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THE AUTOMATIC AND CONTROLLED PROCESSING OF TEMPORAL AND SPATIAL PATTERNS

Ray Eberts and Walter Schneider

REPORT No. 8003

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Automatic and controlled processing of spatial and temporal visual sequences was studied. The sequences were composed of three line segments that rapidly occurred across a single visual channel. Subjects' task was to identify the target sequence from three distractor sequences. Subjects were trained and tested on two kinds of sequences: 1) consistently mapped (CM) sequences where the target sequence was always a target and never a distractor; and 2) variably mapped (VM) sequences where a particular sequence could be

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20. either a target or a distractor on any given trial. Subjects trained for 8680 total trials on both CM and VM sequences. Test experiments showed a) CM sequences were less affected by increasing the number of channels, b) most subjects could perform dual task CM & VM search without deficit, c) there was strong positive transfer to CM sequences with changing stimulus durations, temporarily overlapping line segments, and running segments backward, d) subjects appear to rate CM and VM sequences differently, and e) CM training did not transfer to rotated stimuli. Results suggest the processes developed to identify CM and VM sequences were qualitatively different; CM sequences were automatically processed and VM sequences were control processed. However, the automatic process that developed for these relatively unfamiliar spatiotemporal patterns was weak. The development of an automatic process was compared with skill learning. Skilled CM search was economical and efficient, flexible in components other than the spatial, and less influenced by increases in load.

The Automatic and Controlled Processing

of Temporal and Spatial Patterns

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Report 8003

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February, 1980

Abstract

A four-choice reaction time task was used to study the automatic and controlled processing of spatial and temporal visual patterns similar to the studies undertaken by Schneider and Shiffrin (1977) on spatial patterns. The sequences were composed of three line segments that rapidly occurred across a single visual channel. Subjects' task was to identify the target sequence from three distractor sequences. Subjects were trained and tested on two kinds of sequences: 1) consistently mapped (CM) sequences where the target sequence was always a target and never a distractor; and 2) variably mapped (VM) sequences where a particular sequence could be either a target or a distractor on any given trial. Initially subjects were trained for about 17 hours and 8680 total trials on both CM and VM sequences. The nine experiments that followed tested characteristics of the differential training effects of CM and VM sequences. The first experiments found that CM sequences were less affected by increasing the number of channels than VM sequences. For five of the seven subjects, there was little deficit in doing dual task VM and CM search; a larger deficit existed for the dual VM sequences. The temporal component was manipulated by changing the stimulus durations of the line segments, overlapping the line segments, and running the sequence backwards. In all, CM transfer sequences were better identified than the VM trained sequences; there was very good transfer to CM sequences that subjects had not been trained on. A ratings study suggested that subjects perceive CM and VM sequences differently. In the last two experiments, the spatial component was manipulated by rotating the whole pattern. Results were markedly different from the temporal manipulation experiments: 1) there were very little or no CM/VM differences; and 2) CM transfer sequences were worse than VM trained sequences. It was concluded that the processes developed to identify CM and VM sequences were qualitatively different; CM sequences were automatically processed and VM sequences were control processed. However, the automatic process that developed for these relatively unfamiliar spatiotemporal patterns was weak. The concept of an automatic process had to be revised to include aspects of weak automatic processes. The development of an automatic process was compared with skill learning. Skill was reflected for CM sequences in the economical and efficient search, the flexibility in components other than the spatial, and the low load requirements.

Introduction

The automatic processing of visual stimuli has much in common with skilled performance. Both show qualitative changes in performance with extended training. In previous research a distinguishing characteristic between research done on automatic processing and skilled performance has been a temporal component. Whereas researchers in skilled performance study motor movements - a temporal and spatial pattern - automatic processing has been studied as the response to a single visual stimulus (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977; Laberge, 1973, 1975). There is a need to expand automatic processing to inputs where an event is defined by a sequence of stimuli.

In this series of experiments, the detection and automatic processing of visual stimuli that change both spatially and temporally are studied. In particular, with the expansion of the stimulus set, the generalizability of the findings of Schneider and Shiffrin (Schneider and Shiffrin, 1977; Schneider and Shiffrin, 1977) are tested and revisions and extensions to that theory are proposed. In the process, several areas in psychology - visual and auditory perception and attention, skilled performance, and apparent motion - can be reviewed and integrated.

Background

The earliest work in attention was done in the auditory mode to sounds which are themselves spatial and temporal patterns. Of particular interest is the work done by Moray and his coworkers. In a shadowing task, Moray (1959) found that a person's own name, a spatial and temporal pattern that is responded to consistently whenever heard, would "pop out" and be detected if presented on the unattended channel. In a later experiment using a monitoring technique (Ostry, Moray, and Marks, 1976), the effects of practice on the detection of auditory stimuli were studied further. They found that subjects could monitor two channels with no deficit when compared to single channel performance, a result that is very similar to that found for the automatic processing of visual stimuli (Schneider and Shiffrin, 1977). Apparently, with enough practice and the right kind of practice, spatial and temporal components can be processed automatically. However, the auditory experiments use words, spatial and temporal patterns which are already well-learned before the experiment begins.

In studying visual attention, special problems exist that aren't encountered in auditory attention. Experiments must be designed to control for orientation movements and peripheral presentation of items. These problems become more enhanced when spatiotemporal visual phenomena are investigated. Consequently, there has been only one recent study of the spatial and temporal aspects of visual attention. Neisser and Becklen (1975) studied selective looking, a counterpart to selective attention studies in the auditory mode, to naturalistic scenes. They concluded that in performing the task subjects could attend to the motion which is a spatial and temporal phenomenon. In their use of naturalistic scenes, though, one scene occurred primarily in the fovea and the other primarily in the periphery. A method needs to be devised that more completely controls for eye movements and peripheral presentation when studying spatiotemporal visual attention.

Schneider and Shiffrin (Schneider and Shiffrin, 1977; Schneider and Shiffrin, 1977) reviewed and synthesized research done in visual search and detection. Noting that experiments which used subjects that were highly practiced at consistently responding to a stimulus found qualitatively different results than experiments which used subjects who did not have consistent responding, they hypothesized that two kinds of processes were required to account for the data. They called these two controlled and automatic processing. Furthermore, they found that the development of automatic processing depended on the type of mapping of target to distractor. When the targets are consistently mapped (a CM condition) - a target is always a target and never a distractor throughout the experiment - with practice an automatic processing of the targets will develop. If targets and distractors are in a varied mapping (VM) condition - a target can be a target on one trial and a distractor on the next - controlled processing will be maintained. The general form of a two process theory has been proposed frequently in psychology (e.g., James, 1890; Atkinson and Juola, 1973; Shiffrin and Geisler, 1973; and Corballis, 1975; Posner and Snyder, 1975).

Schneider and Shiffrin (1977; Shiffrin and Schneider, 1977) found quantitative and qualitative differences between automatic and controlled processing. They found that controlled processsing was: 1) highly demanding of attentional capacity; 2) characterized by serial search; 3) easily established; 4) easily altered; 5) easily reversed; 6) easily suppressed; and 7) affected by the load requirements. On the other hand, automatic processing was: 1) not demanding of attentional capacity; 2) characterized by parallel search; 3) established only after extensive training; 4) not easily altered; 5) difficult to reverse; 6) difficult to suppress; and 7) unaffected by load. In an automatic process, it appeared that attention was automatically allocated to the particular stimulus.

In many ways, the characteristics of automatic processing are similar to the characteristics of skilled performance. Welford (1976) describes the components of a skill: 1) it is dependent on training, practice, and experience - not solely dependent on fundamental, innate capacities; and 2) it is efficient and economical in performance. Because of the temporal characteristics of skilled performance, most research and theory has been concerned with the structure of motor programs and timing considerations.

Fitts (1964) concluded that the best way to describe the structure of a skill is in terms of a "mental program", an analogy to a computer program. This mental program has two main characteristics: 1) it has a hierarchical structure of an executive which calls subroutines; and 2) similar to Bryan and Harter (1899) and Miller, Galanter, and Pribram (1960), behavior is organized into larger and larger units called chunks. More recently, much work has been done on the similar concepts of motor schemas and motor programs (Pew, 1974b; Schmidt, 1975; Welford, 1976). A motor program has been described by Keele (1968) as: 1) a sequence of stored commands; 2) structured before initiated; and 3) carried out entirely uninfluenced by peripheral feedback. A motor schema is characterized by its flexibility (Welford, 1976; Pew, 1974b) and must be able to be situation specific and perform novel tasks if it is to be of any use. Schmidt (1975) states that much of this conclusion is based on conjecture - to account for the behavior, certain types of motor programming and schemas seem like the only alternative.

Present visual target acquisition applications emphasize the importance of examining the skill acquisition of spatial and temporal target phenomena. A radar operator finds it hard to distinguish targets from noise. Usually size, shape, or intensity are not salient enough to enable the discrimination. One possible cue could be the motion, a spatial and temporal pattern, of a target across the screen. Scanlan (1975) and Scanlan, Roscoe, and Williges (1971) studied several characteristics of radar screens that would enhance the motion of the target. In a time-compressed display they found that as the time between frames decreased detection became better. Thus, as the apparent movement of targets on the screen was enhanced, detection became better. In the following series of experiments, the task is relatively simple. The simplicity enables an investigation of performance throughout the time course of its development; an investigation that is difficult, if not impossible, to do with more complex skills.

The experiments that follow are designed to study visual processing in a manner similar to that done by Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977). These studies extend the examination of automatic processes to targets defined by the temporal sequence of events.

In the present experiments one group of subjects participated in all twelve experiments. Subjects identified sequences of spatial and temporal patterns. Sequences for each subject were trained differently. For a CM (consistently mapped) sequence, the target sequence was always a target and never a distractor. After training, performance of these sequences was expected to be similar to the characteristics of automatic processes outlined by Shiffrin and Schneider (1977) and should have the structural characteristics of a well-trained skill. For the VM (varied mapping) trained sequences, one stimulus sequence could be a target on one trial and a distractor on the next. Performance on these should be similar to the characteristics of controlled processes outlined by Shiffrin and Schneider (1977), and, like unskilled behavior, should be disorganized in structure and locked into the specific problem. In order to develop a skilled performance, each subject participated for roughly 40 hours - about 17 hours of training and 23 hours of tests. In that time, each subject responded to about 14,000 trials, 6,000 CM and the rest VM. The experiments are not necessarily reported in their chronological order of occurrence but, for ease of presentation, are divided into three groups: 1) three training experiments; 2) three experiments that test the load requirements; and 3) six transfer of training experiments.

A four-channel detection task similar to that used by Schneider and Shiffrin (1977) was used. To eliminate eye movements, the target occurred on one of the four channels with the other three channels occupied by distractors. The whole display subtended about 2.8 degrees of visual angle so that foveal presentation was maintained. Each channel was separated by 1 degree of visual angle so that lateral masking would be minimal (Eriksen and Eriksen, 1974).

A target was defined by a sequence of three line segments occurring across a single channel. Each line segment had a stimulus duration of 100 msec. This particular duration was chosen for two reasons: 1) the stipulation that events must be separate from one another; and 2) to increase the possibility that the pattern could be identified by its movement. Eriksen and Collins (1967) determined that stimuli are integrated if the stimulus onset asynchrony (SOA) is in the range of 0-100 msec. If the events are to be separate, the SOA must exceed that range. In order to enhance possible movement cues, an SOA of 100 msec with an interstimulus interval (ISI) of 0 msec was used. Recent experimentation by Kahneman (Kahneman, 1967; Kahneman and Wolman, 1970) indicated that these values of SOA and ISI result in optimal motion. Therefore, in constructing a display so that each event would be discrete yet capture possible movement cues, each of the line segments had a stimulus duration of 100 msec and an ISI of 0.

Training Experiments

Experiment 1 - Single Sequence

Schneider and Shiffrin (1977) found that the type of mapping of targets and distractors was important. An automatic process would develop if targets and distractors were consistently mapped (CM) and controlled processing would be maintained if they were in a varied mapping (VM) condition. In this experiment, subjects were trained on both CM and VM sequences as in the Schneider and Shiffrin (1977) experiments. However, important differences exist between this experiment and the earlier Schneider and Shiffrin experiment. First, in this experiment the stimuli contain a temporal component. Secondly, subjects were trained on novel patterns which require fairly difficult discriminations. Because of the long time required to develop an automatic process to a difficult spatial and temporal pattern, each subject received CM training on only one sequence. It was expected that, similar to the Schneider and Shiffrin results, a quantitative difference would exist between the CM and VM trained sequences after a short period of training. The differences between the two groups should become larger as the training continues. The purpose of this experiment was mainly to be a training procedure.

Method

Apparatus. The experiments were computer controlled by a PDP 11/34 digital computer. Displays appeared on Tektronics 604 or 620 cathode ray tubes which were equipped with P-31 phosphor with a refresh rate of 10 msec. The scope consisted of a 1024 x 1024 unit matrix such that each cell in the matrix could be individually controlled. Four self-paced subjects, separated from each other by partitions, could be run at a time.

Stimuli. The three line segments of a sequence all occurred within a 60 x 60 unit matrix. The whole matrix subtended about .9 degrees of visual angle to take advantage of any possible movement cues (DeSilva, 1926). Each line segment subtended about .6 degrees of visual angle. The 28 possible line segments were constructed in the following manner: 1) they could be in six orientations - 0, 30, 60, 90, 120, and 150 degree angles with the base line; and 2) they could be in four or six positions within a matrix - the vertical and horizontal lines could emanate from one of the four corners or middle of each of the four sides (16 possible) and the non-vertical and non-horizontal lines could emanate from

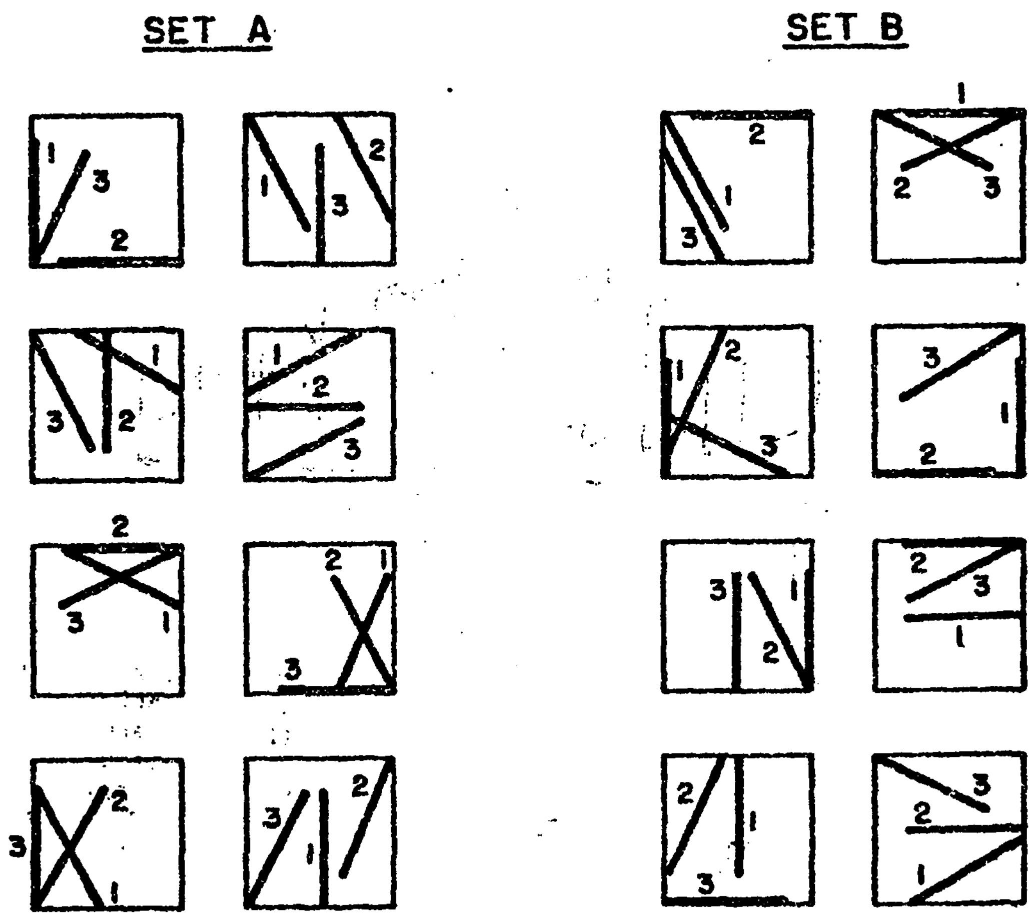

Figure 1. The sequences used are represented. The order of occurrences of the line segments is signified by the number. The sequences were equated for difficulty in a pilot study and divided into two sets, A and B. One group of subjects had set A as CM sequences and set B as VM sequences. The other group had the opposite assignment. The sequences for each set are ordered by ease of identification in the pilot study with the easiest at the top and the hardest at the bottom. The middle four sequences of each set were chosen as CM sequences.

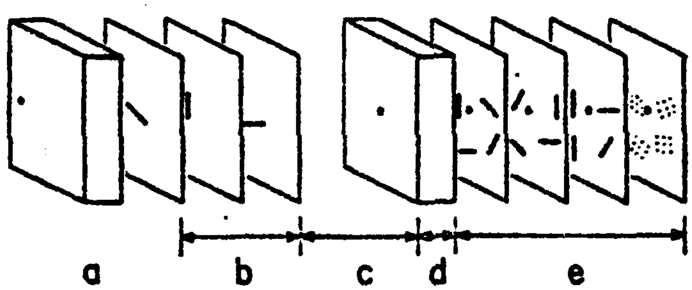

Figure 2. An example of a trial in the single sequence procedure of Experiment 1: (a: 500 msec focus dot at the start of the orientation; b: the presentation of the orientation sequence which specifies the target; c: a one second pause; d: the beginning of the experimental trial with a 500 msec focus dot; e: the trial display of four sequences followed by random dot masks). The target sequence appears in the upper right position.

one of the four corners (12 possible).

If all possible three event sequences were generated from the 28 possible lines without replacement there would be 19,656 sequences to choose from. To limit the possibilities to a manageable number, 35 sequences were chosen pseudo randomly for use in a pilot study, under two stipulations: 1) no single line segment could occur twice within the same sequence; and 2) the 35 sequences generated would have to cover a wide spectrum of movement from lines moving across the screen in good movements to poor movements where the lines made discontinuous jumps. Using the percent correct results of the pilot study, the 16 sequences of intermediate difficulty were chosen from the original group of 35. The 16 sequences were further divided into two sets, A and B, which were equated for difficulty (see Figure 1). Set A was assigned to be the CM set for half of the subjects and set B was assigned the VM set; the rest of the subjects had the opposite assignment. Each subject was assigned one CM target (from their CM set) that remained with him or her throughout the rest of the experiments. The CM targets were chosen from the four sequences of intermediate difficulty, according to the pilot study, in set A or set B depending on the CM set that was assigned to a particular subject. Costs and time considerations prohibited a complete counterbalance which would have required 16 subjects each asigned one of 16 possible sequences as a CM target. Instead, a partial counterbalance resulted where the eight subjects were assigned the eight CM targets of intermediate difficulty.

Insert Figure 1 about here

Subjects. The subjects were eight University of Illinois undergraduates (three male). They were paid for their participation. Because of an illness and later time conflicts, one subject was forced to drop out after the first experiment. Her data will not be reported. The remaining subjects participated in all 12 experiments. All were right-handed and had normal or corrected-to-normal vision.

Procedure. The basic paradigm is illustrated in Figure 2. To start a trial, subjects pushed a button in the upper left corner of a response box with their left index finger. This started the orientation sequence which designated the target sequence the subject was required to search for on the present trial. A 500 msec focus dot appeared, followed by the three segment sequence which had a stimulus duration of 100 msec and ISI of 0.

Insert Figure 2 about here

One second later the trial display began. Directly in the middle of the screen, 2.2 degrees to the right of the position of the orientation sequence, a 500 msec focus dot appeared. Then, four sequences appeared on the four channels. One, and only one, of the four was the target sequence previously displayed in the orientation sequence. The other three sequences were randomly chosen before the start of the trial. After the appearance of the three movements, masks appeared on all four channels. Subjects were instructed to push one of four buttons on their response box, corresponding to the position of the target on the screen, with their right index finger. The buttons were arranged in a square corresponding to the position of the channels on the screen. As an example, if the target occurred in the lower right hand corner, a correct response would be to push the lower right button. Subjects were instructed to make their best guess if they were not entirely certain of the position of the target. They were allowed four seconds for a response.

If the subjects made an incorrect response, an X appeared in the correct position on the screen for 500 msec and a 500 msec error tone sounded over the subject's headset. After the error feedback, and if the subject's response was correct the block percentage score appeared in the lower left corner of the screen. The score remained on the screen for a maximum of 30 seconds. Anytime during this period subjects could start the next trial by pushing the upper left button on the response box. At the end of a block of trials, the subject's percentage score for the entire block would appear in the middle of the screen.

The type of mapping of distractors to targets, CM or VM, was a between block variable. In the CM condition, the individual subject's CM target was always the target. The other three distractors were randomly chosen, without replacement, from the CM set. In the VM condition, the target was chosen from the eight possible VM sequences. The three distractors were randomly chosen, without replacement, from the other seven possibilities.

Within a block of trials, each VM target appeared eight times for a total of 64 trials. A block in the CM condition also contained 64 trials. The position of the CM or VM target was randomly chosen. The order of occurrence of CM and VM blocks was randomized within groups of two. A CM and VM block together will be termed a replication. Subjects participated in 50 minute sessions for a total of 25 replications per condition which lasted approximately 7 hours. Thus, each subject had 1600 CM trials and 1600 VM trials.

<u>Results</u>. Scores were corrected for guessing by subtracting one-third the probability of a miss from the probability of a hit. CM and VM differences existed throughout the experiment (see Figure 3) starting with a 9% initial difference and expanding to a 22% difference by the 25th replication. The CM performance was better for all subjects with the differences ranging from 8 to 44% in the last replication. The CM/VM differences in the first and last replications were analyzed by a one-tailed matched-pairs t-test with 6 degrees of freedom. In the first session, CM sequences were not significantly different from VM items at the .05 level [$t(6)=1.04$]. In the last session, CM sequences were identified significantly better than VM sequences [$t(6)=4.40$, $p<.01$]. Apparently, performance started to level off after about the 17th session; VM performance was within three percentage points of .65 and CM performance was within three percentage points of .87 after that time. Two subjects were consistently at ceiling during the last several replications with scores of 98% and better.

Insert Figure 3 about here

<u>Discussion</u>. This experiment was used mainly for training. CM and VM differences were expected and obtained. To ensure that CM/VM differences in

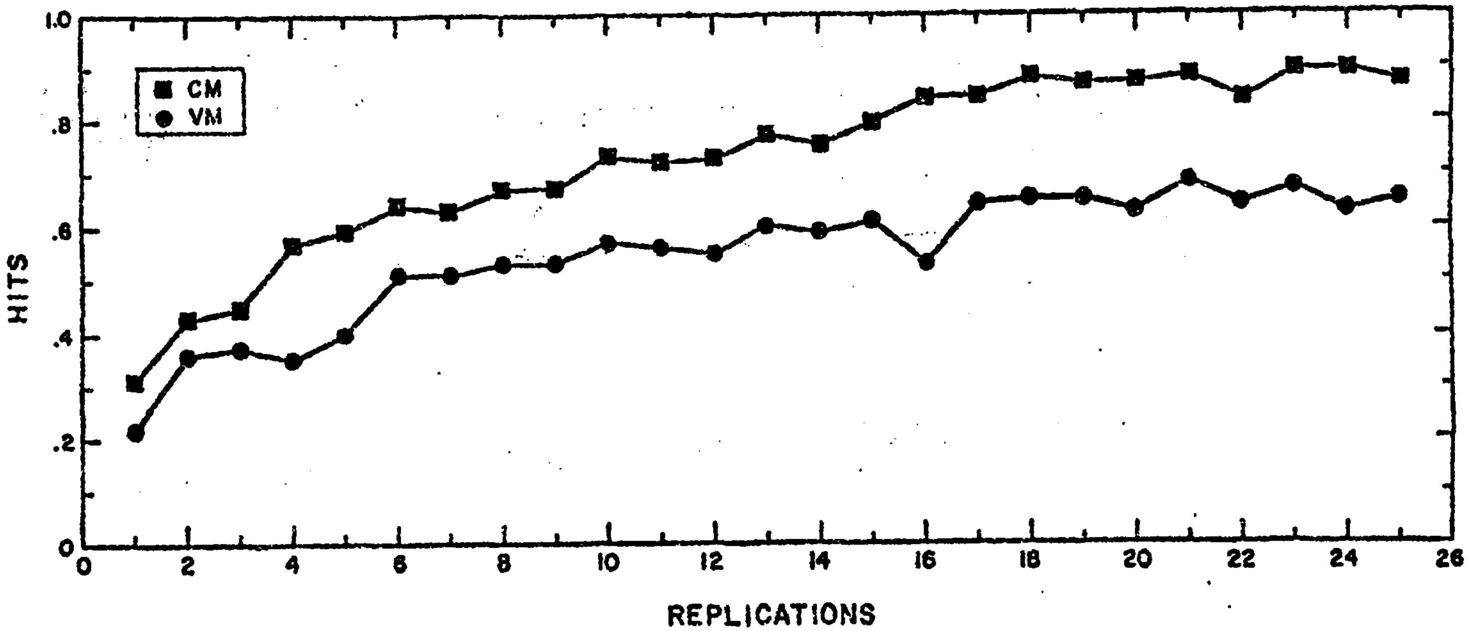

Figure 3. Data from Experiment 1: proportion of trials identified correctly as a function of practice. The hits are corrected for guessing.

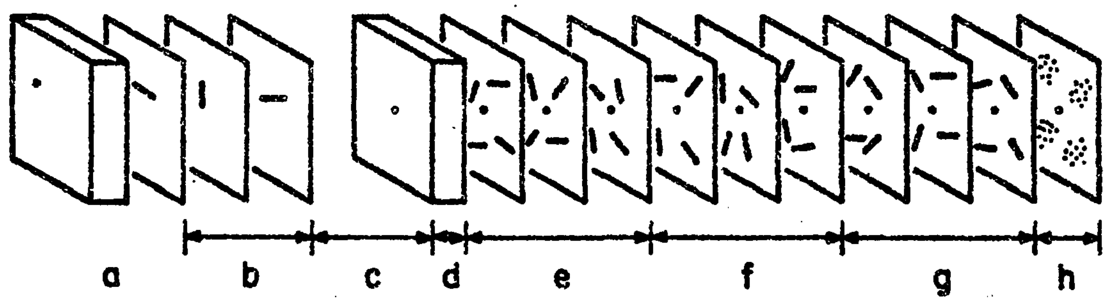

Figure 4. An example of a trial in the intermediate sequence procedure of Experiment 2: (a: 500 msec focus dot at the start of the orientation; b: the presentation of the orientation sequence which specifies the target; c: a one second pause; d: the beginning of the experimental trial with a 500 msec focus dot; e: the first sequential display; f: the second sequential display which must contain the target sequence; g: the third sequential display; h: random dot masks). The target sequence appears in the lower right position of the second sequential display.

later experiments are a product of the training and not due to differences in the ability to identify the two groups of stimuli, it must be established that the two groups, CM and VM, are initially equated for difficulty. Although the 9% difference between CM and VM sequences in the first replication was a fairly large difference, performance was variable and a t-test failed to find a difference between the two groups. In a previous study using the same stimuli, much the same procedure, but different subjects (Eberts, 1979), the CM sequences were better than the VM sequences by only 1%. Also, some training effects are bound to occur within the initial 64 trials. Thus, taking into account the variability in performance, the nonsignificant difference and initial training effects, CM/VM differences found in later experiments cannot be interpreted in terms of differential ability to identify one group of sequences better than the others.

Experiment 2 - Intermediate Sequences

In the previous experiment, two subjects had reached ceiling. In this experiment, the task was made more difficult in order to continue the training. Each line segment in a sequence will be termed a movement. In the previous experiment, subjects were required to identify a sequence of three movements. In this experiment, subjects were required to identify targets of three movements from a stream of nine movements altogether. Thus, in this task, the target sequences do not have a definite beginning and end.

Procedure. The same subjects from the previous experiment participated. All aspects of this experiment were the same as the previous experiment except for changes in the trial display. See Figure 4 for an illustration of the procedure. In this trial display, there were 9 movements altogether per channel.

Insert Figure 4 about here

The target sequence could occur on movements 4-6. Movements 1-3 and 7-9 were members of the VM or CM group, other than the target, that were chosen randomly before the start of the trial. The last line segment of one of the sequences was the same as the first line segment of another. Therefore, a stipulation was that these two sequences could not occur in succession.

Subjects participated for a total of 20 replications (a CM and a VM block of trials together constituted a replication). Altogether, a subject participated in 1280 CM trials and 1280 VM trials. This experiment lasted about 6 hours.

Results and Discussion. The results were similar to the previous experiment (see Figure 5 for the corrected for guessing scores). There was an initial difference of 3% between the CM and VM groups. Using a matched-pairs one-tailed t-test, this difference was not significant at the .05 level [$t(6)=0.15$]. For the CM group there was a 29% improvement and for the VM group there was a 12% improvement at the highest point. CM performance was better than VM performance for all subjects at the 20th replication with differences ranging from 8 to 48%. The 26% difference in the last replication was significant [$t(6)=4.229$, $p<.01$]. Again, there appears to be a leveling off of improvement toward the end of the experiment. The task was much harder than the previous experiment, a target sequence did not have a definite beginning and end, but CM/VM differences still existed.

Insert Figure 5 about here

Experiment 3 - Multiple Sequences with Masks

This experiment was an attempt to devise a task similar to the multiple frame procedure used by Schneider and Shiffrin (1977). In this experimental procedure, there were multiple sequences, 6 sequences per channel, with 18 movements altogether. Subjects were asked to identify spatial and temporal patterns in a stream of patterns. A counterpart in auditory attention would be a monitoring task where subjects are required to identify a target word embedded in a string of words (Shaffer and Hardwick, 1969; Ninio and Kahneman, 1974; Ostry, Moray and Marks, 1976). In monitoring experiments words are separated by gaps and in the multiple frame procedure each character is a discrete event. In this experiment sequences were divided by 100 msec masks so that each sequence would have a definite beginning and end. This experiment was used to conclude the training procedure.

Procedure. The stimuli were the same as those used in the previous experiments. The same subjects participated.

The procedure was the same as the previous experiments except for a change in the trial display. Figure 6 is an illustration of the procedure. The simultaneous presentation of four sequences across the four channels will be termed a sequential display. Thus, the trial display contained 6 sequential diplays. Each sequential display was separated from the next by 100 msec random dot masks. The target could occur on one of the channels in sequential displays 2 through 5. Otherwise, the procedure was the same as experiment 1.

Insert Figure 6 about here

Subjects participated for a total of 15 replications (30 blocks) so that each had 960 trials of CM sequences and 960 trials of VM sequences. This experiment lasted for about 4 hours.

Results and Discussion. Initially, a CM/VM difference of 19% existed (see Figure 7 for the corrected scores); apparently the subjects were well-trained on their CM sequences at this point. Using a matched-pairs one-tailed t-test, this initial difference was significant [$t(6)=3.52$, $p<.01$]. All subjects could identify the CM sequence better than the VM in the last replication with the differences ranging from 17% to 50%. This difference was also significant [$t(6)=5.123$, $p<.001$]. In the CM condition subjects improved from 41% to 59%. In the VM conditions, improvement was from 22% to 31%. Performance apparently leveled off in the VM condition after about the fourth replication. The CM

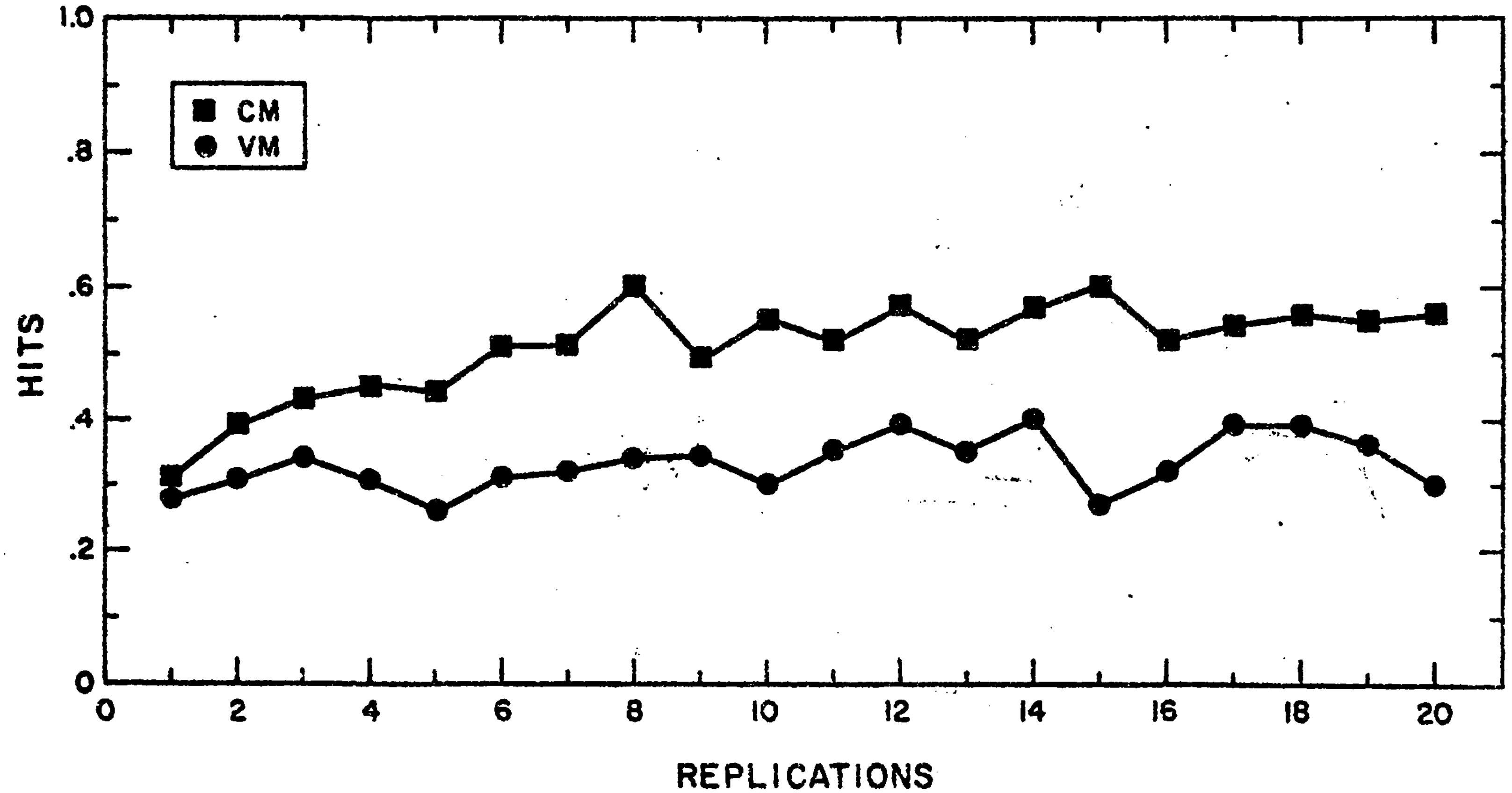

Figure 5. Data from Experiment 2: proportion of trials identified correctly as a function of practice. The hits are corrected for guessing.

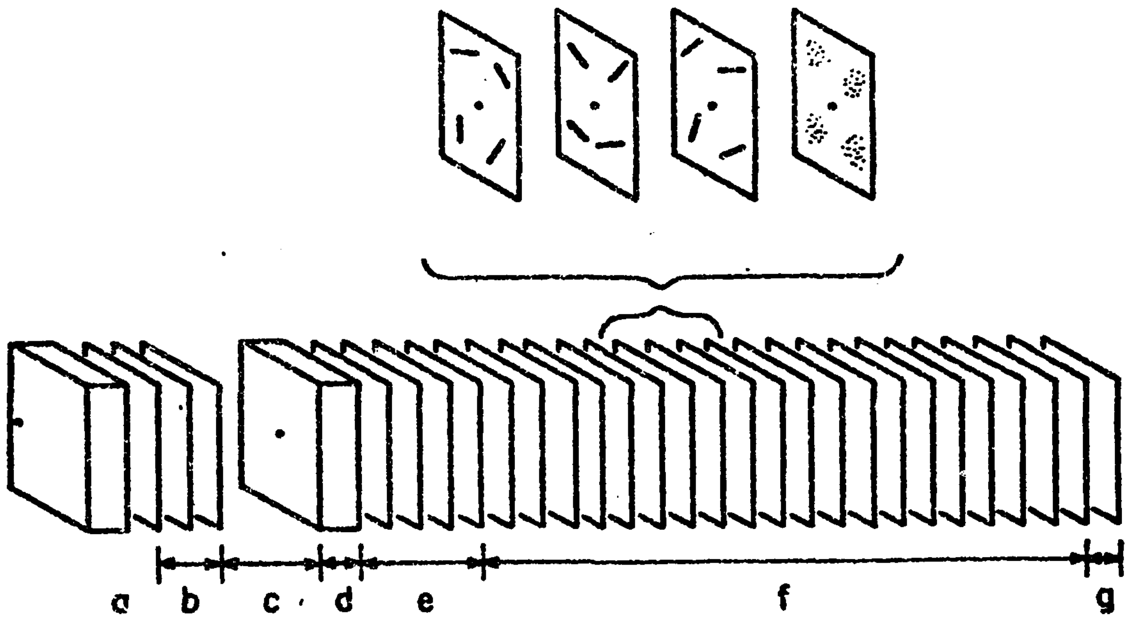

Figure 6. An example of the multiple sequence procedure used in Experiment 3: (a: a 500 msec focus dot for the orientation sequence; b: the presentation of the orientation sequence which specifies the target; c: a one second pause; d: the beginning of the experimental trial with a 500 msec focus dot; e: the first of six sequential displays (a blowup of a sequential display occurs above the third sequential display); f: the remaining five sequential displays; g: the final random dot mask). The target can occur in one of the four positions of sequential displays two through five.

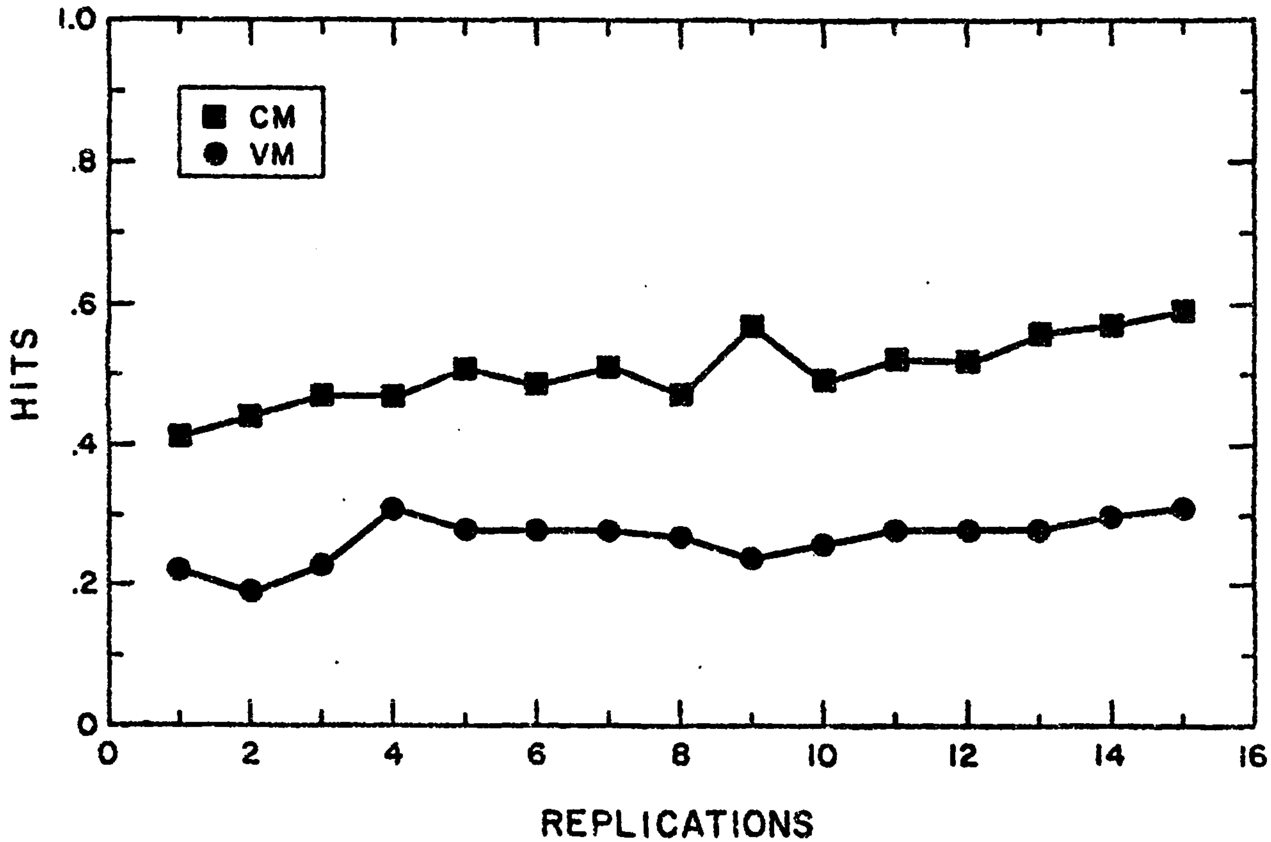

Figure 7. Data from Experiment 3: the proportion of trials identified correctly as a function of practice. The hits are corrected for guessing.

condition was characterized by fairly consistent improvement.

Insert Figure 7 about here

This experiment concluded the training sessions for the subjects. In all the experiments quantitative differences existed between the CM and VM sequences. The next two sections test for qualitative differences between the two groups.

In Experiment 1 subjects clearly showed improvement in the VM conditions (see Figure 3) as well as the CM condition. VM performance improved little if any in Experiments 2 and 3. We hypothesize that subjects are learning to unitize each of the VM sequences during Experiment 1. This unitization incorporates each of the sequential line segments into a unit similar to letter features combining into a letter. Such unitization results in improved performance (LaBerge, 1973, 1976) and can be viewed as developing an automatic unit to the line sequences similar to the development of a category unit for letters (see Shiffrin and Schneider, 1977, Experiment 3). The additional improvement in the CM condition is suggestive of the development of an automatic attention response (see Shiffrin and Schneider, 1977).

Load Requirement Experiments

Experiment 4 - Variable Channel Size

Schneider and Shiffrin (1977) found that detection was relatively unaffected by load for CM trained characters while for VM trained, there was an effect of load as the memory set, frame size, or a combination of the two were increased. In this experiment, the number of channels was varied, a manipulation that was similar to the process of varying the frame size used by Schneider and Shiffrin (1977). It was expected that the CM and VM sequences would have differential load requirements.

Procedure. The same stimuli as in the previous experiments were used. The same subjects participated. This was the fourth experiment in which subjects participated.

A multiple sequence procedure, similar to Experiment 3 and the illustration of Figure 6, was used. In this trial display, however, no masks separated the sequential displays.

The type of mapping, CM or VM, was again a between block variable. The important independent variable in this experiment, the number of channels (1, 2, or 4) was a between block variable. In the one channel condition, the single channel where movements occurred was chosen randomly before each trial began. The other three channels were filled with the random dot masks and remained constant throughout the trial display. In the two channel condition, one of the two possible diagonals was randomly chosen before each trial to contain movements. The other two positions of the off diagonal were filled with random dot masks. In the four channel condition, all four channels were filled with movements.

Each block contained 64 trials. The target occurred on half the trials. Subjects were instructed to rest the index and middle fingers of their right hand on two buttons of the response box. Four of the subjects were told to push the rightmost button with their middle finger if a target occurred and the leftmost button with their index finger if no target occurred. The remaining subjects had the opposite button assignment.

The subjects participated in 18 blocks of trials altogether, 3 blocks for each CM channel size and 3 blocks for each VM channel size.

Results and Discussion. The data are plotted both in terms of d' and A' (see Figure 8 for the d' scores and Figure 9 for the A' scores). A comparison of the two graphs shows that there is not much difference between the two. A' is a measure of the area under the ROC curve ranging from .50 for random guessing to 1.0 for perfect detection (Norman, 1964; Craig, 1979). A' is used because it is distribution free which is desirable when the false alarm rate is low as it was in these data for some of the subjects. An arcsin transform was performed on the average of all the subjects' A' scores before the analysis. Analysis was done by means of a repeated measures 3-way ANOVA with subjects the random factor. The main effect of size was significant [$F(1,6)=36.96$, $p<.0001$] and the CM/VM manipulation approached significance [$F(1,6)=5.30$, $p=.06$]. The interaction was not significant.

Insert Figures 8 and 9 about here

The CM/VM manipulation only approached significance because of the lack of power of the test. There were only seven subjects and considerable between subject variability due to the different CM sequences each subject was trained on. Because there was no interaction, size of display affected both CM and VM sequences about equally. This result is different from that found by Schneider and Shiffrin (1977). In this experiment, as the display size is varied the only difference between CM and VM sequences is a quantitative one. In the single channel condition, subjects were not forced to keep their eyes on the focus dot. In the other two conditions when sequences were presented on the diagonals or the whole square, subjects were forced to fixate the focus dot. Because the foveal presentation was not constant between the single and multiple channel conditions, some of the decrement with increasing channel size could be due to the possiblity that subjects directly fixated the sequences. The decrement in performance between the 2 and 4 channel conditions cannot be explained by the differential foveal presentations and is most likely caused by the increased load.

Experiment 5 - Memory Set Size 2

Besides the frame size, Schneider and Shiffrin (1977) also varied the memory set size to study the differential load requirements of CM and VM trained characters. In their Experiment 1, subjects were required to search for 1 or 4

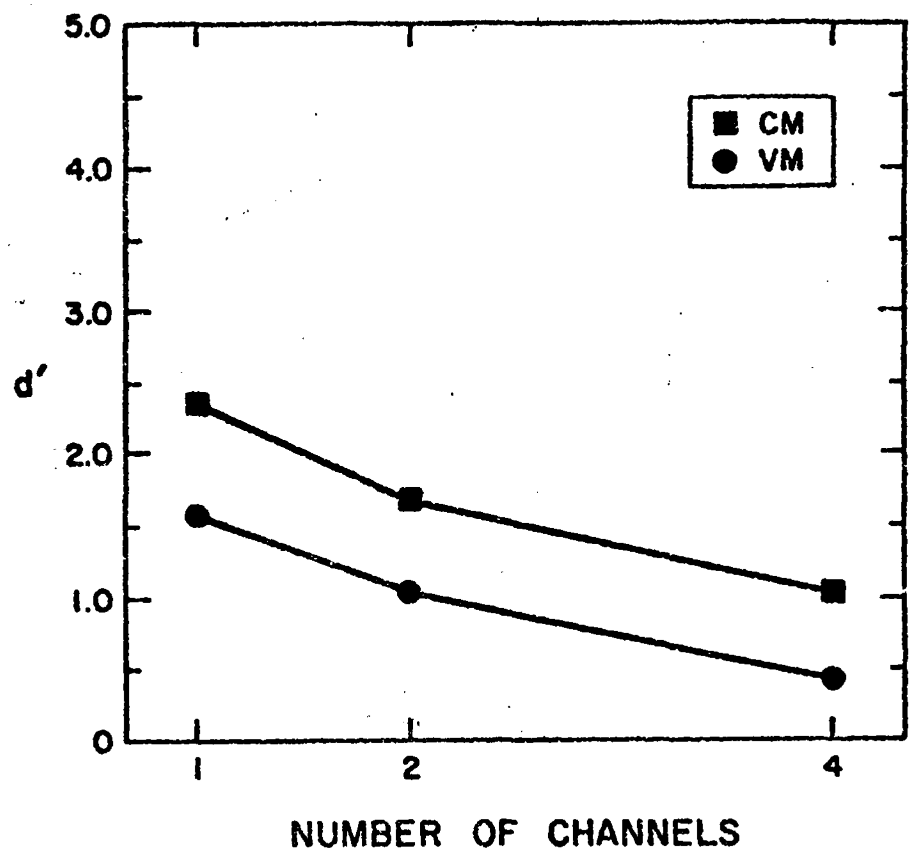

Figure 8. Data from Experiment 4: d' as a function of number of channels for CM and VM sequences.

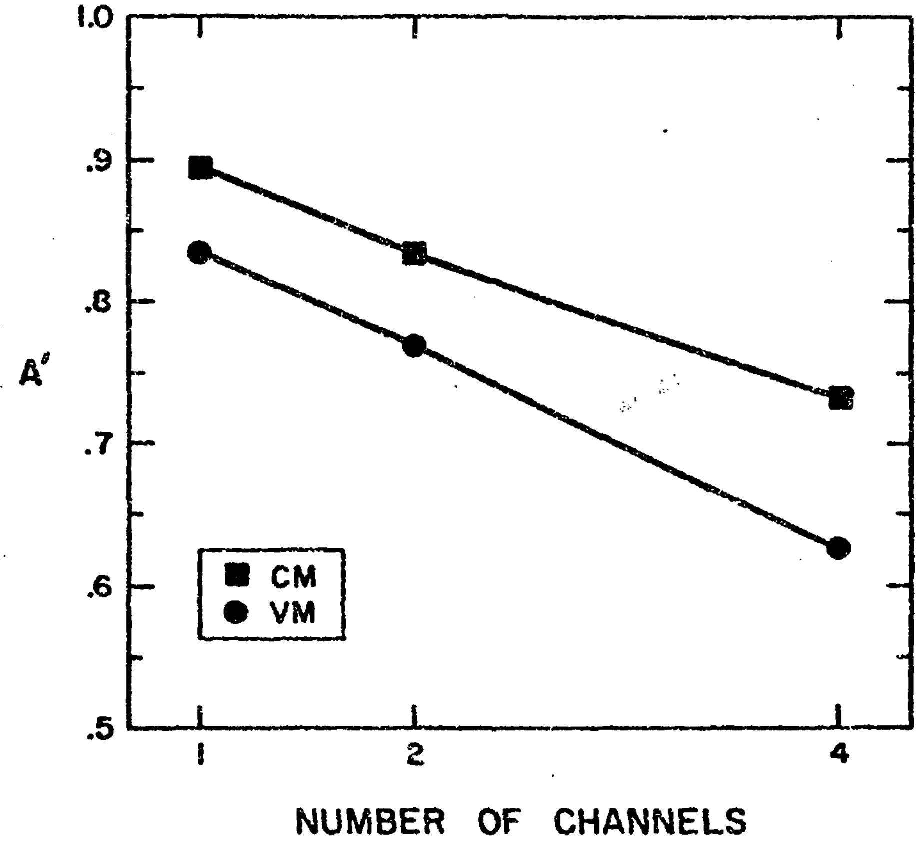

Figure 9. Data from Experiment 4: A' as a function of number of channels for CM and VM sequences.

targets. They found a larger decrement in performance as memory set size increased for VM characters than for CM characters and concluded that CM trained sequences have a smaller load requirement.

During training in this series of experiments, each subject had only been trained on one CM target so that memory set size could not be varied as Schneider and Shiffrin (1977) had done. Instead, a task was devised where subjects were required to search for both a CM target and a VM target during a single trial (CMVM condition). This condition could be compared to control conditions of searching for two VM targets (VMVM condition), searching for a single CM target (CM condition), and searching for a single VM target (VM condition). If the CM sequence does not require resources in order to identify it, then: 1) the CM performance in the CMVM condition should be similar to the single CM control condition; and 2) the VM performance in the CMVM condition should be similar to the single VM control condition. On the other hand, if the CM sequence does require resources, then the CM performance in the CMVM condition should drop when compared to the single CM control condition. The relative amount of resources needed in the CMVM condition can be estimated by comparing the CMVM and VMVM conditions. Schneider and Fisk (1980) have shown that in a letter search paradigm CM search does not require resources.

Procedure. The same stimuli as in the previous experiments were used. The same seven subjects participated. This was the fifth experiment in which subjects participated.

A single sequence procedure similar to experiment 1 was used. In this experiment, there were four conditions: 1) a CMVM condition where subjects were required to search for both a CM and a VM target; 2) a VMVM condition where subjects were required to search for two VM targets; 3) a CM condition where subjects were required to search for their CM target; and 4) a VM condition where subjects searched for a single VM target. The procedures for the single CM and VM conditions were exactly the same as experiment 1 and that depicted in Figure 2. Several aspects of the procedure had to be changed for the two memory set size 2 conditions, the CMVM and VMVM. Two sequences were diplayed in succession on the orientation part of the trial. The first sequence appeared in the same position as orientation sequences in the previous experiments. Then, after a 500 msec delay, a 500 msec focus dot appeared to the right of the previous sequential display. After offset of the dot, the second member of the memory set appeared. The trial display appeared one second after the offset of the second orientation sequence. Subjects were instructed to try to remember both orientation sequences. On half the trials, the first orientation sequence appeared as a target in the trial display and on the remaining trials the second orientation sequence appeared as a target. In the CMVM condition, the CM target sequence occurred randomly as the first orientation sequence on half the trials and as the second orientation sequence on the remaining trials. The VM target was chosen randomly from the set of 8 possible VM targets and placed in the orientation position not occupied by the CM target sequence. In the VMVM condition, the two target sequences were chosen randomly, without replacement, from the 8 possible VM targets. In the CMVM and VMVM conditions, no block percentage scores were reported to subjects after a trial.

Subjects participated in 20 blocks altogether: 4 blocks of CM sequences, 4 blocks of VM sequences, 6 blocks of CMVM trials, and 6 blocks of VMVM trials. The order of presentation of the blocks was A-B-A-B-A-B-A, where A is a VM block and a CM block and B is 2 CMVM blocks and 2 VMVM blocks. The order of presentation within A and B was randomized for each subject.

Results and Discussion. When comparing the corrected for guessing scores from the CMVM condition to the memory set size 1 control conditions (see Figure 10), the CM drops from .92 to .75 and the VM drops from .69 to .40. Using a matched-pairs one-tailed t-test, both of these drops were significant [$t(6)=3.467$, $p<.01$ for the CM drop and $t(6)=6.496$, $p<.001$ for the VM drop]. Overall, the CMVM performance combined was significantly better than the VMVM performance combined, .57 to .48 [$t(6)=4.514$, $p<.01$]. However, the VM performance was better in the VMVM condition than the VM performance in the CMVM condition, .48 to .40.

Insert 10 about here

The results from this experiment were consistent with the previous experiment. The CM sequence requires resources, however, the amount required is less than that needed for VM identification. These results are not necessarily similar to the Schneider and Shiffrin (1977) or Schneider and Fisk (1980) findings; there is more of a deficit in this experiment as the memory set size is increased. It must be emphasized that the stimuli used in this experiment are much more difficult than simple letters in the previous experiments.

The results of this experiment are similar to an experiment by Pew and Wickens reported in Pew (1974a). They used a dual task paradigm where a tracking task was designated primary and a number manipulation procedure was the secondary task. Subjects had been well-practiced on a middle part of the tracking task that was consistently the same from trial to trial. They found as great a decrement in performance of the secondary task for the less well-practiced segments as for the well-practiced consistent segments. Similar to the results of our experiment, the only difference between the two segments was that the well-practiced segment was more accurate. Pew and Wickens conclude that automatically performing the task does not necessarily require less processing capacity or attention. In our experiment, subjects have had eight times more practice identifying the CM sequence than any of the single VM sequences. However, the only differences in processing capacity between the two groups is that the CM trained require less resources than the VM trained.

Experiment 6 - Memory Set Size 2 - VM Protected

Schneider and Fisk (1980) investigated the relationships between a dual task paradigm and searching for multiple targets in a detection task. They found that subjects had a tendency to waste control processing resources on automatic tasks which did not benefit from the resources. This experiment was an attempt to make the procedure more like the dual task paradigm employed by Schneider and Fisk (1980) and Pew and Wickens (Pew, 1974a). In this experiment, subjects were instructed that their primary task was to identify the VM target in the CMVM condition. They were further instructed to not actively search for

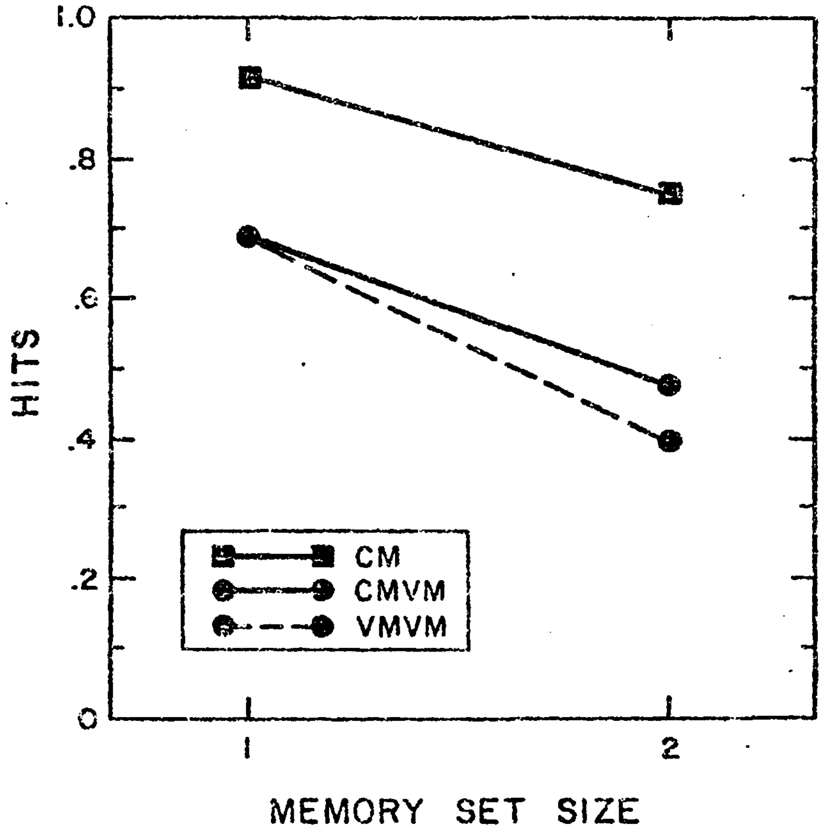

Figure 10. Data from Experiment 5: the proportion of trials identified correctly as a function of the memory set size. CM and VM scores from the CMVM condition are plotted as memory set size 2 (CM square and VM circle). The hits are corrected for guessing.

the CM target but to report identification of the CM target only if they happened to see it. Thus, the VM performance is protected by designating it the primary task. Search for the CM target in the CMVM condition was the secondary task. It is possible that previously subjects might have been over-allocating resources to the identification of the CM target and thus VM performance would suffer. If the CM sequence is automatically detected, then CM dual performance should be similar to CM single. If the CM sequence is not automatically detected, then subjects should miss the occurrences of the CM sequence when instructed not to actively search for them.

Procedure. The same subjects and stimuli as in the previous experiments were used. This experiment was the tenth run for these subjects.

Similar to experiment 5, there were four different conditions: 1) CMVM; 2) VMVM; 3) CM; and 4) VM. In the orientation part of the CMVM condition, the VM target sequence chosen randomly from the eight possible VM targets always occurred in the second orientation sequence. An 800 msec focus dot occurred in the same position as the first orientation sequence of Experiment 5. This focus dot acted as a signal to the subjects that they were in the CMVM condition and to respond to their particular CM target sequence if it occurred. By this time, subjects were well-trained on their particular CM target so that they did not need to be reminded what the target sequence looked like. The VM sequence from the orientation part occurred as the target in the trial display on 75% of the trials. On the remaining trials, the CM target sequence occurred as the target. Subjects were instructed to concentrate on identifying the VM sequence and to not search for the CM target but respond to it if they saw it. They were told the probability of occurrence of the CM target. The VMVM condition was the same as that reported in Experiment 5, except that similar to experiments 1-4, the running block percentage score was given to subjects after each trial and at the end of the block. The CMVM condition also had the running block score feedback. The CM and VM conditions were exactly the same as experiment 1 and the illustration of Figure 2.

The four conditions, CMVM, VMVM, CM, and VM, were randomized within groups of four. Each block contained 64 trials. The subjects participated for a total of 12 blocks, 3 blocks total in each stimulus condition.

Results and Discussion. From the results that were corrected for guessing (see Figure 11), the subjects did a good job of following the instructions by protecting their VM performance in the CMVM condition. The VM score in the CMVM condition was .73 and in the single VM condition it was .72 which was not a significant difference. CM performance dropped from .92 in the single condition to .63 in the CMVM condition. A matched-pairs one-tailed t-test yielded a significant result when these two CM scores were compared [$t(6)=2.19$ $p<.05$]. Although the percentage difference was rather large, .29, the t-score was relatively small. Looking at individual subjects, two of the subjects were at chance for CM sequences in the CMVM condition. The other five subjects had relatively high scores. The CM performance of .63 was actually worse than the VM performance of .72 in the CMVM condition, but it was still better than the VMVM score of .51. Overall, the CMVM combined score, .69, was better than the VMVM score, .51.

Insert Figure 11 about here

Five of the subjects could do the CM dual task without a significant deficit. For those five, CM single performance averaged .96 and the CM in the dual CMVM averaged .86. The drop from the single to the CMVM was not significant [t(4)=1.87] at the .05 level for these five subjects. They also protected their VM performance fairly well having only a 4% drop from VM single to the VM in the CMVM condition. This 4% drop was not significant [t(4)=1.22] at the .05 level. Because of the variability in subjects' performance, it cannot be claimed positively that sequences are not detected automatically. The averaged score indicates that sequences are not, but when individual scores are surveyed, some subjects can do the memory set size 2 task without much deficit in performance when compared to the single condition. Other subjects have trouble with the condition. Since dual CMVM search improves with practice (Schneider and Fisk, 1980), additional practice would increase the probability of automatic detection of the sequences for at least five of the seven subjects.

The results from Experiments 4-6 indicate that when comparing CM and VM search, CM sequence search is a) about equally affected by increases in number of channels, b) less affected by increases in memory set size, and c) can be combined with VM search (at least for some subjects) without a deficit in either task. The equal CM/VM decrement with an increasing number of channels differs from the Schneider and Shiffrin (1977) result. For five of the seven subjects the ability to perform dual CM/VM search without deficit (Experiment 6) replicates Schneider and Fisk's (1980) results for letter search. However, two of the present subjects could not perform the dual task search without deficit. Results from Experiments 4-6 suggest that sequence search is highly similar to letter search but may require substantial training to develop. This is to be expected since the sequences are all novel stimuli to our subjects and the letters in previous experiments are not.

Transfer Experiments

The experimentes up to this point have established quantitative differences between the two types of sequences, CM or VM. In the training experiments subjects found it easier to detect the CM than the VM sequences. In the load requirement experiments, CM targets required less resources than did the VM targets. The ease of identification and the low resource requirements could be a reflection of the greater amount of practice spent on the CM sequences, there had been eight times as many CM trials as there had been trials for any single VM sequence, and CM/VM differences might not necessarily reflect different processing modes. The apparent performance asymptotes in VM but not CM conditions suggests the present differences are not due to practice. Qualitative differences are needed to establish an argument for different processing modes.

The goal of the next six experiments was to change the experimental tasks, devising novel stimuli that subjects had not seen before. The CM transfer stimuli and VM transfer stimuli can then be compared to the CM and VM trained

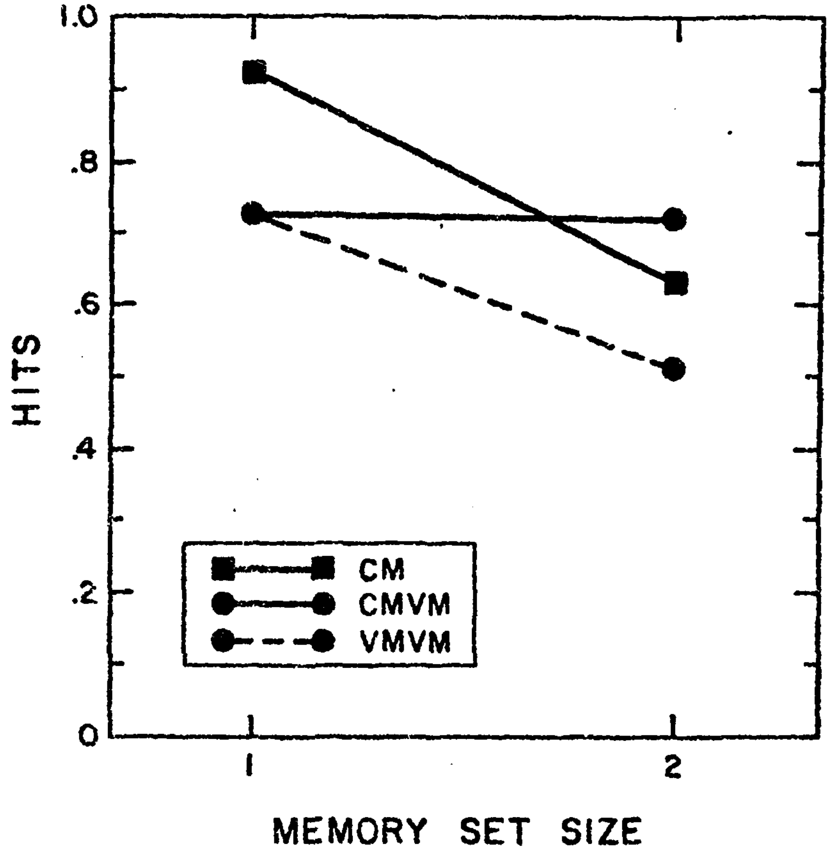

Figure 11. Data from Experiment 6: the proportion of trials identified correctly as a function of the memory set size. CM and VM scores from the CMVM condition are plotted as memory set size 2 (CM square and VM circle). The hits are corrected for guessing.

sequences, respectively.

Experiment 7 - Variable Stimulus Duration

Subjects had been trained on sequences where the duration of each segment was 100 msec. In this experiment, the stimulus duration was varied from 70 msec to 220 msec and the transfer effects were evaluated.

Several factors could affect the outcome of this experiment: 1) apparent motion cues; 2) a decaying memory trace; and 3) the time for identification. The 100 msec stimulus duration was originally selected to take advantage of any motion cues that might exist. Lappin and Bell (1972) and Neisser and Becklen (1975) claimed that subjects performed their respective tasks by identifying motion cues. If subjects have learned to identify the sequences by the particular motion, and if a 100 msec duration and ISI of 0 optimizes the motion cues (see Kahneman and Wolman, 1970; Kahneman, 1967), then identification should be best at those durations close to 100 msec. It should be emphasized that the particular movement of the line segments is not good motion, rather, the lines jump around to different orientations and positions. Another factor that could affect performance is the decay of the memory trace. Subjects are required to remember the target from the orientation sequence and identify the target on the trial display. If the stimulus duration is increased, the memory trace must persist longer and could decay at some of the longer durations. Thus, performance would fall off at the long duration. The last factor that could exert an influence is the time to identify the stimuli. Perhaps at the fast duration the line segments are not on the screen long enough to identify and compare the segments. Thus, the longer durations would be easier to identify than the shorter duration. All three of these factors together, or any combination of the factors, could affect the outcome.

Qualitative differences are expected for the CM and VM transfer sequence. In another report (Eberts, 1979) using the same stimuli and a similar method it was argued that subjects attended to the motion for CM sequences and individual lines for VM sequences. Thus, as the stimulus duration gets longer, one prediction is VM performance should improve and CM performance should drop off.

A characteristic of a skilled performance is its economy and efficiency (Welford, 1976). Thus, a CM sequence should not require extra time to make an identification whereas a VM sequence, because it is not identified efficiently, would require extra time and would improve with longer stimulus duration. If the structure of a mental program for a skill contains an executive and subroutines (Fitts, 1964), then the timing components could be a parameter passed to the particular subroutines as suggested by Brooks (1974). Several examples for this type of flexibility in the temporal component exist. Jagacinski, Burke and Miller (1977) trained subjects on a pendulum type task and found high transfer when the speed of the display was doubled. Welford (1976) gives several real world examples, such as throwing a ball, when flexibility in the temporal component is required. Thus, a characteristic of a skilled performance is that the temporal component is flexible acting like a parameter that is passed to a subroutine. An unskilled task is locked into the specific situation. In this particular experiment, the CM trained sequences should have a flexible time component if the processing of the CM sequence acts like that observed for skilled performances.

Procedure. The same stimuli were used and the same seven subjects participated. This was the sixth experiment in which the subjects participated.

In this experiment, an intermediate sequence procedure similar to experiment 2 (see Figure 4) was used. The independent variable of importance was the stimulus duration which was a between trial variable. On a trial, the line segments of the sequences could have six posible durations: 70, 100, 130, 160, 190, and 220 msec. The target orientation sequence had the same stimulus duration as that used for the trial display. Each block contained 60 trials. Within the block, the 100 msec duration occurred 30 times and the other five durations occurred on five trials each. The type of mapping, CM or VM, was again a between block variable. Subjects participated in a total of 16 blocks - 8 CM blocks and 8 VM blocks.

Results. The patterns are different for the CM and VM sequences (see Figure 12). CM perfomance stays fairly constant, with a 4% increase up to 190 msec, while the VM performance improves 21% up to 160 msec and then drops off. For both the CM and VM conditions, all longer durations are identified better than the 100 msec duration upon which subjects were trained.

Insert Figure 12 about here

A repeated measures 3-way ANOVA with subjects as the random factor was run on the corrected percentage scores after an arcsin transformation. Both factors, the CM/VM manipulation [$F(1,6)=10.82$, $p<.05$] and stimulus duration [$F(5,30)=7.33$, $p<.001$], were significant. The interaction between CM/VM manipulation and stimulus duration was also significant [$F(5,30)=6.70$, $p<.001$]. Because of the significant interaction, a two-way ANOVA on just the CM data was performed. For the CM sequences, the main effect of stimulus duration was not significant [$F(5,30)=0.56$].

Discussion. The interaction between CM/VM manipulation and stimulus duration offers the first evidence of qualitative differences between CM and VM trained sequences. Varying the stimulus duration had an effect on the VM sequences and little or no effect on CM sequences. Even though subjects had never seen the CM transfer sequences at the new stimulus duration, performance was always better than the VM sequence they had seen many times before. Also, VM transfer sequences at the higher stimulus durations were always better than the VM trained sequence.

Results disconfirm the apparent motion hypothesis for the VM condition and are ambiguous for the CM condition. The VM performance peaked at 160 msec stimulus duration, 60% longer than the training time and well beyond the time expected for the best motion cues. Since the CM performance was not affected by stimulus duration it can only be concluded that good motion is not necessary for CM search.

Using the analogy of the mental program in skilled performance, the CM mental program does seem to be efficient and economical. A 70 msec duration is

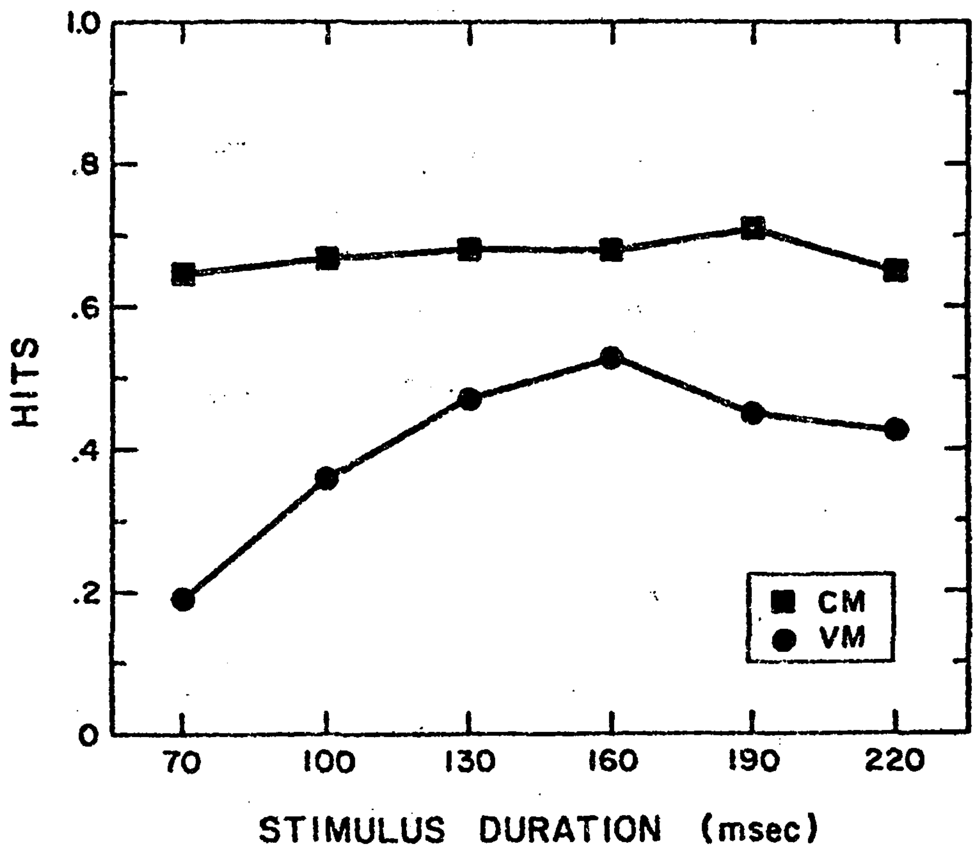

Figure 12. Data from Experiment 7: the proportion of trials identified correctly as a function of the stimulus duration. The hits are corrected for guessing.

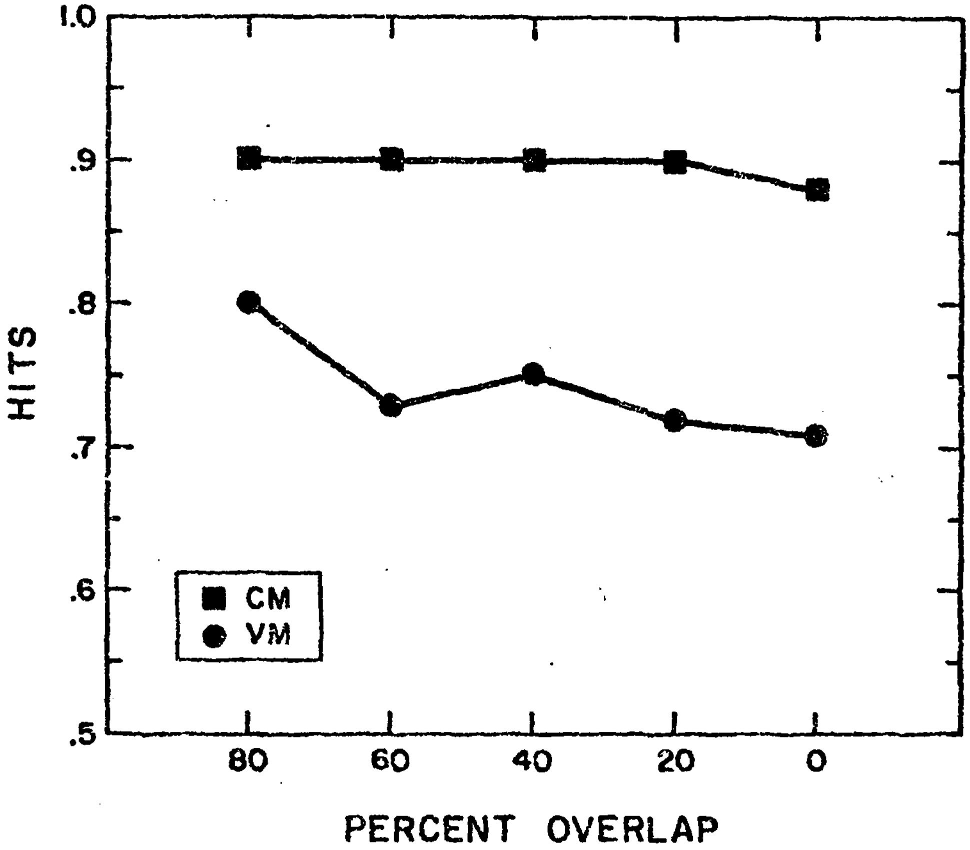

Figure 13. Data from Experiment 8: the proportion of trials identified correctly as a function of the percent overlap of the line segments. The hits are corrected for guessing.

enough time to identify the CM sequence. From the orientation sequence a value for the temporal component could be determined and passed to a subroutine resulting in highly flexible abilities in this task. The VM sequence mental program is not as highly structured. The 70 msec duration performance is much worse than performance at the longer duration. The more time provided for the task, the better the performance. The decrease in performance after the 160 msec duration in the VM condition could be explained by either a loss of motion cues, a deterioration in the memory trace with time, or both together.

Experiment 8 - Overlap

In the previous experiment, subjects could be responding to the spatial pattern rather than the spatial and temporal together. If the spatial component was salient, the performance would be better than expected at the faster durations. In this experiment, the temporal component was removed in successive steps by overlapping the line segments that make up a sequence. Thus, the sequence could range from a figure-like pattern to a spatial and temporal pattern. If spatial and temporal components dominate performance at different times in the development of a skill then CM and VM transfer qualitative differences can be expected.

Method. The same stimuli were used and the seven subjects participated. This was the seventh experiment in which subjects participated.

In the fist 6 experiments, the stimulus duration was always 100 msec with an ISI of 0 and SOA of 100 msec. In this experiment, the SOA was an independent variable having five different levels: 20, 40, 60, 80, and 100 msec. We prefer to view the manipulation of the SOA as a manipulation of the amount of overlap of lines within a sequence. Thus, as an example, a SOA of 20 msec results in an 80% overlap of each line segment with its succeeding lines. In this 80% overlap condition, the stimulus display appears very figure-like. At the other end of the scale, the 0% overlap condition with SOA of 100 msec is the same stimulus pattern subjects viewed in Experiment 1 and that illustrated in Figure 2. Other aspects of the procedure not mentioned here were the same as experiment 1.

The percent overlap was a between block variable of five levels: 0, 20, 40, 60, and 80%. Blocks of 64 trials were also divided into CM and VM blocks for a total of 10 different kinds of blocks. Each subject participated in a total of 20 blocks altogether. This experiment lasted approximately 2 hours.

Results. Different patterns exist for the CM and VM sequences (see Figure 13). CM performance stays fairly constant at 90% identification with a slight 2% dip at the 0% overlap. VM performance, on the other hand, becomes better as the percent overlap is increased to 80%. There is 71% identification at 0% overlap and 80% identification at 80% overlap.

Insert Figure 13 about here

A repeated measures 3-way ANOVA was performed on the corrected for guessing data after an arcsin transform. The CM/VM manipulation was significant [$F(1,6)=117.99$, $p<.0001$]. The overlap [$F(4,24)=1.90$] and the interaction

[$F(4,24)=0.87$] were not signficant.

It must be remembered that subjects had never seen the overlap stimuli before, yet, in the VM condition, all overlap displays were better identified than the stimuli subjects were trained on, the 0% overlap sequence. The CM performance is again characterized by its flexibility - subjects can identify the figure equally well whether it is a spatial pattern or a temporal and spatial pattern. Apparently results on the VM sequences, which are relatively poorly skilled, indicate that early in the development of a skill, subjects try to identify spatial and temporal patterns by the spatial component only.

The flatness of the CM performance can be explained by ceiling effects; six of the seven subjects were above 95% detection in the CM condition for most of the overlap conditions. Because of the nature of the present task, the display could not be made harder to identify. However, using a different measurement technique in the next experiment, evidence was found that the CM and VM sequences were identified differently and the observed effects in this experiment were not due entirely to the ceiling effect.

Experiment 9 - Overlap Ratings

This experiment was much the same as the previous experiment except subjects were instructed to rate whether or not the displays were figure-like or exhibited motion. If the two groups of sequences are processed differently, then the ratings for the CM and VM transfer groups should be qualitatively different.

Procedure. The same stimuli were used. This was the ninth experiment in which the subjects participated.

The trial procedures used in the previous experiment were also used in this experiment. At the end of a block of trials subjects were instructed to rate whether the block of trials was figure-like or displayed a movement pattern. A "1" meant that the lines formed a solid figure and a "7" meant that the line pattern appreared to be a single line moving around. The remaining numbers were to be used as the line pattern fell between those two extremes.

A block now contained only 8 trials. Subjects tried to identify the target as in the previous experiment. At the end of the 8 trials, subjects wrote down the rating for that block on a piece of paper. The experiment consisted of 20 blocks and lasted about 30 minutes.

Results and Discussion. The ratings for the CM and VM sequences are presented in figure 14. A repeated-measures 3-way ANOVA was run on the data. The main effect of CM/VM manipulation was not significant [$F(1,6)=2.04$] and the overlap was significant [$f(4,24)=40.67$, $p<.0001$]. The interaction between the two was significant [$F(4,24)=4.03$, $p<.05$]. The VM sequence ratings appear to be a linear function of the percent overlap. The CM rating pattern is different, though, with a bump in the 0-40% range not present in the VM. The 0% overlap rating is actually higher than the 20% rating in the CM condition.

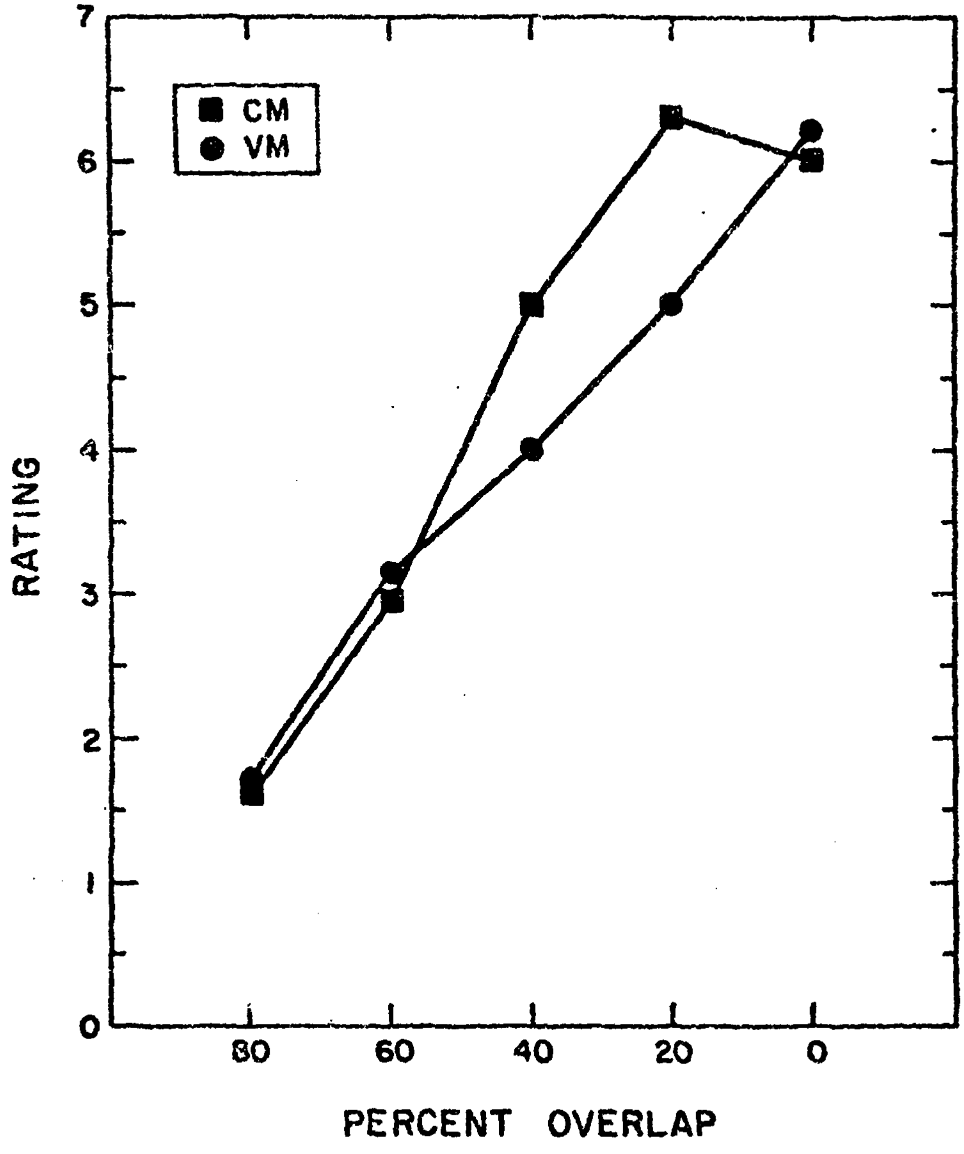

Figure 14. Data from Experiment 9: the ratings score as a function of the percent overlap of the line segments. A "1" means that the pattern was figure-like and a "7" means that the pattern looked like a single line moving around.

Insert Figure 14 about here

The significant interaction suggests the existence of two different processes. Although the ratings are not a direct reflection of the subjects' perception, it does indicate that the CM sequences are perceived differently than the VM sequences. As evidenced by experiments 7 and 8, the temporal component is not as pervasive for the CM sequences. If subjects chose a rating that depended on the temporal component, the rating would be linear if the component is noticeable and nonlinear if not noticeable. Subjects' rating systems could quite possibly be based on the temporal component for VM sequences. This experiment gives support to the hypothesis that CM and VM sequences are processed differently and that the differences witnessed in the previous experiment were not entirely due to ceiling effects.

Experiment 10 - Direction Reversal

In this experiment the direction of the sequence was reversed by having the third line segment appear first and the first line segment occur last. Pew and Wickens (reported in Pew, 1974b) report a similar experimental manipulation. In a tracking task, subjects tracked along the same pattern in the middle of the trial. The beginning and end of the track were randomly generated before the start of the trial. Then, after much practice, they reversed the direction of the middle path. They found good transfer effects between the practiced pattern and the reversed pattern. In the present experiment, like a skill, good transfer effects can be expected for the consistent sequences and poor transfer can be expected for the inconsistent sequences when reversed. If it is unskilled, poor transfer effects are expected.

Procedure. The same stimuli as in the previous experiments were used. This was the eleventh experiment in which subjects participated.

A single sequence procedure similar to Experiment 1 and that depicted in figure 2 was used. The independent variable of importance in this experiment was the direction, forward or backward, of the sequence. The forward direction condition was the same condition in which subjects were previously trained. In the backward direction condition, the first line of a trained sequence now appeared as the third line segment and the third segment of the trained sequence appeared as the first segment of the reversed sequence. The middle line stayed constant for both conditions.

A block of trials consisted of 8 repetitions of each of the 8 VM targets plus 8 repetitions of the CM target which resulted in a block of 72 trials. Therefore, within a block of trials, the CM target received no more training than any of the eight VM targets. Subjects participated in 8 blocks of the backward direction condition. As a control condition, subjects ran in one block of the forward direction condition preceding and succeeding the 8 backward direction blocks. The ten blocks of this experiment lasted about one and a half hours.

Results and Discussion. The corrected for guessing hit rates for the trained and transfer sequences are given in figure 15. A repeated measures 3-way ANOVA with subjects as the random factor found that both main effects of CM/VM manipulation [$F(1,6)=18.11$, $p<.01$] and direction [$F(1,6)=39.66$, $p<.001$] were significant. Six of the seven subjects were at ceiling in the CM condition consistently detecting the targets in the upper 90's. The interaction between these two factors was not significant.

Insert Figure 15 about here

Although the interaction was not significant, for the CM sequences there was a 4% drop in performance as the direction was reversed while for the VM sequences, there was a larger 12% drop. However, the important result is that the CM reversed sequences, a pattern subjects had never seen before this experiment, were better identified than the VM trained, familiar sequences, 91% to 83%. All individual subjects had better identification of the CM backward sequences than VM backward with differences ranging from 6 to 48%. Six of the seven subjects identified the CM backward sequences better than or equal to the VM forward with individual differences ranging from 0 to 29%.

The lack of a significant interaction could be due to ceiling effects for the CM sequences. However, this experiment does provide good evidence for qualitative differences between CM and VM trained sequences. When the direction is reversed, CM backward sequences can actually be better identified than the VM trained sequences. This result is another example of the flexibiliy of the CM trained sequences.

Experiment 11 - Rotation

The previous transfer experiments have all studied manipulation of the temporal component. A high degree of flexibility was exhibited for the well-skilled CM sequences when the temporal component was manipulated. The VM sequences did not seem to be characterized by the flexibility. In the next two experiments the spatial component was manipulated by rotating the sequences. The relationships between the lines and the temporal component remains constant but the spatial pattern changes. If the rotation can be parameterized like the temporal component, transfer was expected to be good for the CM sequences and poor for the VM. However, if the spatial pattern must remain constant, then performance on both groups of sequences was expected to be poor.

Procedure. The stimuli were the same as those used in the previous experiments. This was the tenth experiment in which subjects participated.

A single sequence procedure similar to Experiment 1 and the illustration in figure 2 was used. The independent variable of importance was the amount of rotation. The trial display in figure 2 was rotated either 0, 90, 180, or 270 degrees. The 0 degree condition was exactly the same as the procedure used for Experiment 1. The orientation target sequence was also rotated.

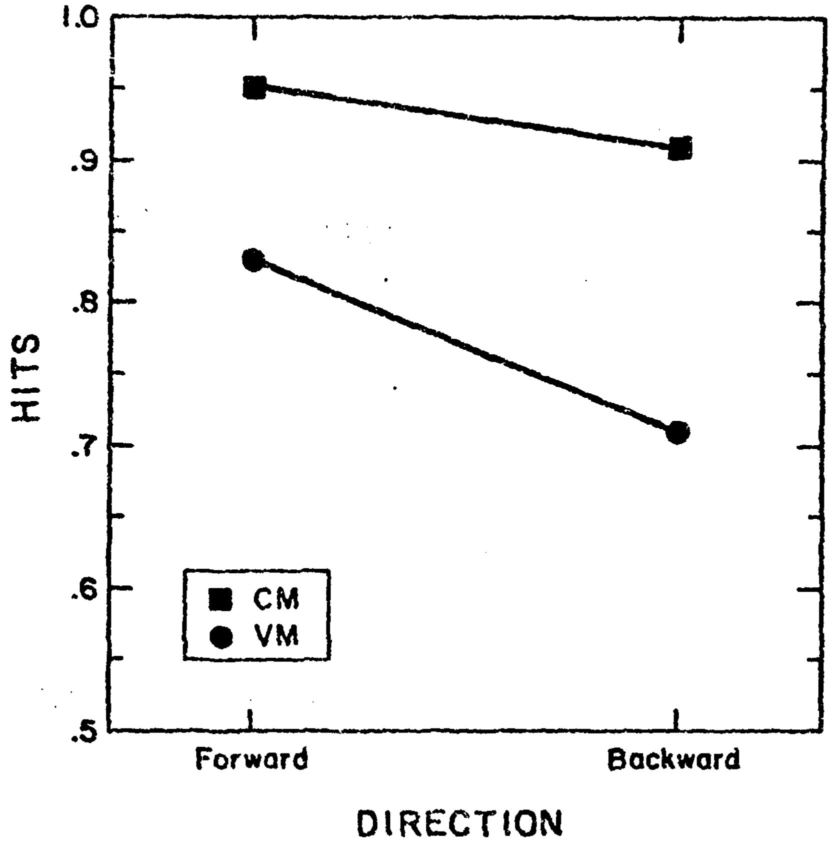

Figure 15. Data from Experiment 10: the proportion of trials identified correctly as a function of the direction. The hits are corrected for guessing.

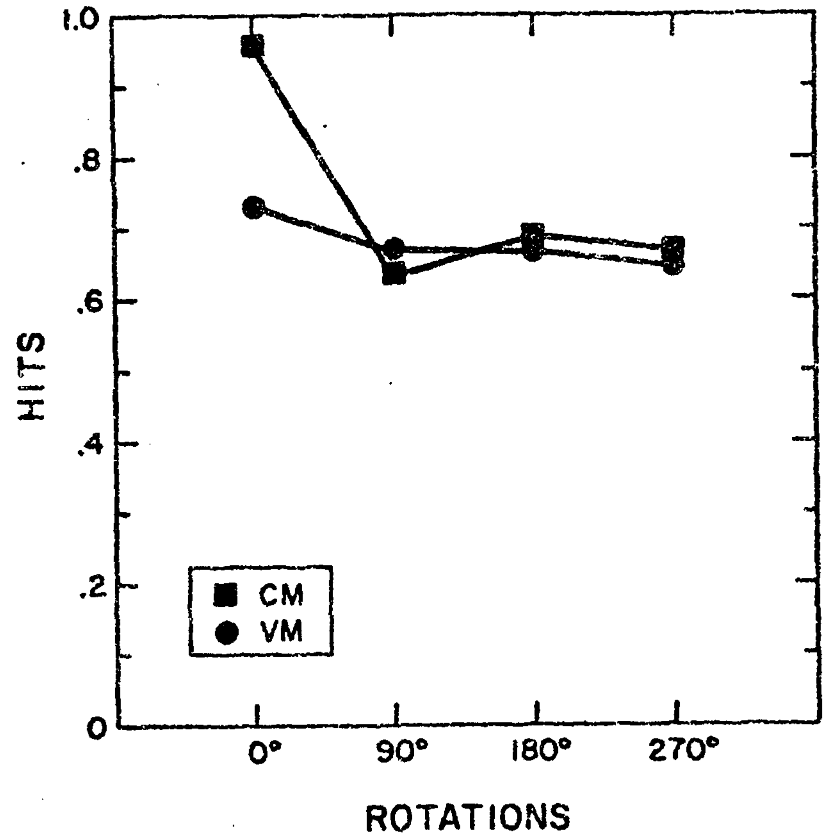

Figure 16. Data from Experiment 11: the proportion of trials identified correctly as a function of the amount of rotation. The hits are corrected for guessing.

Rotation was a between block variable. Each block contained eight repetitions of each of the eight VM targets and eight repetitions of the CM targets for 72 trials altogether. In this experiment, subjects participated for a total of 12 blocks, three repetitions of each of four rotation conditions. The experiment lasted for approximately two hours.

Results and Discussion. A repeated measures 3-way ANOVA with subjects as the random factor was performed on the corrected for guessing percentage scores for the three rotated conditions after an arcsin transformation. The main effects of CM/VM manipulation [$F(1,6)=0.72$] and rotation [$f(2,12)=0.10$] were not significant. The interaction between the two factors was also not significant [$F(2,12)=0.16$].

There was little or no difference between the CM and VM transfer sequences (see Figure 16). Identification of all of the CM rotated sequences was worse than the VM trained 0 degree rotation sequences.

Insert Figure 16 about here

The results of this experiment are markedly different from the results of the trained experiments that manipulated the temporal component. First, CM transfer is not quantitatively better than VM transfer performance. Second, there are no qualitative differences between the two groups. Finally, CM transfer identification is worse than the VM transfer sequences. Apparently, the spatial component must be fixed in order to achieve high transfer.

Experiment 12 - Rotation - 0 Degree Orientation

In this experiment the sequence patterns are again rotated but the orientation sequence is always at a 0 degree rotation. Therefore, for subjects to figure out what the target looks like, they must mentally rotate the orientation sequence the required amount. The previous experiment suggested that the spatial component must remain relatively fixed for high transfer.

Procedure. The same stimuli were used as in the previous experiments. This was the twelfth experiment in which the subjects participated.

The procedure of the experiment was exactly the same as Experiment 11 except for the following change. The orientation sequence always appeared at the 0 degree orientation. Thus, in the 90, 180, and 270 degree conditions, subjects had to imagine, by mentally rotating the orientation sequence, what the target would look like. The number of degrees to mentally rotate the orientation target sequence was displayed in the middle of the screen before each block. The 12 blocks of this experiment lasted approximately 2 hours.

Results and Discussion. CM identification was better than VM identification at all rotations (see Figure 17). On the transfer sequences, the differences range from 12% at 180 degrees to 4% and 2% at 90 degrees and 270 degrees, respectively. Both CM and VM sequences exhibit similar patterns of results. For both, the 180 degree rotation is better than either the 90 or 270 degree rotation. As in the previous experiment, the CM rotated performance transfer was always less than the VM trained performance transfer.

Insert Figure 17 about here

A repeated measures 3-way ANOVA with subjects as the random factor was performed on the corrected percentage scores of the three rotation conditions after an arcsin transformation. The main effects of CM/VM manipulation approached significance [$F(1,6)=4.82$, $p=.07$] and the rotation effect was significant [$F(2,12)=6.69$, $p<.05$]. The interaction between the two factors was not significant [$F(2,12)=0.84$].

The results are similar to the previous experiment except for two aspects: 1) CM sequences are easier to identify than VM when rotated; and 2) the 180 degree rotation is easier than the 90 or 270 degree rotation. If mental rotation requires resources, then the CM/VM difference could be due to the quality, noted in earlier experiments, that CM identification requires less resources than VM identification. The difference between this experiment and the previous one where no mental rotation was required could be due to an effect similar to that found by LaBerge (1973). In the LaBerge experiment, subjects were tested on both familiar and unfamiliar characters. For the familiar characters, LaBerge argued that the separate features were unitized into letters automatically. For unfamiliar characters, subjects could not initially automatically unitize the features. However, the effect only appeared when subjects were required to switch their attention. In our previous experiment, when subjects were not required to switch their attention from orientation sequence to target sequence, automaticity and unitization were not noticeable for the CM sequences. However, in the present experiment when subjects were required to switch their attention from a 0 orientation sequence to a rotated sequence, CM sequences were identified better than VM sequences. Using a similar argument to that of LaBerge (1973), the features of the CM familiar sequences were possibly unitized without attention while the relatively unfamiliar VM sequences required attention for integration and identification of the spatiotemporal pattern. However, an important result again is that CM transfer performance is always low; it is lower than the VM trained. This result suggests that the spatial pattern must be fixed in order to identify it.

Overall Conclusions and Discussion

From the 12 experiments run, several conclusions can be made. In the load requirement experiments, it was discovered that the CM trained sequences required resources to identify. The load requirement was, however, less than that required for the VM trained sequences. The memory set size 2 experiments revealed that CM sequences apparently did not always automatically grab resources. However, when five of the subjects were analyzed together in the VM protected experiment, these five could automatically detect sequences in the CM dual and CM single tasks; the two conditions were not significantly different.

Manipulation of the temporal component in the transfer experiments revealed that the CM trained sequences can be very flexible. High transfer existed when

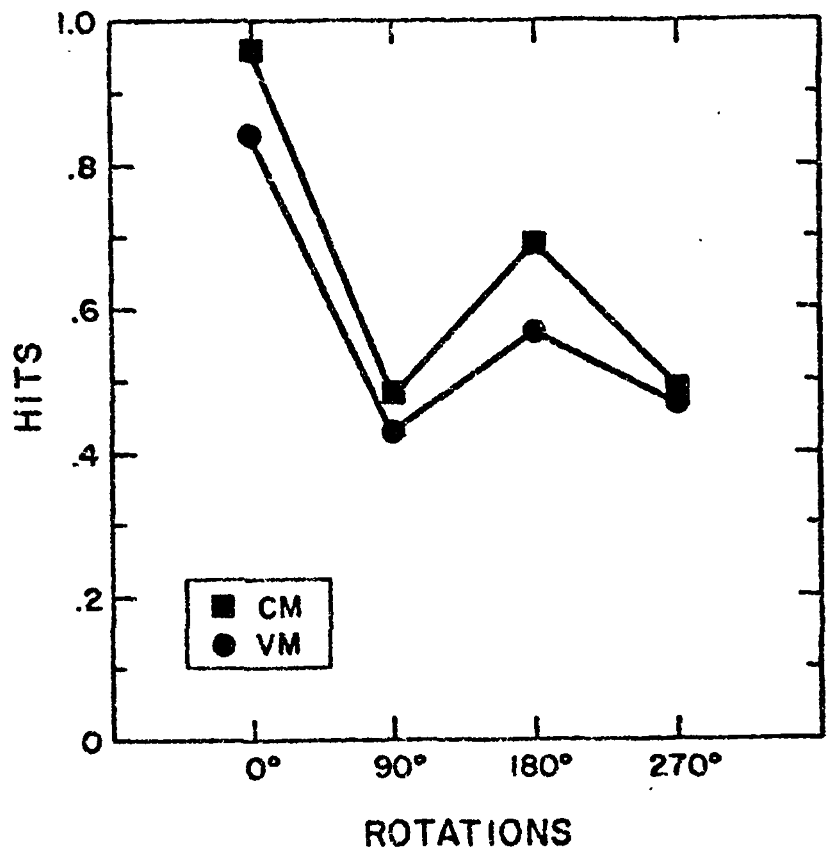

Figure 17. Data from Experiment 12: the proportion of trials identified correctly as a function of the amount of rotation. The hits are corrected for guessing.

the pattern was lengthened, shortened, compressed, and run backwards. A useful analogy is to think of the structure of the CM identification skill as a mental program. Viewed in this way, the temporal component acts like a parameter that is passed from the executive to subroutine. The VM trained sequences were found not to be as flexible as the CM trained. The most significant result was that in every experiment that manipulated the temporal component, the CM transfer sequences were always better than the VM trained sequences.

Manipulation of the spatial component resulted in less flexibility. For the rotation experiments, CM transfer identification was always worse than VM trained identification. Using the analogy of the mental program, the spatial component can be viewed as a constant not amenable to parameterization. The overlap experiment revealed that subjects might try to view the spatial and temporal pattern as a purely spatial pattern early in the development of a skill.

Motor program and schema theorists remark on the flexibility of skills (Pew, 1974b; Schmidt, 1975; Welford, 1976). In the reported experiments here, flexibility was exhibited only when the temporal component was manipulated and not the spatial component. Of course, many variables, such as size, which might allow high transfer were not varied in these experiments.

Why were the CM sequences better identified than the VM sequences? There are three possible reasons: 1) the particular CM sequences were easier to discriminate than the VM sequences; 2) subjects had more practice on the CM sequences; and 3) CM and VM sequences developed into two qualitatively different processes. The first reason can be dismissed rather quickly. Although there were initial differences between CM and VM sequences, the differences were not significant and other experiments (Eberts, 1979) using the same stimuli and procedures did not reveal any differences. Also, a partial counterbalance was used. Some sequences were CM for one group of subjects and VM for the other group. The other two possible reasons for CM/VM differences require much more discussion.

One reason why CM sequences might be better identified than VM sequences could be because of the differential detection practice subjects had with the two groups. Subjects had about eight times more practice on their particular CM sequence than on any single VM sequence. Indeed, if the simple performance measures are overlapped throughout the 12 experiments, then the probabilities of identifying a sequence correctly given that it is the CM sequence or any one of the eight VM sequences are about equal. It is possible that this particular CM/VM manipulation produced only simple practice effects and results from the two groups of sequences, CM or VM, should be evaluated in terms of well-practiced and less-practiced groups. However, as the next discussion will show, the differences cannot be entirely explained by simple practice effects.

Schneider and Shiffrin (Schneider and Shiffrin, 1977; and Shiffrin and Schneider, 1977) argued from their findings and an extensive literature search that CM trained stimuli developed into an automatic process while VM trained stimuli maintained controlled processing; two qualitatively different kinds of processes. Two very general patterns of results enabled the hypothesis of the qualitatively different processes: 1) an asymptote in VM performance such that even with more practice, VM identification would not approach CM performance; and 2) qualitative differences between CM and VM trained sequences.

VM sequences had apparently not asymptoted when this series of experiments was terminated. Although it appeared that VM performance had asymptoted at 74% detection in the last 8 replications of the first experiment, at the end of all 12 experiments, VM detection had improved 10%. As the task was varied, subjects saw the sequences as spatial patterns, rotated, and reversed, VM performance improved. CM detection was at ceiling much of the duration of the experiments and ended at 96% detection in the last experiment. However, good qualitative differences between CM and VM trained sequences are reported in Experiments 7-10 which cannot be explained solely by practice effects. The varied stimulus duration experiment and the ratings experiment provided especially good evidence that two qualitatively different processes developed. Yet, in terms of the two criteria for automatic and controlled processing, a VM asymptote and the qualitative differences, the present results are ambiguous.

There are several possible reasons why the present results are ambiguous. First of all, the stimuli studied in this experiment, composed of equal length line segments in a limited number of orientations and positions, are much less discriminable than the letters and digits of a typical visual attention study. Second, the stimuli are not familiar; subjects had never seen the particular patterns before the experiment.

It is quite possible that the CM/VM manipulation did not produce the strong effects evidenced by Schneider and Shiffrin (Schneider and Shiffrin, 1977; Shiffrin and Schneider, 1977), especially in the load requirement experiments, because the discrimination was so difficult. It was perhaps difficult for subjects to be aware that distractors could be targets in the VM conditions and not in the CM condition. Possibly with much more practice on a harder task, to get rid of the ceiling effects for CM sequences, the CM/VM manipulation would have more of an effect. These experiments may have only examined automatic and controlled processes early in their development. Much more practice would be needed to bring performance up to the level studied by Schneider and Shiffrin with the easier and more familiar stimuli (letters).

In the development of an automatic process, three very rough components were identified by Schneider and Shiffrin: 1) the initial controlled processing; 2) the automatic process; and 3) the automatic attention response (AAR). In this series of experiments, an AAR may have been developed. An AAR is a kind of automatic process that requires no resources to activate, is difficult to inhibit, and results in an automatic detection. The present data showed an effect of load, flexibility, and CM/VM differences. The five subjects in Experiment 6 were able to perform joint CM/VM search without deficit, suggesting the development of an AAR (see Schneider and Fisk, 1980). If subjects had CM sequences with good movement (Eberts, 1979) or had greater practice all of the subjects might have performed dual CM/VM search without deficit. The present demonstration of probable visual temporal AAR's complements the existing auditory literature. The classic cocktail party phenomenon is an example of an automatic detection of a temporal auditory sequence (Moray, 1959).

The present data shows the development of automatic encoding in both VM and CM conditions. For adults the encoding of the features of a letter into the letter or set of phonemes into a word is probably automatic (see Shiffrin and Schneider, 1977, pp. 162-164). Hence the improvement seen in the VM condition represents the development of an automatic encoding unit which processes the three temporal units into one higher level unit. This is analogous to coding three phonemes into a word. The sensitivity of the CM performance to the number of channels (Experiment 4) suggests the development of an automatic process but not an AAR. It should be noted that Experiment 4 was one of the earliest and the effect of the number of channels may have declined with additional practice.

In light of the results of this series of experiments, the concept of an automatic process must be slightly revised in order to include characteristics of weak visual temporal processing. Several characteristics of such an automatic process are: 1) they require less resources than controlled processing but possibly the requirement is greater than 0; 2) they show reduced load effects but not necessarily 0; 3) they are established with much difficulty; 4) they are flexible in components other than spatial; 5) they are more resistant to noise; and 6) they are economical and efficient in structure.

Our overall view of an automatic process has been expanded in light of the present results and the comparison to a skilled performance. On a more theoretical level, Shiffrin and Schneider (1977) described an automatic process as a sequence of memory nodes that nearly always become active in response to particular input sequences. They can be initiated by external stimuli and/or internal context (possibly initiated by a controlled process). Fitts (1964) describes predefined sequences which can be run off as a subroutine. His use of a mental program is very similar to the node structure theoretical explanation of Shiffrin and Schneider (1977). A very similar concept, developed by Anzai and Simon (1979) in the area of problem solving is that of a pre-compiled Production System. All of these conceptions seem to capture the development of skill seen in these studies. They all indicate that as one gets more skilled less resources are required, processing is faster, the task is less susceptible to noise, performance becomes more accurate, and the internal structures become more economical and efficient.

Several future directions are indicated by this series of experiments. The controlled process could possibly act as an executive. When the mental program is not well-structured, processing requires repeated conscious intervention by the executive. As skill increases, the mental program becomes better structured and thus requires less executive intervention. The resulting chunk of behavior between executive interventions occurs automatically. The efficiency of performance is increased as the chunks become larger and the automatic process itself can manipulate the internal context which initiates the next automatic process. Unfortunately, our theories are too vague and the paradigms are too limited to presently specify the microstructure of an automatic process and the automatic-controlled process interaction. Future experiments should be directed toward identifying this microstructure.

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