may give preference to each channel (stimulus) individually. In the simultaneous condition information is presented on all channels simultaneously. In either condition the subject must identify the target, the presence of the target, or its position. If a single channel can be given preference, then subjects should be far superior when they need process only one channel at a time than if they must deal with many channels at once.

Eriksen and Spencer (1969) presented nine stimuli with the interstimulus interval (ISI) ranging from 5 msec (effectively simultaneous) to several seconds. They found no benefit for the successive condition. Shiffrin and his colleagues have demonstrated similar simultaneous and successive performance for visual stimuli (Shiffrin & Gardner, 1972; Shiffrin, Gardner & Allmyer, 1973; Shiffrin, McKay, & Shaffer, 1976), auditory speech stimuli (Shiffrin, Pisoni, & Casteneda-Mendez, 1974), tactile stimuli (Shiffrin, Craig, & Cohen, 1973), and across modalities (Shiffrin & Grantham, 1974). In all cases there was no benefit for processing the channels successively. These results indicate that processing is parallel and not capacity limited (at least within the ranges tested).

Since a long history of research results indicates the existence of selective attention bottlenecks, the results of the simultaneous-successive studies are somewhat puzzling. Many attention experiments show a decline in performance as simultaneous processing load increases (see Kahneman, 1973). The solution to this puzzle depends on the fact that the simultaneous-successive studies have all used consistent mapping. That is, the target stimuli remain fixed over trials, as do the distractor stimuli. Under these circumstances, the subject may learn to attend automatically to a target whenever it appears. As a result target position is attended first even in the simultaneous conditions, thereby producing equal performance.

This situation and the argument are best demonstrated through an example. Let us suppose that a simultaneous display consists of four alphabetic characters arranged in a square. Three positions are occupied by distractors (e.g., the letter "L"). The other position is either the letter T or F, and the subject's task is to say which occurs on a given trial. The target position and identity vary randomly from trial to trial, but the set of target characters (T, F) and the distractor characters (L) do not change over trials. Masking displays precede and follow each character, and the character presentation time, $\underline{t}$, is adjusted until performance is at threshold (e.g., .75 correct choice).

The successive condition is similar, except that a trial consists of successive presentation of the stimuli, each stimulus preceded and followed by masks, and each presented for $\underline{t}$ msec. In a typical paradigm, two stimuli along a display diagonal are presented together for $\underline{t}$ msec, followed 500 msec later by the two stimuli on the other diagonal. In this successive condition also, the targets and distractors remain fixed over trials.

We argue that the consistent training over trials leads the targets (e.g., T and F) to attract attention automatically. The targets become figures which appear to "pop out" from the background distractors (for models see Hoffman, 1979; Shiffrin & Giesler, 1973). Because performance is equivalent in the simultaneous and successive conditions, we conclude that the information extraction that leads to the automatic allocation of attention is minimally affected by the number of stimuli being processed simultaneously (except when lateral masking is allowed to vary between conditions). Information from all channels comes in with performance being minimally affected by processing of non-confusable stimuli in the other channels. If automatic processing directs limited control processing to the channel with the target, only one short-term memory comparison will be required for the subject to respond to the presence of a target. Therefore processing should be independent of the number of simultaneous channels.[3]

In summary we suggest that benefits and costs of selective attention are seen when control processing is used (as induced by varied mapping conditions). On the other hand, automatic processing in the right situations can sometimes bypass the selective attention bottleneck. Finally, note that our suggested basis for the effects seen in these studies is a training of <u>attention</u> itself. Thus attention may be thought of as a trainable response in its own right. We shall return to this point later.

A major research paradigm used to examine limitations in information processing is <u>dichotic listening</u>. In dichotic listening experiments subjects are presented different streams of auditory stimuli in each ear: the subject is told either to attend to one ear, or to attend to both. For the unpracticed subject, target detection performance drops substantially when subjects shift from attending to a single ear to both ears (Treisman, 1960). However, after extended CM training at detecting a specific target (4-10 hrs.), performance is equivalent whether subjects are attending to one or both ears as long as both channels do not simultaneously contain targets (Duncan, 1980; Moray, 1975).

In <u>auditory shadowing</u> paradigms subjects are required to repeat orally a stream of speech presented in one ear while also trying to process information presented in the other ear (see Cherry, 1953; Moray, 1959; Treisman, 1960, 1969). Treisman (1960) found that target detection in the shadowed ear was far superior to that in the unshadowed ear except when the targets differed from the shadowed message on some simple acoustic feature (e.g., targets were tones). Moray (1959) showed that the information on the nonshadowed ear could not be recalled, recognized, or relearned with savings. These experiments suggest that information in the non-shadowed ear is not processed or not remembered. The results from the simultaneous/successive paradigm suggest that the loss might be due to memory decay rather than the absence of processing. Such shadowing experiments generally present subjects with little practice, and hence a selective attention benefit due to control processing is expected. However if subjects are given CM training on detecting a target, automatic processing should develop and the nonshadowed information should also be responded to. Moray (1959) found that subjects did detect their own name when it was presented in the nonshadowed ear, suggesting that the extra-laboratory CM training of responding to one's own name results in an ability to detect it on an unattended channel.

In a <u>multiple frame visual search</u> paradigm subjects are presented a series of frames in immediate succession, each presented for a brief period of time referred to as the frame time (Schneider & Shiffrin, 1977a). In advance of each trial the subject is presented with several characters referred to as the memory set and is then required to detect any memory set items that appear in subsequent frames. In experiments by Schneider and Shiffrin (1977a) the elements presented on each frame were characters or random dot masks. The frame time was kept constant across the 20 frames of each trial and the basic dependent variable was the psychometric function relating accuracy to frame time in each condition. The independent variables were the frame size (number of characters per frame), memory set size, frame time, and the type of mapping, CM or VM. In one CM condition subjects consistently searched for digits among letters. In a comparable VM condition subjects searched for a random subset of target letters on each trial. The results (Figure 1, right panel) showed that performance (accuracy) in the VM conditons was strongly affected by increases in memory set size and frame size. Performance in the CM conditions (Figure 1, left panel) was virtually unaffected by frame and memory set size. In fact, all the CM conditions were superior to even the easiest VM condition. CM performance was qualitatively different from VM performance, showing superior performance, minor effects of load, and performance limited by perceptual factors. Similar CM and VM differences have been found in an auditory version of the multiple frame task (Poltrock, Lansman, & Hunt; 1982).

Insert Figure 1 about here

A <u>single frame search</u> paradigm is similar to the multiple frame paradigm except subjects are presented only one frame and the primary dependent variable is reaction time. Subjects are presented a memory set of one or more items and required to detect the presence of any of the items in a single display containing at most one target and possibly multiple distractors. Visual search experiments (e.g., Neisser, 1963) measure the length of time necessary to detect a given member of the memory set in a single display containing a large number of distractors. Memory search experiments typically measure the time necessary to compare a single display item to a series of items in memory (Sternberg, 1966, 1969a,b; 1975). VM and CM conditions have shown substantially different results in either type of single frame experiment (for a review, see Schneider & Shiffrin, 1977a).

The Schneider and Shiffrin (1977a) studies varied both frame size and memory set size within subjects. In the VM condition reaction time increased linearly with memory set size and frame size, and the slope of negative reaction times was twice that of positive. For the CM conditions there was little effect of memory set size, no[4] effect of frame size, and positive and negative slopes were about equal.

Fisk and Schneider (Note 1) have examined CM and VM single frame search with words and categories. In the category condition subjects were presented one to four category names, and then two words. If either of the two words were members of any of the presented categories, subjects pressed the target present button; else they pushed the target absent button. The results for the VM conditions are presented in the left panel of Figure 2. In the category VM search the memory comparison time was 92 msec for positive responses and 202 msec for negative. For the VM word search, the slopes were 47 and 68 msec respectively. In contrast, in the CM conditions (right panel Figure 2) the category slope was 2 msec for positives and 10 msec for negatives. In the CM word search the slope was 19 msec in both conditions. The contrast between the left and right panels of Figure 2 illustrate the large differences between VM and CM search. In the category search condition the CM slope was 98% less than the VM slope. The similarity of character, word, and category search results indicates that the characteristics of automatic and control processing generalize to various levels of stimulus processing complexity.

Insert Figure 2 about here

Single frame search experiments have demonstrated that extended training reduces the slope of the search function (i.e., the comparison time per character) only in CM conditions. In CM conditions, performance improves substantially with training; for example, the memory comparison slope decreased from 28 msec per item to 19 msec per item over 30 days of practice (Kristofferson, 1972b). In the category search condition (Fisk & Schneider, Note 1) the slope dropped from 92 msec to 2 msec. Generally performance on the first block of CM training is equivalent to VM performance, but with training CM performance improves.

In contrast, Kristofferson (1972a) found that the memory search slope in VM conditions was 36.8 msec on days 1-5 and 36.0 msec on days 26-30. Thus single frame VM search rate does <u>not</u> change with practice. Similarly, Shiffrin and Schneider (1977, Experiment 2) found no differences in slope between the second week and the twentieth week of training. (In both Kristofferson's and Shiffrin & Schneider's studies, the base reaction time level continues to decrease with practice. Presumably the base reaction time represents consistent aspects of the task that are becoming increasingly automatized with practice.) In a word search experiment, Fisk and Schneider (Note 1) found no improvement with VM practice. In a category search condition, they found a 23% reduction in slope early in practice and then the slope was stable.

In summary, these results from the selective attention paradigm illustrate two generalizations. First, performance in the same paradigm can be quite different depending on the degree to which automatic and control processing takes place, with bottlenecks appearing when control processing is utilized. Second, performance changes dramatically as subjects are provided CM training but not when they are provided VM training. For a more detailed review of the selective attention literature bearing on these matters see Schneider and Shiffrin (1977a) and Shiffrin and Schneider (1977).

<u>Focused Attention</u>

Focused attention studies examine the ability of subjects to reject irrelevant messages. A classic example involving the need to ignore irrelevant inputs is a cocktail party situation in which a guest tries to listen to one conversation and ignore all others. An understanding of automatic and control processes helps explain why focusing succeeds or fails.

Eriksen and Eriksen (1974) demonstrated an inability of subjects to ignore irrelevant inputs in a choice reaction time task. One of four letters was presented just above a fixation point. If the letter was H or K subjects pushed one button, if it was S or C, they pushed a different button. The target letter was flanked by three letters on each side. The flanking conditions of present interest were: a) no letters, b) the same letters, c) different letters with the same response, d) different letters similar in shape to a letter with the same response, e) different letters similar in shape to a letter with a different response, or f) a letter with the opposite response. Response latencies at the closest letter spacing were 430, 455, 460, 495, 515, and 555 msec respectively. The presence of neighboring letters slowed reaction times. The more similar the neighboring letters were to letters with an incompatible response, the slower the response. The differences between conditions decreased as flanking letters were moved further from the target letter. If subjects could focus only on the target letter, flanker letters would have been irrelevant, but clearly they could not. These effects were not simply due to lateral masking because the interference effect was clearly dependent on the response mapping of the stimulus. Note that subjects received extensive CM training in responding to the target letters only. Thus this training on a relevant location was not sufficient to block automatic processing of neighboring letters. Neither was any controlled process invokable by the subject capable of blocking the distraction by the flanking letters. The names of the flanking letters are apparently processed automatically, causing interference which could not be completely suppressed.

Shiffrin and Schneider (1977, Experiment 4a) found subjects can focus attention in VM search conditions (in which controlled search is used). Utilizing a multiple frame procedure, they required subjects to search with frame size (F) of 2, 4, and 4/diagonal. In the F=4/diagonal condition each frame contained four letters but only letters along one diagonal were relevant. In the F=2, two positions contained targets and two contained random dot masks. In the F=4 condition each of the four positions contained a letter which could be a target. Estimated detection probabilities were F=2, .80; F=4/diagonal, .80; and F=4, .63. The equivalence of the F=2 and F=4/diagonal conditions shows subjects were clearly able to ignore the irrelevant letters. We suggest that the names of all letters were processed in all conditions, but that the order of the comparison process, and the speed, were not affected by this processing. In the F=4/diagonal condition subjects compared the two positions on the diagonal without wasting comparison time on the off diagonal items.

Even in a search paradigm, however, evidence is available that the comparison process can be affected by automatization of responses to the various stimuli. Shiffrin and Schneider (1977, Experiment 4d) tested this directly by having subjects carry out a VM search along one diagonal in a multiple frame task. Previously valid CM targets (referred to as foils) occasionally appeared on the diagonal which was to be ignored. Hit rate for the No Foil condition was 84%. If the foil occurred during the same frame as the VM target the hit rate was 62%, and if the foil followed the target by 200 msec, the hit rate was 77%. The CM foil not only interfered with VM processing when it occurred simultaneously with the VM target, but even if the foil appeared 200 msec later. These results demonstrated that CM processing is not under direct subject control. CM targets can not be ignored even when they are known to be irrelevant, when they occur in consistently invalid display locations, and when subjects are instructed to ignore them.

The classic example of the inability of subjects to exclude irrelevant information is the Stroop (1935) Color-Word Interference Test. This task requires that subjects vocalize the color of ink in which incompatible color names are printed (e.g., say green to the word "RED" printed in green ink). Subjects have a great deal of difficulty ignoring the incompatible printed word when trying to vocalize the color of the ink. The vocal reaction time is much slower when the printed name is incompatible with the ink color than when the printed name is compatible or neutral (see Dyer, 1973). Since subjects have consistently responded to the word RED vocalizing "red" this automatic process should interfere with vocalizing a different color ink. A poor reader who has not yet developed automatic word encoding of the color names should not, and does not (Gibson, 1971) show Stroop interference effects as strongly as expert readers.

Note the Stroop results do <u>not</u> show that subjects can <u>not</u> counteract automatic processes, but rather that such counteracting is difficult and resource consumptive. Subjects <u>can</u> respond correctly even when there are strong competing automatic processes. Logan (1980) has demonstrated that attentional processing can reduce Stroop interference. Posner and Snyder (1975) have reviewed evidence that effortful control processing is necessary to block automatic activation of priming words (see also Logan, 1980).

The difficulty of blocking automatic processes can result in negative transfer effects when subjects are asked to perform tasks incompatible with previously learned automatic processes. Utilizing a multiple frame paradigm, Shiffrin and Schneider (1977, Experiment 1) consistently trained subjects to search for targets from the first half of the alphabet in frames with distractors from the second half. After extensive training the target and distractor sets were reversed, so subjects now had to search for targets from the second half of the alphabet with distractors from the first. The results were quite dramatic. The hit rate just after reversal dropped well below that seen at the start of training when subjects were completely unpracticed. Very gradually thereafter the hit rate recovered so that after 2400 trials of reversal training subjects reached the level of 900 trials of original training.

Subjects are able to exercise some control over automatic processing by the use of effortful control processing. The need for such control is illustrated in reading. If all the words in the focal field of view were processed in parallel, one could not comprehend the text, because the parallel activation of all of the words would overload a limited short term memory. Through the use of effortful control processing, subjects may set up an enabling condition to limit the number of words activated in short term memory.

The ability of subjects to counter competing automatic processes via effortful use of focal attention is shown in probe indicator paradigms. Eriksen and his colleagues have used a probe indicator technique in which a bar appears before a display of nine letters in a circle (Colegate, Hoffman, & Eriksen, 1973; Eriksen & Collins, 1969; Eriksen & Hoffman, 1972, 1973; Eriksen & Schultz, 1979). The subject's task is to make a response appropriate to the probed letter. The earlier the probe indicator is available the less affected is the response mapping of the neighboring letters (Eriksen & Hoffman, 1973).

These results support the generalization that subjects have difficulty controlling automatic processes but that such control is possible. Control processing may be providing some stimulus components necessary for automatic processing to take place. Once the appropriate enabling stimuli occur (both external and internal), the automatic process may take place without additional control or effort by the subject. Subjects have difficulty ignoring or excluding automatic processes if the appropriate internal conditions are met and stimuli elicit competing automatic responses. Subjects appear to have little difficulty focusing attention when only control processing (e.g., VM search) is involved.

Attentional Capacity and Effort

Much research in attention assumes that there is a limited pool of attentional resources or capacity that can be distributed across tasks (e.g., Kahneman, 1973). Capacity experiments typically examine how subjects' performance trades off between two tasks as task demands and subject effort change (see Navon & Gopher, 1981). One conceptualization is that if you have 100 units of capacity and you are required to perform two tasks each requiring 75 units, performance should decline when shifting from performing the tasks individually to simultaneously.

Automatic/control processing theory assumes attentional capacity limitations are the result of competition between control processes. Control processing is assumed to be capacity limited to the availability of control processing resources. Hence combining tasks in which control capacity is exceeded should result in reduced performance. Control processing resources are assumed to be severely limited and may be somewhat differentiated (see Wickens, 1980). On the other hand, combining automatic processes can occur in parallel without reductions in performance and not be limited by control processing resources. Thus combining tasks can have quite different consequences, depending on whether they are carried out primarily with automatic or control processes. Schneider and Fisk (in press) have examined subjects' ability to perform automatic and control processing simultaneously. The experiment required subjects to perform a VM search (digit among digits) on one diagonal and a CM search (letter among digits) on the other diagonal. Subjects pushed a button at the end of 12 frames indicating whether they saw a target. In the dual task conditions subjects searched on the CM diagonal for any letter and on the

VM diagonal for a specific digit. In the single task conditions subjects searched for a target on one diagonal only. The results are presented in Figure 3. The measures on the axes are A's a non-parametric analog of d' (see Craig, 1979; Norman, 1965) which has a range of .5 for chance performance to 1.0 for perfect detection.[5]

Insert Figure 3 about here

Performance in the single task conditions that required automatic detection only (CM) is shown on the horizontal axis. Performance in the single task conditions that required controlled search only (VM) is shown on the vertical axis. Joint performance levels in which both tasks had to be performed simultaneously are graphed in the interior of the square. The different curves correspond to different frame times; the frame time determined the level of difficulty. The rectangular form of these POC curves indicated that both tasks could be carried out together without noticeable loss (see Norman & Bobrow, 1976). At least one of the tasks, presumably the CM search, required no resources.[6] These results were obtained in conditions when CM and VM targets never occurred simultaneously and subjects were instructed to devote their entire capacity to the VM task.

In a second experiment subjects attempted to perform <u>control</u> processing on both diagonals simultaneously. In this experiment A' dropped 10 to 15 percent on each diagonal below the single task controls (Figure 3, right panel). Even with extended training subjects could not perform both VM tasks without deficit.

Fisk and Schneider (Note 1) have had subjects perform an automatic category search detection task while simultaneously performing a digit recall task. Subjects could carry on a digit span task and simultaneously determine whether each of 16 words were members of the categories four-footed animals, human body parts, fruits and furniture without measurable (less than 2%) deficit in either the digit span or detection tasks. It should be noted that this dual task is extremely difficult. Subjects initially felt the dual task was impossible, but with training they could perform both tasks without deficit. In contrast, subjects could not perform the digit task in combination with a VM category search task without deficit.

These results indicate that some automatic processes do not require control processing resources. Actually, since two targets never occurred simultaneously, it would be more accurate to say that the requirement to monitor the stimuli for the possible presence of CM targets does not require resources (see Dumais, 1979; Duncan, 1980). This fact has several implications. First, whether or not one can perform multiple tasks without deficit depends critically on whether the additional tasks depend primarily upon automatic or control processing. Second, automatic processing can allow subjects to perform very complex tasks because the automatic components can be effectively cost free. The evidence that semantic categorization can be effectively cost free (Fisk & Schneider Note 1) indicates that processing stimuli at the feature, word, and semantic meaning levels can be done without reducing resources available for other tasks. This suggests that there is no inherent limit to complexity of an automatic process.

After a great deal of consistent practice, subjects in a number of studies have been able to perform complex dual tasks with little or no dual process performance decrement. For example, subjects have been able to read while writing (Downey & Anderson, 1915), type while shadowing prose (Shaffer, 1975), read one passage while transcribing dictation (Hirst, Spelke, Reaves, Caharack, & Neisser, 1980; Spelke, Hirst, & Neisser, 1976), shadow verbal messages while playing a piano (Allport, Antonis, & Reynolds, 1972), and fly complex aircraft formation maneuvers while digit cancelling (Colle & DeMaio, 1978). In each case it seems that at least one of the simultaneous tasks comes to be carried out largely by automatic processes that do not require substantial resources.

The automatic/control processing framework contrasts with the "attention-is-a-skill" hypothesis (Hirst et al., 1980; Spelke et al., 1976) which proposes that extended time sharing training is sufficient to eliminate dual task interference. We have found extended training is <u>not</u> sufficient to eliminate dual task trade offs. In situations where stimuli and responses are variably mapped, dual task tradeoffs occur even after extended training (see Logan, 1979; Shiffrin & Schneider, 1977; Schneider & Fisk, Note 2; Fisk & Schneider, Note 1; see above). The reasoning behind the "attention-is-a-skill" hypothesis seems to involve the view that only "simple" tasks and processes can be automatized (Hirst et al., p. 116). However, we argue that automatic processes can be very complex.

Any physiological or psychological effects which reduce capacity should primarily affect the performance of control processes and have only a minor effect on automatic processing. Research on "vigilance" provides an illustration. A <u>vigilance decrement</u> is a decrement in performance that occurs during the course of continuing performance on some task (see Parasuraman, this volume). One interpretation of this decrement is that it results from an inability of subjects to maintain proper allocation of control processes for extended periods of time (Fisk & Schneider, 1981). Such an argument leads to the prediction that VM search would show vigilance decrements but CM search would not. In a continuous multiple frame experiment of 50 minutes duration, Fisk and Schneider (1981) showed that detection sensitivity dropped considerably in the VM condition (from .91 to .81 A' units), but dropped in the CM condition only slightly (from .88 to .84 A' units). The VM decrement over time was highly significant whereas the CM drop was not. The experiments indicate that subjects find continual control processing very effortful and reductions in effort result in performance decrements.

Alcohol ingestion can also reduce capacity. A review of the alcohol literature reveals that alcohol tends to affect effortful processing to the degree that limits are placed upon short term memory, the task situation is relatively novel, stimuli are at perceptual threshold, and the subject's responding and/or attending is inconsistent. Generally alcohol causes a slowing of reaction time in choice RT tasks. However, there are exceptions which show little or no effect of alcohol on reaction time with tasks of high S-R compatibility (e.g., Carpenter, 1962; Huntley, 1972; Moskowitz, 1973). Well practiced "real world" skills, which may be considered largely automatic, seem to show a resistance to the normal effects of alcohol. For example, a string of well learned words (e.g., months of the year) is readily recallable when the subject is under the influence of alcohol (see Birnbaum & Parker, 1977, p. 101). Forney, Hughes, Hulpiew, and Davis (reported in Huntley, 1973, p. 153) found that low levels of alcohol had little effect on driving ability in skilled driving competition when the subject was driving forward. However, it was found that alcohol significantly reduced performance when driving in reverse (presumably unfamiliar and requiring control processing).

Recently Fisk and Schneider have examined the effects of alcohol on automatic and control processing performance. Subjects were tested in a sober and alcoholic state (.1% blood alcohol level). In a CM search task alcohol resulted in a 2.2% drop in detection performance. In VM search the drop was 9.6%. In a VM search task in which subjects had to also maintain an inconsistent mapping, performance dropped 28.3% (CM search in this condition reduced by only 0.16%). The data suggests that alcohol reduces the ability to perform control processing, particularly if control processing must be divided in two regions (e.g. dealing with a variable mapping both at the comparison and response stage).

In summary, whether two tasks can be performed without deficit will depend on whether the resource demands of both tasks exceed control processing capacity. If subjects are consistently trained and performance on one task is largely automatic, that task should not reduce control processing resources. Since control processing is effortful and resource limited, manipulations which make the task more arduous or decrease capacity should reduce performance in control processing tasks.

There are three important qualifications we would like to make before this discussion of capacity limitations can be brought to a close. Our summary conclusions concerning capacity limitations (and attention as well) are true only to the extent that the attention process itself is not placed in an automatic mode of action. In several studies we have shown that attention can be automatized. For example, stimuli can be trained to attract attention automatically. In such cases, whenever the instigating stimulus invokes the automatic call for attention, the system's control processing will be disrupted (at least briefly). In these instances the effects of automatic processing will be difficult to distinguish from those of control processing (because, in effect, the automatic process "controls" the control processing system). Thus, for example, in the Schneider and Fisk (in press) search studies, the requirement to look for a single target did not hinder a simultaneous controlled search. However, the presence of an actual automatic target on a trial can be quite harmful to simultaneous controlled search (Shiffrin & Schneider, 1977, Experiment 4d; Duncan, 1980). The automatic processing, up until the call of attention, can be done without reducing control process resources. The generalizations we have been drawing here should not necessarily apply during those intervals in which automatic processes direct control processes.

Some initial evidence suggests that automatic processing of targets can be done without consuming control processing resources given the proper training. Schneider and Fisk trained two subjects to perform a joint CM category word search and a VM digit search concurrently. After over eight hours of dual task training (some 1500 trials, subjects could perform both tasks together without deficit given the targets did not occur simultaneously. Performance was then tested for both simultaneous targets and nonsimultaneous targets. Initially the deficit for simultaneous targets relative to nonsimultaneous targets (with at least a 4 second delay between targets) was 46% for word targets and 34% for digit targets. However with 1008 additional dual task training trials in which most of the trials contained simultaneous or nearly simultaneous targets, the deficit for simultaneous targets was reduced to 18% for words and 14% for the digits. Schneider and Shiffrin (1977a, Experiment 3a, b, c) found no deficits for detecting simultaneous CM tarets when the two targets are different. The data clearly suggests that with the proper training, subjects can detect simultaneous targets without deficit. Hence automatic processing of both targets and distractions can become effectively resource free.

The second qualification is that the proposal that automatic processes are not limited by control processing resources does not imply that there are no limits to automatic processing capacity. As the number of stimuli processed through a modality increase, the stimuli will cause interference (e.g. lateral inhibition) and result in degradations in processing. Most of the research showing no performance reduction with increasing numbers of channels have tested in the range of 1 - 9 simultaneous inputs (although there is one study examing 49 inputs; Shiffrin, McKay & Shaffer, 1976). We know that as the amount of consistent training increases so does the number of stimuli that can be processed simultaneously without interference. Greatly reducing attentional resources, via the use of secondary tasks does not reduce automatic processing accuracy in both simple and complex search tasks (see above). Future research will have to determine how the capacity of automatic processing changes as a function of the number of stimuli, interitem confusability, and practice levels.

The third qualification is that predicting that automatic processing does not consume limited control processing resources, does not imply that task performance of an automatic process can not benefit from the allocation of control processing resources. In the simplest case, if automatic and control processing are parallel and independent, and there is some overlap in the distribution of the completion times of the two processes, using both processes to perform a task will improve performance. If automatic processing can be performed without reducing available control processing resources, then automatic component processes can be cascaded to perform complex processing tasks. In reading for example, word encoding can be performed fairly accurately with minimal resources (judging from the high correlation between verbal and reading comprehension for good readers). The possibility that word encoding might be improved if attentional resources are allocated to the encoding task, does not reduce the importance of developing automatic component skills. For it is through the use of automatic components that word encoding can occur at least with substantial accuracy while almost all control processing resources are allocated to the semantic integration aspect of reading.

Automatization of Attention

In this section we will discuss the automatization of attention. Although the search paradigms to be discussed ensure that attention is one of the processes being automatized, we think it likely that the conclusions should generalize to the automatization of other processes as well.

1. Consistency

In non-laboratory situations, training is unlikely to be perfectly consistent, yet automatic responses develop. Schneider and Fisk (1982) examined the automatization of attention when the degree of consistency during training was experimentally varied. They manipulated consistency by holding constant the number of times various items appeared as targets, and varying the number of times these items appeared as distractors. The target and distractor sets were selected from a set of nine consonants. Five consistency conditions were used; a given item could be: 1) always a target and never a distractor (CM control); 2) a target twice as often as a distractor; 3) a target and a distractor equally often; 4) a target half as often as a distractor; 5) a target approximately one seventh as often as a distractor. This last condition is a VM control, since the ratio is typical of those holding in previous VM conditions (e.g., Schneider & Shiffrin, 1977). After an average of 670 such training trials per CM letter, they found that detection accuracies across conditions were 83, 74, 68, 58, and 54%, respectively. The last two conditions did not differ significantly either from each other or from initial performance. In the case where a letter appeared as a distractor twice as often as it was a target (33% consistency), 670 training trials resulted in no improvement in performance. The results indicate that automatic processes develop as a <u>multiplicative</u> function of the number of trials and degree of consistency. Practice alone does not produce automatization, fairly consistent practice is needed. Consistency has also been shown to be critical in sequential motor response procedures (see Schneider & Fisk, in press b). In consistent responding paradigms, pauses between responses reduced and became less variable with practice. However if the button sequence was varied from trial to trial, there was no benefit of practice.

2. Automatization of a Consistent Component Process

Performance improvements associated with automatic processing occur in consistent processing stages even when the total task is not consistent from stimulus to response. Fisk and Schneider (Note 3) ran subjects in conditions where they attended consistently to a given letter but responded in different ways on different trials (i.e., on half the trials, they responded with the position of the target, and on half the trials they responded with the position opposite the target). There were no differences in asymptotic detection performance between the consistent-attending/consistent-responding group and the consistent-attending/inconsistent-responding group although the inconsistent group did not perform as well during training. The data indicate that automatic processing will develop when the processing for one component of a task is consistent, even if the entire task from stimulus to response is not consistent.

3. Searching vs. Detecting

During consistent training, subjects in search tasks both search for and detect targets. Schneider and Fisk (Note 4) removed this confounding. Subjects searched for a target in a 12-frame multiple-frame procedure. When a given stimulus was sought 6 times per block, as the number of target presentations increased from 2 to 4, CM hit rate improved from 64% to 71%. When the number of "target present searches" was constant (at 4), increasing the number of target absent searches from 2 to 16 resulted in a decrease in detection accuracy from 71% to 57%. All search conditions were significantly better than a VM search condition (45%). These results suggest that automatic attending develops as a consequence of consistent repetition of the appropriate stimulus response mapping (detection), not from simply the attempt to execute it (searching).

4. Transfer of Automatic Processes

Automatic processes show high transfer to processing stimuli in the same class as the trained stimuli. Schneider and Fisk (Note 2) trained subjects to detect CM words from a category (e.g., colors). After extensive training, subjects were presented new words from the categories they had been trained to detect. Performance on the new words from the trained category was compared to performance on the words used in training and new words from a new category. Using a reaction time measure, there was a 92% positive transfer to new words from the trained category. Using a detection measure under high workload, the transfer was 70%. The demonstration that automatic processes show high positive transfer is particularly critical when considering "real world" learning. There are few individual stimuli that are normally processed the number of trials (e.g., 200) required to show substantial automatic processing. However there are many classes of stimuli which are consistently processed (e.g., learning to catch flying objects, rather than a specific object).

5. Other Factors Affecting Automatization

Although we cannot describe the results in any detail (Schneider, Note 8), it is useful to list several other factors affecting the rate of automatization: 1) Similarity or feature overlap between target and distractor set -- learning is faster with greater dissimilarity. 2) History of training -- prior antagonistic CM training hinders automatization; in addition, prior VM training appears to slow automatization compared to no prior training. 3) Type of task -- multiple frame tasks requiring accuracy appear to lead to faster automatization than single frame tasks requiring rapid responding. The development rate may be very slow, still improving after years of training. Crossman (1959) found that cigar rolling was still improving after two years of practice and digit addition after 10,000 trials.

The Role of Attention in Distinguishing Automatic from Control Processes

Table 1 provides a partial listing of the characteristics that have been proposed to distinguish automatic and control processing. None of these characteristics provide a necessary and sufficient basis for distinguishing the two types of processes. Perhaps the best properties for distinguishing the two processing types are those involving attentional control and resource demands. The problem in stating any general rule, however, lies in the fact that attention itself can be automatized (orienting response). Thus an automatic process can call attention and thereby cause a demand upon resources (indirectly).

We suggest a two-part definition that is sufficient to establish the presence of a large class of automatic and control processes may be stated as follows:
RULE 1: Any process that does not use general, non-specific processing resources and does not decrease the general, non-specific processing capacity available for other processes is automatic.
RULE 2: Any process that demands resources in response to external stimulus inputs, regardless of subjects' attempts to ignore the distraction, is automatic.
The above rules provide a working definition for asymptotic automatic processing (see Shiffrin, Dumais, & Schneider, 1981, for more details). In processes that are poorly developed, automatic processing might somewhat decrease general processing capacity.

Insert Table 1 about here

Functions and Limitations of Automatic and Control Processing

It is important to consider the potential functions of automatic and control processes. We suggest that control processing performs at least the following functions. First, control processes should be instrumental in the development of new automatic processes. For example, storage in long term memory seems to occur primarily when control processing occurs (see Underwood, 1976, chap. 4; Schneider & Fisk, Note 6). Second, control processing is used to deal with tasks that cannot be carried out by automatic processing. These tasks include novel tasks, and tasks whose requirements are inconsistent (i.e., they change over time). Such tasks might include those of threshold detection (where the stimuli are sometimes ambiguous) and those of fine motor control in the early stages of practice. Third, control processing is used to maintain the activity of nodes in memory. An unattended automatic process input will decay rapidly. For example, digits presented in an unattended ear would automatically activate their nodes, but the nodes would decay to chance in no more than three seconds (Glucksberg & Cowen, 1970). Hence if an automatic process is to maintain performance for greater than 3 seconds, the top node must be activated either by control processing, or by continuous stimulation from external stimuli (e.g., external context). Fourth, control processing is used to activate nodes in order to enable automatic processes to occur. In effect, this allows indirect control of automatic processing. Fifth, control processing may be able to block and modify existing automatic processes. To illustrate this, consider that one normally brakes for a red light, but may run the light without braking in special circumstances. It may be in this way that old automatic processes are modified. Note, however, that control of automatic processing can be quite difficult (e.g., consider a Stroop task).

Functions of automatic processing include the following: First, they are used to perform habitual behaviors. Second, they may be used to interrupt ongoing control processing and forcefully re-allocate attention and resources (see Rabbitt, 1978; Shiffrin & Schneider, 1977, p. 153). Third, they may be used to bias or prime memory in preparation for later inputs (Logan, 1980; Neely, 1977; Posner & Snyder, 1975).

There is rarely any task in which processing is purely controlled or purely automatic. In general the two processes share the same memory structure and continuously interact. Automatic processing may initiate control processing by causing an orienting or attentional response, and controlled processing may activate an automatic process. For example, in playing tennis, an expert player may adopt a strategy to place the ball in the right far corner. Automatic processes are used in executing this strategy. In this example control processing is used to set and maintain the top level of a behavior hierarchy, and automatic processes execute the appropriate movements.

The continual interaction of automatic and control processing complicates any attempt to provide an operational definition of automatic processing. Just as we think all memory is a joint product of retrieval from short and long-term memory systems, we believe all behaviors are the joint result of automatic and control processing.

The complementary interaction of automatic and control processing enables a system with a stringent capacity limitation to perform complex processing. Those aspects of behavior which can be processed consistently are automatically processed and do not use up resources. However, since nodes activated by automatic processing decay rapidly, control processing can be used to maintain a few critical nodes in memory.

The interaction of automatic and control processes allows a limited capacity processor to accomplish very complex tasks (see also Schneider & Fisk, Note 1). We assumed that control processing modifies memory and leads to the development of automatic processing. In this sense the limited control processing system lays down "stepping stones" of automatic processing (Schneider & Shiffrin, 1977b). As long as the stimuli can consistently evoke a given response, no limited control processing resources need be expended. Thus automatic processes can be cascaded, enabling complex processing to be carried out. Fisk and Schneider (Note 1) have shown that subjects can categorize words into superordinate categories without reducing short-term memory capacity, suggesting that feature extraction, word encoding, and semantic categorization can all be done with no cost in control processing resources.

Control processing may be able to provide flexible control of normally inflexible automatic behavior. In many activities there is a need to produce unexpected or novel action patterns. The tennis player who changes strategy does not modify his overlearned patterns of meeting the ball, but rather chooses among many possible sets of automatic responses. The choice may be made by changing an internal stimulus which acts as a trigger for the automatic behavior (in combination with the external stimuli). In this way classes of automatic processes can be switched quickly, although the automatic behaviors are not individually changed.

Concluding Remarks

We have very selectively reviewed certain findings concerning divided attention, focused attention, and attentional capacity. The results suggest that: 1) performance differs to the degree that automatic or control processing determines performance; 2) performance improves with extensive CM training; 3) automatic processes are difficult to control; and 4) capacity reductions primarily harm control processing. The development of automatic processes were examined, and performance was seen to improve as a function of consistent executions. We have discussed the functions, limitations and interactions of automatic and control processing and have suggested that automatic processing can be defined in terms of capacity limitations and control. Although the automatic/control processing framework can be used to organize much of the attention literature, at present it raises more questions than it answers. Future research will have to unravel the complex interactions of these qualitatively different but complementary processes.

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6. Schneider, W., & Fisk, A. D. The connection between memory modification, levels of processing, and attentional processing. Manuscript in preparation.

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Footnotes

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[2]Note consistency need not be assumed to occur only when simple stimulus response relationships are consistent. For example, subjects can consistently respond to animal names even though the particular animal names vary across trials. As long as the category is consistently a target and never a distractor automatic processing may develop.

[3]This argument is bolstered by a recent study of this type carried out by Dave Foyle and Richard Shiffrin at Indiana University. In the consistent training paradigm described in the text, successive and simultaneous performance was equal. However, when the targets and distractors changed roles from trial to trial, then successive presentation was superior to the simultaneous presentation. They argued that information extraction for each display position in the varied mapping condition is unaffected, but that attention is not drawn automatically to the target position. Thus the decision process must consider each position in turn. Since memory decays as the decision process proceeds, there is a deficit in the processing of simultaneous displays. In the consistent mapping conditions attention is directed toward the target stimulus via automatic processing. Since the target stimulus position is the first to be compared for a target decision, memory decay is not a factor, and simultaneous and successive performance are equivalent.

[4]The reaction time variances also show marked CM and VM differences. The CM variance is uneffected by processing load and the VM variance increases substantially with processing load (see Schneider & Shiffrin, 1977a).

[5]The A' measure is used here because a considerable bias shift occurred for the CM task in the dual condition. That is, subjects in the dual task condition were much less likely to emit a CM response than in the CM single condition. This conservatism reduced "hits" when targets were present, but also dropped "false alarms" when targets were absent, so that sensitivity for CM items remained unchanged.

[6]In an earlier experiment in which subjects tried to divide their capacity between the two diagonals, the VM performance decreased. This finding suggests that subjects do not realize that automatic detection requires no resources -- given free choice they devoted unneeded resources to the diagonal that could be handled by automatic detection.

TABLE 1

SOME CHARACTERISTICS OF AUTOMATISM & CONTROL

CHARACTERISTIC	AUTOMATISM	CONTROL
Central Capacity	Does Not Require	Requires
Control	Not Complete	Yes
Continuation	Runs to Completion	Is Alterable
Indivisability	Wholistic	Fragmentized
Practice	Improves Gradually	Fairly Stable
Modification	Hard to Change	Easily Altered
Serial-Parallel	Parallel-Independent	Serial-Dependent
Storage in LTS	Little or None	Produces Large Amounts
Performance Level	High	Low, Except When Simple
Simplicity	Irrelevant	Irrelevant
Awareness	Low	High
Attention	Does Not Require But May Call	Requires
Effort	No	Yes

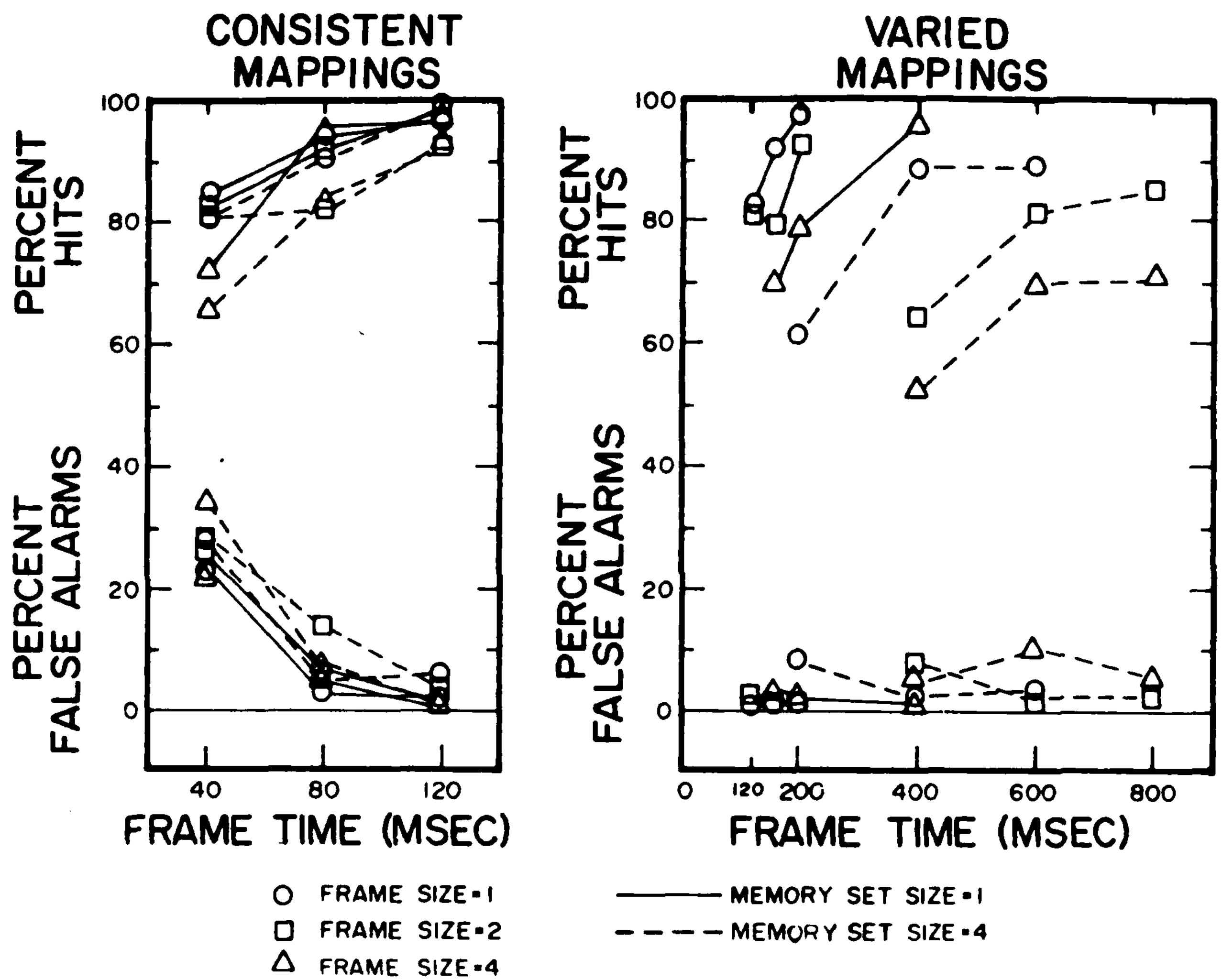

Figure 1. Hits and false alarms as a function of frame times for each of 12 conditions (from Schneider & Shiffrin, 1977a)

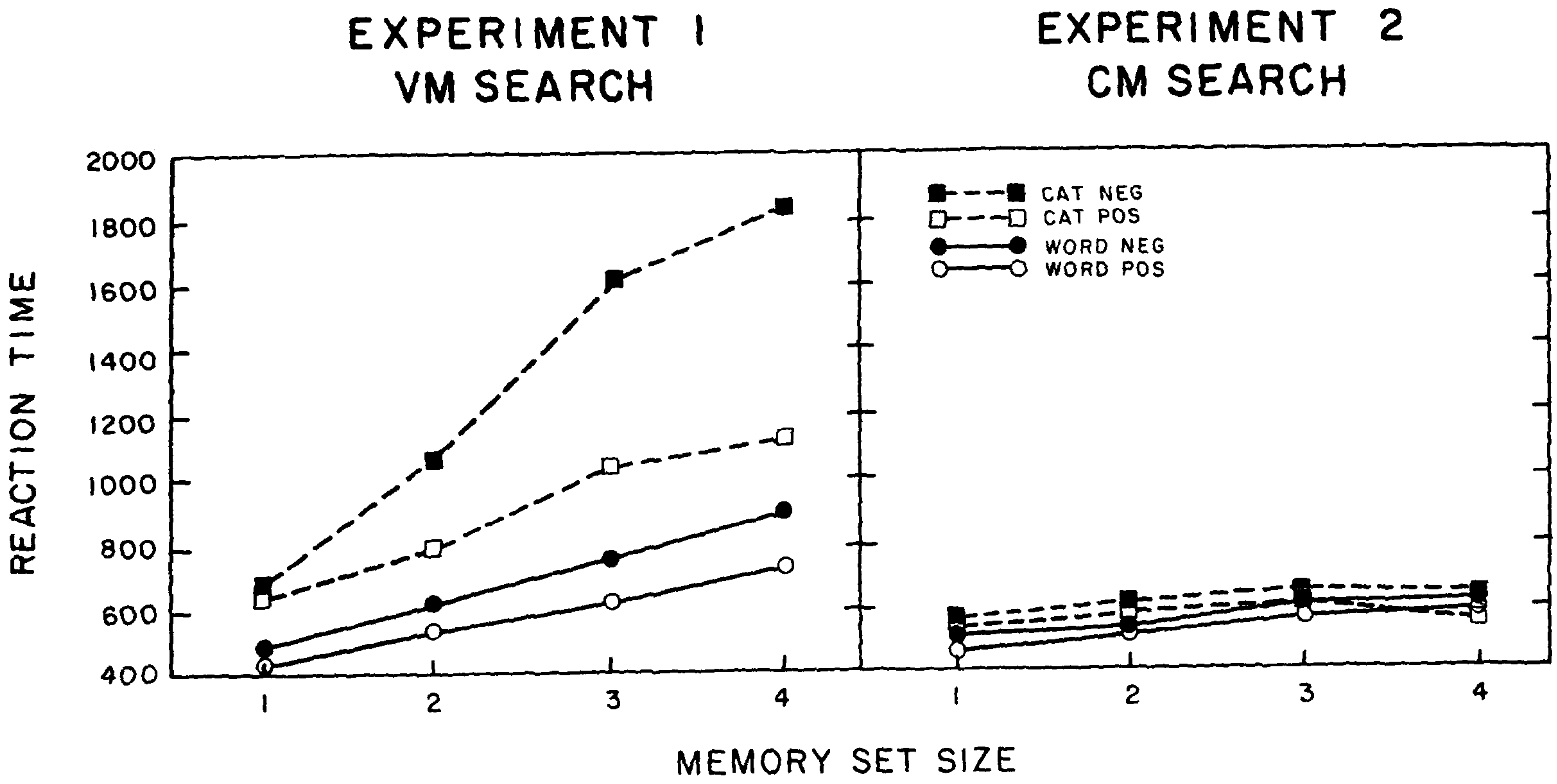

Figure 2. Category and word search reaction time as a function of the number of items in memory. Left panel VM search, right panel.CM search. The probe display always contained two words. Both panels represent performance after extensive training (over 2880 trials per subject per condition) (from Fisk & Schneider, Note 1).

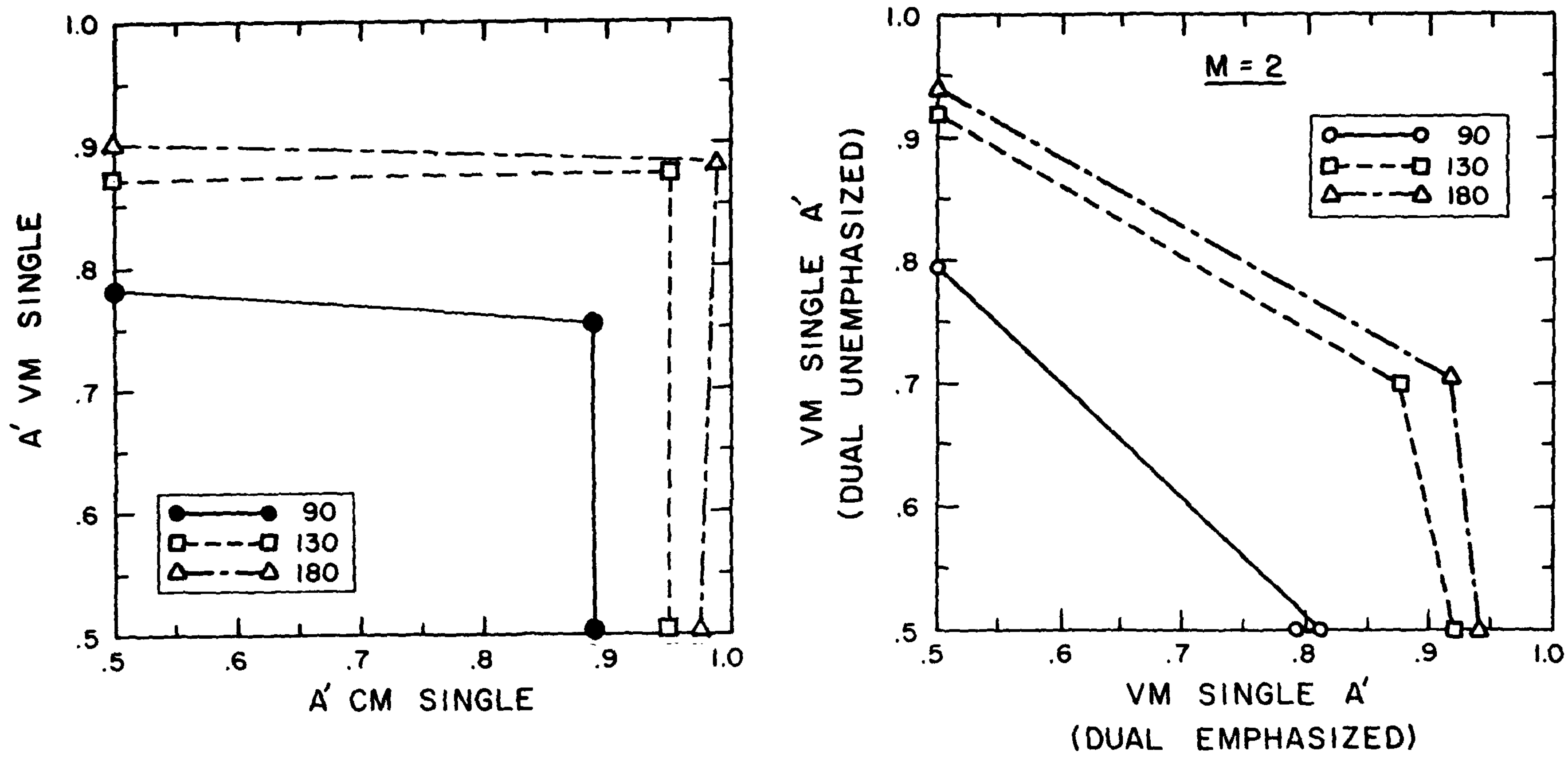

Figure 3. Dual task POCs for a CM and VM letter search task (left panel) and two VM letter search tasks (right panel; from Schneider & Fisk, in press-b). The left panel POC accounts for 98.1% of the area which would result from rectangles projected from the single task performance levels. The right panel POC accounts for 68.7% of the area of the projected single task rectangles.

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