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ATTENTION THEORY AND MECHANISMS FOR SKILLED PERFORMANCES

Walter Schneider and Arthur D. Fisk

Report HARL-ONR-8201

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This research was sponsored by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N000-14-81-K0034, Contract Authority Identification No. NR154-460.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER HARL-ONR-8201	2. GOVT ACCESSION NO. AD-A119679	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Attention Theory and Mechanisms for Skilled Performances		5. TYPE OF REPORT & PERIOD COVERED Technical Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Walter Schneider and Arthur D. Fisk		8. CONTRACT OR GRANT NUMBER(s) N000-14-81-K-0034
9. PERFORMING ORGANIZATION NAME AND ADDRESS Psychology Department University of Illinois 603 E. Daniel, Champaign, IL 61820		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NR 154-460
11. CONTROLLING OFFICE NAME AND ADDRESS Personnel and Training Research Programs Office of Naval Research Code (458) Arlington, VA 22217		12. REPORT DATE July 1982
		13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work was also supported in part by NIMH grant 5 R01 MH 31425-04; this report also appears in R.A. Magill (Ed.), Memory and control of motor behavior. Amsterdam: North Holland, in press.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Attention, skilled performance, human information processing, dual process attention theory, controlled and automatic processing, motor skills, perceptual skills.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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Unclassified

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20 Abstract

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Attention Theory and Mechanisms for Skilled Performance

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Abstract

Current attentional research and theory are related to the development of skilled performance. Emphasis is given to how performance changes with practice. Dual process attention theory is reviewed examining the distinctions between automatic and controlled processing. The changing interactions between automatic and controlled processing in the development of skill are discussed. It is proposed that consistent practice produces automatic productions which perform consistent transformations in a heterarchial system. Automatic productions are proposed to: be modular; show high transfer; become resource free; not be under direct control, and be fast, accurate, and coordinated. Controlled processing is assumed to develop automatic processing, maintain strategy and time varying information, and perform problem solving activities. Perceptual data, some motor data, and several motor performance examples are presented to illustrate automatic/controlled processing effects. The relationship to current theories of motor skill are discussed. New research paradigms suggested by the current approach are discussed.

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Attention Theory and Mechanisms for Skilled Performance
Walter Schneider and Arthur D. Fisk

Since William James (1890), mainstream theories of attention have been central to theories of skill. James felt that the key to producing skilled performance was making behaviors automatic so the behaviors could be done without consciousness.

For the past twenty years there has been little interaction between the areas of attention and skill development. In attention research, issues of practice, feedback, coordination of activities, and transfer of training have received little emphasis. In the skill development literature there has been little empirical concern about attentional load, operator control, information chunking, and extended practice. Our goal is to describe the beginning of a theory for the mechanism of skilled performance. The major concepts were derived primarily from attention theories of perceptual tasks. The attempt here is to describe the mechanisms by which component skills can be built so that expert performance is fast, accurate, and flexible.

The acquisition of almost any cognitive or motor skill involves profound changes that have impressed researchers since the earliest days of psychology (James, 1890; Solomon & Stein, 1896). Consider, for example, the changes that occur while learning to type, to play a musical instrument, to read, or to play tennis. At first, effort and attention must be devoted to the smallest movement or minor decision, and performance is slow and error-prone. Eventually, long sequences of movements or cognitive processes are carried out with little attention, and performance may be quite rapid and accurate. The changes that occur are striking enough that performance of the task seems qualitatively different before and after practice.

A number of researchers have interpreted the qualitative differences between novice and skilled performers as being the result of two qualitatively different forms of information processing (James, 1890; LaBerge, 1976; Logan, 1978, 1979; Norman, 1976; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). In this paper these two forms will be referred to as <u>automatic</u> and <u>controlled</u> processing. Automatic processing is a fast, parallel, fairly effortless process which is not limited by short-term memory capacity, is not under direct subject control, and performs well-developed skilled behaviors. Automatic processing typically develops when subjects deal with the stimulus consistently over many trials. The quick effortless playing of a well learned pattern of notes by an expert musician is an example of an automatic process. Controlled processing is characterized as a slow, generally serial, effortful, capacity limited, subject controlled processing mode that must be used to deal with novel or inconsistent information (see Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Controlled processing is expected when the subject's response to the stimulus <u>varies</u> from trial to trial. The novice trying to play a six chord sequence is an example of a person using a controlled process.

Mechanisms of Skilled Performance

To apply automatic/controlled processing concepts to skilled performance, the roles and mechanisms of each process must be elaborated. The following is a series of assumptions about the mechanisms through which skilled performance is accomplished. It is important not just to focus on the individual assumed mechanisms, but rather on how the mechanisms might interact to allow complex performance.

1. Practice leads to the development of a large vocabulary of automatic productions which perform consistent stimulus to response transformations. We are using the term "productions" in the Newell sense (1973, 1980; see also Anderson, 1980) of a generalized condition-action rule that, when its appropriate stimulus conditions are satisfied, performs a given action. You might think of this as a generalized stimulus-response mechanism. The terms stimulus and response are *not* interpreted in the limited sense of a physical stimulus and motor response. Rather, the stimuli and responses can be either internal or external and may refer to classes of conditions and responses as well as individual instances. It is important to note that the productions perform only consistent transformations. The productions are modular and are built into heterarchial systems. By heterarchial, we mean the same component production may be involved in the processing of many component stimuli. For example, in reading, the same letter may appear in many words, the same word in many concepts (see Figure 1).

Insert Figure 1 about here

2. Practice makes automatic productions resource free, autonomous, fast, accurate, and coordinated. This is an important principle because resources are freed for other processing roles and actions will generally not be limited by central information processing speed.

3. Changing the contents of short-term memory can change the enabling (test) conditions that switch in different sets of productions appropriate for a given situation. Automatic productions cause actions only if the test conditions are satisfied. If one of the test conditions requires particular information in short-term memory, that production will be enabled only when the appropriate information is active. By making rapid changes in the contents of short-term memory, the performer can enable a different strategy and hence, different productions which are appropriate to that strategy. It is important to note that the maintenance of information in short-term memory consumes controlled processing resources.

4. Practice can incorporate both internal and external context cues to enable appropriate sets of productions. Both internal and external stimulus cues can cause a strategy shift which is then maintained in short-term memory.

5. Practice improves chunking of information about the outputs, goal states, and inputs of the situation. This chunking allows very detailed information about rapidly changing events to be maintained in a very limited short-term memory.

Review of Empirical Evidence and Description of Mechanisms

In both the perception and motor training research there is substantial evidence that human performance changes qualitatively as a function of practice (see Shiffrin & Schneider, 1977; Schneider, Dumais, & Shiffrin, in press). As practice proceeds, automatic component productions develop to perform consistent transformations. Early in practice limited controlled processing resources are allocated to the development of these new productions. Late in practice, the developed productions perform all of the routine transformations, and controlled processing resources are utilized to maintain strategy information and time varying information.

A) Automatic productions and consistent practice.

Consistent practice leads to the development of productions which can perform consistent transformations. By consistent practice we mean that at some level of processing, the activation of a node in memory is followed consistently by the activation of a particular node in memory (e.g., the activation of the word "bear" is followed by the activation of the category node "animal").

The importance of consistency is shown in paradigms that manipulate the mapping of stimuli to responses across practice. In a visual detection paradigm, automatic processing develops only when subjects can consistently deal with stimuli. For example, if every time you saw the letter "b" you pushed a button indicating that you saw it, the letter would be consistently mapped (CM) to evoke the button push. In a varied mapping (VM) paradigm, however, a given stimulus can not be dealt with consistently over trials. That is, on some trials you would be required to search for the letter "b", and you push the appropriate button when it appears. On other trials, however, you might be required to search for a different letter, and you ignore the occurrence of "b" (because on that trial the letter was not a member of the search set). The important distinction to be made is that in the varied mapping paradigm the response to the stimulus "b" would vary across trials; whereas, in the consistently mapped paradigm the response to 'b' would not vary. Note that the use of the term "consistency" refers to consistency of mapping, as opposed to consistency of the practice sequence. In the motor learning literature, practicing of skills in a random order rather than blocked order improves performance (e.g., practicing skills ABC in the fixed order of AAABBBCCC results in poorer learning than ABCBACCAB, see Shea & Morgan, 1979; also Shea, this volume).

In a search experiment, Schneider and Fisk (1982) examined how the degree of consistency over trials of a target determined performance improvement with practice. On a block of trials, subjects searched for a given letter 10 times and indicated the position of the target letter. The ratio of the number of times that a letter would appear as a target versus a distractor was varied across trials. In the perfectly consistent condition, every time a given letter appeared it was a member of the search set. In the 33% consistency condition, for every trial that a given letter appeared as a target, it appeared on two other trials as a distractor while the subject searched for a different letter. The results are shown in Figure 2 as a function of practice and degree of consistency. The data represent performance over 670 search trials for each letter (5600 toral trials). In the perfect consistency condition (100% consistent) there was substantial improvement across blocks of practice. If the consistency was 33% or less, there was no benefit of practice. Subjects' performance on the 670th search trial was equivalent to their performance on the first search trial. There was no benefit of the 669 previous training search trials for that letter. We have trained subjects for over 4 months of searching for letters in a varied mapping condition and have found no performance improvement after the first one or two sessions.

Insert Figure 2 about here

We have examined the effects of consistency in a motor response button pushing paradigm (Schneider & Eberts, Note 1). Subjects were presented a sequence of eight digits and then pushed buttons indicating the presented digits. There were seven different types of digit sequences. In the consistent sequence the subjects always responded with the same eight digit pattern. In the varied condition the eight digit sequence was randomly ordered on each trial. In the other five lists, groups of digits in the sequence were alternated between trials. In addition to the digit tasks, subjects were required to tap a key at a .5/second rate. This put subjects under high workload and accented pauses between responses. Figure 3 shows the proportion of trials on which the subject entered all eight responses correctly. There were 10 trials per session. The accuracy of the consistent sequence improved slowly from .4 to 1.0 over 40 trials. The varied sequence improved during the first session, but then accuracy remained at .7. The pause data for the first and last two sessions are presented in Figure 4. The standard deviation of responses after the first response provide an estimate of response timing variability. For the varied condition the standard deviation was 87 msec on sessions 1 and 2 and 87 msec on sessions 4 and 5. In the consistent sequence the standard deviation was 55 msec for sessions 1 and 2 and 43 msec for sessions 4 and 5. In the consistent sequence the pause pattern was reduced with practice. However, in the varied condition the pause pattern did not change with practice. The improvement for the consistent sequence data suggests automatic processing may be developing even with only 50 training trials. We have shown similar improvements with small numbers of trials in perceptual experiments (Schneider & Fisk, Note 2).

Insert Figure 3 and 4 about here

The motor response button pushing results appear analogous to the perceptual experiments. Consistent practice resulted in more accurate, faster, and more uniform responding. Varied practice had little effect on performance.

The above results suggest that practice improves performance <u>as a quasi-multiplicative function of the degree of consistency and the amount of practice</u>. It is not simply practice that leads to the development of automatic productions but rather consistent practice. If consistency is below some minimal level there is no benefit for practice. If there are too few practice trials there is no benefit for consistency.

In another character detection experiment (Schneider & Fisk, Note 2), we examined whether performance improved as a function of the number of searches or the number of actual detections. If practice at searching is the key to improving performance, searches without detections would result in a benefit. However, the results showed that performance improved only as a function of the number of successful detections. Experience at searching without detection actually resulted in a decrement in performance. The results suggest that these automatic productions develop as a function of the overlaid traces of consistent repetitions of the appropriate stimulus response pattern.

If consistent execution is a necessary condition for the development of automatic productions, then mechanisms that promote consistent responding should promote automatic production development. We feel much of the benefit of knowledge of results (see Adams, 1971), and the benefits of guided training (see Welford, 1976), can be interpreted as promoting consistent performance in the learner.

B) Modularity of automatic productions.

<u>Automatic productions are modular and will develop when component processes are consistent even if the entire task is not</u>. If automatic productions could only develop when processing was consistent from the external stimulus to the final motor response, few human behaviors would be done by automatic productions. If however, automatic productions develop for component skills which are consistent, the vast majority of human skilled performance would probably involve such productions.

In a detection paradigm, Fisk and Schneider (Note 3) examined the effects of consistent attending versus consistent responding. We examined what happens when the subject always attends to a particular stimulus (i.e., a given letter) but is required to make an inconsistent motor response across trials (i.e., on some trials subjects responded with the actual position of the target, on other trials they responded to the position opposite the target). The results showed that the inconsistent responding may have somewhat slowed the development rate of the automatic production for detecting the letter, but the inconsistent response training did not change the asymptotic performance level.

In the eight digit button pushing task, some of the digit sequences were divided into two groups of four (Schneider & Eberts, Note 1). The order of which group of four digits came first in the sequence alternated within the list. In this case the set was inconsistent across trials, but the elements within each set of four did maintain their order consistency. Figure 5 (solid line) shows that in this case the pauses within a set were basically eliminated with practice whereas the pause between sets (position 5, the break between consistent components) was maintained even after 50 trials of practice. If automatic processing develops for the consistent components and controlled processing remains for the inconsistent component, we would expect the data for positions 1, 2, 3, 4, 6, 7, and 8 to show pauses like Figure 4 (consistent responses) and the varied component (position 5) to show a pause like Figure 4 (varied responses). The "predicted" data in Figure 5 represents the predicted pauses from Figure 4. The very close agreement between the predicted and observed data suggests that automatic processing develops to consistent component sequences even if the total task is not consistent.

Insert Figure 5 about here

The training of automatic productions shows substantial transfer to elements in the same class of stimuli that were trained. In a semantic category search experiment, we trained subjects to detect words from a given taxonomic category (Schneider & Fisk, Note 4). After training we tested subjects' performance on words that were from the trained category but had not been presented during the training period. Reaction time data showed that if subjects trained on a set of eight words from a category, there was nearly perfect transfer (92%) to the untrained members of the trained "category." In an accuracy experiment, where subjects were put in a very heavy workload condition (see below), training on a subset of category members resulted in a 72% transfer to new members of the category which were not trained. These data indicate that it is not the specific stimulus response pattern that must be repeated but rather the class of stimuli and responses.

Variability in initial training can produce a more generalized automatic production. In a category search experiment, subjects were trained to detect either 4 or 8 words from a category and then tested to see how well they could detect untrained words from the category (Schneider & Fisk, Note 4). The transfer with a training set of 4 words was 60%; the transfer with a set of 8 words was 92%. The data suggest that greater variability of the training instances results in more generalization of the automatic production to the non-trained category members. Note however that the consistency is maintained at the category level. The subject always responds to words from the target category and never ignores them. The words that the subject responds to vary from trial to trial, but at the category level the response is always consistent.

In the motor literature, variability in initial training also produces better transfer to similar motor responses (see Schmidt, 1975). In the same sense that someone might learn to deal with a category of inputs, one might learn to produce a class of outputs. If the subject searches for a category and always detects the same word then the automatic production will be specialized for that word and show little transfer to related words. In a slide positioning task, learning to move to one stop will develop a skill fairly specific to that stop. When training to move to several stops, the automatic productions operate on a more general set of task features and hence, there is more transfer to novel members of the trained set.

Another indication of the modular nature of these productions is that the learning of the new set of productions results in transfer to the previously developed skill. For example, Kolers (1975) has shown that subjects can be trained to read text in which each of the letters are rotated 180 degrees. After two months of training (160 pages), subjects can read the rotated text at speeds approximating that of normal text. Note that the learning to translate orthographic patterns into words normally requires years of training. The present data suggest that word encoding is modular at the letter level.

A motor illustration of this modular nature of the automatic component processes is the learning involved in driving a car with a different gear shift pattern. After perhaps 20 trials one can be fairly efficient at dealing with a new shift pattern. In essence, all the operator need do is learn what positions correspond to each gear. Once this new information is tied into the existing structure for operating a gear shift, performance can once again be automatic.

We would like to make a brief comment about the efficiency of modular organization of information (see also Turvey, 1977; Turvey, Shaw, & Mace, 1978). Modular processing systems can be heterarchial with the same module being part of many different skills. In general, the number of links that must be learned *in a heterarchial system is equal to the addition of the number of element* connections at each level. In contrast, if stimuli are mapped directly from initial feature patterns to final higher level information, the number of links that must be learned is a multiplicative function of the number of elements at each level. To illustrate, to learn a vocabulary of 10,000 words in a *heterachial process would require the learning of 31,080 links* (10,000 words x 3 grapheme patterns per word + 160 grapheme patterns x 3 letters per pattern + 26 characters x 2 cases x 10 fonts). If one had to learn to map the particular letter fonts to the individual words one would have to learn 1,200,000 patterns (10,000 words x 6 letters x 20 symbols [upper and lower case of 10 fonts]). In *the heterachial system one can quickly transfer to new fonts by just learning* the new letter set. In the feature to word level system one would need to relearn all of the vocabulary in the new font.

C) Practice and attentional resources for automatic productions.

A critical feature of practice is that it can make automatic productions resource free. Kahneman (1973) proposed that attention was an undifferentiated resource pool, and that all processing tasks consumed resources from this limited pool. *The proposal that all processes consume significant resources* from one limited pool implies that there is an upper limit to human processing capacity. Our research proposes that automatic productions can become effectively resource free. Hence, there is no necessary limit to the number of automatic processes which can be active at any one time.

A number of experiments carried out in our laboratory indicate that subjects can concurrently perform complex automatic and controlled processing with no significant deficit in either task. One experiment required subjects to concurrently perform a dual task serial digit recall and visual category search (Fisk & Schneider, in press). In the *digit recall task eight random digits* were presented sequentially, one every 1.6 seconds. At the end of the sequence subjects entered the eight digits on a keyboard. There were three search conditions. In the CM-4 search condition, the subject responded every time a word occurred from one of four categories (i.e., fruit, body parts, furniture, or animals). Words from the four categories that were consistently mapped always appeared as targets and never appeared as distractors. In the VM-1 condition, subjects searched for words from a single category but the words were variably mapped. For example, the word RIFLE might require a response on one trial while searching for WEAPONS, but that word might be a distractor on the next trial while searching for TREES. In the VM-2 condition subjects searched for words from two categories. In the search tasks, subjects searched two words every 1.6 seconds responding if either of the words matched any of the categories. Subjects performed digit span and search tasks as single tasks and combined them in dual task conditions. *In the dual task conditions subjects were strongly encouraged to emphasize the digit task and maintain dual task digit performance at single task levels.*

The results show that, after some 600 trials of training, subjects could maintain the digit recall at 6.5 digits in both the single and dual task conditions. The search results are presented in Figure 6. In the CM-4 condition there was only a small (2%) non-significant dual task decrement when switching from the single to dual task conditions. In the VM-1 condition the decrement was 26%. In the VM-2 condition the decrement was 43%.

Insert Figure 6 about here

These results support the hypothesis that automatic processing can be done with little or no measurable resource cost. In the CM-4 condition subjects could carry on a digit span task and simultaneously determine whether each of 16 words were members of four categories with no dual task deficit. We have replicated the nearly resource free CM search in two other experiments requiring decisions to be made every 400 and 200 msec with equivalent results (Schneider & Fisk, 1982a). Although we find no statistical evidence of resource cost, it is possible that with additional tests one could find a significant decrement in performance. We have shown that tasks which originally required all available resources (i.e., resource limited) can, after sufficient practice, be performed with no measurable cost. Whether there is a 98% reduction in required resources or 100% is not critical to the arguments made here (see also Schneider & Fisk, 1982a).

It should be emphasized that practice makes CM performance apparently resource free but has little effect on VM performance. In the above category search and two other experiments with extensively practiced subjects, we have found their VM performance does not become resource free. <u>Practice leads to apparently resource free automatic productions for consistent processing but does not reduce resources needed for a varied processing task.</u>

<u>The apparently resource free processing occurs typically only after substantial overtraining.</u> In a letter search experiment, we found that subjects' CM letter search performance had nearly asymptoted in about 1000 trials (Schneider & Fisk, 1982a). However, when the CM search task was treated as a secondary task and combined with a high workload primary task, the CM task continued to improve for 2600 trials. LaBerge (1973) showed in a perceptual matching experiment that when subjects could devote full attention to a task performance asymptoted in the first 2 sessions. But when attentional resources were not available until the to be matched stimuli were presented, performance did not asymptote for 6 sessions.

The reader is cautioned <u>not</u> to assume that automatic processes require thousands of trials to influence behavior. We have found significant benefits for ten CM trials. In our laboratory, we use a rule of thumb that with appropriate training procedures automatic productions develop in about 200 CM

trials. We frequently observe automatic type behaviors (i.e., little resource sensitivity, large differences between CM and VM) after two hours of training.

With sufficient overlearning, motor performance tasks can be executed with no apparent attentional resources. Allport, Antonis, and Reynolds (1972) demonstrated that skilled pianists could shadow verbal messages while sight reading music without deficits in either task. Colle and DeMaio (1978) found that highly trained pilots could perform complex aircraft formation maneuvers with no deficit while digit cancelling.

In perceptual and motor tasks, extensive training on consistent tasks reduces the resources needed to perform the task. This reduction in resource sensitivity of the automatic component production is important because: a) it makes the automatic productions more reliable; and b) it frees resources to either develop new productions or to maintain temporary information in short-term memory (see below).

D) Loss of direct control of productions.

<u>Practice makes automatic productions autonomous, reducing direct conscious control of the subject.</u> Training develops a production that will be executed whenever the test conditions are satisfied. Hence, after sufficient training the productions will execute even when the subject does not consciously intend for the behaviors to occur. In a detection search experiment (Shiffrin & Schneider, 1977, Experiment 4d), subjects were trained to detect digits in frames of 4 characters presented every 200 msec. Thereafter subjects were required to perform a varied mapping search for letters along one diagonal of each frame. In addition, subjects were told that digits would sometimes appear on the other diagonal but these were foils and were supposed to be ignored. These foils were <u>automatic foils</u> -- in that the subjects had previously received over 10,000 trials of consistently responding to the digits. Subjects' detection for searched letters without foils was 84%, detection when the foil appeared on the same display as the target letter detection dropped to 62%, and if the foil appeared in the display after the detected letter, detection performance dropped to 77%. The results show that automatic foils interfere with the processing of letters on the attended diagonal. This interference occurred on the same frame as the target letter and when the foils occurred 200 msec after the target letter. In essence, these automatic productions can interrupt ongoing processing even when the subject is directed to ignore these automatic foils.

A subjective comment by one of our subjects illustrates the difficulty in inhibiting automatic processes. The subject had searched for the target letter "E" in her experimental session. She reported that after participating in our experiment, she could not read normal schoolwork for about two hours. She claimed that when trying to read, the "e"'s in the text appeared to pop out at her and attract her attention. An example of a similar pop out effect is common to researchers. In reading papers one's attention can be attracted to his/her name in a citation several lines before reaching that portion of the text.

It is difficult to counter an automatic production and hence, automatic productions can produce large negative transfer effects. In a search experiment, subjects were required to search for letters in the first half of the alphabet in frames which included distractors from the second half of the alphabet (Shiffrin & Schneider, 1977, Experiment 1). After 2400 training trials, subjects were asked to search for the opposite pattern, letters from the second half of the alphabet with distractors from the first half. Negative transfer of the previous training resulted in slowing the learning rate to one third that of a novice subject. It originally took 900 trials to reach 90% accuracy criterion. After reversal, subjects required 2400 trials to reach the same level of performance. Subjects reported that the negative transfer was caused by attention being "dragged" around to the old display characters making it very difficult to search for the new characters.

Norman (1981) presents many examples of lack of control of motor activities in what he refers to as "slips" of action. Slips are actions slipping out when other actions are intended. For example going to a vending room to purchase cigarettes and by mistake putting your money in the coffee machine and selecting coffee. In sports one often makes a movement which would elicit an automatic movement by the opponent which is disadvantageous to the opponent (e.g., a play-action pass in football).

<u>Performers must learn to allow automatic productions to be executed without direct control or the use of limited resources</u>. If the performer consciously initiates each response component, the initiation becomes a bottleneck and performance will be slow and effortful. In dual task experiments, subjects can perform a categorization with no measurable reduction in attentional resources (Fisk & Schneider, in press). However, on a number of occasions we have found subjects who were not willing to let go of their attentional resources. By "let go", we mean to perform an automatic task without allocating any resources to the task. We find that subjects have a tendency to allocate resources to the automatic production even though performance on the automatic task is insensitive to resource allocation. Getting people to let go can be very difficult. In order to show no tradeoff in dual task experiments, Schneider and Fisk (1982a) have had to require subjects to perform equivalently on the primary task, give subjects no feedback on their performance on the automatic task, and train subjects extensively (e.g., up to 20,000 trials). Only after these procedures were used could we get subjects to de-allocate resources from the automatic task to other tasks.

A particular class of poor readers illustrates the problem of not letting go. Poor readers who are concerned about their accuracy frequently expend much of their attentional capacity on word encoding (see LaBerge & Samuels, 1974). A reader who divides his limited controlled process resources between word encoding and comprehension will typically have poor comprehension.

The category search experiment described above and in Schneider and Fisk (in press) illustrates how critical it is for subjects to "let go" of an automatic process. There were eight subjects in a dual task category and digit search experiment. Of the eight subjects, six could perform equivalently on single or dual task CM category search. However two of the subjects could not. Their single task CM search performance accuracy level was 95% and their dual task performance level 30% (see Figure 7). After this experiment, we trained these two subjects to search for words from an easier semantic category and a different set of distractor words. When the subjects were successful at

learning this new easier category, we returned them to the original condition in which they were having difficulty. Subjects' dual task performance increased from the previous 30% level to 84% even though they had had no training on either the category target words or the distractors between those two sessions. Subjects reported that during interim training they had learned to just "let go" and have the words pop out to attract their attention. Once subjects had learned to "let go," they could perform the CM detection task at high accuracy even when it was the secondary task.

Insert Figure 7 about here

A motor instance of the need to let go is provided by the player who gets too concerned about a component skill and attends to it, resulting in a decrement of the total task. Absence of "letting go" can cause a slump in performance. The first author once found himself skiing down a difficult slope and made the mistake of worrying about which foot was carrying his weight in a turn. That attending to the component skill resulted in substantial performance decrements (i.e., many falls) for the remainder of the slope.

E) Increases in processing speed, accuracy, and coordination.

<u>Automatic production development results in substantial increases in speed, accuracy and coordination</u>. In a category search experiment (Fisk & Schneider, in press), 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 a "target present" button; if not they pushed the "target absent" button. Figure 8 shows the reaction time data plotted as a function of number of categories in memory. The VM condition reaction time slopes as a function of the number of comparisons (Figure 8, left panel) were 96 msec for target present and 202 msec for target absent searches. The results indicate that the comparison was a serial self-terminating comparison with a comparison time of about 200 msec. In contrast, the consistently mapped comparison time was 2 msec per category (Figure 8, right panel). In summary, the automatic comparison marginal increase in comparison processing time was 100 times less than that of the controlled process comparison in this experiment.

Insert Figure 8 about here

Consistent motor processing also shows faster responding with practice. The sequential button pressing pause data (Figure 4) showed a reduction in pauses with practice for consistent sequences. Crossman (1959) showed that subjects' cigar rolling time was about three times faster with practice over two years and then speed was limited by the cigar making machine cycle time. The speed with which subjects can perform automatic productions suggests that the production execution time is generally not the limiting factor for performing consistent, well practiced responses.

Automatic productions can process different stimuli at different stages simultaneously as in a production line. We assume automatic productions can be cascaded through a number of stages with different stimuli being processed at each stage. Referring to Figure 1, one set of stimuli might be at the letter level, another set at the word level, and a third at the category level. Different information is processed at each stage of the heterarchy. In a CM condition search experiment, we found subjects could accurately detect a target letter in a new set of four characters presented every 30 msec. In a VM procedure subjects required 120 msec per display to detect targets at comparable accuracy levels. However, the reaction times for both CM and VM conditions were approximately equal at about 450 msec. The data suggest that in CM conditions subjects could process several different displays in parallel at several stages (i.e., one display would be processed at the feature level while the previous display would be processed at the letter level; see Schneider & Shiffrin, 1977, p. 37).

The typing literature provides a motor example of processing different information in parallel at different levels. Shaffer (1973) has shown that expert typists are encoding about two words ahead of what they are outputting, indicating input and output operations are processing different stimuli at the same point in time.

The characteristics of automatic productions should facilitate coordinated behavior. Automatic productions are fast, can be triggered by many external conditions, are always ready, and require little or no controlled process resources (see Shiffrin & Schneider, 1977). Such productions can incorporate peripheral feedback and timing information into their enabling conditions. There appears to be little fall off in speed as more conditions are met or as more productions are enabled. Such systems would have the capability to perform quick coordinated movements.

Controlled Processing in Skilled Behavior

Up to this point in the paper we have concerned ourselves with the development and performance of automatic productions. Controlled processing resources were considered necessary for initial performance and to develop automatic productions. To the extent that automatic productions are not fully developed, controlled processing resources would be necessary to perform the task. However the use of controlled processing resources is also important in the performance of skilled behavior. There are clear limitations to what types of processing activities can be performed by automatic productions. Through the complementary interaction of automatic and controlled processing many of these limitations can be greatly reduced. In situations where automatic productions are fully developed, controlled processing can perform three functions which can not be accomplished through automatic processing.

<u>The first function of controlled processing is the maintenance of strategy information in short-term store to enable sets of automatic productions.</u> Skilled performers exhibit a great deal of flexibility. A performer can rapidly change strategies that substantially alter performance. This presents a theoretical problem because the productions are quite fixed and even exhibit negative transfer effects (see above). The subject cannot change the

productions quickly, but can rapidly change the enabling conditions. For example, in a tennis game, a player may switch from trying to tire an opponent to forcing the opponent to the rear of the court. Such a strategy shift would be presumed to change the contents of short-term store, and thus enable or tune different classes of automatic productions. In the same sense that external stimulus conditions, such as the speed of the ball, should determine how the resulting production is executed. Internal conditions such as strategy nodes should also determine which productions are executed. Note we use the term short-term store to refer to activated nodes in memory including both verbal or non-verbal information (see Shiffrin & Schneider, 1977, p. 157; and Shiffrin, 1976).

In a number of search experiments we have attempted to train subjects to consciously switch strategies in order to perform two incompatible automatic searches (Schneider & Fisk, Note 5). Subjects searched a sequence of twelve frames containing four characters presented every 90 msec. Subjects either searched for digit targets in displays containing letter distractors [D(L)], or letter targets with digit distractors [L(D)]. After 3500 trials of digit and letter search training, subjects searched 4500 trials in which the D(L) and L(D) conditions alternated. The alternation condition was a varied mapping condition (at the trial level) and hence, would be expected to show little improvement with practice. Figure 9 shows the data for one subject. Detection improved substantially during the training period when searching for a consistently mapped set [L(D)]. In the alternating search conditions the L(D) performance dropped slightly. The D(L) search started low but improved steadily until nearly reaching the L(D) level. Here we have a case where a subject appeared to be able to exhibit automatic process performance in conditions where the mapping was inconsistent across trials. However the mapping was consistent for all the trials for a given strategy. Hence, if its strategy provided a salient internal context, an automatic production for searching for digits in the D(L) context and searching for letters in the L(D) context could develop. By switching the contents of short-term memory (e.g., maintain "digit search" on one trial and "letter search" on another) the two antagonistic automatic processes could alternately be enabled across trials. It should be noted that the three other subjects' alternation data did not converge on the previous L(D) level (Schneider & Fisk, Note 5). Although further research is needed, these results and other context results (Schneider & Fisk, Note 5) suggest that subjects can develop automatic productions which are enabled by the contents of short-term memory.

Insert Figure 9 about here

The activities of a baseball batter provide an illustration of enabling a motor sequence. If the batter's strategy is to hit the ball into deep center field, he maintains the strategy information (e.g., "deep center") in short-term store. When the ball is thrown, productions which are enabled by "deep center" and the stimulus characteristics of the incoming ball are executed. Note, there would be a range of pitches which would result in different motor output patterns that place the ball in a similar location. Given the time constraints between when the pitch is evaluated and when the ball is hit, the decision of when and how to hit the ball must be done by the fast, parallel, automatic processing. The batter's strategy behavior is flexible because the contents of short-term memory can be altered in a fraction of a second. However, in order to be effective at the different strategies, the batter must have consistently practiced hitting a wide variety of pitches to appropriate locations while maintaining the strategy information in short-term store.

Through the interaction of a very slow but flexible controlled processing with a very fast but inflexible automatic processing, fast flexible performance is possible in situations where the performer has practiced the behaviors many times and has sufficient controlled processing capacity. Should controlled processing resources be consumed by a secondary task (see above) subjects may still be able to perform the task but their flexibility might be markedly reduced.

A second function of controlled processing in skilled performance is the maintenance of time varying information in short-term store. Automatic processing may activate information in short-term memory, but, without additional controlled processing, that information will decay in several seconds (see Schneider, Dumais, & Shiffrin, in press). In sports, for example, the player may have to maintain information not currently available to the sensory system such as the positions of key players who are not visible. Automatic processes may determine what information is encoded and in what form, but controlled processing resources must be used to maintain that information.

One aspect of the development of skill is the ability to chunk complex information so it can be maintained in a limited capacity short-term memory. For example, in basketball if the player remembers the opponents are using a zone defense, the player has information on the approximate position of all the players while maintaining only one chunk in short-term memory. The maintenance of this information in memory can then enable appropriate sets of automatic productions.

A third function of controlled processing is skilled behavior in problem solving and strategy planning. Problem solving is an extensive area of psychology which cannot be covered in any detail here. We wish only to make three points. First, the skilled performer must solve problems such as "what is the strategy of my opponent and what is my best counter strategy?" Second, that such problem solving requires extensive controlled processing resources. Certain performance situations are often novel and hence, are unlikely to evoke automatic productions. And third, that effective strategic planning occurs either when not engaged in the task (e.g., between plays in football), or when the task can be performed almost entirely by automatic productions alone.

Relation to Theories of Motor Skill

The automatic/controlled processing approach, although derived from the attention literature, incorporates many of the concepts of theories of motor skill learning. The concept that with practice there is a switch in the form of processing (i.e., from controlled to automatic) is a theme apparent in the proposed shifts from a "conscious" to "automatic" stage (James, 1890); a closed loop to open loop stage (Pew, 1966); a verbal motor to motor stage (Adams, 1971); and initial learning to motor program stage (Keele, 1973). The

importance of consistent execution was emphasized by James (1890) and more recently by Pew (1974a). The concept that as skill develops attention is allocated at more abstract levels of processing and provides enabling conditions has been suggested by Pew (1966; 1974b). The importance of modularity in motor systems is emphasized by Turvey (1977). The reduction of attention with extended practice at motor acts has been commented upon by Bahrick and Shelley (1958), Keele (1973), and Pew (1966, 1974b). The concept that presenting variable instances increases generalizability of the skill is central to schema interpretations of motor skill development (Schmidt, 1975). Adams (1971) emphasizes that knowledge of results promotes problem solving to produce consistent execution. Welford (1976) suggests that guided training procedures which result in early consistent correct performance speed motor learning. From the automatic/controlled processing view, it is the consistent executions that produce new automatic productions that are necessary for skilled performance.

We feel the present approach differs from preceding approaches in the degree of specification, limitations, and interactions of the two processes. Automatic processes perform well learned consistent behaviors. Controlled processes develop automatic processes, maintain enabling conditions, maintain critical time decaying information, and are used in problem solving. Automatic processes are fast but difficult to change and require extended consistent practice to develop. Controlled processes are flexible but slow, severely capacity limited, and serial. Through the interaction of the two processes human performance can be both flexible and very fast. The flexibility is produced by changing enabling conditions that are maintained by controlled processing. The speed is produced through the execution of previously developed automatic productions.

The automatic/controlled approach emphasizes different issues for future research. It emphasizes the importance of consistency of performance in skill development. It phrases transfer issues in terms of modularity and consistency at a level of a processing heterarchy. It suggests that more research emphasis should be given to performance after extended training (e.g., past 200 practice trials). It emphasizes that extended training makes automatic productions nearly resource free and those resources can be used to perform new functions. It suggests that learners must be taught to "let go" of component processes to reserve resources for strategy control. It proposes that different stimuli can be processed in parallel in different stages. It interprets flexibility of skilled performers as being accomplished through changing the contents of short-term memory to enable and tune sets of automatic productions. It specifies that the major limitations of human information processing capabilities will be determined by the amount of information processing that must be done by controlled processing (e.g., maintenance of variably mapped time decaying information).

The automatic/controlled processing approach has evolved from the attention research and suggests new research paradigms for motor learning. First and foremost is the examination of extended practice effects. In the attention literature there were serious conflicts over a decade before researchers appreciated the importance of consistent practice effects (see Schneider & Shiffr[illegible] [illegible]roach suggests emphasis on attentional issues. For examp[illegible] and performance influenced by a reduction in contr[illegible] ng [illegible]sources? How much is the flexibility of skilled

Footnotes

This research was supported in part by funds from the Office of Naval Research Personnel and Training contract N0000-14-81-K-0034(NR 150-460) and NIMH grant 5 R01 MH 31425-04.

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performance dependent on the availability of controlled processing resources? When training a multiple level skill, what is the effect of shifting attention from the sequential response level to a higher representation level of the output (see below)?

Summary and an Illustration

As skill develops the qualitative nature of performance changes dramatically. We have described data showing large quantitative and qualitative differences as a function of practice in consistent perceptual and motor paradigms.

An illustration of the changes that occur is provided by a brief description of learning to play the piano. At the novice level performance is very slow, serial, and capacity limited. The learner must concentrate on how to move the fingers and position the hand to play a chord. He must translate every note pattern from the musical page into finger and hand requirements. Controlled processing resources are consumed in placing the fingers in the proper position. Guidance, feedback, and knowledge of results are useful in getting the performer to execute each note efficiently and consistently. The learner must allocate attention to the motor task. Timing is choppy at best. As tens of hours of practice pass, automatic productions for particular note patterns develop. The learner builds up a vocabulary of playable notes consistently repeating each note in a given phrase thousands of times. This vocabulary has two aspects: (1) notes recognized on the musical page and (2) those same notes played by the hands.

As the automatic productions develop the performer can speed the responses, incorporate more complicated rhythm information, and begin to have sufficient capacity available to attend to patterns of notes. Musical arrangements organize themselves into familiar scales and chords. After hundreds of hours of practice, the automatic productions develop for executing phrases or entire sections in music.

A critical distinction at this point is whether the performer "lets go" of concentrating on the sequences of notes and attends to the intepretation of the music. If the performer does not "let go" the performances may be judged as technically correct but lacking the feeling the composer intended.

With thousands of hours of practice the performer learns to play many *pieces; and, if properly trained, he/she expresses the proper interpretation.* The performer must practice with awareness of the emotional quality of the pieces so that the playing expresses the proper mood. At this stage, the performer can perform well learned pieces with technical accuracy while engaging in a high workload secondary task (e.g., shadowing, as in Allport, Antonis, & Reynolds, 1972). However, most of the emotional content is lost in performance under high secondary workload.

After ten-thousand hours of practice the now expert performer's use of controlled and automatic processing shows little resemblance to the novice level. The expert giving a concert performance never considers the placement of fingers for a chord. The expert attends to aspects of the piece being played

such as form, dynamics, tempo and the movement of the music. *Much of the* controlled processing resources are utilized in communicating the emotion of the piece. The controlled process maintained information enables automatic productions which also incorporate timing and sensory feedback to execute the movements with proper precision and feel. In addition, controlled processing resources might be used for assessing audience reaction and problem solving activities such as how to adjust the playing to deal with the acoustics of the concert hall.

The mechanisms we have described provide an interpretation for the qualitative changes that occur with practice. The proposed mechanisms are well supported by attentional research examining practice effects particularly in perceptual paradigms. A great deal of theoretical and empirical work must be done before we can quantitatively specify the nature of skill development. We feel that the development of skilled performance and the role of attention are ultimately related topics. Major advances in either area will likely relate to central concepts in the other. We are hopeful that a merging of current attention theory and skill development research will provide significant advances in the coming decade.

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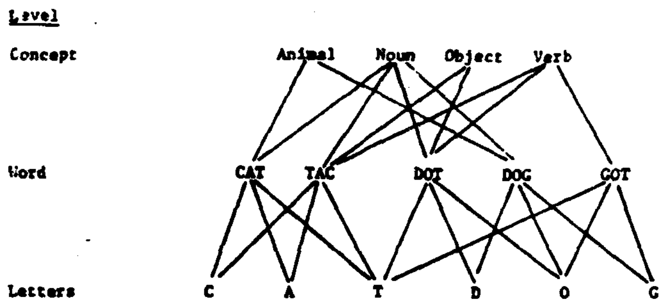

Figure 1. Example of a perceptual heterarchy. Note each element may connect to multiple elements at the next higher level.

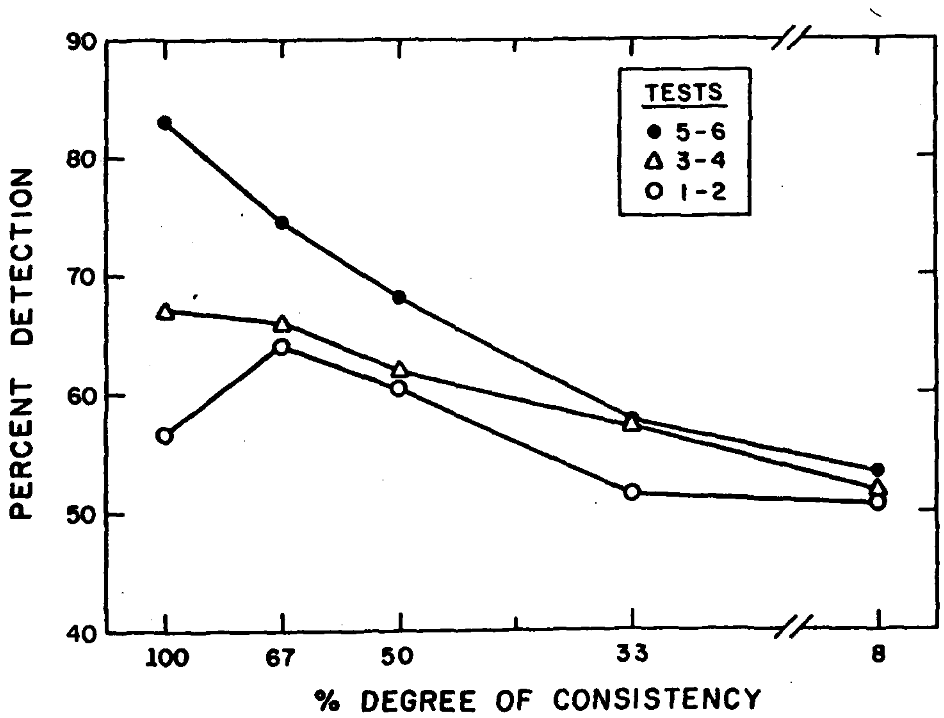

Figure 2. Detection accuracy as a function of degree of consistency (from Schneider & Fisk, 1982).

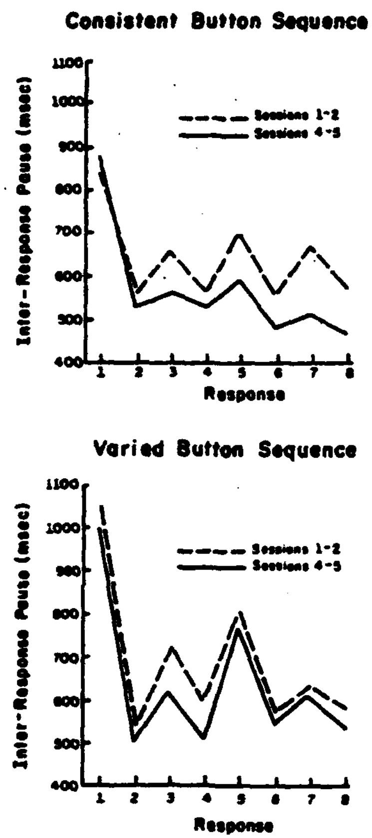

Figure 4. Interresponse times during repetitions 1 - 20 (sessions 1 - 2) and repetitions 40 - 50 (sessions 4 - 5) of outputting eight button sequences. The top sequence illustrates performance when the subject has a new eight button sequence (varied mapping) on each trial. The bottom sequence illustrates performance when the same sequence is repeated (consistent mapping).

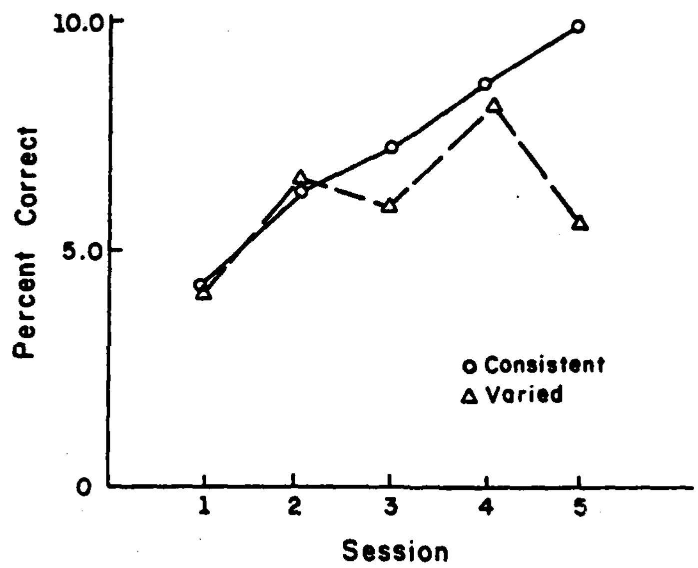

Figure 3. Response accuracy of pushing an eight button sequence as a function of practice.

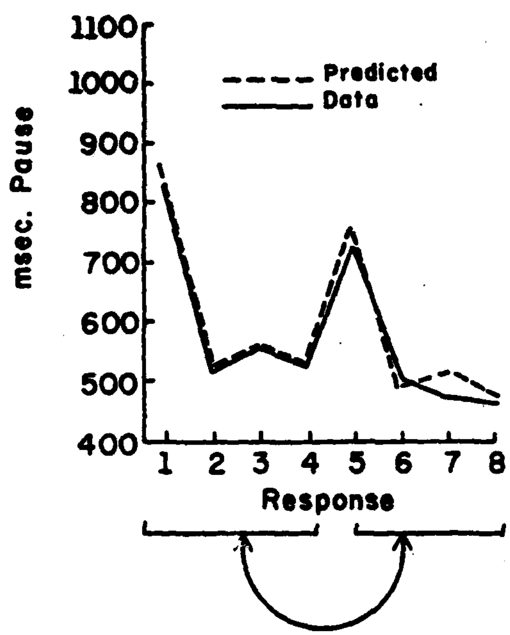

Figure 5. Pauses when the list was composed of two consistent sets of four elements but which set of four was first varied from trial to trial. The dashed lines represented predicted pauses based on Figure 4 data. The predicted data for responses 1, 2, 3, 6, 7, and 8 are from the consistent sequence and response 5 from the varied sequence of Figure 4.

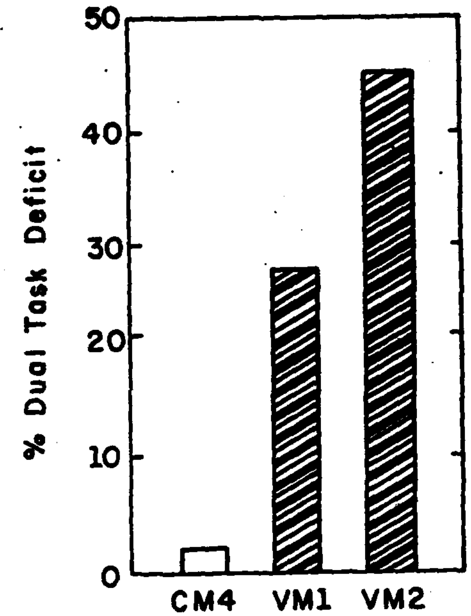

Figure 6. Category search performance deficit resulting from subjects performing a concurrent digit span task.

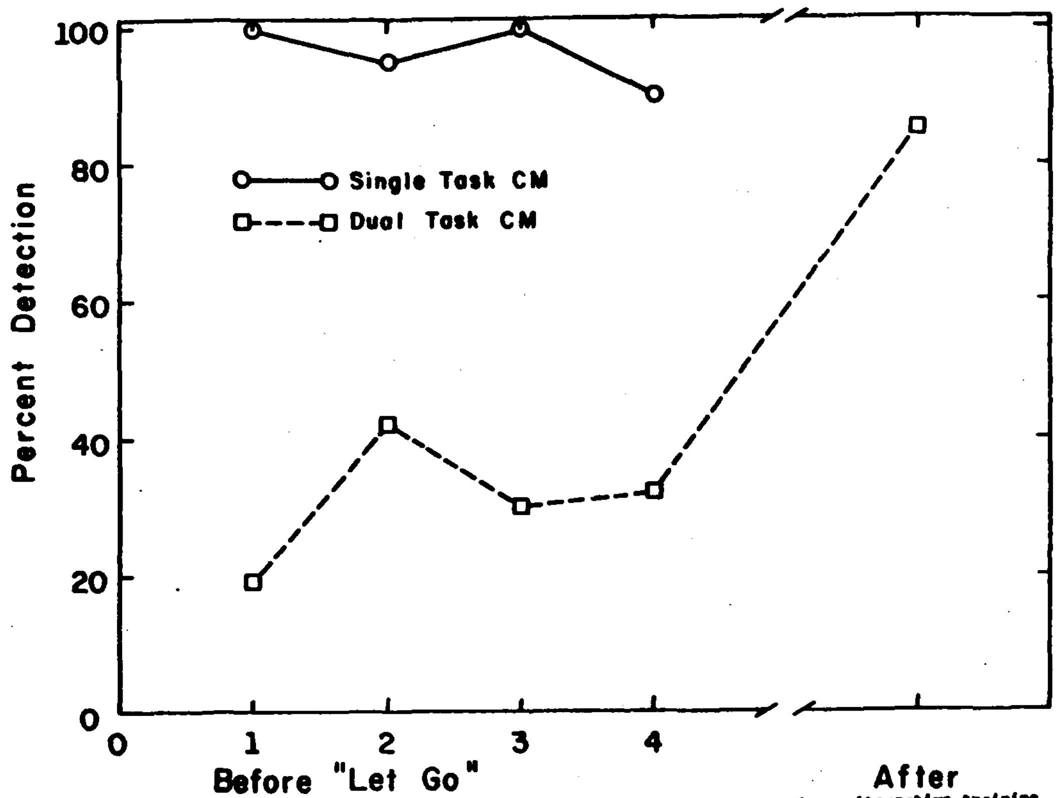

Figure 7. Subjects' CM word detection accuracy. After session 4 subjects were given alternative training to facilitate "letting go" of the automatic process.

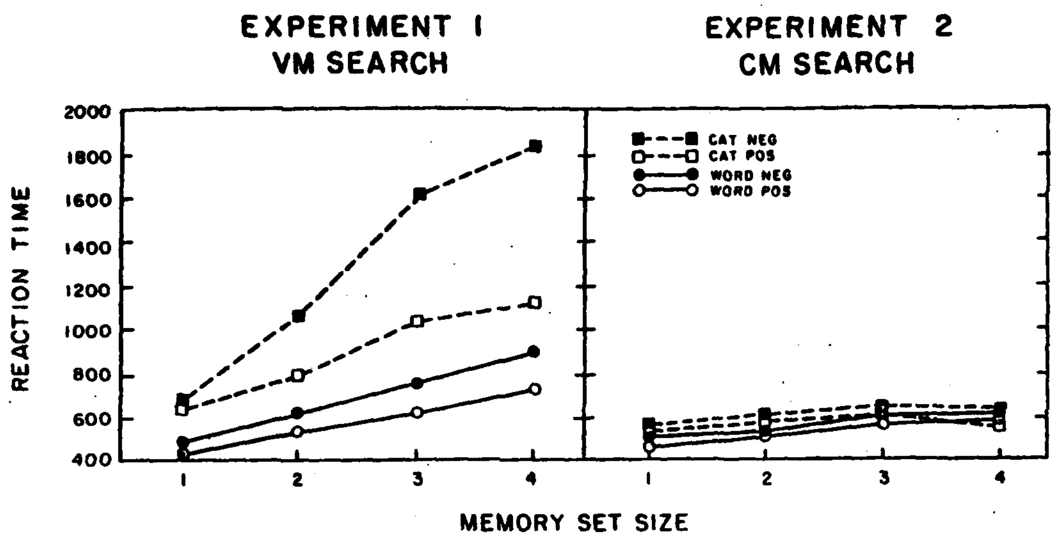

Figure 8. Reaction time as a function of the number of memory items to compare in VM and CM conditions for both category search and word search.

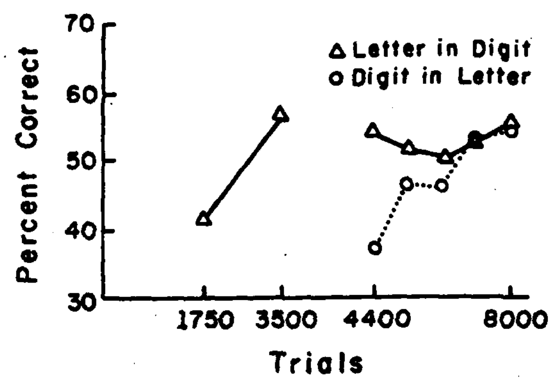

Figure 9. Developing antagonistic automatic productions which are enabled by the contents of short-term memory.

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