The Development of Skill: The Coefficient of Variation as an Index of Skill Acquisition

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ABSTRACT

The Development of Skill: the Coefficient of Variation as an Index of Skill Acquisition

Vivien Watson

Previous research has found that extensive practice usually leads to faster more stable reaction times (RTs). The goal of this study was to distinguish practice effects which are due to a speed-up (where reduced RTs and correspondingly reduced variability in RT indicate that the task is being performed faster but in the same way), from practice effects due to increased automaticity (where faster RTs and reduced RT variability indicate a restructuring of task components). Subjects performed a memory search task in which 2000 trials were in a consistent mapping (CM) condition and 2000 were in a varied mapping (VM) condition. VM training has been shown to improve speed of performance but not to increase automatization. CM training on the other hand has been shown to improve performance, beyond considerations of speed alone, by automatizing performance. In the present study it was found that the coefficient of variation ((CV) the standard deviation divided by mean RT) was significantly reduced after CM but not after VM practice, showing that the CV may be a useful index of changes, other than speed, in the organization and execution of processes underlying a skilled action. The results were interpreted in terms of how practice contributes to the acquisition of performance skill.

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STATEMENT OF THE PROBLEM

There has been a great deal of interest recently in identifying the changes in information processing that accompany the acquisition of a cognitive skill (Balota, Black & Cheney, 1992; Laberge & Samuels, 1974; Logan, 1988; Neely, 1977; Posner & Snyder, 1975; Schneider & Shiffrin, 1977). One way in which the transition from unskilled to skilled performance has been described is by the distinction between "controlled" and "automatic" performance. Slow, effortful and variable performance before practice has been characterized as "controlled". Fast, effortless and stable performance after practice has been characterized as being "automatic". For example, when we first learn to drive a car, we must adjust our speed by constantly monitoring the pressure of our foot on the gas pedal, or when rounding a curve in the road, we must decide when and how much to turn the wheel. However, after practice, we no longer have to monitor our performance so closely, driving becomes much easier and we may even be able to carry on a conversation at the same time.

However, this distinction between automatic and controlled performance is not as straightforward as would appear from early studies in this area. The development of skill is thought to involve the integration and coordination of a number of component processes, automatic and controlled

(Laberge & Samuels, 1974; Logan, 1985). Thus task performance which is highly skilled need not be considered as due entirely to automatization of its component processes, and to the elimination of controlled processes. Both kinds of processes are required for any skilled performance, and especially for complex skills such as driving, athletic performance, musical performance and reading. Thus, performance of the highly skilled individual can be seen as having a greater number, but not all, of its underlying component processes as automatized as compared to the performance of the novice. Similarly, the performance of the novice can be seen as having a greater number, but not all, of its underlying component processes as requiring control mechanisms to guide their execution as compared to expert performance.

A central topic of interest in this area is how to describe this change from predominantly "controlled" processing to predominantly "automatic" processing. A few researchers have suggested that the change from slow, effortful, controlled processing before practice to fast, effortless automatic processing, after practice is a general facilitatory change in that the processes are being carried out faster but in essentially the same way (Anderson, 1982) (a quantitative change). Others have described this transition as a qualitative change which indicates a change in the underlying structure of the component processes involved in performing a task (Logan, 1988; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Thus components contributing to performance may be organized differently so that old, less efficient processes are replaced by new more efficient processes or controlled, decision-making processes may drop out (Cheng, 1985; Segalowitz & Segalowitz, 1993).

A major interest in this area concerns how to assess or measure the qualitative change associated with increased automaticity (Bargh, 1989; Cheng, 1985; Logan, 1985). In the past, this has been done by measuring response latency or error scores. For example, Schneider & Shiffrin (1977) found that responses to stimuli practiced in a consistent manner led to significantly faster response times and lower error scores in a visual matching task. In fact, it was found that response times were almost equivalent regardless of the number of items to be processed. From this they concluded that a qualitative change in performance had occurred, a transition from controlled to automatic processing. Response latency and error scores have been further used as an indication of whether certain qualities of automaticity are present. The distinction between automatic and controlled processes has traditionally been described in the following way. Controlled processes have been defined as those that are slow, effortful, limited by available processing resources and under the intentional or strategic control of the individual. Controlled processes have also been characterized as being conscious (Posner & Snyder, 1975). On the other hand, automatic processes were initially defined as those that are fast, effortless (not limited by general processing resources), occurring without intention and without any awareness of the initiation or operation of the process.

These definitions of controlled and automatic processes have been subjected to a fair amount of criticism. In general, questions have arisen as to whether the "package" of properties described above - e.g. fast, effortless - necessarily always co-occur, as assumed by these traditional definitions. While it has been widely accepted that response times are faster and less variable for automatic than for controlled performance, these are probably the only properties of automatic performance which have not been called into question.

One idea that has been challenged is whether automaticity, when characterized by unintentional responses, is necessarily also effortless requiring no resources. An example of such a challenge comes from the dual task literature. In a dual task design, subjects are asked to perform two tasks simultaneously. It has been assumed that if a primary task can be carried out without interfering with the secondary (resource consuming) task, then the primary task is not using resources and is therefore automatic. Posner and Boies (1971) used this type of dual task technique to investigate the processing demands of two tasks performed concurrently. The primary task was a letter encoding task and the secondary task was the simple detection of white noise. They found that performance on noise detection appeared to be free of interference when the subject was reading and identifying a letter, and thus it was concluded that letter recognition did not require processing capacity and is therefore automatic.

However, Paap and Ogden (1981) also used the concurrent task paradigm to study capacity limitations and intentionality. They used similar concurrent tasks to the ones used by Posner and Boies (1971), but their task used baseline measures different from Posner and Boies. Whereas Posner and Boies used as a baseline measure, the detection of white noise during the intertrial interval (ITI), Paap and Ogden used as a baseline the detection of white noise during trials when no letter was presented. Thus the subjects' overall level of alertness remained the same in both conditions. Also Posner and Boies manipulated subjects' expectancies. On some trials the first letter presented was not predictive of the second, but on others it was predictive 90% of the time. Unlike

Posner and Boies (1971), Paap and Ogden found a decrement in performance on the secondary task in both the nonpredictive and predictive conditions indicating that the letter encoding task had interfered with performance on the detection of white noise. They concluded that while automatic performance can occur without intention (the subjects could not *choose* to read the target letter), it does not necessarily do so without using some of a limited pool of general resources.

Several authors (Navon & Gopher, 1979; Wickens, 1984) have suggested that performance does not rely on a pool of general resources but that it depends on a number of different resources, each of which is limited in quantity. In other words, different tasks may depend on different resources. Thus dual-task interference will probably occur only when tasks share common resources. Therefore the interference a particular task produces will not be a characteristic of that task; it will depend, instead, on the type of task it is combined with. It has also been argued that skilled performers do not simply use fewer resources than novices, but rather they use different resources, suggesting that there is a change in the composition of processes underlying skilled performance (Logan, 1985).

In addition, it has been proposed that lack of awareness is not a necessary property of automaticity (Logan, 1990). Logan speculates that automatic performance based on declarative knowledge is open to awareness. An example of this would be a task in which subjects were required to retrieve information from memory and thus must be open to awareness of the memory underlying performance. In contrast, automatic performance based on procedural knowledge, as for example when riding a bicycle, does not rely on awareness of the memory trace. Thus the presence of awareness may or may not accompany automatic performance - it will depend again on the type of task and the experimental manipulation.

Also, considerable debate has developed over the question of whether tasks which are characterized as "automatic" actually occur without intention. According to Logan and Cowan (1984), most performance previously considered to be automatic such as typing, reading and driving is actually highly controlled and therefore intentional. In fact, every skilled performance includes some components that can be characterized as automatic well as those that can be characterized as controlled (Ackerman, 1987; Laberge & Samuels, 1974).

Jacoby (1991) recently developed a two-factor theory of task performance in which one factor relies on automatic processes and the other relies on intentional (controlled) processes. Thus, rather than designating overall task performance as being "automatic" or "controlled" Jacoby proposes that task performance is always a blend of automatic and intentional component processes and that the balance of component processes which contribute to performance will change from one task to another. He compared performance on a task in which automatic and intentional uses of memory act in concert, a facilitation paradigm, with performance on a task in which the two types of processes act in opposition, an interference paradigm. This created a situation in which it was possible to estimate the separate contributions of automatic and controlled processes to performance of a memory task and to investigate how the proportions of automatic and controlled components changed from task to task and from one situation to another. It was found that the proportion of automatic and controlled components which contribute to performance were to a great extent dependent on the type of task and situation.

Another technique which has been used to study the automatic/controlled distinction is that implemented by Neely (1977). Neely investigated how automatic and controlled processes contributed to performance in a lexical decision task (subjects were asked to decide whether a target letter string spelled a word or a nonword). Previous research has found that reaction times are faster if the target string is preceded by a semantically-related word prime (Meyer & Schvaneveldt, 1971; Schvaneveldt & Meyer, 1973). This is known as the semantic facilitation effect and automatic or controlled processes may be responsible for it. It has also been shown that subjects' expectancies can influence the magnitude of the semantic facilitation effect (Neely, 1977) and this is typically taken to indicate the presence of controlled attentional processes. Neely manipulated the pre-existing semantic relation between words, subjects' expectancies and the length of time between prime and target in order to distinguish between the impacts of automatic and controlled processes. He found that when there was a short interval between prime and target, the pre-existing *semantic relation* between words (but not subjects' expectancies) had a facilitatory effect on response time, which was taken to reflect the influence of automatic processes. However, when the interval between prime and target was long, it was found that subjects' *expectancies* (but not the semantic relation between words) had an effect on performance, reflecting the influence of controlled processes. Thus it was apparently possible to operationally distinguish between controlled and automatic processes (see also Favreau & Segalowitz, 1983; Burke, White & Diaz, 1987).

Balota, Black and Cheney (1992) explored these issues further using Neely's paradigm and found that there was an interaction between semantic-relatedness, subjects' expectancies and the length of time between prime and target. From this they concluded that in this type of task automatic and controlled processes were not independent of each other. Thus the important point to be taken from these studies is that the relative contribution of automatic and controlled components to performance of a task, can be a function of the type of task.

The challenges which have been raised regarding the issues of effortlessness, intentionality and awareness lead us to question the wisdom of designating performance as either automatic or controlled simply by referring to lists of properties or definitions. For example, as indicated earlier, task performance may have become relatively effortless, but may still occur with intention. Overall, speed of response, effortlessness, lack of intention and awareness do not necessarily co-vary in a manner that neatly separates automatic from controlled processing. This poses a challenge if, in our wish to devise experimental measures of the transition from unskilled to skilled performance, we investigate the transition from controlled to automatic processing. Thus the question of how to define automaticity would have to be answered.

An alternative exists. Each of the approaches described earlier focused on one or another characteristic thought to be important to the "automaticity" of skilled performance. While they obviously differ in the emphasis they place on a particular characteristic, they have in common the idea that the transition from unskilled to skilled performance involves something more than the speeding up of underlying processes. Rather, what seems to be involved is a qualitative change in the underlying processing that results in more stable, less vulnerable (to interference) as well as faster performance. Put another way, it could be said that *the qualitative change that takes place during the transition from unskilled to skilled performance involves a change in the blend of automatic and controlled subprocesses required to carry out the task.* Thus while skilled performance will continue to involve underlying subprocesses that could broadly be called "controlled" as well as "automatic", there will be a greater preponderance of fast, stable and less vulnerable underlying subprocesses than in the case of unskilled performance.

The question of devising experimental measures of the transition from unskilled to skilled performance that results from practice can now be cast differently. Instead of asking how to measure the transition from controlled to automatic processing one can ask how to measure the change *in the blend of controlled and automatic processes* that takes place as skill develops from practice. This thesis explores one way to answer this question in the context of memory search tasks.

MEMORY SEARCH TASKS

One of the tasks which has been used to study the development of automaticity after practice is the memory search task. Shiffrin and Schneider (1977) have conducted several studies employing memory search tasks to investigate their theory of automaticity. In their memory search tasks, subjects were presented first with a set of items to memorize (the memory set) followed by a second set of items (the display set). Subjects were then required to decide if any of the items presented in the display set matched any of the items in the memory set. For example, a set of items to be memorized might be presented (e.g., 1, 3) followed by the display set (e.g., A, J, 3, B). Subjects would be required to respond "YES" to this display set because one of the characters in the display set matched one of the items in the memory set. If none of the items in the display set matched any of the items in the memory set, the subject would be expected to respond "NO".

Schneider and Shiffrin used several variations of this task. First of all, the memory set size was varied from one to four. Secondly, the display set size was varied from one to four. Thirdly, in some studies only one display set followed the memory set, while in others, subjects were required to respond to a number of display sets after each memory set.

Many studies in memory search have found that an increase in memory set size results in an increase in reaction time. In fact, it has been found that reaction time increases linearly with increments in memory set size and display set size (please see Sternberg, 1975 for a review).

However, under special circumstances, practice at performing a task leads to changes in performance that merit being characterized as "automatization of responses". The kind of practice involved here has been operationally defined as "consistent mapping" practice and is contrasted to "varied mapping" practice. This distinction has become quite central to the literature on automaticity and will be elaborated upon below (Kramer & Strayer, 1990; Logan, 1991; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

As discussed above, Shiffrin and Schneider (1977) contrasted two types of memory search - consistent mapping and varied mapping. In the display set, the presented items can be referred to as distractors (items which are not part of the memory set for that trial) and targets (items which are part of the memory set for that trial). In consistent mapping, the items which are used to compose the memory sets throughout the course of the experiment are never used as distractors. For example, the set of potential targets could be 1, 3, 7, 9 and the set of potential distractors could be A, D, J, Z. The memory set items (and therefore also targets) would always be taken from the above set of digits. However, the letters (distractors) would never appear as memory set items and so could never appear as a target, but only as distractors. Thus the mapping of stimuli onto responses is consistent in that the same items require the same responses throughout practice. Items which serve as targets never serve as distractors or vice versa.

If subjects are given extended practice with consistent mapping, an increase in memory set size or display set size does not lead to a concomitant increase in response latency (Logan, 1978; Schneider & Shiffrin, 1977; Strayer & Kramer, 1990). In other words the reaction time remains almost the same whether there is one item in the memory set or four (or one item in the display set or four). Thus an increase in processing load does not result in a corresponding increase in reaction time. This result has been accepted as an indication of automatization (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Shiffrin and Schneider (1977) have proposed that a qualitative change in the way items are processed has taken place and that items which have been practiced in a consistent manner appear be processed in parallel, which results in lower reaction times. Thus, for positive responses, items appear to "pop out" of the display.

It has been assumed that at the beginning of consistent mapping practice, each item in the memory set is compared with each item in the display set in serial fashion, whereas after a great deal of consistent mapping practice, items become relatively well-learned in long-term memory and processing occurs in parallel. This leads to faster reaction times and to a reduction in response time variability (Ackerman, 1987).

In contrast to consistent mapping, the memory set and distractors in varied mapping are sampled from the same population of items, so that items that once were distractors can become targets and vice versa: The mapping of items onto responses varies. In other words, items which are targets on one trial could be distractors on the next trial. As an example, targets and distractors could be chosen from the letters A, D, F, J, M, P, Y, Z. There is no consistent mapping of memory set items to a specific set of targets. In the varied mapping condition the memory search task is serial in nature, that is each item in the memory set is compared with each item in the display set, one at a time, leading to relatively long reaction times (Shiffrin and Schneider, 1977). In other words, as the processing load increases, there is a corresponding increase in reaction time. In addition, performance shows greater response time variability (Ackerman, 1987). The fluctuation in reaction times could reflect whether the target is the first item to be compared or not. It could also reflect the fact that no "pop out" response has developed or that there is a predominance of variable, decision-making components contributing to performance. In their studies, Shiffrin and Schneider (1977) found that in varied mapping conditions the reaction time increased 20-40 ms. per memory set item. Extended practice did not result in the reduction in the effect of memory set or display set size which is seen with consistent mapping practice. Both reaction time and variability remained high after varied mapping practice and this is assumed to indicate controlled processing.

In summary, all memory search tasks are assumed to require controlled processing initially. Automaticity is expected to develop as a result of consistent mapping practice but not varied mapping practice. After practice with consistent mapping, both reaction time and RT variability drop and there is very little effect of memory set size or display set size. On the other hand, with varied mapping tasks reaction time and variability remain high and the effect of memory set and display set size remains relatively constant because controlled processing is always needed.

Thus consistent mapping memory search is one of the tasks which has been implemented to operationalize conditions which produce automatized, skilled performance after practice and which is expected to produce a qualitative change in the blend of subprocesses underlying performance. Before discussing how this task might be implemented to investigate measurement of this qualitative change, this thesis will first review several interpretations of the consistent mapping/varied mapping performance data.

MORE RECENT THEORIES

Memory-based Theories

Recent approaches to this issue interpret automaticity as a memory phenomenon (Logan, 1988; Schneider, 1985). The memory-based theory proposed by Schneider is a strength theory. At the beginning of practice the task is carried out in short-term memory but following consistent mapping practice, input-output relations are strengthened. Thus, accessing the memory trace is more rapid, accurate and reliable than using a computational algorithm in short-term memory. In contrast, because the input-output relations vary with varied mapping practice, the trace is so weak that the algorithm finishes prior to the direct memory access. Therefore subjects must rely on controlled processing (the algorithm) even after extended practice.

According to the instance theory, proposed by Logan (1988), the development of automaticity reflects a transition from a computational algorithm to reliance on direct memory access. Logan assumes that each encounter with a stimulus is encoded, stored and retrieved separately. This theory also postulates that performance is determined by the outcome of a race between the algorithm and direct memory access. Initially, the algorithm is more rapid and reliable and dominates performance. However, after extensive practice, direct memory access finishes prior to the algorithm and dominates performance. The direct memory access speeds up because the minimum retrieval time decreases as the number of instances in memory increases.

A common theme of memory-based theories is that performance is determined by a race between the algorithm, which computes the required answer in short-term memory, and direct memory access to a trace of the required answer that had been computed on a previous trial.

Restructuring Theories

As previously discussed, several researchers have suggested that performance on a task is actually made up of a number of controlled and automatic component processes (Jacoby, 1991; Logan, 1989). While both automatic and controlled components are thought to be involved at all levels of task performance, one or the other may predominate at different stages of practice. For example, although performance on a task may include both automatic and controlled component processes, skilled performance may include a larger proportion of automatic component processes than less skilled performance. Thus it is important to make the distinction between the idea that overall performance is either *automatic or controlled,* and the idea that *underlying unskilled performance there is a predominance of controlled component processes and that underlying skilled performance there is a predominance of automatic component processes.*

Several theories have suggested that practice leads to the reorganization or restructuring of the controlled and automatic task components which might underlie performance. Cheng (1985) proposed that the improvement in performance in consistent mapping memory search could be due to a restructuring of task components so that they are coordinated, integrated or reorganized into new perceptual, cognitive or motor units, thereby allowing the procedure involving the old components to be replaced by a more efficient procedure, involving the new components. She argued that the lack of effect of memory set size, taken as evidence of automaticity, could also be taken as support for her restructuring hypothesis.

Shallice (1982) proposes that automatic performance may be less subject to monitoring by higher level supervisory processes (controlled). At the beginning of practice performance is slow, effortful and is thought to consist of mostly controlled components. After consistent mapping practice, however, it is probable that a restructuring occurs causing most of the controlled supervisory components to drop out or be replaced by more automatic components.

Segalowitz & Segalowitz (1993) have detailed a hypothetical example of the changes in the contributions of various task components which may affect response latency and variability in the performance of a task. In their example, there are ten hypothetical components which could form a blend of mechanisms underlying some complex activity, such as word recognition. They assume that these components contribute additively to response time and variability. Five of the hypothetical processes are relatively fast-acting and stable, corresponding to more automatic processes. The remaining five components are relatively slow and variable, corresponding perhaps to controlled, effortful, decision-making components.

They distinguish between two different situations in which practice leads to improvement in performance. In the first situation there is no qualitative change in the manner in which the task is being carried out (only a quantitative change has occurred) and therefore, although the components may be processed faster, the number of components contributing to performance of the task would not change.

In the second situation, they propose that if practice leads to a qualitative change in the functioning of underlying processes, a restructuring may result in the elimination of some of the processes whose response latency and variability are relatively high.

Thus practice may improve skill by reducing reliance on the slower, less stable components, those most likely involving decision-making and supervisory functions. In other words, the improvement in performance will be due to a change in the number and relative variability of components contributing to the response latency and overall variability.

To summarize, a number of theories have been proposed to account for the transition from controlled to automatic performance. Some theories have proposed that a quantitative change occurs, suggesting that while processing is more efficient, there is no fundamental change in the way the task is being carried out. Others have suggested that a qualitative change occurs in that there is a transition from an algorithm (in short-term memory) to direct memory access (long-term memory). Others have suggested a change from serial processing to parallel processing resulting in the development of a "pop out response". It has also been proposed that there could be a restructuring of the components of a task or that the controlled supervisory components drop out leaving mostly automatic components.

CRITICISMS OF THE MEMORY SEARCH TASK

Lately the studies which have employed the memory-search task have received critical examination (Cheng, 1985; Logan, 1991; Ryan, 1983). Cheng (1985) argued that Shiffrin and Schneider's evidence was confounded by a category difference between targets and distractors, for example when targets were digits and distractors were letters. She states further that the lack of effect found for memory set size which has been cited as evidence for automaticity is in fact the result of a non-automatic strategy used by the subject. In some of their experiments, Schneider & Shiffrin (1977, Experiments 1 and 2) used digits as targets and letters as distractors. Thus, after very little practice, it would be quite possible for the subject to accept or reject an item in the display set without holding the memory set items in short-term memory at all. They would only have to remember that digits were always targets. In later experiments Shiffrin and Schneider (1977, Experiment 1 and 3) used only letters as targets and distractors, but it is still not clear what mechanism was responsible for the superior performance. For example, in Experiment 1, targets were chosen from the first nine consonants in the alphabet, and distractors from the last nine consonants in the alphabet. Thus subjects may have been able to categorize the letters and thus rely to a great extent on strategic processing. In Experiment 3 targets and distractors were chosen from a very small pool of letters (eight) and thus the task could possibly be performed without a transition to automatic processing. This will be discussed further below.

Logan and Stadler (1991) proposed that there are at least four distinct mechanisms that could produce the improvement in performance shown in consistent mapping tasks. All four predict that there would be no effect of memory set size although only one would involve a transition to automatic processing.

Process Improvement

The first mechanism suggested was a process improvement mechanism in which the task is performed in basically the same way from the beginning to the end of practice, only more efficiently (this appears to be consistent with previous theories of quantitative changes). The three other remaining mechanisms suggested by Logan and Stadler are process-switching mechanisms. For these three mechanisms the subject is performing the task in a different fashion.

Process Switching

The first process-switching of the three process-switching mechanisms involves item-based learning. It is thought that if subjects implement this mechanism they learn to associate particular items with particular responses and base performance on retrieved associations from long-term memory. The display set is initially compared with an explicit representation of the memory set in short-term memory, but after consistent mapping practice, items in the display set access responses or response categories directly from long-term memory. After extensive practice subjects may not even compare the display set with the memory set. This appears to be the mechanism suggested by Logan (1988) and Schneider (1985).

The second process-switching mechanism is the category comparison strategy. This is thought to be a conscious strategy and not an automatic process. Subjects learn a general category that distinguishes targets from distractors and then respond to items in the display set by assessing their category membership. For example, subjects could learn that digits are always targets and letters are always distractors. Thus they could respond to a display item on the basis of its membership in a particular category.

This is consistent with Cheng's (1985) view of category comparison. By using a category comparison strategy, subjects do not need to compare a display item to a memory set item. Therefore, performance is also independent of set size if this mechanism is used.

Logan and Stadler proposed a third process-switching mechanism called the superset strategy. This is also a conscious strategy. It involves learning the superset of possible targets from which memory sets are taken and then comparing the display set against the superset rather than the current memory set. The superset and not the current memory set is represented explicitly in short-term memory. As an example, the subject would learn the complete set of targets (e.g., 1,3,7,9) and remember this set in short-term memory. When the display set was presented, the subject would compare those items against the superset in short-term memory rather against the memory-set. Because the display set is compared to the same superset, regardless of the size of the memory set, there is no effect of memory set size.

Logan and Stadler Studies

Logan and Stadler (1991) performed several experiments, using the memory search task, to try to distinguish which of these four mechanisms is actually being implemented. In the first experiment, Logan tried to differentiate process-improvement from process-switching mechanisms by examining performance on catch trials after consistent mapping practice. Subjects were given 768 practice trials followed by a catch trial. On catch trials subjects were presented with a memory set and then with a display item which was a member of the positive superset (target set) but not a member of the current memory set. Logan reasoned that if subjects were performing the task in essentially the same manner, only more efficiently (process-improvement) they would respond "NO" on the catch trial. However, if they were using a process-switching mechanism and were no longer relying on rehearsal in short-term memory they would show a tendency either to make a false alarm on the catch trial or to respond significantly slower. It was found that subjects did show a tendency to make false alarms and to respond more slowly on catch trials, indicating that they had implemented a process switching mechanism.

Logan and Stadler's last three experiments tried to differentiate between the three process-switching mechanisms. In the first of these they tried to distinguish item-based learning from the category comparison and superset strategies. It was hypothesized that if item-based learning were the mechanism used, direct access to long-term memory should become stronger with practice and the tendency to make a false alarm on catch trials should increase accordingly. On the other hand, if either the general category or superset strategy were implemented, the transition to that strategy could be made relatively fast. In this case the tendency to make a false alarm would occur early in practice and would not increase at later stages in practice. Therefore the amount of practice was varied before catch trials. Catch trials were given on the 97th, 193rd, 385th and 769th trials. Only a consistent mapping condition and memory set sizes of one and three were tested. The display set size was always one. There were four words in the positive superset (possible targets) and forty-eight words in the negative superset (distractors). The results indicated that very little practice (96 trials) was needed to induce the tendency to make a false alarm. Extended practice produced a small but not significant increase in error rates and reaction times on the later catch trials. Although the slight practice effect could be taken as weak support for item-based learning, Logan and Stadler suggested that the small amount of practice needed to induce the tendency to make a false alarm indicates that the subject used the superset strategy or some kind of category comparison strategy.

However, at least two alternative explanations for this result can be suggested. First, the type of mechanism or strategy used in this experiment could have been induced by task requirements. Only four words were included in the positive superset. Thus, it is quite possible that the easiest strategy was either to use the superset strategy in short-term memory or some kind of category comparison strategy. In other words, the superset strategy may have been used because in this situation it was the easiest. Second, it is possible that because the set of targets was so small, item-based learning actually occurred very early in practice. As stated previously, only four words were used as the target set. Because an equal number of positive and negative trials were given (48) by the 96th trial, subjects had been asked to respond to each word in the target set approximately twelve times by the 96th trial (first catch trial). The distractors, on the other hand, would only have been viewed once. Thus it is quite possible that item-based learning would already have occurred by the 96th trial. This could also account for the tendency to make a false alarm on the catch trials early in practice. Some learning would occur later in practice creating the slight trend towards making false alarms. Therefore, although it is possible that item-based learning does occur in this type of task, this issue has yet to be resolved.

It would appear that further studies are necessary in order to decide what mechanism is being employed in consistent mapping memory search.

In fact, it is quite possible that different mechanisms are implemented depending on the different task requirements. Put another way, item-based learning could occur in some variations of the memory search task but some type of strategy could be implemented in other variations.

In summary, the use of the memory search task to measure the development of automaticity has incurred a great deal of controversy. Most of the debate has centered on the issue of memory set size and why decision time is independent of the number of targets in memory. It has been proposed that subjects may have learned the item in long-term memory or that they may actually be using some type of strategy, in which case it can be questioned whether we are dealing with automaticity at all.

This leads to the question of whether the memory search task is a viable tool for investigating the development of automaticity. As previously discussed, most of the controversy has involved the issue of what mechanism is being used to reduce reaction times when memory set size is varied and this problem has still to be resolved. However, it is possible to perform memory search experiments without relying on the effect (or lack of effect) of memory set size.

Many experiments have manipulated the number of items in the display set instead of, or in addition to, the number of items in the memory set. In other words, two different forms of search may be involved in many of these experiments (Flach, 1986). Flach found that even though there are similarities between memory and display search, these tasks appear to involve different processing mechanisms. In one, the set of items in memory is scanned and subjects may learn to associate targets with a positive response (memory search). He suggests that memory search is greatly affected by the ability to treat the memory set as a single equivalence class (where targets are treated as a single class of items). Thus memory search profits from an ability to integrate targets into a single equivalence class. However, in display search, a set of items presented concurrently in a visual display is scanned and targets appear be processed in parallel (to "pop out") after training. In contrast to memory search, he proposes that display search (leading to automaticity), may depend at least partly, on the ability to ignore or filter out distractors. This means that the characteristics which differentiate distractors from targets are used in tuning a cognitive filter. Thus display search profits from the ability to distinguish targets from distractors and to filter out distractors. With consistent mapping practice, performance on both types of scanning becomes independent of the number of items in memory or in the display.

Thus, although practice in both memory and display search leads to the development of increased automaticity, they appear to involve two different processing mechanisms. Therefore in studying the development of automaticity either memory set size or display set size can be manipulated. In the thesis experiment described later, a choice between memory set or display set size manipulation had to be made. Because of the controversy surrounding the manipulation of memory set size, it was decided for this thesis that it would be advantageous to manipulate display size to study the transition from unskilled to skilled performance.

What is also needed is a technique that will allow us to investigate whether, after extensive practice, a qualitative change has occurred, during the transition from unskilled to skilled performance, whatever that qualitative change may be. Because the nature of this qualitative change may differ with amount of practice and from task to task, it is important to find a measure that can be used for many different task situations.

RESPONSE LATENCY VARIABILITY

The main focus of this thesis is to explore one possibility for determining whether, after extensive practice, a qualitative change has occurred during the transition from unskilled to skilled performance and thus, to find a technique which will be useful for many different task situations. One possible approach to this problem is to study response latency variability. While it has been found that consistent mapping practice leads to the reduction of response latency variability, very little is known about this phenomenon in the context of automatic performance (but see Ackerman, 1987). As will be discussed below, however, changes in response latency variability with consistent mapping practice may prove to be a valuable index for the qualitative changes that occur during the transition to skilled performance.

Logan (1988) has discussed latency variability in terms of the power law of practice. According to the power law (Newell & Rosenbloom, 1981) learning obeys a simple quantitative rule. Newell and Rosenbloom suggest that the reduction in response latency (speed-up) follows a regular function which is characterized by a substantial drop in response time early in practice with smaller gains later in practice. The reduction of response latency (speed-up) is not a controversial property of automaticity and has been observed in most performance in which practice leads to improvement. This theory does account for the speed-up (reduction in response times) in processing that results from practice.

Response latency variability as assessed by the standard deviation, also shows a substantial reduction early in practice which tapers off later in practice. Based on this finding, instance theory (Logan, 1988) predicts that response time variability (as measured by the standard deviation) will decrease as a power function of practice. Logan suggests that the same factors that affect the reduction in the mean reaction time, affect the reduction in variability. He assumes, therefore, that the rate of learning is correlated for the reaction time and the standard deviation. Logan has found results to support this prediction in several practice experiments for tasks ranging from lexical decision to alphabet arithmetic (an alphabet counting task in which letters stand for numbers).

However, a reduced standard deviation, even one that correlates with reaction time, is not convincing evidence of a qualitative change in performance indicative of increased automatization of underlying processing subcomponents. This is because the standard deviation as a measure of response latency variability confounds variability with absolute reaction time (Segalowitz & Segalowitz, 1993). An overall reduction in response latency will almost always (for arithmetical reasons) be accompanied by a proportional reduction in response variability as assessed by the standard deviation and thus it is difficult to assess whether reduced variability is due to a reduction in relative variability (variability for a given level of response latency) or is merely a reflection of a general decrease in response time. A solution to this problem is to use the coefficient of variation (CV) which is the standard deviation/mean reaction time (SD/MRT) as a measure of the variability for a given level of response latency. The CV, as a measure of relative variability for a given response level, has been implemented in previous studies (McManus, Kemp & Grant, 1986; Weismer & Elbert, 1982). When a reduction in response latency is accompanied by a proportional reduction in variability as assessed by the SD, the CV necessarily remains constant over time. For example, if both the SD and the RT have been reduced by 50%, the CV will obviously not change. In contrast, when practice leads to a more than proportional drop in variability, the CV will drop as reaction time drops. For example if the RT drops by 50% and SD drops by 65% the CV will drop, indicating that a more than proportional drop in reaction time variability has occurred.

Segalowitz and Segalowitz (1993) have proposed how one can address the problem of how to distinguish practice effects resulting from a simple quantitative change (a general speed-up) from those which result in the development of increased automaticity and a qualitative change by examining the behaviour of the CV.

They have proposed a cognitive theory which relates changes in relative performance variability, as assessed by the CV, to the change from unskilled to skilled performance. As stated previously, a reduction in response latency accompanied by a proportional reduction in variability (as assessed by the SD) will cause the CV to remain relatively constant over time. They have proposed that such a proportional change indicates only a general speed-up effect in the underlying processes. This could indicate that although component processes may have become faster, they are essentially being carried out in the same way and no change in the organization of component processes (restructuring) has occurred.

In contrast, when practice leads to a more than proportional drop in reaction time variability, the CV will drop as reaction time is reduced, indicating that a qualitative change has taken place. They suggest that this qualitative change could take the form of a restructuring of task components. Therefore, instead of just speeding up task components, practice may result in processes being organized differently, or for inefficient, variable, decision-making processes to drop out or for more efficient processes to replace less efficient processes. In this case the blend of controlled and automatic processes underlying task performance will have shifted in the direction of greater influence from "automatic processes".

Segalowitz and Segalowitz investigated the ideas put forth in this theory in two recent experiments. The first was a simple reaction time task requiring only that the subject detect the onset of a visual stimulus. It was expected that for this task individual differences would be unlikely to involve differential use of effortful processes but would mainly involve a difference in speed of the underlying component processes. Thus for this task, the dropping out or restructuring of task components would be unlikely for any of the subjects. It was found that reaction time was reduced and that SD was also reduced in proportion to the reduction in reaction time, and consequently the CV did not change. It was proposed that for this task, there were only quantitative differences between subjects in their operation of the underlying performance mechanisms. Segalowitz and Segalowitz suggested that although it appeared that some subjects processed faster than others, they did not differ in their reliance on effortful processes.

The second experiment investigated the relationship of RT, SD and CV in a more complex task, where individual differences were expected to involve differential reliance on effortful processes. In other words it was expected that faster subjects would show lower relative variability, while slower subjects would show higher relative variability for a given level of response latency. Subjects performed an English language lexical decision task. The subjects were language students who varied widely in level of skill in their second language, English. During the task, some words were presented only once while others were repeated six times.

For words presented only once mean RT correlated significantly with both SD and CV, indicating that faster subjects showed less variability than slower subjects and that this difference reflected a more than proportional reduction in SD simply due to faster responding. To investigate this hypothesis further, skilled subjects were compared with less skilled subjects. It was found that CV and RT did not correlate for the slower performers, indicating that there were only quantitative differences between subjects and that individual differences did not reflect differential use of effortful processes. In other words, all subjects were relatively dependent on effortful processes. In contrast there was a correlation between CV and RT for the more skilled group indicating that within this group individual differences reflected differences in the blend of automatic and controlled processes. This could also indicate that a restructuring had occurred whereby faster subjects within this skilled group were less dependent on variable, effortful task components than slower subjects.

In the analysis of repeated words it was found for less skilled subjects, CV and RT did not correlate significantly for responses to first presentation of an item but did for the last presentation of repeated items (there were six repeats of each item). Again this would appear to indicate that for the less skilled subjects, practice (6 repetitions) with target items led to a restructuring of task components so that by the end they were less reliant on effortful, variable processes.

In summary, the results of Segalowitz and Segalowitz (1993) are consistent with the idea that the CV as a measure of the relative variability of response latency can be implemented as an index of the transition in the way skilled performance is carried out.

Given these findings, it is reasonable to ask whether the CV will behave as predicted with respect to skill development observed under consistent mapping and varied mapping practice. Ackerman (1986), as previously discussed, has shown that both response time and variability (as measured by the standard deviation) are reduced after consistent mapping practice. He also found that although response latency is reduced somewhat after varied mapping practice, variability (SD) is not. Although Ackerman did not calculate CVs for his experiment, it is possible to do so, after the fact, from the mean RT and SDs which he has reported. After consistent mapping practice, it was found that there was a 46% drop in RT, a 60% drop in SD and consequently a 26% drop in CV, indicating that there was a more than proportional drop in variability over time and that a qualitative change had occurred over time. In comparison, RT dropped 22%, SD dropped 4% and the CV actually increased by 33% in the varied condition. This indicates that only a small quantitative change had occurred. It also illustrates that once the problem of the correlation between variability and RT is eliminated, a very different picture may emerge.

The goal of this study was to try to distinguish between practice effects which are due to a simple quantitative change (in which the task is performed faster but in essentially the same way) from those which are due to a qualitative change (in which there has been a restructuring or reorganization of task components). This was attempted by implementing the CV as an index of performance skill. The present research used a modified version of Schneider and Shiffrin's memory search task. Subjects were presented with a memory set of two words and were required to decide as quickly as possible if any of the items in the memory set matched any of the items in the display set. If the target was present in the display, the subject responded "YES" (a positive response) and if the target was not present in the display, the subject responded "NO" (a negative response). Display set size was varied (two or four words) for the reasons discussed earlier. There were two training conditions: one in which subjects were given 2000 trials of consistent mapping practice (1000 trials each for display sizes two and four) and another in which subjects were given 2000 trials of varied mapping practice (also 1000 trials each for display sizes two and four).

Thus the present experiment tested the factors of type of training (consistent vs. varied mapping), display size (two vs. four), practice block (first vs. last) and response type (positive vs. negative).

A quantitative change after practice would be indicated by a reduction in reaction time which was not accompanied by a reduction in the CV, suggesting that only a proportional reduction in response time variability had taken place. A qualitative change would be indicated by a reduction in the reaction time which was accompanied by a reduction in the CV, suggesting that a more than proportional reduction in response time variability had occurred.

It was expected that before practice, variability would be high in both consistent and varied mapping tasks. This is because performance would require a blend of underlying components that included a relatively high proportion of slow, variable supervisory processes. After consistent mapping practice, however, the CV was expected to drop as RT dropped for both display sizes two and four. This is because there would have been a restructuring such that certain task components would have dropped out equally for both display sizes. However, the CV was not expected to drop in relation to the RT after varied mapping practice since performance, while perhaps faster than before, would still require the same blend of underlying components as was required when practice began. In other words, only a quantitative change would have occurred, and therefore no restructuring would have taken place.

METHOD

Subjects

Six females and two males between the ages of 22 and 36 participated in this experiment. They were all student volunteers who were enrolled in psychology courses at Concordia University. English was their first language. Each subject was right-handed and had normal or corrected-to-normal vision. Subjects participated in ten 1-hour sessions and were paid $50.00 for their participation. There were four additional subjects whose data were not included in this study. One of these dropped out because of medical reasons, the second was dyslexic, and the other two were excluded because their reaction time data did not follow the normal results for consistent mapping (CM) and varied mapping (VM) tasks. Thus interpretation of their CV data could not be expected to be meaningful.

Design

The experiment employed a 2 (CM vs. VM) x 2 (display size 2 vs. 4) x 2 (practice block 1 vs. 20) x 2 (positive vs. negative trials) design with all experimental factors being within-subjects factors. Each subject participated in 1000 trials each of CM2 (consistent, display size 2), CM4 (consistent, display size 4), VM2 (varied, display size 2) and VM4 (varied, display size 4) practice. Each set of 1000 trials was divided into 20 blocks of 50 trials. Subjects performed eight blocks of 50 trials in each session (one hour). Thus each set of 1000 trials (for example, all trials for CM2 practice) was completed in two and one-half sessions and the total of 4000 trials was completed in ten sessions. All conditions were counterbalanced so that no two sets of CM or VM training conditions occurred consecutively (for example, CM2 and CM4 training conditions would not occur consecutively). Order of presentation of conditions was also counterbalanced across subjects.

The probability of a target occurring in the display set was 0.5 and positive/negative trials were randomly varied between trials with the exception that no more than three trials of the same type of trial (positive or negative) occurred consecutively.

Apparatus

The experiment was controlled by an Apple IIe computer. The computer was programmed to present the appropriate stimuli, collect responses and control timing of the display presentation. Stimuli were displayed using a green monochrome monitor and using the standard character set of the computer (40 characters per line). Subjects made their responses by pressing one of two paddles connected to the computer. The subject pressed the right paddle if the response was "YES" and the left paddle if the response was "NO".

Stimuli

The stimuli were five letter words selected from nonoverlapping categories. Two lists were used with a total of eighteen words in each list. Thirty-two of the words were chosen from semantic category norms as collected by Favreau and Segalowitz (1980). The remaining four were chosen from other categories in order to complete the lists. Only one word in each list was chosen from each category.

Because all subjects participated in both CM and VM training, two stimulus lists were created, one for each kind of training. Four subjects were presented with words from List A for CM practice and words from List B for VM practice. The remaining four subjects were presented with words from List B for CM practice and List A for VM practice. The presentation of lists was counterbalanced across subjects and across conditions.

In the CM task the stimuli were divided into two separate sets of words for the memory set (possible targets) and the distractor set. In the CM procedure there is a consistent relationship between target and distractor words. Words used as targets never occurred as distractors and vice versa. In the consistent condition nine words were designated as targets and nine were distractors. Words chosen as targets for the first list were *wasps, steel, green, juice, theft, apple, heart, drill*, and *linen* and words chosen as distractors were *eagle, shirt, trout, tulip, table, chain, birch, train* and *floor*. The words chosen as targets for the second list were *tiger, canoe, nurse, radio, paper, beans, pearl, rifle* and *month* and as distractors were *dress, shark, house, daisy, couch, watch, maple, truck,* and *robin*.

In the varied condition the stimuli were not divided into two separate target/distractor sets. Here the nine words used as targets in the CM conditions were used as both targets and distractors in the VM conditions. The words used as distractors in the CM condition were not used at all in the VM condition. That is, only a total of nine words were used in the VM condition. This was to ensure that subjects responded the same number of times to targets in both the consistent mapping and the varied mapping conditions. Please see Appendix A for the list of targets and distractors.

The stimuli were randomized such that each target word was presented as a target approximately equally as often. Also, each word used as a distractor was presented approximately equally as often as a distractor. In addition the words were presented in a different random order for each of ten consecutive blocks. Then the random order presented for the first ten blocks would be repeated for the next ten blocks.

Procedure

Subjects performed a memory search task. Figure 1 presents a schematic representation of a typical trial. A trial began with the presentation of a fixation point (a cross) in the center of the screen for 1000 milliseconds (ms). The fixation point was immediately followed by the two items in the memory set which were presented in lowercase letters. The first item was positioned one line above the previously presented fixation point while the second was presented one line below the previously presented fixation point. The memory set remained on the screen for 1000 ms. A mask consisting of five ampersands (&&&&&) was then displayed for 1000 ms in the positions which had been previously occupied by the memory set items. The mask was immediately replaced by the display set. The display set was presented in uppercase letters to prevent subjects from performing the task by making a simple visual pattern match without actually reading the display words fully. For example, a display set of two consisted either of two distractors (a negative trial) or one distractor and one target (a positive trial). The display set remained until the subject responded or until 3072 ms had elapsed. A mask of "&&&&&" immediately followed the display set and was presented in the exact positions previously occupied by the display set for 1000 ms. The mask was followed by a 1000 ms delay and then the next trial began with the presentation of the fixation point.

For example, on a positive trial with a display set of four, the subject was first presented with a fixation cross in the center of the screen. This was immediately followed by the presentation of a memory set consisting of perhaps, the words "apple, drill". The subject then saw the mask followed by the display set which could have contained the words "APPLE, SHIRT, EAGLE, TRAIN". In this situation a subject would respond correctly by pushing the "YES" button because the target was present. Following this a mask again appeared and a new trial began. Subjects were allowed short breaks between each 50 trial block.

At the beginning of each session subjects were given general instructions about the nature of the task. A copy of the instructions given to subjects for display size four is presented in Appendix B. The words used as examples in the instructions were not shown at any further time in the experiment. These words were *stars, queen, globe, cloud, plate,* and *sheet*. Subjects were asked to respond as quickly and as accurately as possible. Incorrect

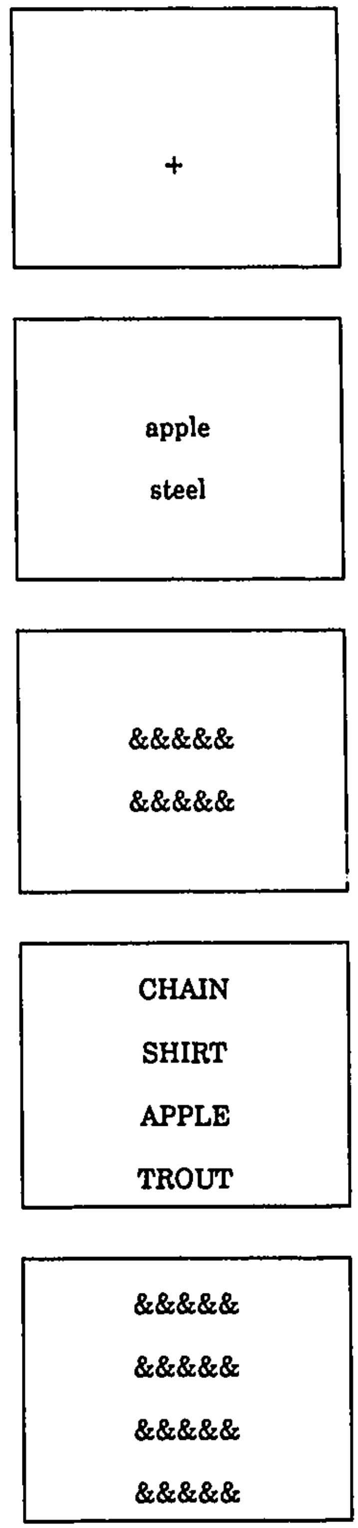

Figure 1. Schematic representation of the memory search task.

responses and those responses for which RT was longer than 3072 ms were signalled by a beep produced by the computer.

All subjects were given a practice session before starting the main experiment. This practice session consisted of 20 trials of varied mapping practice with a memory set size of two and a display size of two. The words presented in the practice session were not presented elsewhere in the experiment. These words were *child, brick, grass, paint, music, block, uncle, magic* and *ocean.*

RESULTS

The primary focus of this thesis was to investigate the transition from unskilled to skilled processing by examining the reduction in reaction time variability (as assessed by the CV) which should accompany the development of increased automaticity after consistent, but not varied, mapping practice. The purpose was to try to differentiate between a reduction in response time variability caused by a quantitative change (speed-up effects) from that caused by a qualitative change (transition to automatic processing).

Before we can interpret the results in relation to these questions, it is essential to know that the experimental conditions replicated standard effects in the memory search literature for mean reaction time (MRT) and the standard deviation of response times (SD) for CM and VM tasks. This is necessary to ensure that the CM task produced the requisite change from unskilled to skilled performance differently from the VM task. Thus the presentation of results is divided into three sections: The first deals with changes in mean reaction time and the second deals with changes in the standard deviation. The third deals with changes in the coefficient of variation (CV), the main focus of this thesis.

Mean reaction times (MRT), standard deviations and coefficients of variation were calculated for each subject in each type of training (consistent or varied mapping), display size (two or four), practice block (first or last) and response type (positive or negative). Each practice block consisted of 50 trials (25 positive and 25 negative). The MRT, mean standard deviation (MSD) and mean CV (MCV) data for correct positive and negative responses are presented in Table 1 and Table 2 respectively. In general, subjects maintained high levels of accuracy (approximately 96% correct) throughout practice. The percent error rates for List A and List B are presented in Appendix C.

A preliminary analysis of variance was performed which showed that there were no significant differences in performance as a result of the two different stimuli lists implemented in the study. Please refer to Appendix D for the ANOVA summary table. Overall MRT for subjects who were presented with List A for CM practice and List B for VM practice was 799 ms, while MRT for subjects who were presented with List B for CM practice and List A for VM practice was 731 ms, $F(1, 6) = 2.03$, $MSe = 71,733.48$ (no significant difference). Therefore, in subsequent analyses the data were collapsed across the two different lists.

Table 1.

Mean Reaction Times (MRT) (in Milliseconds), Mean Standard Deviations (MSD) and Mean Coefficients of Variation (MCV) for Correct Positive Responses as a Function of Type of Training, Practice Block and Display Size.

	MRT	MSD	MCV
	Consistent Mapping		
First Block			
Display Size 2	612	118	0.189
Display Size 4	775	258	0.329
Last Block			
Display Size 2	551	100	0.182
Display Size 4	603	160	0.262
	Varied Mapping		
First Block			
Display Size 2	633	162	0.255
Display Size 4	844	281	0.329
Last Block			
Display Size 2	626	139	0.222
Display Size 4	817	288	0.350

Table 2

Mean Reaction Time (MRT) (in Milliseconds), Mean Standard Deviations (MSD) and Mean Coefficients of Variation (MCV) for Correct Negative Responses as a Function of Type of Training, Practice Block and Display Size.

	MRT	MSD	MCV
	Consistent Mapping		
First Block			
Display Size 2	602	108	0.180
Display Size 4	1062	216	0.206
Last Block			
Display Size 2	600	114	0.188
Display Size 4	855	166	0.194
	Varied Mapping		
First Block			
Display Size 2	680	125	0.180
Display Size 4	1076	197	0.186
Last Block			
Display Size 2	714	166	0.232
Display Size 4	1192	208	0.178

Mean Reaction Times

The reaction time data were submitted to a four-way (2 x 2 x 2 x 2) repeated measures analysis of variance (ANOVA) in which the factors were TYPE OF TRAINING (consistent vs varied mapping), DISPLAY SIZE (two vs. four), PRACTICE BLOCK (first vs last practice block) and RESPONSE TYPE (positive vs negative response trials). Please see Appendix E for the ANOVA summary table. There was a significant main effect of TYPE OF TRAINING, where the MRT was 708 ms and 823 ms for CM and VM conditions respectively, $F (1, 7) = 32.94$, $MSe = 12{,}923.51$, $p < .001$. The main effect of DISPLAY SIZE was significant where the MRT was 627 ms for display size two and 903 ms for display size four, $F (1, 7) = 115.42$, $MSe = 21{,}104.98$, $p < .001$. Positive responses were found to be faster than negative responses with MRTs of 683 ms for positive responses and 848 ms for negative responses, $F (1, 7) = 97.76$, $MSe = 8{,}918.21$, $p < .001$.

The interaction between TYPE OF TRAINING, DISPLAY SIZE and PRACTICE BLOCK was significant, indicating a reduction in the effect of display set size after consistent mapping, but not after varied mapping practice, $F (1, 7) = 9.40$, $MSe = 7{,}588.51$, $p < .05$. There were also significant interactions of TYPE OF TRAINING and PRACTICE BLOCK, $F (1, 7) = 21.05$, $MSe = 7{,}423.48$, $p < .01$ and DISPLAY SIZE and

RESPONSE TYPE, $F(1, 7) = 86.72$, $MSe = 5{,}461.09$, $p < .001$.

The four-way interaction of TYPE OF TRAINING, DISPLAY SIZE, PRACTICE BLOCK and RESPONSE TYPE, was also significant indicating that the pattern obtained in the positive trials differed from that obtained on the negative trials, $F(1, 7) = 8.17$, $MSe = 2334.01$, $p < .05$. Please refer to Figure 2. A series of post hoc comparisons (Neuman-Keuls) were conducted in order to further identify the nature of this interaction. On positive trials, it was revealed that consistent mapping practice resulted in a significant decrease in MRT for display size four (from 775 ms to 603 ms) ($p < .01$) but varied mapping practice did not (from 844 ms to 817 ms). In addition, MRT was significantly less for display size two than for display size four (612 vs 775 ms) before practice in the consistent mapping condition ($p < .01$) but not after practice (603 vs 551 ms), indicating a reduction in the display set size effect after practice. However, a significant difference between display size two and display size four was revealed both before (633 vs 844 ms) and after practice (626 vs 817 ms) in the varied mapping condition ($p < .01$) suggesting no reduction in the display set size effect.

On negative trials it was found that after practice MRT decreased in the consistent condition for display size four (from 1062 to 855 ms) ($p < .01$) but

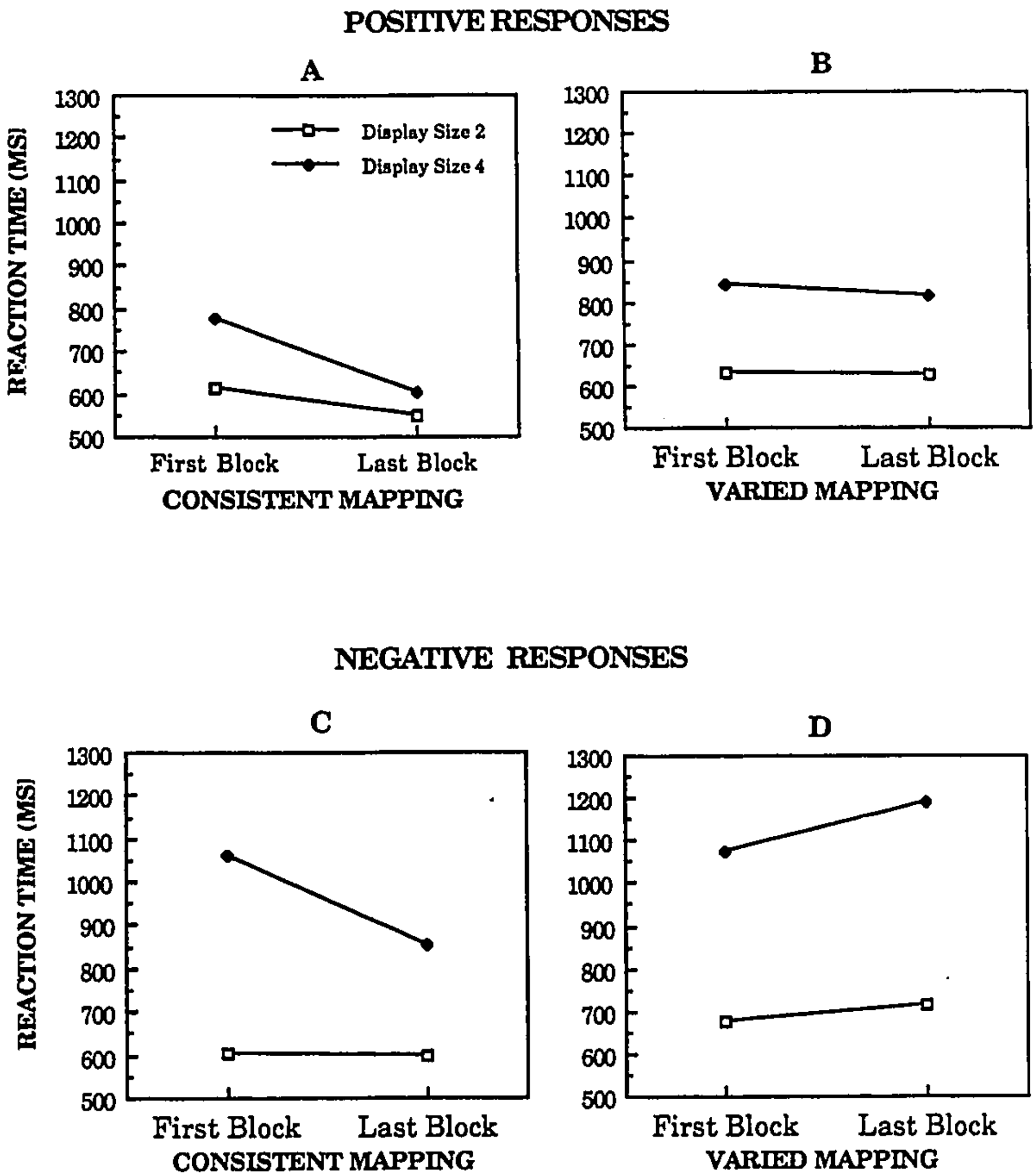

Figure 2. Mean Reaction Times (in Milliseconds) for Correct Responses as a Function of Type of Training, Practice Block, Display Size and Response Type. (Note that for Figure 2A there is a convergence of Display Sizes 2 and 4 after practice which is absent in Figure 2B. See text for further explanation).

not in the varied condition (actually increased from 1076 to 1192 ms).

In summary, the results from analysis of the reaction time data replicated many of the standard effects in the literature which are characteristic of the memory search task. In particular, the reduction in the display set size effect in consistent mapping conditions for positive responses is considered to be one of the hallmark predictions in the development of automatic processing, and indicates that after consistent mapping practice, an increase in processing load did not result in a significant increase in reaction time (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; Strayer & Kramer, 1991). This result also confirms the effectiveness of the CM/VM manipulation in promoting automaticity in the present experiment and thereby justifies deeper exploration of the data.

Standard deviations

The standard deviations of reaction time were also submitted to a four-way 2 x 2 x 2 x 2 repeated measures ANOVA in which the factors were again TYPE OF TRAINING, DISPLAY SIZE, PRACTICE BLOCK and RESPONSE TYPE. Please see Appendix F for the ANOVA summary table. Again there was a main effect of TYPE OF TRAINING where the mean standard deviation (MSD) was 155 ms for consistent practice and 196 ms.

for varied practice, $F(1, 7) = 17.91$, $MSe = 2{,}958.54$, $p < .01$. There was also a main effect of DISPLAY SIZE where the MSD for display sizes two and four was 129 and 222 ms respectively, $F(1, 7) = 76.36$, $MSe = 3{,}609.93$, $p < .001$. The main effect of RESPONSE TYPE was significant where the MSD for positive trials was 188 and 163 ms for negative trials, $F(1, 7) = 6.11$, $MSe = 3{,}446.76$, $p < .05$. The interaction between TYPE OF TRAINING, DISPLAY SIZE and PRACTICE BLOCK was significant, indicating that for both positive and negative responses, consistent mapping practice led to a decrease in the display set size effect but that there was no decrease in the display set size effect after varied mapping practice, $F(1, 7) = 9.64$, $MSe = 958.98$, $p < .05$. Please see Figure 3. The four-way interaction between TYPE OF TRAINING, DISPLAY SIZE, PRACTICE BLOCK AND RESPONSE TYPE was not significant, indicating no significant difference in the pattern of results for positive and negative responses.

Post hoc comparisons (Neuman-Keuls) were performed to further investigate the nature of the three-way interaction. It was revealed that there was a significant reduction in the mean standard deviation for display size four after consistent mapping (from 237 to 163 ms) ($p < .05$) but not varied mapping practice (239 to 248 ms) for both positive and negative

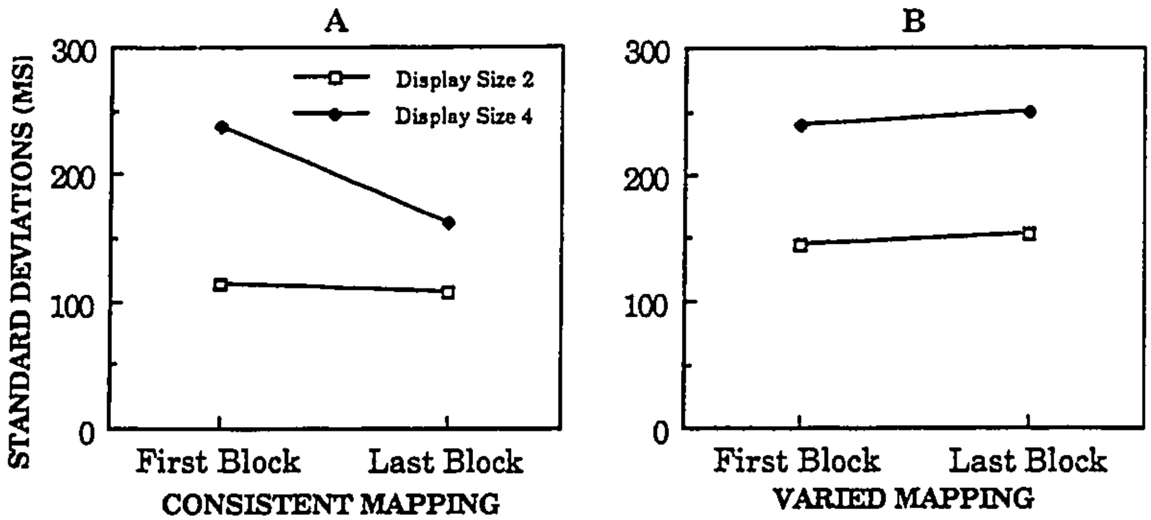

Figure 3. Mean Standard Deviations (in Milliseconds) for Correct Responses as a Function of Type of Training, Practice Block and Display Size. (Note that for Figure 3A there is a convergence of Display Sizes 2 and 4 after practice which is absent in Figure 3B. See text for further explanation).

responses. In addition, it was revealed that there was a significant difference between display sizes two and four ($p < .05$) before consistent mapping practice (113 vs 237 ms) and after consistent mapping practice (107 vs 163 ms). There were also significant differences between display set sizes two and four both before (144 vs 239 ms) and after varied mapping practice (153 vs 248 ms) ($p < .01$). However, the overall interaction was significant indicating a reduction in the display set size effect for consistent practice. In other words, while there was a reduction in the display set size effect after consistent mapping practice, there was no decrease in the display set size effect after varied mapping practice.

There were several other interactions which are subsumed under the interpretation of the three-way interaction examined above. Included are a significant interaction between TYPE OF TRAINING and PRACTICE BLOCK, $F(1, 7) = 7.77$, $MSe = 2471.05$, $p < .05$; DISPLAY SIZE and PRACTICE BLOCK, $F(1, 7) = 7.23$, $MSe = 1269.64$, $p < .05$; DISPLAY SIZE and RESPONSE TYPE, $F(1, 7) = 7.90$, $MSe = 2{,}362.41$, $p < .05$) and PRACTICE BLOCK and RESPONSE TYPE, $F(1, 7) = 9.19$, $MSe = 1{,}062.94$, $p < .05$.

In sum, the results from the analysis of the SD data are also in accordance with previous findings from the memory search literature. There was an overall reduction in RT variability for consistent mapping conditions but not for varied mapping conditions.

In general, the effects which are characteristic of the research in memory search have been replicated. Both reaction times and standard deviations were significantly reduced after consistent but not after varied mapping practice. However, as discussed earlier in the thesis, a reduction in the standard deviation is not by itself, necessarily convincing evidence that the decreased reaction time variability is associated with increased automaticity. The standard deviation could naturally decrease as the mean RT is decreased for simple mathematical reasons and may therefore merely reflect a proportional reduction in variability associated with a speed-up effect. Thus in order to differentiate between a proportional reduction in variability (due to speed-up effects) and a more than proportional reduction in variability (indicating a qualitative change associated with increased automaticity) analyses were performed on the CV data.

Coefficients of Variation (CV)

The CV data were submitted to a four-way (2 x 2 x 2 x 2) repeated measures ANOVA in which the factors were TYPE OF TRAINING, DISPLAY SIZE, PRACTICE BLOCK and RESPONSE TYPE. Please see Appendix G for the ANOVA summary table. There was a main effect of TYPE OF TRAINING indicating that the mean CV (MCV) was lower for consistent mapping practice (.216) than for varied mapping practice (.242), F (1, 7) = 7.21, MSe = .003, $p < .05$. There was also a main effect of DISPLAY SIZE, indicating that the MCV was lower for display size two than for display size four (.204 vs .254), F (1, 7) = 22.51, MSe = .004, $p < .01$ and RESPONSE TYPE indicating that the MCV was lower for negative responses than for positive responses (.193 vs .265), F (1, 7) = 30.55, MSe = .005, $p < .001$. The four-way interaction of TYPE OF TRAINING, DISPLAY SIZE, PRACTICE BLOCK and RESPONSE TYPE was also significant, F (1, 7) = 12.70, MSe = .001, $p < .01$. This was a complex but interpretable interaction. Please see Figure 4.

Post hoc comparisons for positive trials revealed that the MCV decreased for display size four from the first practice block (.329) to the last (.262) for consistent mapping practice ($p < .01$) but that there was no significant change after varied mapping practice (from .329 to .350). In fact, what change there was, represents a small but non-significant *increase* in the MCV after practice in the varied mapping condition for display size four.

Thus the most important result from these data was that *for positive responses, reaction time variability as assessed by the MCV decreased after*

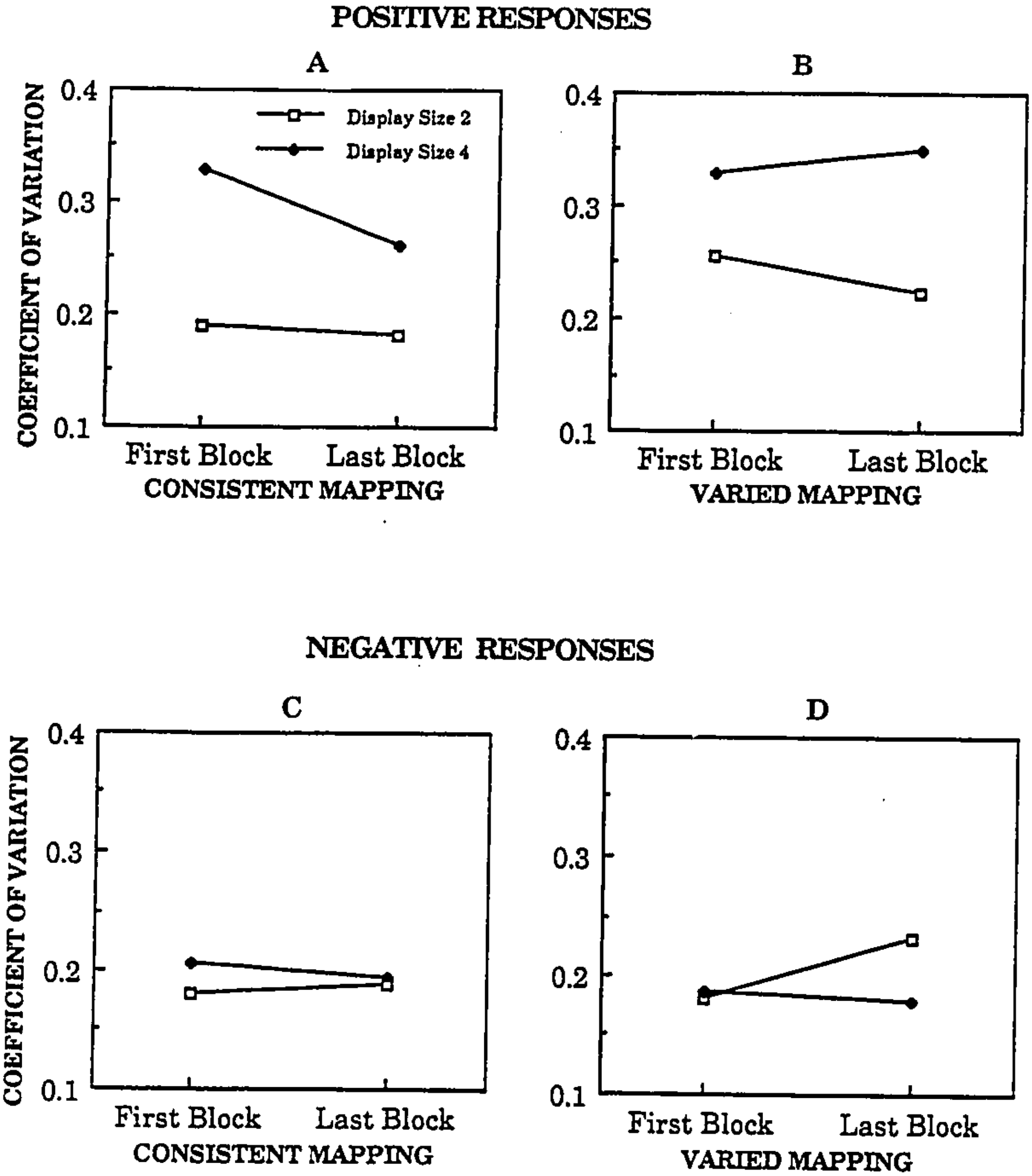

Figure 4. Mean Coefficients of Variation (MCV) for Correct Responses as a Function of Type of Training, Practice Block, Display Size and Response Type. (Note that for Figure 4A there is a reduction of the CV for Display Size 4 after practice which is absent in Figure 4B. See text for further explanation).

consistent mapping practice, indicating a more than proportional drop in variability while there was no corresponding decrease in the MCV after varied mapping practice.

The pattern of results which emerged from the analysis of negative responses indicated a different picture. Post hoc comparisons revealed no significant differences as a function of practice block, display size or type of training for consistent responses. The MCVs for the first block of consistent mapping practice were .180 and .206 for display sizes two and four respectively and .188 and .194 for the last block.

Post hoc comparisons for the CV data for negative responses in varied conditions suggested that here again there were no significant differences found, where the MCV for the first block of varied practice was .180 and .186 for display sizes two and four respectively. The MCV for the last block of varied practice was .232 and .178 for display sizes two and four respectively.

Subsumed under the four-way interaction were interactions of DISPLAY SIZE and RESPONSE TYPE, $F(1, 7) = 30.95$, $MSe = .003$, $p < .001$ and PRACTICE BLOCK and RESPONSE TYPE, $F(1, 7) = 5.36$, $MSe = .001$, $p = .054$).

Thus the most important result from these data was that *for negative* *responses the MCV did not change significantly after consistent nor after varied mapping practice.* In light of the previously reported analyses showing decreases in MRT and MSD, these results indicate that the changes in variability that did occur, were proportional to changes in MRT.

In summary, it was found that most standard effects in the memory search literature were replicated in the present experiment, indicating a drop in both reaction times and standard deviations after consistent mapping practice. More importantly, however, it was found that the MCV also dropped after consistent mapping practice for positive responses. This indicates a more than proportional drop in variability as a function of practice. In contrast, it was found that the MCV did not drop after varied mapping practice, indicating that changes were at most, only proportional to a drop in MRT.

The CV analysis of negative responses led to a very different conclusion from that reached in the SD analysis. While the SD data appeared to indicate that response time variability was significantly reduced for both positive and negative responses after consistent mapping practice, the CV analysis revealed that the reduction in response time variability for negative responses was not greater than that expected from a proportional decrease in response times. This has important implications as to the type of processes which are involved in negative responses.

DISCUSSION

The question addressed in this thesis was how to differentiate between practice effects which result from a qualitative change (a transition to more automatized processing) from those in which a simple quantitative change has taken place (where processes have simply become faster across the board). Following Segalowitz & Segalowitz (1993) it was hypothesized that the CV could be a useful index of the increase in automaticity achieved after practice. Segalowitz and Segalowitz found a pattern of CVs associated with a greater than proportional drop in variability compared to RT in a cognitively complex task (lexical decision in a second language) where a qualitative transition to automaticity was expected to occur. In contrast, they found a pattern of CVs associated with only a proportional drop in RT variability compared to RT in a cognitively simple task (detection of a stimulus onset) where no increase in automaticity was expected to occur. The present experiment was designed to further investigate the usefulness of the CV as an index of performance by examining performance before and after consistent and varied mapping practice in a memory search task.

The reaction time data in the present study replicated standard effects in the memory search literature: consistent practice produced a reduction in the display set size effect typical of consistent practice while varied practice did not. The analysis showed that the SD data also replicated the standard effects characteristic of the memory search literature, including the reduction in the display set size effect for consistent but not varied mapping practice. These results confirmed the effectiveness of the experimental manipulation. However, since the purpose of this research was to attempt to distinguish the qualitative changes inherent in the transition from controlled to automatic processing from those which merely indicate a quantitative change or speed-up effect, the main focus of the discussion below is the pattern of CVs obtained.

Positive Responses

The CV analysis provided strong support for the claim that the CV can be implemented as an index of automaticity. Of central importance to the present research was the finding that for positive responses, the CV decreased after consistent mapping practice, indicating a more than proportional drop in variability in relation to RT. This leads to the conclusion that the reduction in reaction time variability for consistent responses is not simply a reflection of decreased response time but suggests that there has been a qualitative change in processing. As discussed earlier, the reduction in the display size effect could indicate a restructuring or reorganization of task components in the sense that some of the controlled, effortful, decision-making task components which contribute to the greatest variability in performance have been eliminated.

These results are in accordance with the calculations which were performed on the data obtained from the study by Ackerman (1986). As mentioned earlier in this paper, those data also indicated a more than proportional drop in variability (as assessed by the CV) after consistent mapping practice, and no drop in variability after varied mapping practice.

These results can be related to current theories of the development of automaticity in the memory search literature. The restructuring or reorganization of task components could mean that items in the display set are being processed in parallel, yielding a "popping out effect", thus reducing the effect of processing load (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). It could also mean that there has been a transition from reliance on an algorithm in short-term memory (memory set items are compared to display set items in serial fashion) to direct access from long-term memory (Logan, 1988). This restructuring could also indicate that some of the controlled supervisory components contributing to the execution of the task have been eliminated (Segalowitz & Segalowitz, 1993) and that there has been a shift in the blend of automatic and controlled components which underly performance.

An alternative view is that the reduction in CV indicates that the variability associated with each component has been reduced, rather than indicating the actual dropping out of controlled, variable task components. However, previous research suggests that there is a qualitative difference in performance between consistent and varied mapping tasks indicating that there is a change in the manner in which the task is carried out (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). As discussed above, several studies suggest that possibly a "pop out response" develops or subjects may switch from using an algorithm in short-term memory to direct access of responses from long-term memory. Thus it would appear that some type of reorganization of task components takes place. However, further research is necessary to investigate this matter more fully.

In contrast to what happened with consistent mapping practice, the CV remained stable after varied mapping practice (i.e. there was no reduction in the CV for display size four), even as the reaction time decreased. This suggests that although processes were functioning faster, possibly indicating that many of the components of the task were being performed more efficiently, there was no essential change in the structure or organization of task components. In other words the contribution of relatively slow, variable, supervisory task components was not eliminated. In terms of the memory search literature, this could indicate that subjects continued to be reliant on short-term memory, and the search appeared to remain serial in nature so that each item in the memory set was compared with each item in the display set, one at a time. The high variability in response times could be the result of fluctuation in reaction times caused by whether the target was the first item to be compared or not. It could also be related to the fact that no "pop out" response had developed or that there was no elimination of controlled, decision-making supervisory processes. Therefore, for varied mapping practice, the decrease in reaction time and high level of response time variability reflects only speed-up effects and indicates that only a quantitative change in the underlying component processes had taken place.

Negative Responses

The importance of the use of the CV as a measure of response latency variability is illustrated by examining the differences between the SD analysis and the CV analysis for negative responses. In the consistent mapping condition the SD data appeared to indicate a reduction in variability and a decrease in the display set size effect usually assumed to reflect a transition to more automatic processing. However, analysis of the CV data revealed that this reduction was not greater than a proportional reduction in variability compared to RT. Thus, once changes in variability had been corrected for changes in latency of responding, it became apparent that only a proportional reduction in response time variability had taken place. This suggests that the reductions in variability shown by the SD data indicate that only a quantitative change had occurred. Thus, examination of only the RT and SD data could have led to the conclusion that a transition from controlled to automatic processing had taken place, when in fact only a speed-up in processing had occurred. This makes sense in terms of what we would expect to be happening in the negative trials (i.e. an exhaustive search both at the beginning and end of practice).

There were some individual differences between subjects for both positive and negative results, but the analyses reported here reflect the overall pattern of results found for seven out of the eight subjects who participated in the experiment. However, it should be noted that, on positive trials, not all subjects obtained optimal performance in the last block of trials for consistent mapping. For this experiment, the last block of trials was arbitrarily chosen to measure peak performance, but it should be recognized that some subjects reached optimal performance on earlier blocks. Generally, it is difficult to devise a simple test that will determine at which point the subject is performing optimally. This matter will require further investigation.

In summary, the focus of this research was to try to distinguish between two types of practice effects: Those caused by a quantitative change indicating that the task was being carried out in essentially the same way, and those in which a restructuring of task components had taken place suggesting that an increased automatization of components had developed (qualitative change). It was found that the CV could be a much better index of increased automaticity of responding than the RT or the SD alone and permits us to differentiate between these two types of practice effects.

CONCLUSIONS

The question "how should we define automaticity" still remains to be answered. It is clear from the earlier discussion of the literature that we can no longer distinguish between skilled and unskilled performance by simply relying on traditional definitions of automaticity or by referring to lists of properties. Previous research has to a great extent emphasized these definitions of controlled and automatic performance and the differences between them but much controversy still surrounds these issues.

Perhaps it is a better idea to think in terms of measurement of the qualitative change or transition from unskilled to skilled performance and the change in the blend of automatic and controlled component processes required to perform a task. As discussed previously, unskilled performance can be thought of as being composed of both automatic and controlled components but with a predominance of controlled components. These controlled components could possibly be slow, variable decision-making components which are vulnerable to interference and could be thought of as adding a fair amount of "noise" to the whole system. When a transition takes place (a qualitative change) from unskilled to skilled performance, perhaps some of these variable, decision-making components drop out or are replaced by more automatic components. Thus performance would now be composed of mainly automatic components and the whole system would have become less "noisy" and vulnerable to interference.

As these variable, controlled components drop out, there would be a corresponding drop in relative overall variability. As this thesis has shown the CV is a useful measure of relative variability and thus can monitor the reduction in variability which could signal a change in the blend of underlying component processes.

Because this is a flexible technique which could encompass many tasks, the study of response latency variability (as assessed by the CV) may be a useful complement to previous research methods such as those used by Neely (1977) or Jacoby (1991). In particular, experiments which manipulate the relative contribution of controlled and automatic components to performance of a task could reveal a great deal about the subprocesses which underly performance. For example, many studies in the past have manipulated subjects' expectancies (thought to involve many controlled components). Thus a task could be set up which manipulates degree of expectancy and therefore the relative involvement of controlled variable decision-making components.

This analysis of the difference between speed-up effects and the restructuring of task components could also be a promising addition to previous research methods which have investigated the development of skill, such as visual word recognition (i.e. lexical decision), memory tasks or resource allocation. In addition this technique could be applied to many other areas of cognitive development in which latencies and their variability can be measured such as analysis of the wave forms for utterance time and variability, auditory word recognition and evoked potentials.

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Appendix A

Target and Distractor Words

List A

Targets	Distractors
wasps	eagle
steel	shirt
green	trout
juice	tulip
theft	table
apple	chain
heart	birch
drill	train
linen	floor

List B

Targets	Distractors
tiger	dress
canoe	shark
nurse	house
radio	daisy
paper	couch
beans	watch
pearl	maple
rifle	truck
month	robin

Appendix B

Instructions

You are going to be asked to perform a memory skill task. Each trial will consist of the following steps:

1. A "+" will be presented in the center of the computer screen in front of you.

2. Then two words in lowercase letters will replace the "+". Please memorize these two words.

3. A pattern consisting of ampersands (&&&&&) will replace the two words in lowercase letters.

4. Following this, four words in UPPERCASE letters will appear. Please decide if any of the words in UPPERCASE letters is the same word as either of the words in lowercase letters. If any of the words in UPPERCASE letters matches either of the words in lowercase letters, press the button marked **YES.** If none of the words match, press the button marked **NO.**

5. Then a second pattern of ampersands (&&&&&) will appear.

6. The trial will end and a new trial will begin.

To summarize, your task is to memorize the first set of words to appear (the set in lowercase letters). Next you will be asked to decide if any of the words in the second set (the set in UPPERCASE letters) is the same as any of the words in the first set. If any of the words in UPPERCASE letters matches any of the words in lowercase letters, please press the button marked **YES**. However if none of the words is the same, press the button marked **NO.**

Please respond as quickly as possible without making errors. If you do make an error or if you take too long to decide you will hear a tone.

EXAMPLE: First you will see a cross on the screen. Then you may see the two words

stars
queen

Following this you will see a pattern and then you may see four more words such as

STARS
GLOBE
PLATE
SHEET

As one of the four words (i.e. **STARS**) is the same as one of the words previously memorized, you should press the button marked **YES.**

If, however, the first two words were:

stars
queen

and the next four words were

GLOBE
SHEET
CLOUD
PLATE

you should press the button marked **NO** because none of the words in the second set matches any of the words previously memorized.

Please respond as quickly and as accurately as possible. If you have any questions we will be happy to answer them.

Appendix C

Percent Errors (%) for Positive and Negative Responses as a Function of Type of Training, Practice Block and Display Size

	LIST A %	LIST B %	OVERALL %
Consistent Mapping			
First Block			
Display Size 2	4.00	3.50	3.75
Display Size 4	4.50	2.50	3.50
Last Block			
Display Size 2	0.50	3.50	1.50
Display Size 4	1.00	2.50	1.50
Varied Mapping			
First Block			
Display Size 2	2.50	3.00	2.75
Display Size 4	5.00	4.50	4.75
Last Block			
Display Size 2	2.50	2.00	2.25
Display Size 4	3.50	4.00	3.75

Appendix D

Summary Table for Analysis of Variance Performed on Data for Reaction Times for the Factors: Type of Training, Display Size, Practice Block, Response Type and List

SOURCE	SS	DF	MS	F	P
BETWEEN SUBJECTS					
List	145,800.00	1	145,800.00	2.03	0.204
Error	430,400.88	6	71,733.48		
WITHIN SUBJECTS					
Type of Training	425,733.78	1	425,733.78	38.78	0.001
Type of Training x List	24,586.53	1	24,586.53	2.24	0.185
Error	65,878.06	6	10,979.68		
Display Size	2,435,976.28	1	2,435,976.28	100.81	0.000
Display Size x List	2,756.53	1	2,756.53	0.11	0.747
Error	144,978.31	6	24,163.05		
Practice Block	52,569.03	1	52,569.03	2.96	0.136
Practice Block x List	2,646.28	1	2,646.28	0.15	0.713
Error	106,754.06	6	17,792.34		
Response Type	871,860.13	1	871,860.13	87.17	0.000
Response Type x List	2,415.13	1	2,415.13	0.24	0.641
Error	60,012.38	6	10,002.06		
Type of Training x Display Size	59,168.00	1	59,168.00	2.57	0.160
Type of Training x Display Size x List	22,366.13	1	22,366.13	0.97	.363
Error	138,404.50	6	23,067.42		

SOURCE	SS	DF	MS	F	P
Type of Training x Practice Block	156,240.50	1	156,240.50	18.26	0.005
Type of Training x Practice Block x List	630.13	1	630.13	0.07	0.795
Error	51,334.25	6	8,555.71		
Type of Training x Response Type	13,162.53	1	13,162.53	2.92	0.138
Type of Training x Response Type x List	12,521.53	1	12,521.53	2.78	0.146
Error	27,020.56	6	4,503.43		
Display Size x Practice Block	32,131.13	1	32,131.13	2.56	0.161
Display Size x Practice Block x List	4,753.13	1	4,753.13	0.38	0.561
Error	75,459.88	6	12,576.65		
Display Size x Response Type	473,607.78	1	473,607.78	76.33	0.000
Display Size x Response Type x List	1,001.28	1	1,001.28	0.16	0.702
Error	37,226.31	6	6,204.39		
Practice Block x Response Type	21,580.03	1	21,580.03	4.32	0.083
Practice Block x Response type x List	457.53	1	457.53	0.09	0.772
Error	29,975.06	6	4,995.84		

SOURCE	SS	DF	MS	F	P
Type of Training x Display Size x Practice Block	71,347.53	1	71,347.53	8.21	0.029
Type of Training x Display Size x Practice Block x List	957.03	1	957.03	0.11	0.751
Error	52,162.56	6	8,693.76		
Type of Training x Display Size x Response Type	392.00	1	392.00	0.13	0.727
Type of Training x Display size x Response Type x List	11,325.13	1	11,325.13	3.88	0.096
Error	17,503.75	6	2,917.29		
Type of Training x Practice Block x Response Type	13,122.00	1	13,122.00	3.57	0.108
Type of Training x Practice Block x Response Type x List	3,003.13	1	3,003.13	0.82	0.401
Error	22,084.00	6	3,680.67		
Display Size x Practice Block x Response Type	24.50	1	24.50	0.01	0.928
Display Size x Practice Block x Response Type x List	128.00	1	128.00	0.05	0.838
Error	16,782.88	6	2,797.15		

SOURCE	SS	DF	MS	F	P
Type of Training x Display Size x Practice Block x Response Type	19,061.28	1	19,061.28	10.29	0.018
Type of Training x Display Size x Practice Block x Response Type x List	5,227.53	1	5,227.53	2.82	0.144
Error	11,110.56	6	1,851.76		

Appendix E

Summary Table for Analysis of Variance Performed on Data for Reaction Times for the Factors Type of Training, Display Size, Practice Block and Response Type

SOURCE	SS	DF	MS	F	P
WITHIN SUBJECTS					
Type of Training	425,733.78	1	425,733.78	32.94	0.001
Error	90,464.59	7	12,923.51		
Display Size	2,435,976.28	1	2,435,976.28	115.42	0.000
Error	147,734.84	7	21,104.98		
Practice Block	52,569.03	1	52,569.03	3.36	0.109
Error	109,400.34	7	15,628.62		
Response Type	871,860.13	1	871,860.13	97.76	0.000
Error	62,427.50	7	8,918.21		
Type of Training x Display Size	59,168.00	1	59,168.00	2.58	0.153
Error	160,770.63	7	22,967.23		
Type of Training x Practice Block	156,240.50	1	156,240.50	21.05	0.003
Error	51,964.38	7	7,423.48		
Type of Training x Response Type	13,162.53	1	13,162.53	2.33	0.171
Error	39,542.09	7	5,648.87		
Display Size x Practice Block	32,131.13	1	32,131.13	2.80	0.138
Error	80,213.00	7	11,459.00		

SOURCE	SS	DF	MS	F	P
Display Size x Response Type	473,607.78	1	473,607.78	86.72	0.000
Error	38,227.59	7	5,461.09		
Practice Block x Response Type	21,580.03	1	21,580.03	4.96	0.061
Error	30,432.59	7	4,347.51		
Type of Training x Display Size x Practice Block	71,347.53	1	71,347.53	9.40	0.018
Error	53,119.59	7	7,588.51		
Type of Training x Display Size x Response Type	392.00	1	392.00	0.10	0.767
Error	28,828.88	7	4,118.41		
Type of Training x Practice Block x Response Type	13,122.00	1	13,122.00	3.66	0.097
Error	25,087.13	7	3,583.88		
Display Size x Practice Block x Response Type	24.50	1	24.50	0.01	0.923
Error	16,910.88	7	2,415.84		
Type of Training x Display Size x Practice Block x Response Type	19,061.28	1	19,061.28	8.17	0.024
Error	16,338.09	7	2,334.01		

Appendix F

Summary Table for Analysis of Variance Performed

on Data for Standard Deviations for the Factors Type of Training,

Display Size, Practice Block and Response Type

SOURCE	SS	DF	MS	F	P
WITHIN SUBJECTS					
Type of Training	52,975.13	1	52,975.13	17.91	0.004
Error	20,709.75	7	2,958.54		
Display Size	275,653.13	1	275,653.13	76.36	0.000
Error	25,269.50	7	3,609.93		
Practice Block	7,564.50	1	7,564.50	2.43	0.163
Error	21,758.13	7	3,108.30		
Response Type	21,063.78	1	21,063.78	6.11	0.043
Error	24,127.34	7	3,446.76		
Type of Training x Display Size	276.13	1	276.13	0.15	0.712
Error	13,087.25	7	1,869.61		
Type of Training x Practice Block	19,208.00	1	19,208.00	7.77	0.027
Error	17,297.38	7	2,471.05		
Type of Training x Response Type	10,117.53	1	10,117.53	3.77	0.093
Error	18,775.84	7	2,682.26		
Display Size x Practice Block	9,180.13	1	9,180.13	7.23	0.031
Error	8,887.50	7	1,269.64		

SOURCE	SS	DF	MS	F	P
Display Size x Response Type	18,672.78	1	18,672.78	7.90	0.026
Error	16,536.84	7	2,362.41		
Practice Block x Response Type	9,765.03	1	9,765.03	9.19	0.019
Error	7,440.59	7	1,062.94		
Type of Training x Display Size x Practice Block	9,248.00	1	9,248.00	9.64	0.017
Error	6,712.88	7	958.98		
Type of Training x Display Size x Response Type	6,469.53	1	6,469.53	3.52	0.103
Error	12,879.84	7	1,839.98		
Type of Training x Practice Block x Response Type	3.78	1	3.78	0.00	0.974
Error	22,405.59	7	3,200.80		
Display Size x Practice Block x Response Type	731.53	1	731.53	0.26	0.625
Error	19,646.59	7	2,806.66		

SOURCE	SS	DF	MS	F	P
Type of Training x Display Size x Practice Block x Response Type	3,633.78	1	3,633.78	4.12	0.082
Error	6,179.59	7	882.79		

Appendix G

Summary Table for Analysis of Variance Performed on Data for Coefficients of Variation for the Factors Type of Training, Display Size, Practice Block and Response Type

SOURCE	SS	DF	MS	F	P
WITHIN SUBJECTS					
Type of Training	0.021	1	0.021	7.21	0.031
Error	0.020	7	0.003		
Display Size	0.082	1	0.082	22.51	0.002
Error	0.026	7	0.004		
Practice Block	0.001	1	0.001	0.47	0.516
Error	0.017	7	0.002		
Response Type	0.165	1	0.165	30.55	0.001
Error	0.038	7	0.005		
Type of Training x Display Size	0.005	1	0.005	4.21	0.079
Error	0.008	7	0.001		
Type of Training x Practice Block	0.006	1	0.006	1.77	0.225
Error	0.023	7	0.003		
Type of Training x Response Type	0.017	1	0.017	4.20	0.080
Error	0.028	7	0.004		
Display Size x Practice Block	0.004	1	0.004	3.66	0.097
Error	0.007	7	0.001		

SOURCE	SS	DF	MS	F	P
Display Size x Response Type	0.096	1	0.096	30.95	0.001
Error	0.022	7	0.003		
Practice Block x Response Type	0.008	1	0.008	5.36	0.054
Error	0.010	7	0.001		
Type of Training x Display Size x Practice Block	0.003	1	0.003	1.13	0.323
Error	0.017	7	0.002		
Type of Training x Display Size x Response Type	0.002	1	0.002	0.93	0.367
Error	0.014	7	0.002		
Type of Training x Practice Block x Response Type	0.000	1	0.000	0.03	0.879
Error	0.019	7	0.003		
Display Size x Practice Block x Response Type	0.003	1	0.003	0.93	0.367
Error	0.020	7	0.003		
Type of Training x Display Size x Practice Block x Response Type	0.012	1	0.012	12.70	0.009
Error	0.007	7	0.001		