FORGETTING IN SHORT-TERM MEMORY: THE EFFECT OF TIME

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by
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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled

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and hereby certify that, in their opinion, it is worthy of acceptance.

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ABSTRACT

Forgetting in short-term memory has been studied extensively and yet no consensus has emerged to explain its cause. Two theories continue to provide competing explanations of forgetting in short-term memory: decay and interference. Decay presupposes that the memory trace for a set of stimuli to be remembered weakens in proportion to the amount of time that passes whereas interference posits one stimulus interacting with another as the cause of forgetting. Recent evidence has suggested that decay should no longer be considered a viable mechanism to explain forgetting; but the current set of studies provides compelling evidence to the contrary. Hence these studies argue that decay should not be abandoned.

Chapter 1

Introduction to Forgetting in Short Term Memory

What causes forgetting in memory? Experimental Psychologists have attempted to answer that question since the inception of the discipline. William James (1890) and the forgetting curves of Herman Ebbinghaus (1885 / 2003) provide some of the earliest insights on forgetting in memory. However these pioneers of psychological memory research by no means definitively answered this vexing question and it remains. The current thesis examines the perplexing issue of forgetting and, specifically, examines whether decay should continue to be considered a viable mechanism to account for this forgetting.

This Introduction has four parts. The first part will provide an introduction to the general ideas of decay and interference through three classical studies. The second part will expound upon these introductions by providing more rigorous definitions. The third part will discuss a modern incarnation of decay and interference. And the section will conclude with a formal statement of the thesis to be defended in the current work and the general methodological approach used throughout the current set of studies.

Classical Introduction

Some of the first formal tests of the theory of decay were performed by Brown (1958). His initial formulation of the decay hypothesis (p.13) follows:

> When a sequence of items is presented, the interval between the perception of each item and the attempt to recall that item will depend on the length of the sequence. If the sequence exceeds a certain length, decay of the memory traces of some of the items will proceed too far for accurate

> recall of the sequence to be possible. This length is the memory span. Thus the trace-decay hypothesis can explain both the origin of the span and why forgetting occurs when the span is exceeded.

Brown qualifies this definition by noting that decay can only be observed when rehearsal is blocked. Three experiments tested the decay hypothesis in Brown's original paper; but only the first will be presented here. Experiment 1 required participants to memorize a series of two-digit letter pairs presented visually. At least one pair and at most four pairs were presented on any given trial. Participants spoke the letter pairs aloud as they were presented. Participants were then exposed to one of two conditions before recall. In the first condition participants saw, and spoke, five pairs of numbers. The amount of time that elapsed during the presentation of the numbers was about 5 seconds. In the second condition participants did not see number pairs in the 5-second interval following the presentation of the letters. Then participants recalled the letters by writing them down. The results of Experiment 1 are presented in Table 1. The results demonstrate the operation of decay in that performance for the first condition, where participants could not rehearse, was markedly worse than performance in the second condition where rehearsal was possible. And this difference manifested even though the amount of time that elapsed after the presentation of the letters, but before recall, was 5 seconds in both conditions. So decay requires the passage of time along with the blockage of rehearsal.

Another classic study by Peterson and Peterson (1959) demonstrated similar results as Brown's work while using a more dynamic experimental design. Instead of using the same interval of time after presentation of the consonants to be remembered, but before recall, Peterson and Peterson compared several time intervals. In the first experiment the retention intervals were 3, 6, 9, 12, 15 or 18 seconds in length. Participants were required to memorize three letters while they counted backwards (by three or four, depending on the condition) from a number given by the experimenter during the retention interval and then recall the three letters. This manipulation demonstrated another dimension to the decay hypothesis: even when rehearsal was prevented (through counting backwards of the numbers) longer time intervals of retention led to significantly worse memory recall compared to shorter intervals. So, for instance, recall accuracy was about 70% for a 3 second retention interval; but this dropped to less than 10% for an 18 second retention interval. In fact ability of the participants to recall the letters decreased logarithmically with increased time. Figure 1 depicts the relationship.

The studies by Peterson and Peterson (1959) and Brown (1958) provide compelling evidence for decay. But a reasonable skeptic might object: perhaps decay, especially when rehearsal is suppressed with secondary stimuli, should not be considered the cause of forgetting because the stimuli from the secondary stimuli actually create interference with the items to be remembered.

Waugh and Norman (1965) voiced such a concern and experimentally documented the case for interference as the primary cause of forgetting in short-term memory. Their procedure required participants to memorize a 16-digit sequence. They could rehearse each digit as it was presented, until the next digit was presented, but they were explicitly instructed not to rehearse beyond the most recently presented digit. An entire sequence of 16 digits was presented at either the rate of 1 digit per second or 4 digits per second. The last digit of the sequence cued the participants to recall the digit that followed that same digit earlier in the sequence and the digit to be recalled could have followed position 3, 5, 7, 9, 10, 11, 12, 13 or 14. If decay operated it would have been expected that the fast and slow rates of presentation of the digits would show differing rates of recall accuracy. But the results supported the role of interference (see Figure 2) because the two conditions did not differ significantly in terms of their recalled accuracy. What becomes apparent from Figure 2 is that the number of numbers that have passed in the list, or interfering items, accounts for the fall-off in recall accuracy and not the rate of presentation.

Formal Definitions of Decay and Interference

The foregoing work by the Peterson and Peterson (1959) and Brown (1958) cites decay as the mechanism responsible for forgetting in short-term memory. The decay of representations of stimuli in short-term memory refers to a reduction in the strength or precision of these representations as a function of the amount of time since the representations were added to short-term memory. As the representations weaken their probability of correctly being recalled from short-term memory simultaneously diminishes. Thus an inverse relationship, between the passage of time and the probability of correct recall of a stimuli representation from short-term memory, can be posited. And from this relationship it can be predicted that longer time intervals, over which the representations are maintained, should lead to poorer memory recall as compared to maintaining the same set of representations over shorter time intervals.

One empirical method to test the decay hypothesis is to measure the accuracy of forward serial recall for a stimulus set when the recall pace is manipulated. Recall pace reflects the amount of time that passes between the recall of two consecutive stimuli. A fast pace of recall would lead to less time passing than a slow pace of recall. Recall accuracy provides an index of the strength of the stimuli representation. When a quick recall pace is compared to a slow recall pace one would expect differences in recall accuracy to emerge based upon the decay hypothesis. If decay exists a quick recall pace would lead to lead to greater recall accuracy than an identical set of stimuli recalled slower because, as less time would have passed, recall performance would not have been as harmed by the effect of time. Figure 3 provides a graphical representation contrasting quick and slow recall paces, or short and long time intervals, respectively.

In Figure 3 the curves represent a quick pace of recall (short time interval) and a slow pace of recall (long time interval) and they gradually separate as the serial position increases from the first to the sixth position. This phenomenon, called serial fanning, is a hallmark indicator for the presence of decay. If decay is present in the serial recall of a list of stimuli serial fanning will manifest as the difference between the short and long conditions increases across serial positions. In Figure 3 the two lines begin at the same point which represents equivalent recall performance on the first serial position because the same amount of time has elapsed for both conditions. Transitioning from the first serial position to the last reflects a substantial increase in time. If, in the above case, the short condition represents a 500 ms interval between items during recall and the long condition represents a 1000 ms interval between stimuli during recall then the sixth serial position represents the passage of 3 seconds overall for the short condition and 6 seconds overall for the long condition. So although the difference of time at a single serial position might seem negligible, the total time, summed across all serial positions, becomes substantive. Decay can be represented graphically in an interaction of the short and long conditions with serial position.

The reverse argument also holds: when recall accuracy, for a short and long recall interval, does not separate as a function of serial position, serial fanning is not present. When serial fanning does not occur one has tentative evidence that decay has not occurred (see Figure 4). Another major problem in isolating decay is its confounding relationship with rehearsal. Rehearsal is the mechanism by which stimuli held in short-term memory can be reactivated. So if one assumes that a stimuli representation in short-term memory forms then rehearsal can be construed as a strengthening of that original representation or the establishing of a new representation. And if decay had been operating then rehearsal reverses the observable effects of decay. Hence rehearsal needs to be controlled to reasonably expect to observe decay and, insofar as rehearsal has not been sufficiently blocked, the effects of decay will not be expected to be observed.

Sub-vocal rehearsal is the most intuitive and well-documented type form of rehearsal. A person trying to retain information in short-term memory repeats, either aloud or internally, the information to be remembered. According to Baddeley (1986) this process engages the phonological loop. Through this process the short-term memory representation is either re-established anew with each utterance, reset to the same, or nearly the same, strength obtained with the first memorial encoding or simply strengthened (Cowan, 1992). In the absence of interference from other stimulus the rehearsal of the decaying trace will lead to perfect, or nearly perfect, recall of the stimuli from short-term memory. This assumes that the stimuli are within the capacity and temporal limitations of the working memory system. This type of rehearsal assumes that most, if not all, of an individual's attention can be devoted to the task of rehearsing the stimuli. In order to effectively observe decay this form of rehearsal needs to be blocked. A single suppressor word uttered repetitively will capture attention to prevent phonological rehearsal. This type of rehearsal, however, does not appear to capture the entire pool of attention in adults (Guttentag, 1984) and it stands to reason that some of the attention not allocated to this process can be allocated to another form of rehearsal.

Attention-based refreshing is a second rehearsal mechanism (Raye et al., 2007). Residual attention, not being allocated to sub-vocal rehearsal, can be used to reactivate the decay trace but in a much more covert manner. Instead of requiring explicit repetition of the entire stimulus set to be retained in memory this form of rehearsal might only reactivate part of the list to be remembered and, furthermore, can be accomplished in very small intervals of time (Reitman, 1974). Since this amount of attention is probably less than that needed for subvocal rehearsal it stands to reason that it will not be as effective at fully re-establishing the memory traces; but it can none-the-less counteract the decay of a memory trace. Attention-based refreshing is based on findings from work with the psychological refractory period (PRP) paradigm (Pashler, 1994). The basic idea from the PRP is that an individual cannot process a second task until the first one no longer occupies the central bottleneck, where the central bottleneck refers to a restriction on the general ability to process information. But information can pass through this bottleneck very quickly; and, moreover, saying repetitive words (as one would do to prevent subvocal rehearsal) does not fully inhibit this information processing loop. However if one articulates different words, or same words at irregular rates, it has the capacity to disrupt the flow of this system. As a result, if this attention-based refreshing system is blocked this means another means to re-establishing memory traces has been stopped and that means decay will be more likely to be observed.

An alternative mechanism underlying attention-based might be memory searches (Cowan, Nugent & Elliott, 2000). This requires focusing attention on the list of items to be remembered and it can have the effect of reactivating their strength. This is akin to a mental scanning of the contents of working memory. Moreover this type of rehearsal can be accomplished while one is engaged in another task, like sub-vocal rehearsal for instance.

Since it is possible to use sub-vocal rehearsal, attention-based refreshing or both to reactivate memory traces it is imperative to block both of these rehearsal mechanisms in order to observe decay. The approach traditionally implemented to control rehearsal has been the introduction of a secondary task, such as some variety of articulatory suppression (AS). AS is the process whereby a person repeats a word, a series of words or different words out loud while they are engaged in a primary short-term memory task. When AS is comprised of one word that does not change this is believed to suppress subvocal rehearsal. If the word changes or has more complexity than just a single, same word this might be able to control the attention-based refreshing form of rehearsal. Hence AS serves as an important tool to prevent rehearsal and thereby observe decay; but it simultaneously muddles the interpretation of the cause of forgetting. In introducing AS to control for decay one simultaneously introduces stimulus that interfere with those to be remembered.

Suppose one had designed an experiment in which they believed they had blocked, or controlled, for both forms of rehearsal and that, relative to a condition where a participant did not have rehearsal blocked performed much worse in short-term memory recall. One interpretation of that result would be evidence for decay because, as more time had passed in the condition where rehearsal had been blocked, memory recall decreased. And decay is defined precisely as the decreasing probability of correctly recalling stimuli from short-term memory as more time passes. But another interpretation of that same result is that, because memory performance only decreased in the condition where secondary stimuli were introduced, the poorer recall might actually arise from the interaction of the stimuli to be remembered and the stimuli introduced to control rehearsal. This would be the effect of interference.

Decay may have initially looked very straightforward to find and interpret; but it is obvious that proving or disproving its existence is very difficult and it should not be surprising that this problem is over 100 years old. Deciding definitively between the interpretations of decay and interference as the cause of forgetting in short-term memory has been elusive. A theoretically ideal, but practically impossible, method for differentiating the two would be to hold time constant and introduce secondary stimuli to observe if forgetting still occurs and, if it did, this could be reasonably interpreted as evidence for interference. The other equally unlikely possibility is to prevent rehearsal entirely by asking the participant not to rehearse, for instance, and if their memory recall performance decreased conclude that the memory trace decayed. But this is not fruitful, either, because it is nearly impossible to prevent a person from rehearsing or, at the very least, from knowing whether they have actually stopped rehearsing or not—especially with more covert types of rehearsal. These two approaches might represent ideal methods to decipher the causes of forgetting in short-term memory; but they can not be achieved at this point in time. Hence two reasonable compromises to these extreme cases have been adopted for the current set of studies and will be provided at the end of this Introduction. Before outlining those approaches a couple of modern studies instantiating the decay and interference debate of forgetting in short-term memory will now be examined.

A Modern Reincarnation of the Decay-or-Interference Issue

A recent study by Lewandowsky, Duncan, and Brown (2004) postulated that, in a serial recall task, if they could not find evidence for serial fanning among three different recall paces then this would be strong evidence for the role of interference as causing forgetting and not decay. They implemented a technique whereby participants were trained to recall a serially presented list of six letters at three rates of recall. They learned this rate of recall by being trained to speak the word “Super” out loud either once, twice or three times in between the recall of each letter such that saying the word once approximately took 400ms, saying the word twice took 800ms and saying the word three times took 1600ms. Decay theory predicted serial fanning for the serial recall curves: the 400 ms condition would lead to the best performance while the 1600ms condition would lead to the worst performance and the 800 ms condition would be intermediate to the other two conditions. The results showed a lack of serial fanning, provided refuting evidence for decay and, in their view, supporting evidence for interference.

One important question that can be asked regarding the Lewandowsky et al. (2004) study is the following: would the same outcome be anticipated if participants had to say different words out loud in between each letter of serial recall? There is good reason to suspect that the type of interfering words spoken, in conjunction with the time allowed to speak them, might have an effect on serial recall. One line of evidence comes from Experiment 7 by Barrouillet, Bernardin and Camos (2004) where participants performed a serial recall task where different numbers, interspersed between the letters to be remembered, had to be spoken out loud.

In this reading span task the number of numbers to be said out loud, and the amount of time allowed to say those numbers, varied systematically according to a ratio. The numerator of this ratio consisted of the number of numbers to be said aloud while the denominator reflected the amount of time allowed to speak those numbers. Nine different number-to-time ratio conditions were formed. The nine ratios were derived from all possible permutations of dividing one of the possible three numeral sets for the numerator (4, 8 or 12 numbers) by one of the possible three time spans for the denominator (6, 8 or 10 seconds). The results of this study showed that recall performance decreased linearly as the magnitude of the ratio increased. It is apparent that as the secondary task became denser, that is saying more numbers in a shorter time interval, rehearsal was more effectively blocked, leading to lower rates of recall. It stands to reason that this manipulation effectively blocked both overt and covert forms of rehearsal.

These two studies provide conflicting results when viewed from the perspective of time. Lewandowsky et al. (2004) found that memory performance was nearly equivalent across different rates of recall whereas Barrouillet et al. (2004) found that memory performance decreased with denser ratios (more numbers in less time) during stimulus presentation. In order to see how methodological differences in these two studies might have given rise to the different outcomes the experimental manipulations in Experiment 1 of this thesis were implemented to reconcile these divergent findings.

Thesis and Method

The foregoing has made apparent the complexities of the simple question: should forgetting in short-term memory be attributed to decay or interference? Given the long-standing nature of this problem in memory research it is apparent this question defies an easy answer. The current thesis will defend the position that decay should continue to be viewed as a viable mechanism to compete with the interference explanation.

To document this claim two general methodological approaches have been implemented. Each has associated shortcomings and neither is theoretically ideal. The first approach relies on articulatory suppression (AS) throughout the entire recall interval. Depending on the experiment this AS will sometimes be constant across the entire recall interval and sometimes it will be irregular. One disadvantage of this approach is that AS necessarily introduces some interference. Nonetheless an assessment of the relative contribution of decay to forgetting can be ascertained by presupposing that certain forms of AS are more attentionally demanding than others. When comparing one type of AS to another the more attentionally demanding form of AS should lead to worse memory recall accuracy than simpler forms. And in some cases they can be compared to a baseline condition where AS has not been utilized. Experiments 1, 2 and 3 all rely on this framework.

The second approach will be called perceptual interference. Comparisons will be made between a condition that actually has the participant perform a secondary task that will require attention (and, by extension, create interference) to conditions without a secondary task that will not require additional attention (and, by extension, create no interference). The secondary task will always be searching for a target digit at recall. Participants will not know which trials this target digit will be embedded within. It is expected that always searching for a digit will always be attentionally demanding. In analyzing the data conditions that actually contained a target digit will be removed. In this way the only trials that will be analyzed will be those that did not have any interfering stimuli but yet still were attentionally demanding because there was the searching for an expected digit. If a difference in recall accuracy emerged, in comparing short and long intervals of time, this would make for a very strong argument that rehearsal was blocked, interference was not present and that decay was most likely operating. The potential drawback of this approach, however, is that perceived AS might not be strong enough to actually block rehearsal and, as a result, not discriminate between the type of forgetting occurring. Experiments 4, 5 and 6 implemented this approach.

All of the following studies used the common experimental paradigm of forward serial recall. In this method six letters are presented, one at a time, for the participant to commit to memory. Recall of each letter was typed on the keyboard. The various manipulations took place after the presentation of the letters, during recall.

Chapter 2

Experiment 1

Introduction

The primary difference that most likely accounted for the contrasting findings between Lewandowsky et al. (2004) and Barrouillet et al. (2004) was probably the nature of the AS. Lewandowsky (2004) utilized a constant suppressor, the word 'Super', whereas Barrouillet (2004) utilized a varying suppressor. In order to test this conjecture, that the nature of the suppressor accounted for the different findings, the suppressor will be manipulated in Experiment 1. In addition the rates of recall will also be manipulated. These manipulations predict certain outcomes.

The decay hypothesis predicts a longer retention interval, which will be manipulated by the pace of recall of letters, will lead to poorer serial recall as compared to a quick recall pace. When time interacts with serial position in this fashion serial fanning of the serial recall curves will manifest. In the Lewandowsky et al. (2004) study a manipulation of the pace of recall, which had the effect of creating different intervals of time over which the letters were recalled, did not lead to different memory performances, a finding that starkly contradicts the decay hypothesis. Contrariwise when Barrouillet et al. (2004) manipulated the time intervals memory performance did, in fact, change as a function of those different intervals. Stimuli that require more time should lead to worse performance. Prediction one is an interaction between serial position and the speed of recall.

This prediction can be instantiated in the word length effect research by Baddeley, Thompson and Buchanan (1975). In their Experiment 3 participants were presented with a series of 5 words. All of the words had two syllables but differed in how long it took to pronounce the words. For instance the word 'Friday' or 'harpoon' requires more time to speak than 'bishop' or 'ember' even though they all have two syllables. The words were recalled in the same order as presentation. A strong serial position by word length effect emerged, meaning that the recall accuracy decreased as serial position increased and that effect was more pronounced for long words compared to short words. Since the longer words took more time to speak (.77 seconds, on average) than the short words (.46 seconds, on average) this result supports decay because the overall amount of time necessary to recall the longer words was greater than that needed for the shorter words. Likewise Experiment 1 of this study predicted that recalling letters over a longer interval of time would lead to worse performance than recalling letters over a shorter interval.

The second variable manipulated in Experiment 1 was the nature of the suppressor. In the Lewandowsky et al. (2004) study participant had to say “Super” either once, twice or three times between recall of the letters. This same word was always predictable within and across trials. Expected stimuli should require negligible attention demands and, hence, allow for more rehearsal of the original letters. Moreover they should block sub-vocal rehearsal only. Contrariwise the Barrouillet et al. (2004) study required participants to say different numbers out loud. Because these numbers were always randomly selected they systematically inhibited the prediction of the number to be said aloud within and across trials. Therefore the participant must allocate more attention to saying the number and have less available to rehearse the letters in short-term memory. Saying these numbers probably blocked sub-vocal rehearsal and attentional refreshing. Experiment 1 of the current study altered the nature of the AS. Specifically numbers that were always changing were compared to numbers that were always the same and these numbers served as the suppressor. Prediction two is a significant serial position by suppressor type interaction or just a significant main effect of suppressor type.

Method

Participants. 25 students (10 female, 15 male) at the University of Missouri-Columbia participated in a one hour session. Their participation counted towards fulfillment of course credit of an Introduction to Psychology class. Good typing skills served as a prerequisite for participation.

Apparatus, stimuli, and procedure. The experimental procedure is visually depicted in Figure 5**.** The four conditions derived from 2 levels for each of 2 variables, the variables being speed of recall (relatively short or long) and the nature of the suppressor (repetitive or varying). The four conditions were presented within subjects. A fast recall pace and repetitive suppressor is represented by 1S and a slow recall pace with repetitive suppression is represented by 5S. A fast recall pace with a varying suppressor is represented by 1D and a slow recall pace with varying suppressors is represented by 3D. In these abbreviated conditions the 'D' always represents *different* numbers at each recall position while the 'S' always represents the *same* number(s) at each of the recall positions. The digit preceding the 'S' or 'D' represent how many numbers appeared at each recall interval. More numbers are tantamount to longer time intervals. These four conditions were chosen so as to have two time comparisons, a short- and long-time represented by comparing the 1 with the 3 and 5 conditions, respectively, and two suppressor conditions, one low and the other high represented by the S and D conditions, respectively. Given that it took longer to repeat each number in a varying series than in a same-number series, the conditions were selected on the basis of pilot data in the expectation that the 3D and 5S conditions would result in responses of comparable durations.

In a given block of four trials, each of the four conditions (1S, 5S, 1D and 3D) was randomly selected once without replacement. There were 25 trials of each condition, for a total of 100 trials for the entire experiment. Reaction time was the interval from the onset of the number(s) to the point at which the participant entered their response via keyboard. Accuracy data was obtained for each serial position. All lists were comprised of the same six letters: h, j, m, q, r and v. They were selected randomly each time, without replacement, on each trial, for a total list length of six letters. The letters, and all other stimuli described below, were presented on the monitor of a Dell computer running E-prime software.

Each trial began with the presentation of six lowercase letters, serially presented, at the vertical and horizontal center of the computer screen. Each letter appeared for 400ms and the inter-stimulus interval between letters, consisting of a blank screen, lasted for 100ms. After all 6 letters were presented a blank screen appeared in the center for 1000ms and then the prompt for the first number, or suppressor, appeared on the screen.

The recall portion of the trial consisted of the participant speaking, out loud, the number or numbers (depending on the condition) centrally presented on the screen. After the number was presented a prompt, a '?' followed by underscore characters, served as the cue to type the first serially recalled letter from the initially presented list. This alternating interval occurred six times in each trial, corresponding with the six letters presented. For example, in a trial within the 1S condition, a participant might receive the letter series *h, m, j, r, v, and q*. The computer would then present *13* and the participant would speak that number aloud and then type h (or an incorrect response); the computer would then present *13* to be said aloud again, after which the participant would type *m*.

This alternating of speaking numbers and typing letters continued until the participant typed six responses. In a trial within the 3D condition, the procedure would be the same except that, instead of seeing and repeating *13* before each typed response, the participant might see and speak *27 23 29* before typing the first response, see and speak *23 26 28* before the second response and continue this sequence until six responses had been typed.

In multiple number conditions each number was horizontally centered in its own row and the entire column was vertically centered; the numbers were "stacked" on top of one another. Single-numbers were presented on the screen for 750ms, three numbers were presented for 1750 ms and 5 numbers were presented for 2750 ms. When the suppressor was repetitive the same number was always presented across all six recall intervals. When the suppressor varied, different numbers were always presented across the six recall intervals. Moreover in the varying suppressor condition with three numbers different digits were always randomly chosen. 13 was always the number used in the constant suppressor and quick recall condition. 13 14 15 16 17 was always used in the constant suppressor slow recall condition. In the varying suppressor, short recall, a single two-digit number was randomly selected from a set consisting of any two-digit integer combination between twenty-one and ninety-nine that had three syllables. In the varying suppressor, long recall condition, 3 such random numbers were selected.

Participants kept their hands on the keyboard, in the formal typing position, at all times. A number, or numbers (depending on the condition), always preceded the typing of the first serially recalled letter. After the number(s) were presented a single row of underscore characters (_) , a question mark (?) and already typed letter responses for the trial (a) were centered on the screen on one row, proceeding from left to right. The first recall prompt would have a question mark followed by 5 underscore characters: *?* _ _ _ _ _. If two letters had been already typed the screen might look like this: *q r ?* _ _ _. The participant could only respond with the 26 letters of the alphabet.

Results

In order to assess the equivalency of the fast and slow paces of recall the reaction times were analyzed (see Figure 6). The reaction time for each serial position equaled the time from the onset of the suppressor to the keyboard response.

A response was scored correct only if it was typed in the correct serial position. The proportion correct for each of the four conditions, across the six serial positions, is presented in Figure 7. A 2x2x6 within subjects ANOVA was used to analyze these accuracy data. Speed of recall had two levels (fast or slow), Suppressor type had two levels (repetitive or varying) and Serial Position had six levels (1-6). Two two-way interactions emerged as significant, those being Speed by Serial Position [$F(5,120)=6.25$, $MS_e=.0066$, $p<.001$] and Speed by Suppressor type [$F(1,24)=6.99$, $MS_e=.0080$, $p<.014$]. Significant effects did not emerge for the other two-way interaction between Suppressor type and Serial Position [$F(5,120)=1.14$, $MS_e=.0079$, $p>.34$] nor was the triple interaction significant [$F(5,120)=1.87$, $MS_e=.0072$, $p>.10$]. The three main effects, Speed [$F(1,24)=39.56$, $MS_e=.037$], Suppressor [$F(1,24)=31.51$, $MS_e=.018$] and Serial Position [$F(1,24)=117.07$, $MS_e=.039$] were all significant with p-values less than .001.

A further analysis split the data from all trials by Suppressor type into two groups: repetitive and varying suppressor. A two-way, within-subjects, ANOVA with Speed of recall (fast or slow) and Serial Position (1-6), did not reveal a significant interaction for the varying suppressor trials [$F(5,120)=1.73$, $MS_e=.0069$, $p>.13$]. However the interaction between Speed of recall and Serial Position was significant for the repetitive suppressor trials [$F(5,120)=6.17$, $MS_e=.0070$, $p<.001$]. A post-hoc Newman-Keuls test indicated that the fast and slow conditions differed in all serial positions except the first, p's < .05.

Discussion

Figure 6 shows that the two fast conditions, 1S and 1D, took approximately equal amounts of time to complete. But the two slow conditions, 5S and 3D, required different amounts of time on average. Hence recall accuracy differences for the slow condition could have been influenced by this time discrepancy. If participants had more time they might have used it to rehearse and this would lead to better rates of recall for the 5S condition than the 3D condition.

Prediction one posited that the passage of more time would lead to worse performance and Experiment 1 supported this decay hypothesis. This can be evidenced by the significant interaction between speed of recall and serial position. When participants took longer to recall the words (the 5S and 3D conditions) their performance was worse as compared to when participants had a quicker recall pace (the 1S and 1D conditions). Moreover this effect occurred across serial positions. Figure 7 reveals hardly any separation between the fast and slow conditions at serial position one; but the fifth and sixth serial positions show a large amount of separation. This is serial fanning and provides strong evidence for decay. Furthermore when the trials were decomposed into repetitive and varying suppressors the interaction between serial position and time was *only* significant for the same trials. This result contradicts Lewandowsky et al.

(2004) who used the same word in between the recall of letters (the word 'Super') but found no evidence for decay.

The second prediction claimed that a varying suppressor, in contrast to a repetitive suppressor, would produce more forgetting. The significant interaction between Suppressor type and Speed of recall supported this claim. This means that more difficult suppressors bind attention better and, as a result, prevent rehearsal more effectively. Insofar as rehearsal is prevented recall accuracy will decline. .

By manipulating the nature of the suppressor in Experiment 1 the observed differences between Lewandowsky et al. (2004) and Barrouillet et al. (2004) can now at least partially be explained. When a suppressor is used that requires more attention, and most likely blocks sub-vocal rehearsal and attention-based refreshing, rehearsal will more effectively be blocked. And the better that rehearsal is blocked the more likely decay can be observed. Experiment 1 has provided support for the decay hypothesis and, simultaneously, contradicts Lewandowsky (2004). So the logical question that now arises is this: what difference between Lewandowsky (2004) and the current study might account for the opposite pattern? Lewandowsky's study only had one type of suppressor whereas Experiment 1 had four conditions and they were randomly presented each time. As a result participants never knew which type of trial to expect and this could have influenced their ability to recall the letters. The next experiment will reduce the number of conditions to better match that of Lewandowsky and make the comparison between the two studies more equal.

Experiment 2

Introduction

Experiment 1 produced findings inconsistent with the work of Lewandowsky and colleagues (2004) despite the implementation of a very similar methodology. Experiment 2 is a simpler version of Experiment 1 in that only two conditions are used: a fast and slow pace of recall with a repetitive suppressor. By excluding the conditions with a varying suppressor a more precise analysis of the effects of pacing at recall can be ascertained. It is still predicted that a difference in memory recall will emerge between the fast and slow conditions, further supporting the hypothesis of decay.

Method

Participants. 24 students (15 female, 9 male) at the University of Missouri-Columbia participated in a one hour session. Their participation counted towards fulfillment of course credit of an Introduction to Psychology class. Good typing skills served as a prerequisite for participation.

Apparatus, stimuli, and procedure. A visual overview of Experiment 2 is presented in Figure 8. The only difference between the current experiment and Experiment 1 is that, instead of having suppressors that vary and are constant, only a constant suppressor is used. The fast and slow paces of recall for this repetitive suppressor will be retained, however. In the fast recall condition participants spoke the same single number out loud once within a 750 ms interval in between typed responses. This number was always the same number, 13, for the entire experiment. In the slow recall condition participants spoke a five-number series out loud within a 2750 ms interval in between typed responses. The series was always the same, 13-14-15-16-17, for the entire experiment. The two trial types were randomly presented every two trials. The design remained within-subjects; but instead of 96 trials (24 trials per each of four conditions, as in Experiment 1) there were only 48 trials in Experiment 2 (24 trials each in the fast and slow conditions.) The remainder of the procedure is identical to Experiment 1.

Results

The main effects of speed [$F(1,23)=59.01$, $MS_e=.021$, $p<.001$] and serial position [$F(5,115)=87.28$, $MS_e=.020$, $p<.001$] were both significant. Additionally the two-way interaction between speed and serial position was significant [$F(5,115)=2.91$, $MS_e=.0075$, $p<.017$]. These results are evident in Figure 9.

The RT data can be found in Figure 10. The mean RT, averaged across all six serial positions, for the Fast condition was 1416 ms (with a standard error of 81 ms) while the mean RT for the Slow condition was 3326 ms (with a standard error of 116 ms).

Discussion

Experiment 2 provided further evidence that time can account for differences in memory recall in a serial recall task. At the very least, even if one is hesitant to accept the hypothesis that time causes forgetting, the results still diverge significantly from the findings of Lewandowsky et al. (2004) who made a strong case that different recall paces (tantamount to shorter versus longer amounts of time to recall letters) do not lead to different rates of forgetting.

Experiments 1 and 2 essentially replicated the original Lewandowsky et al. (2004) study in its method. Despite this close correspondence, the results differ. What other factors might be accounting for this discrepancy?

First the current study controlled the delay between the end of the stimulus list and recall of the first item, whereas Lewandowsky et al. (2004) appeared to have influenced the pace of recall only after the first item in recall. Perhaps their participants mentally reorganized their representation of the stimuli during the preparatory interval before the first item in the list was recalled, making the memory trace more stable and resilient to the effects of time. Another possible difference is in the presentation of the instructions. Participants in Lewandowsky et al. (2004) read the recall pace instructions at the beginning of each trial, after the stimulus presentation, whereas in Experiments 1 and 2 of the current thesis participants only knew which suppressor type they would be presented by virtue of the first number presented. Perhaps having the foreknowledge of suppressor type could allow for more attention being allocated to rehearsal. Finally the procedure implemented here was a mixture of the procedures Lewandowsky et al. (2004) used in their Experiments 1 and 2. In their first experiment, lists were visually presented and the timing of recall was controlled with pacing instructions between the list and the recall. In their second experiment, lists were acoustically presented and the timing of recall was controlled with the pronunciation of one, two, or three repetitions of a word between the recall of each word and the next. The current study used visual presentation of all stimuli (as in their Experiment 1) but controlled the pacing of recall by having the participant pronounce distracting stimuli a variable number of times between recalls (as in their Experiment 2). Any of these differences might account for the divergent findings; but as it turned out the actual explanation arose from a difference in the suppressor manipulation.

Experiment 3

Introduction

Saying '13-13-13-13-13' as a suppressor versus '13-14-15-16-17' over recall is sufficiently different to lead to differing rates of recall accuracy. A similar subtle difference in suppressor type led to divergent results in serial recall accuracy in a study by Lewandowsky, Geiger and Oberauer (in press). That study did not actually utilize numbers as a suppressor; but if their logic was implemented it would be expected that those different sets of suppressors would lead to different rates of recall. In the Lewandowsky, Geiger and Oberauer study (in press) participants spoke aloud either 1 or 3 suppressors, which were the names of the months. This number of spoken suppressors corresponded with the pace of recall: a single spoken suppressor equaled a fast recall pace whereas three spoken suppressors was a slow recall pace. These suppressors could either be simple (the same month) or complex (different months). In addition, the suppressors could be steady or changing across recall. If they were steady then the months used after the first recalled letter were the same ones used for the recall of all letters. But if they changed then the months used were always different in between each recalled letters. To better illustrate these conditions the suppressor cases will be examined. 'January-January-January' across all recall positions would be same-steady. 'January-February-March' across all recall positions would be complex-steady. 'January-January-January' after the first recalled letter, 'February-February-February' after the second recalled letter, and then March, April, May spoken three times after the third, fourth and fifth recalled letters, respectively, was same-changing. And complex-changing would be ‘January-February-March’ after the first recalled letter, ‘April-May-June’ after the second recalled letter, ‘July-August-September’ after the third recalled letter, ‘October-November-December after the fourth recalled letter and ‘January-February-March after the fifth recalled letter.

Most significantly the same steady condition, or saying the same months out loud all the way throughout recall, the slow and fast recall paces did not diverge. If numbers had been used this would mean that saying a single ‘13’ out loud would not differ in recall accuracy from saying ’13-13-13’ out loud. However in the same complex condition, equivalent to saying ‘January-February-March’ across all recall positions for three suppressors or just ‘January’ for the single suppressor recall accuracy for the fast and slow recall paces diverged. Translating the logic of these outcomes into suppressor numbers this would be the same as a condition where participants were required to say ‘13’ out loud in between each recall position versus ’13-14-15-16-17’ out loud in between each recall position. And this would be expected to lead to divergent recall accuracies for the fast and slow paces of recall. Experiment 2 results of the current thesis map perfectly onto the experimental results obtained by Lewandowsky, Geiger and Oberauer (in press) using months instead of numbers. To further buttress the argument they used arbitrary words at recall instead of the well-memorized months of the year in another experiment to obtain identical results.

Their interpretive framework construed the different outcomes arising from the subtle difference between same-steady and same-complex conditions as due to interference and not decay. The logic was that differing stimuli, even if the same ones are used across recall, add a little bit of additional interference that actually drives the serial fanning effect observed between a slow and fast pace of recall. Moreover, even from the rehearsal perspective, any difference in the nature of the suppressor should be expected to lead to different recall results because a more demanding suppressor, even if only slightly so, will better prevent rehearsal. So even though '13-13-13-13-13' seems identical to '13-14-15-16-17' the latter condition actually requires a little more attention and has a little more interference than the latter and, as a result, leads to worse rates of recall than the former condition..

So what clearly looked like evidence for decay in Experiments 1 and 2, based on the new findings of Lewandowsky, Geiger and Oberauer (in press), can actually be reinterpreted as evidence for an interference position. This illustrates perfectly the nature of the problem of trying to discern the cause of forgetting in short-term memory. None-the-less one further attempt was made to use suppressors across the entire recall interval to document the case for decay. In this version a participant spoke a consistent suppressor; but the pace was inconsistent. The inconsistent pace should require more attention but not introduce more interference.

In order to test this prospect five conditions were used. As in Experiments 1 and 2 there was still a fast and slow pace of recall (either 750 or 2750 ms). The suppressor was always the number 13. In the novel condition added for Experiment 3 participants had to speak either three or four 13's at an irregular pace. This was implemented by having one or two pauses, where participants said nothing aloud, interjected in the string of suppressors. This condition alternated 13's with pauses, and the sequence of this alternating varied across recall. The details of this implementation are elucidated in the Methods section below.

In introducing this novel manipulation two goals were sought. First it would keep the nature of the suppressor constant which is very important for not introducing extraneous interference. Second, and equally important, the amount of time to speak the suppressor would be longer than speaking a single 13 but take the same amount of time as saying a series of five 13's. This is important, because, if a difference emerges between the irregular paced slow condition and the fast condition, a strong argument can be made for forgetting over time and not forgetting due to interference.

Two predictions were posited for Experiment 3. The first is that the recall accuracy in the novel condition would be significantly worse than the recall accuracy than in the conditions where the suppressor is constant. This will happen because, in addition to just the number of suppressors being spoken, the attention required in the timing of the irregular suppressor will be more than speaking a string of constant suppressors. The second prediction is that serial fanning will be manifest in comparing the irregular slow condition to the fast condition. This would provide evidence for decay. It should be expected that the conditions in the current study, mimicking the 'January' versus 'January-January-January' condition of Lewandowsky, Geiger and Oberauer (in press), should not lead to a separation of the serial recall curves. That is, there should not be a separation of serial recall curves between the single 13 condition and the five spoken 13's.

Method

Participants. 31 students (19 male, 14 female) at the University of Missouri-Columbia participated in a one hour session. Their participation counted towards fulfillment of course credit of an Introduction to Psychology class. The data for two participants was removed from analysis because they failed to fully comply with the articulatory suppression procedure.

Apparatus, stimuli, and procedure. The current study consisted of five conditions. Two of these were baseline conditions where participants did not say anything in between the recall of letters, termed 0 Fast and 0 Slow, where the Fast refers to 750 ms and the Slow refers to 2750 ms. Two of the remaining three conditions were the speaking of a constant suppressor, '13', out loud either once or five times. The former is called 1 Fast while the latter is called 5 Slow. The final condition is the novel one introduced for this study where the speaking of the number 13 was paced irregularly. It is called 3 or 4 Slow because the participant would always speak either 3 or 4 '13's' in a 2750 ms interval of time. For clarity these five conditions are laid out in Figure 11.

In the 3 or 4 Slow condition a blank underscore character represented a pause. Participants were instructed to "pause for the precise length of time it would take to say the number of 13 but not actually speak the word 13 out loud or silently during those pauses". In this condition the suppressor sequence always began and ended with a 13. The middle three positions could either be a single 13 and two underscore characters or two 13's and a single underscore character. The order of presentation of these middle three positions always varied from one serial recall position to the next within a trial and the precise order of digits and underscore characters was always randomly selected.

In the 3 conditions where participants were required to speak a suppressor out loud they were instructed, and trained, to begin speaking the suppressor with its onset on the screen and complete speaking the last digit just as the next screen appeared. The 5 conditions were presented in a within-subject design and, for a given set of 5 trials, each of the conditions was randomly selected to appear once. There were a total of 100 trials, for a total of 20 trials of each condition per participant.

Each trial began with the presentation of six lowercase letters, serially presented, at the vertical and horizontal center of the computer monitor. Each letter appeared on the screen for 400ms and the inter-stimulus interval between letters, consisting of a blank screen, lasted for 100ms. After all 6 letters were presented a 'Recall' appeared in the center for 500 ms to prompt the beginning of recall. Following the recall screen the participant was prompted to recall, and type, the first letter that they had been presented with. After typing that letter the suppressor was presented on the screen and, if it was not a baseline condition, the participants spoke the number(s) out loud. After the screen containing the suppressor(s) the prompt to type the next letter was presented. This sequence, of alternating between typing a letter and saying the presented suppressor, continued until all 6 letters had been recalled. The participant pressed the space bar to begin the next trial. Figure 12 shows the procedure for Experiment 3.

Results

The two-way interaction between Serial Position (1-6) and Condition (0 Fast, 1 Fast, 0 Slow, 3 or 4 Slow, 5 Slow) was significant [$F(20,600)=16.85$, $MSe=.007$, $p<.001$]. Both main effects were also significant. The results of this Serial Position by Condition interaction are presented in Figure 13.

Since the gross analysis of all 5 conditions interacting with serial position revealed a significant result a more refined analysis was executed on just the 1 Fast, 3 or 4 Slow and 5 Slow conditions. These results still produced a significant two-way interaction of Serial Position by Condition type [$F(10,300)=16.84$, $MSe=.007$, $p<.001$]. The main effect of Serial Position [$F(5,150)=102.3$, $MSe=.040$, $p<.001$] and Condition [$F(4,120)=82.4$, $MSe=.021$, $p<.001$] were also significant. These results are presented in Figure 14.

The RT data for Experiment 3 is in Figure 15. The reaction times for the first serial position are equivalent for all conditions. This is due to the fact that no time elapsed, or no suppressor was uttered, before the first serial position. The first serial position, then, reflects this reaction time without any manipulation. But a manipulation did precede serial positions two through six, thus accounting for the similar RT across the remaining positions.

Discussion

Experiment 3 provides powerful evidence for the operation of decay. It is represented by clear serial fanning in Figure 14 in contrasting the 1 Fast with the 3 or 4 Slow or the 5 Slow conditions. Decay is defined as the decrease of recall accuracy over time and, so, for a condition that takes longer to recall (either the 5 Same or 3 or 4 Same) performance should be worse compared to a condition that is quicker to recall (1 Fast). This was expected because the 3 or 4 Slow condition more effectively blocked attention than the 1 Fast condition, thereby preventing rehearsal more effectively and thus allowing for decay to be observed.

Experiment 3 clearly supports a decay hypothesis; but it simultaneously provides mixed evidence for the role of interference. Figure 13 shows a main effect of condition when comparing the 3 or 4 Slow and the 5 Slow conditions. This main effect reflects a decrease in recall accuracy for the 3 or 4 Slow condition compared to the 5 Slow condition; but this effect does not interact with serial position and, as a result, is not decay. Hence this difference can be construed as support for interference. But evidence against interference can also be found in Experiment 3. The 1 Fast and 5 Same condition of Experiment 3 are conceptually identical to the study of Lewandowsky, Geiger and Oberauer (in press) where participants spoke 'January' for the fast condition and 'January-January-January' for the slow condition. But in that study recall accuracy did not separate for the fast and slow conditions. In the current study, saying '13' led to better recall accuracy compared to saying '13-13-13-13-13' across time. The findings of Lewandowsky et al. (in press) do not predict serial fanning between these two conditions. A possible explanation to account for why the separation between the fast and slow condition manifested here is due to the fact that these two conditions were embedded within the context of a condition with irregular pacing. Participants may have adopted a strategy of perceiving, and speaking, each number as a discrete units and not a single chunked item because of the irregular condition containing pauses and 13's and then continued to use this strategy in speaking all suppressors. The consequence of this strategy is that discrete units require more attention to utter and, hence, will lead to worse performance. This strategy was probably only adopted in the context of a condition with an irregular pace. In an experiment without this irregular pace the effect should vanish.

Chapter 3

The first three experiments utilized a constant suppressor between each serial position during recall in order to allow decay to be observed. The evidence from these experiments provided strong support that decay should continue to be considered a viable mechanism to explain forgetting in short-term memory. However, because a suppressor was introduced to prevent rehearsal to observe this decay, the role of interference cannot entirely be ruled out as an explanation for the forgetting. The question still remains for any experiment that introduces a suppressor to block decay: does accuracy in memory recall drop because of the passage of time or because the suppressor interfered with the items to be remembered?

To address this question experimentally it is necessary to implement the following logic: Rehearsal must be blocked to observe decay; but in order to prevent interference extraneous suppressors must not be introduced. One way to achieve this goal is to introduce a manipulation that introduces interference in some trials, but not others. Those trials that actually introduce interference would be discarded from the analysis while those that did not contain any experimenter introduced interference would be the ones examined for evidence of decay. The key, however, is that this suppressor must be strong enough, or attentionally demanding, so that it prevents one from rehearsing even in trials where there is not any interference in the trial.

The suppressor chosen was a digit search task. In this task a digit could randomly appear before any one of the six serially recalled letters but the participant would never know which position it might occur in nor on which trials it might appear. Moreover because the digit was presented very quickly the participant always had to be vigilant.

The requirement to always search for a digit demands attentional resources; but it would only introduce interference in the trials where a digit was actually presented. In the other trials not containing the digit the participant would still need to search but would never find an item because one would not be present. In these latter types of trials it could be claimed that rehearsal would be blocked while interference was not introduced and if memory accuracy decreased it could strongly be argued that the decline was due to decay and not interference. Of course all of this rests on the assumption that a search task can prevent rehearsal even on trials without an item to be searched for.

A precedent exists that searches embedded in a working memory task can impair recall (Reitman, 1974). In Reitman's study participants were required to memorize a series of four nouns. Before they recalled the words they engaged in one of two possible search tasks. One search consisted of detecting "toh" presented in a series of "doh" utterances. In a 15 second interval "toh" could be presented between 0 and 14 times. So it was possible that the differentiation never had to be made or it could have occurred a maximum of 14 times. It was necessary to allocate attention to listening for the utterance. If "toh" was heard a key was pressed. The other possible search task before recalling the words was tonal detection. This consisted of detecting a pure tone (100 msec, 1000 Hz square wave) in white noise and, once again, pressing a key if the tone was present.

The question that Reitman (1974) asked was whether rehearsal interfered with tonal detection. It was determined that when participants engaged in the pure tone detection task this disrupted memory recall by 15% whereas the syllable detection task disrupted memory recall by 56%. These percentages were derived from a comparison to a baseline condition where the words were recalled after 15 seconds but did not have a search task. Obviously this study documents how a search task can impair memory recall.

The following set of three experiments rest on the finding of Reitman (1974) and the foregoing logic. A single digit was searched for in the context of the serial recall procedure. But the digit was only in some trials. The trials that actually had a digit were separated from those without a digit in the analysis so as to determine if a loss in memory recall performance was due to the inability to rehearse or interference. Perceptual interference is the term used for searching for a digit but not having one present. Actual interference denotes searching for a digit when a digit was actually present. If the logic is correct, and the methodological implementation of this logic is strong enough, then it is expected that trials with perceptual interference will demonstrate decay.

Experiment 4

Introduction

The serial recall paradigm used in the first three experiments was retained for Experiment 4. Moreover the fast and slow conditions at recall were also retained. But instead of manipulating recall pace there was only a short or long blank interval in between each of the typed letter responses. This change removed the possibility of the numbers interfering with the letters and created baseline conditions where no suppressors were spoken. The other change is that in half of the trials a single target number was briefly flashed in between the typed recall of the letters and the participant had to identify it. This required attention and, if demanding enough, would suppress rehearsal to make decay observable. On the trials without a target number, less attention was required because a number was never identified. So the current study made two predictions. The first is that recall accuracy would be worse for the trials with an embedded target digit (actual interference) than trials without a target digit (perceptual interference only). And the second is that, in the trials without a target number, a speed by serial position interaction would manifest.

Method

Participants. 11 students (3 male, 8 female) at the University of Missouri-Columbia participated in a one hour session. Their participation counted towards fulfillment of course credit of an Introduction to Psychology class. Good typing skills served as a prerequisite for participation. Given the within-subjects design of the experiment, all participants were exposed to both conditions of the study.

Apparatus, stimuli, and procedure. Fast and slow paces of recall were still utilized, reflecting time intervals of 750 ms or 2750 ms in between each typed letter during recall. There were only two conditions: No Number and Number. In the No Number condition there was only a blank interval in between each of the serially recalled letters and these 48 trials comprised half of the experiment. The Number and No Number conditions were randomly presented so the participant did not know which trial type to expect.

In the Number condition the target digit could temporally precede any one of the typed recalled letters in one of the six possible intervals. This interval was always randomly chosen for each trial. This number was only presented for 35 ms and it was followed by a mask (the pound sign, '#') for 200 ms. The number was always a single digit, randomly chosen, from the set of digits between 0 and 9. The digit was centrally presented on the screen. The onset of this number could occur anywhere between 0 ms of the interval (the very beginning) all the way up to 235 ms before the interval ended and the possible increments of onset increased by 35 ms. So, for instance, number onset could be 0 ms, 35 ms, 70 ms, 105 ms or any multiple of 35 ms. This onset time was always randomly determined within a given interval. A visual overview of just the recall portion is provided in Figure 16.

As with all previous variations of this experiment the participant had to memorize the 6 letters as they were initially presented. Typed recall of these letters, in their correct serial position, was also identical as before. If participants were in a No Number trial then they were free to rehearse the letters, though no specific instructions were provided to do so. They would, as before, type the letter with each '?' prompt and their previous typed responses would be reflected back. In the Number condition letters would be recalled as in the No Number trials. But whenever a participant saw a target digit they had to type the number that they saw instead of the next serially recalled letter. Then the participant would skip that letter for which the number had substituted and recall the next letter for the next serial position.

Results

To determine if the perceptual interference (No Number trials) versus actual interference (Number trials) manipulation was effective all trials were collapsed into two groups: Number or No Number. The main effect of this analysis was significant [$F(1,10)=11.04$, $MS_e=.009$, $p<.01$].

For the next analysis the 48 Number trials were discarded. Only 48 No Number trials were included in what follows. The two-way interaction between Serial Position and Speed was not significant [$F(5,50)=.93$, $MS_e=.005$, $p<.48$]. The main effect of Speed was not significant [$F(1,10)=.0005$, $MS_e=.006$, $p<.99$] but the main effect of Serial Position was significant, however [$F(5,50)=7.63$, $MS_e=.019$, $p<.001$]. These results are presented in Figure 17.

The RT data from Experiment 4 can be found in Figure 18. The mean RT across all serial positions for the Fast condition was 1595 ms (with a standard error of 107 ms) and the mean RT for all serial positions in the Slow condition was 2696 ms (with a standard error of 82 ms).

Finally, whenever a target digit was presented, participants perceived this digit 73% of the time on average. This average is based on a participant typing any digit in the serial recall position immediately following the presentation of the digit. On the remaining 23% of the trials participants typed a letter instead of a digit. Furthermore they only correctly identified the same digit that was presented on 57% of these trials where a number was perceived. The rate of correct identification of the digit stands in contrast to the rate of correctly typing the serially recalled letter which, on average, was 84% for all trials where a target digit could appear.

Since the timing of the presentation of the digit was critical for this study the data for presentation rates are included. The programmed duration of the target digit was 35 ms in the E-prime software used in the current study. The average refresh rate for the computer screen in the experiment was 75.03 Hz. Dividing 1000 ms by this refresh rate equals a screen refreshing every 13.3 ms. Stimuli can only be displayed at multiples of this screen refresh rate. Therefore the digit would either have been displayed for 26.7 ms (13.3 times 2 refreshes) or 40.0 ms (13.3 times 3 refreshes).

Discussion

Based on the significant main effect arising from comparing the Number and No Number trials it is apparent that recall accuracy was indeed impacted by whether interference was actually present or just anticipated. Hence the first prediction was supported.

The second prediction, that a Speed by Serial Position interaction would occur for the No Number Trials only, did not find support in Experiment 4. In order for this effect to emerge rehearsal would have had to have been effectively suppressed. There is some reason to suspect that participants were not fully allocating attention to always looking for the number. And if they were not always anticipating a number then it stands to reason they could be allocating attention to rehearsal.

When participants were presented a number, and if they were always seeing that number and paying attention by looking for it, they should have been typing a number around 100% of the time. But in reality they only typed a number, on average, 73% of the time. This value does not reflect whether that typed number was identical to the number flashed but only whether they typed any number after being presented with a digit. Since the identification accuracy was less than optimal it is possible that participants were allocating attention to rehearsing instead of looking for a digit.

Moreover the tradeoff between the speed of presentation of the digit and the participant's perceptual ability to identify the digit may have been compromised. Morey has indicated, based on research in their lab, that participants need about 250 ms of time to correctly identify a digit correct nearly every time (R. Morey, personal communication, March 8, 2008). On one hand it might seem reasonable to increase the presentation of this digit to its most optimal perceptual window. But it needs to be borne in mind that insofar as the participants have plenty of time to see the digit, and would always be assured to see it even if their attention is tied up by rehearsal, the distinction between actual and perceptual interference would break down because participants need to allocate attention to search for the target digit. So the next experiment will compromise on this position by increasing the presentation of the digit by a small amount to facilitate its perception but not so much so that participants can rehearse fully.

Experiment 4 provided preliminary support that the actual versus perceptual interference method has potential to tease apart decay from interference; but the current application was not effective. The next experiment modified the procedure in an attempt to rectify this situation.

Experiment 5

Introduction

A clear outcome from the previous experiment is that creating an actual and perceptual AS condition is effective at influencing recall. But it fell short in finding the operation of decay in trials without any AS. This failure may have been due to a couple of factors.

First the current study increased the presentation of the digit in the Number trials to 50 ms. While this is still fast it is more perceptible than 35 ms. But it is not so slow that the participants could have completely ignored the task of looking for a target digit. They always needed to be vigilant and this tied up some attention that would otherwise have been allocated to rehearsal.

Second the two different trial types, Number and No Number, were blocked. Moreover the participants always knew which block they were in. The objective was to make participants more aware of the possible presence of a target digit, thereby leading to a greater likelihood that an effect of looking for the number might emerge in the Number block that does not have a target digit. Within the Number condition the trials were split in half where some trials contained the target number while the other trials were identical to the No Number condition trials. The target number trials were excluded from the analysis as before.

Once again it was predicted that recall performance in the No Number block should be significantly better than recall performance in the No Target trials of the Number block.

Method

Participants. 25 students (16 male, 9 female) at the University of Missouri-Columbia participated in a one hour session. Their participation counted towards fulfillment of course credit of an Introduction to Psychology class.

Apparatus, stimuli, and procedure. The current study was identical to Experiment 4 in that there was still Number and No Number trials. It differed, however, in that these two conditions were blocked. In the No Number block there was only a blank interval in between each of the serially recalled letters and these 48 trials comprised half of the experiment. In the Number condition there were two trial types. One of the trial types, which comprised 24 trials of the Number condition, was identical to the No Number condition, containing just a blank interval of short or long duration (depending on the speed of recall). These trials are called the No Target trials of the Number block.

In the other 24 trials of the Number block, called the Target trials, a single digit number appeared in one of the six intervals preceding the recalled letter. In the Number condition the Target and No Target trials were randomly presented. The Number and No Number conditions were blocked and the order of assignment was randomized by participant. Moreover the participant was reminded of which block he or she was working on at the beginning of each trial.

In the Target trials of the Number condition the digit could temporally precede any one of the typed recalled letters, manifesting in one of the six possible intervals. The interval for the location was always randomly chosen. This number was only presented for 50 ms and it was followed by a mask (the pound sign, '#') for 200 ms. The number was always a single digit, randomly chosen, from the set of digits between 0 and 9. The digit was centrally presented on the screen. Depending on the speed condition (either 750 ms or 2750 ms) the onset of this number could occur anywhere from 0 ms of the interval (the very beginning) all the way up to 250 ms before the interval ended and the possible increments of onset increased by 50 ms. So, for instance, number onset could be 0ms, 50 ms, 100 ms, 150 ms, etc. and the chosen onset time was always randomly determined within a given interval. Figure 19 presents a diagram of the procedure for a fast recall condition for a Target trial of the Number block and a No Number trial.

Results

To test whether blocking the Number and No Number trials was successful a within subjects ANOVA was performed on the condition type: No Number, No Target of Number and Target of Number Block. A significant main effect emerged for condition [$F(2,48)=21.82$, $MSe=.03$, $p<.001$]. These results are illustrated in Figure 20.

The next part of this analysis excluded Target trials from the Number block. So this means that for each participant, 48 trials from the No Number block (24 fast and 24 slow) were compared to 24 No Target trials in the Number block (12 fast and 12 slow). The triple interaction among Serial Position, Speed (fast or slow) and Number condition was not significant [$F(5,120)=1.10$, $MSe=.005$, $p<.37$]. The graph featuring this non-significant triple interaction can be seen Figure 21. None of the two-way interactions were significant and the only significant main effect arose with Serial Position [$F(5,120)=14.11$, $MSe=.042$, $p<.001$].

Figure 22 provides the RT data from Experiment 5. It is evident that the fast and slow rates of responding, whether a Target Digit was present or not, nearly overlap.

Finally, whenever a target digit was presented, participants perceived this digit 88% of the time on average. This average is based on a participant typing any digit in the serial recall position immediately following the presentation of the digit. On the remaining 12% of the trials participants typed a letter instead of a digit. Furthermore they only correctly identified the same digit that was presented on 60% of these trials where a number was perceived. The rate of correct identification of the digit stands in contrast to the rate of correctly typing the serially recalled letter which, on average, was 79% for all trials where a target digit could appear.

Once again since the timing of the presentation of the digit was critical for Experiment 5. The programmed duration of the target digit was 50 ms in the E-prime software. The average refresh rate for the computer screen in Experiment 5 was 75.01 Hz. Dividing 1000 ms by this refresh rate equals a screen refreshing every 13.3 ms. Stimuli can only be displayed at multiples of this screen refresh rate. Therefore the digit would either have been displayed for 40.0 ms (13.3 times 3 refreshes) or 53.3 ms (13.3 times 4 refreshes).

Discussion

The effect of blocking the Number and No Number trials was still effective at leading to differences in recall accuracy for the different conditions. The increased presentation of the Target digit to 50 ms might also have contributed to this effect. However this difference between perceptual and actual interference did not hold up when the trials were analyzed for the presence of decay.

It is worth noting that the increased rate of presentation of the target digit increased the rate of identification of a target digit compared to the previous experiment where it was only presented for 35 ms. In the current Experiment identification of the digit was 88% whereas in Experiment 4 this identification rate was only 73%. Even though the change in the time of the presentation of the target digit did not produce a decay effect this effect does show that participants were paying more attention to the digit search task.

So, while this method might conceptually represent the most ideal approach to tease apart decay from interference, it is apparent that achieving this ideal has proved elusive to achieve experimentally. The final experiment combined suppression with the target digit search task.

Experiment 6

Introduction

The current study nearly replicated Experiment 5. The only addition was constant articulatory suppression during recall where participants spoke 'THE' aloud throughout recall. Perhaps Experiments 4 and 5 were not attentionally demanding enough for the Target digit search to be effective. But adding suppression that prevents sub-vocal rehearsal might be necessary for the digit search to block attention refreshing. And both forms of rehearsal must be blocked to observe decay.

Method

Participants. 28 (14 male, 14 female) students at the University of Missouri-Columbia participated in a one hour session. Their participation counted towards fulfillment of course credit of an Introduction to Psychology class. The data for two participants was removed from analysis because one accidentally aborted the experiment prematurely and another failed to comply with the articulatory suppression procedure.

Apparatus, stimuli, and procedure. The current study repeated Experiment 5 precisely with the exception of the addition of articulatory suppression (AS). As soon as the letters to be remembered had been presented participants saw the word 'THE' presented in the center of the screen. They were instructed to begin speaking this suppressor out loud, at the rate of two utterances per second, at the onset of this prompt. And they continued to speak 'THE' aloud at the same rate, all throughout recall, until all letters had been recalled. Participants were trained in the pacing of the AS procedure for 20 practice trials before the experiment began. Continued compliance of AS throughout the experiment was monitored from the outside of the testing booth by a two-way radio system. Figure 23 demonstrates this procedure.

Results

To assess the effect of the AS manipulation the three trial types were compared: No Number, No Target in the Number Block and Target in the Number Block. A 6*2*3 within-subjects ANOVA, with Serial Position (1-6), Speed (Fast or Slow) and Block type (No Number, Target trials of Number Block, and No Target trials of Number Block) was executed. The triple interaction did not reach significance [$F(10,230)=.63$, $MSe=.011$, $p<.80$] nor did any of the two-way interactions. See Figure 24 for these results. The main effect of condition reached significance [$F(2,46)=3.27$, $MSe=.080$, $p<.047$], however.

Target trials from the Number block were excluded from this next analysis. The 6*2*2 triple interaction among Serial Position (1-6), Speed (Fast or Slow) and Block type (No Number or No Target of Number Block) was not significant [$F(5,115)=.69$, $MSe=.0117$, $p<.64$]. None of the two-way interactions were significant. These results are presented in Figure 25.

Figure 26 presents the reaction times for the No Target conditions of the Number Block and the No Number conditions. The equivalency of the speeds of recall for the fast and slow conditions is readily apparent.

Whenever a target digit was presented, participants perceived this digit 87% of the time on average. This average is based on a participant typing any digit in the serial recall position immediately following the presentation of the digit. On the remaining 13% of the trials participants typed a letter instead of a digit. Furthermore they only correctly identified the same digit that was presented on 55% of these trials where a number was perceived. The rate of correct identification of the digit stands in contrast to the rate of correctly typing the serially recalled letter which, on average, was 64% for all trials where a target digit could appear.

The timing of the presentation of the digit was critical for Experiment 6. The programmed duration of the target digit was 50 ms in the E-prime software. The average refresh rate for the computer screen in Experiment 6 was 75.01 Hz. Dividing 1000 ms by this refresh rate equals a screen refreshing every 13.3 ms. Stimuli can only be displayed at multiples of this screen refresh rate. Therefore the digit would either have been displayed for 40.0 ms (13.3 times 3 refreshes) or 53.3 ms (13.3 times 4 refreshes).

Discussion

Once again, as in Experiment 5, there was a significant difference in recall accuracy for the three trial types: No Number, Target trials of the Number block and No Target trials of the Number block. This indicated a difference in condition type. However, even adding constant AS, in conjunction with a digit-probe task in some trials, still was not sufficient to block rehearsal so as to observe decay. Once again there is slight evidence for the effect of trial type; but these manipulations did not interact with serial position to provide evidence for decay. As a result, while this approach has demonstrated that a number search can be effective at requiring some attention, it just is not demanding enough to demonstrate decay. Looking for a single number across a total of 6 serial positions is just not demanding enough. Perhaps if the number of items being recalled was only one or two, and a probe-digit had to be identified, then this might be effective at leading to a decay effect. But for the current serial recall paradigm this manipulation is not effective.

Interestingly the suppressor also had the effect of bringing the accuracy rates for the target trials into closer proximity than Experiments 4 and 5. Here the rates for correct responding were 55% for digits and 63% for letters. In Experiment 5, however, these rates were 60% for digits and 79% for letters. This should be expected because speaking a constant suppressor would consume more attentional resources that could otherwise be allocated to rehearsal. And insofar as more resources are being consumed the worse recall accuracy on the serially recalled letters should be.

Chapter 4

Conclusion

Brief Review of Findings

The following section summarizes the key findings from each of the six experiments. Experiments 1, 2 and 3 implemented a suppressor technique which required participants to say suppressors across all recall positions. They all demonstrated effects of decay in that conditions where participants uttered suppressors at recall that took longer to say led to worse performance than uttering suppressors at recall that took less time to say whenever rehearsal was appropriately blocked. Evidence for decay derived from the interaction of recall speed with serial position, a phenomenon called serial fanning. While some of these findings were qualified by recent work of Lewandowsky et al. (in press) to possibly support an interference-based account of forgetting, decay cannot entirely be ruled out. The manipulation driving the effect in Experiments 1 and 2 arose from participants speaking ‘13’ versus ’13-14-15-16-17’. As Lewandowsky et al. (in press) pointed out recall accuracy should separate for the two conditions because the ’13-14-15-16-17’ was actually introducing a small degree of interference by using different numbers, even though the same set of numbers was being used throughout the entire recall interval. But Experiment 3, by virtue of introducing a condition with irregular pacing, still produced strong support for decay that cannot be explained away by interference because the same number, 13, was always used.

Experiments 4, 5 and 6 implemented a perceptual interference approach to observe decay. This procedure required participants to search for a target digit on all trials at recall and, if they ever identified this target digit, they had to type it in place of the letter they normally would have typed. Requiring participants to search for this digit, theoretically, tied up attention that might otherwise have been used for attention-based refreshing. Only some trials contained this target digit. In the analysis for these three experiments the data was examined with the target trials to see if the manipulation was successful at creating differences in recall. It was successful for all three experiments; but the effect did not hold up when the Target trials of Number conditions were removed and the comparisons between the fast and slow conditions were made to check for the presence of decay. Had significant differences been found in comparisons where the trials with target digits had been excluded this would have been compelling proof that interference was lacking and that decay was most likely operating. But in all versions of this manipulation the procedure just was not robust enough to demonstrate differences in memory recall performance. One likely reason for this is that looking for a single digit, over six recall positions at recall, just was not attentionally demanding. And this held even when AS was introduced across all serial positions to block overt rehearsal. Hence this method provided a potentially powerful way to differentiate decay from interference; but the results in the last 3 experiments provided inconclusive results.

Conclusions and Implications

Should decay continue to be entertained as a viable mechanism to explain forgetting in short-term memory? The evidence from this set of studies, especially Experiment 3, argues convincingly that decay theory should not be abandoned. This evidence supporting decay is important also because some theorists (Lewandowsky et al., 2004) have argued that decay does not exist At the very least this research requires proponents who claim only interference operates to refute these findings that support decay.

This finding should not be construed as the last word on decay. Without evidence from an ideal method that blocks rehearsal without introducing interference an explanation of forgetting in short-term memory cannot definitively rule out decay or interference at this point in time. Thus research must continue to update and debate each new piece of evidence supporting or refuting decay or interference.

One possible compromise in understanding forgetting in short-term memory is to accept the premise that perhaps both interference and decay operate and play a role. Barrouillet et al. (2004) advocate a “time-based resource sharing” which might exemplify such a compromise between the two sides of the debate. This theory claims that the passage of time is instrumental in forgetting as items that are held longer are less likely to be recalled. But it simultaneously posits that attentional allocation possibly mediates this likelihood of forgetting. When more attention is consumed by engaging in a secondary task, like doing math problems, this prevents that attention from being allocated to rehearsing the stimuli to be remembered but it simultaneously interferes with the items to be remembered. So maybe it is this interference over time that is the true state of affairs.

Future Directions

Perhaps one of the most fruitful and immediate extensions of the foregoing research is to continue to explore how different types of suppressors differentially impact forgetting in a short-term serial recall task. Experiment 3 provided strong evidence that the pacing of a suppressor can significantly draw down attentional resources. The net effect of diminished attention is reduced recall accuracy. Another possibility which will be explored in a future study is how different rates of finger tapping, either in isolation or in conjunction with speaking a simple suppressor, impact forgetting. It is expected that the tapping and speaking will be more difficult than tapping alone and, furthermore, when irregular patterns of tapping and speaking are used this will lead to an even greater reduction in ability to recall than regular tapping patterns.

Another possibility is to consider secondary tasks that rely on a different modality, like a tone search or a choice-reaction task. The Reitman study (1974) relied on a bimodal approach in that the words to be remembered were presented visually whereas the tones were aurally presented. Perhaps having the primary task presented in one modality and the secondary task in a different modality is necessary to achieve decay. But more importantly a bimodal task could buttress the argument that decay is operating instead of interference because the stimuli would be very different from one another. Using non-verbal suppressors also allows for the possibility that the number of suppressors does not need to be considered. When the suppressor is verbal in nature, as in the first three experiments, one can obviously count the number of suppressors uttered. But when one engages in a search task, for instance, the attentionally demanding nature of that task need not be evaluated exclusively on how many items are searched for. It might also depend upon the pitch or the loudness, for instance, if a tone search task was used. This could be advantageous because the interference-based side of the debate might claim that just having more suppressors, even if they are the same creates additional interference. Decay, as a time-based theory, does not necessarily depend on the number of suppressors but only on differences in time between two or more conditions when rehearsal is suppressed. And rehearsal need not necessarily be prevented by adding more suppressors, just as Experiment 1 indicated that different types of verbal suppressors are better at preventing rehearsal than others.

Coupling two or more suppressor activities might even be more effective at tying up attention and allowing decay to emerge than just a single suppressor. And if having the items to be remembered are presented in a different modality than the secondary task then perhaps having two different tasks in different modalities might genuinely suppress rehearsal even further but simultaneously not introduce interference.

In Experiment 3 one explanation for the strategy used by participants in uttering the suppressor was that they could not chunk the suppressor as one item because the irregularly paced item caused them to process each item separately. A further study could test the logic that participants chunk suppressors to be spoken instead of speaking each suppressor individually. This is one strategy participants might have learned to utilize in the irregular paced condition and continued to use it in all conditions. This could be done simply by running two experiments. One experiment would contain an irregular paced condition with 5 same suppressors. In the other experiment only 3 or 4 suppressors would be used, but with regular pacing, and this would be compared to a 5 suppressor condition in the same experiment. If participants do not adopt a different strategy for the irregular pacing then recall accuracy in the 5 same suppressor condition should be the same for both experiments. But if there is a genuine difference for this condition between the two experiments, then this would support the fact that the irregular pacing is probably forcing participants to rely on a different strategy. While this result would not guarantee that the strategy being used is a chunk versus discrete item approach to processing the suppressor it would lend support to the supposition.

Other research could also pick up where the perceptual interference failed here. Experiments 4, 5 and 6 demonstrated that searching for a Target digit consumes some attentional resources, probably those otherwise used for attention-based refreshing. But searching for a single digit was just not demanding enough. Perhaps if participants had to search for multiple digits over recall, instead of just one, more attention would be required. In the previous experiments, once a target digit had been found participants did not need to devote attention to looking for another one. As a result they could rehearse freely again. But if a different number of digits, anywhere from zero to six, could be presented across the recall period, then this might consume more attention and produce different results. Another possibility is to introduce a search task that relied on a different modality than the one in which the to-be-remembered items were presented in. This would be quite like the Reitman (1974) study.

The series of studies presented in this thesis apply only to forgetting in serial recall in short-term memory. A very closely related, and important, avenue of further research would be testing the effects of all these manipulations at encoding using the same paradigm. For instance if the perceptual interference approach implemented in Experiments 4, 5 and 6 were used at encoding an effect of decay might manifest. For encoding is probably a lot more vulnerable to the influence of suppressors because the memory trace is less consolidated and, as a result, a suppressor that was powerless at recall to evoke differences in recall performance might prove quite effective at encoding. Or would having an irregular suppressor in between items that are being encoded be more detrimental to memory loss than at recall? Since the memory trace is more fragile at encoding it might be expected these manipulations would be more effective at causing forgetting. But also, since they would be introduced at the same time as the stimuli are being remembered, interference would have to be judiciously monitored.

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Tables

Table 1. Results from Brown (1958). Number of letter pairs correctly recalled by condition. Condition 1 required speaking digit pairs out loud while Condition 2 contained a silent interval. Maximum refers to the total number of trials possible in a given condition.

Table 1: Results from Brown 1958

	Number of required stimuli (letter-pairs)			
	1	2	3	4
Condition 1	176	244	221	181
Condition 2	----	358	505	471
Maximum	180	360	540	720

Figure Captions

Figure 1. Logarithmic decrease in recall accuracy as a function of increasing time. Peterson and Peterson, 1959.

*Figure 2***.** Waugh and Norman, 1965. Results from Experiment 1 indicating that recall accuracy is a function of the number of interfering items.

Figure 3. Theoretical depiction of decay arising from short and long intervals of time across six serial positions.

Figure 4. A lack of separation between the short and long conditions represents absence of decay.

Figure 5. Overview of Experiment 1. The suppressor type was always the same across an entire trial.

Figure 6. Reaction times, measured from suppressor onset to keyboard response for each serial position, for Experiment 1.

Figure 7. Proportion correct as a function of serial position in Experiment 1. Solid lines are the fast condition and dashed lines indicate the slow condition. The left graph is same numbers while the right graph is different numbers. Error bars are standard errors of the mean.

Figure 8. Overview of Experiment 2 with a constant suppressor and a fast and slow pace of recall.

Figure 9. Experiment 2 results. Proportion correct as function of serial position for fast and slow conditions. Error bars are standard error of the mean.

Figure 10. Response times for fast and slow conditions in Experiment 2. Error bars are standard error of the mean.

Figure 11. Suppressor spoken in each of the 5 conditions for Experiment 3.

Figure 12. Experiment 3 procedure. There were two possible recall speeds: fast (750 ms) or slow (2750 ms). There were 4 suppressor types: baseline (no suppressor), 1 suppressor, 3 or 4 same suppressors irregularly paced or 5 same suppressors.

Figure 13. Experiment 3 results. Proportion correct as a function of serial position for each of the 5 experimental conditions. Error bars are standard error of the mean.

Figure 14. Experiment 3 results for proportion correct as a function of serial position for the 1 Fast, 3 or 4 Slow and 5 Slow conditions only. Error bars are standard error of the mean.

Figure 15. Reaction times for each condition in Experiment 3. Error bars are standard error of the mean.

Figure 16. Fast recall condition only in Experiment 4. The diagram above the diagonal 'TIME' line is for a Number trial and the diagram below this line is for a No Number trial. In the Number trial presented here the target digit appeared in the 2^{nd} position, at the beginning of the interval.

Figure 17. Results from Experiment 4 for the No Number trials only. The only significant effect was the main effect of serial position. Error bars represent standard error of the mean.

Figure 18. Reaction times for Experiment 4 for No Target trials only. Error bars are standard error of the mean.

Figure 19. Overview of fast recall conditions for Experiment 5. Above the diagonal 'TIME' line is an example of a Target digit of the Number Block where the number is

presented in the second serial position. Below the diagonal is an example of a No Number trial.

Figure 20. Comparison of the three conditions in Experiment 5 to determine if the blocking manipulation was successful. Error bars represent standard error of the mean.

Figure 21. Results from Experiment 5. Left panel includes only trials not containing a Target digit in the Number Block. Right panel includes all trials from the No Number Block condition. Error bars are standard error of the mean.

Figure 22. Reaction time results from Experiment 5. The No Target conditions were from the Number Block and the No Number conditions are from the No Number block. Error bars are standard error of the mean.

Figure 23. Overview of fast recall conditions for Experiment 6 with AS. Above the diagonal 'TIME' line is an example of a Target digit of the Number Block where the number is presented in the second serial position. Below the diagonal is an example of a No Number trial.

Figure 24. Comparison of three trial types in Experiment 6 to assess the effect of condition.

Figure 25. Experiment 6 recall accuracy results for the No Target digit conditions in the Number Block (left panel) and the No Number Block (right panel). Error bars are standard error of the mean.

Figure 26. Reaction time for Experiment 6. No Target conditions are from the Number Block. Error bars are standard error of the mean.

Figures

Figure 1: Peterson & Peterson 1959

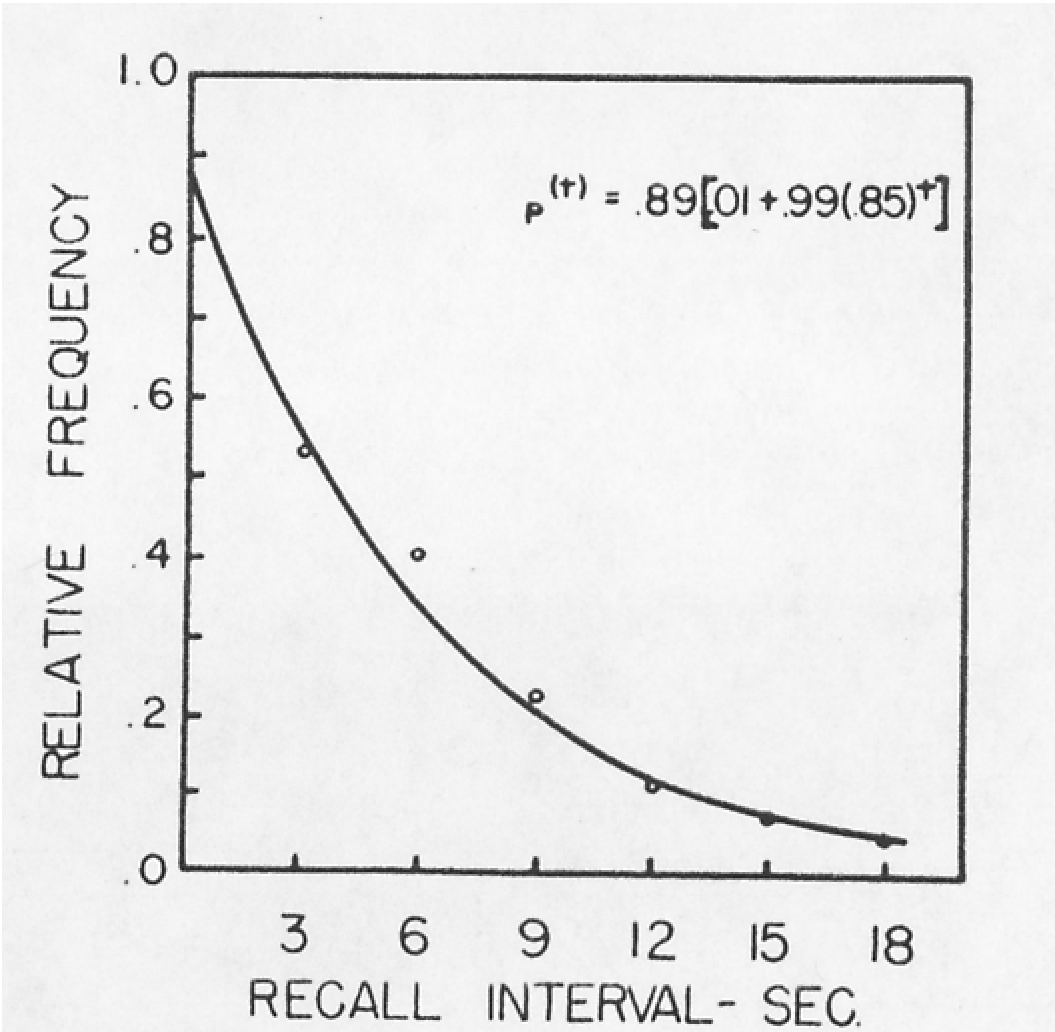

Figure 2: Waugh & Norman 1965

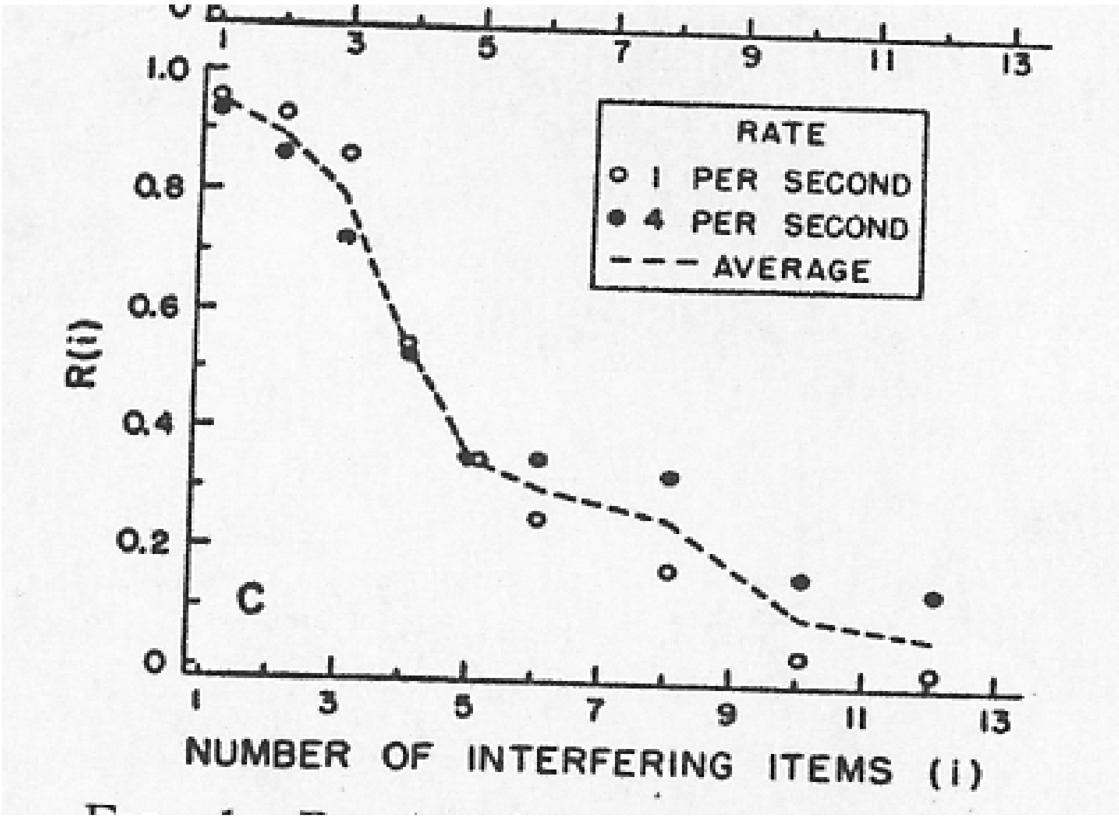

Figure 3: Hypothetical Serial Fanning Curves

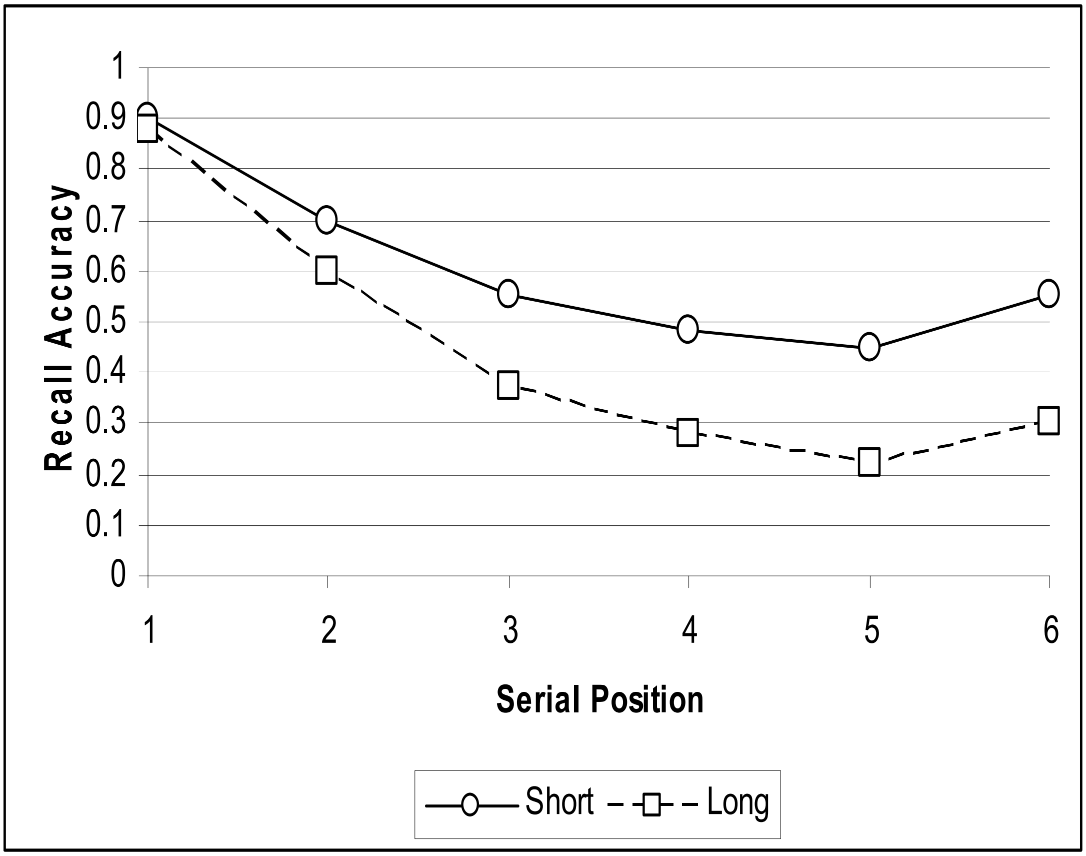

Figure 4: Hypothetical Absence of Serial Fanning

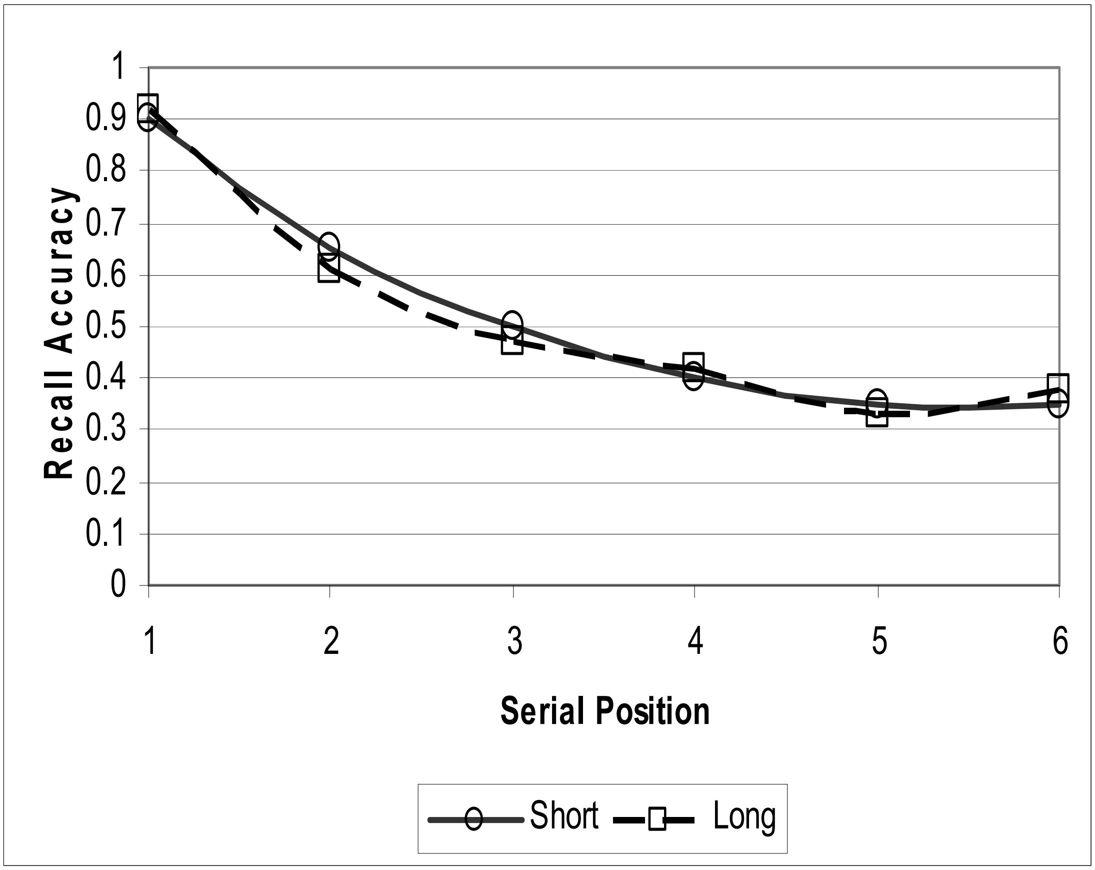

Figure 5: Experiment 1 Design

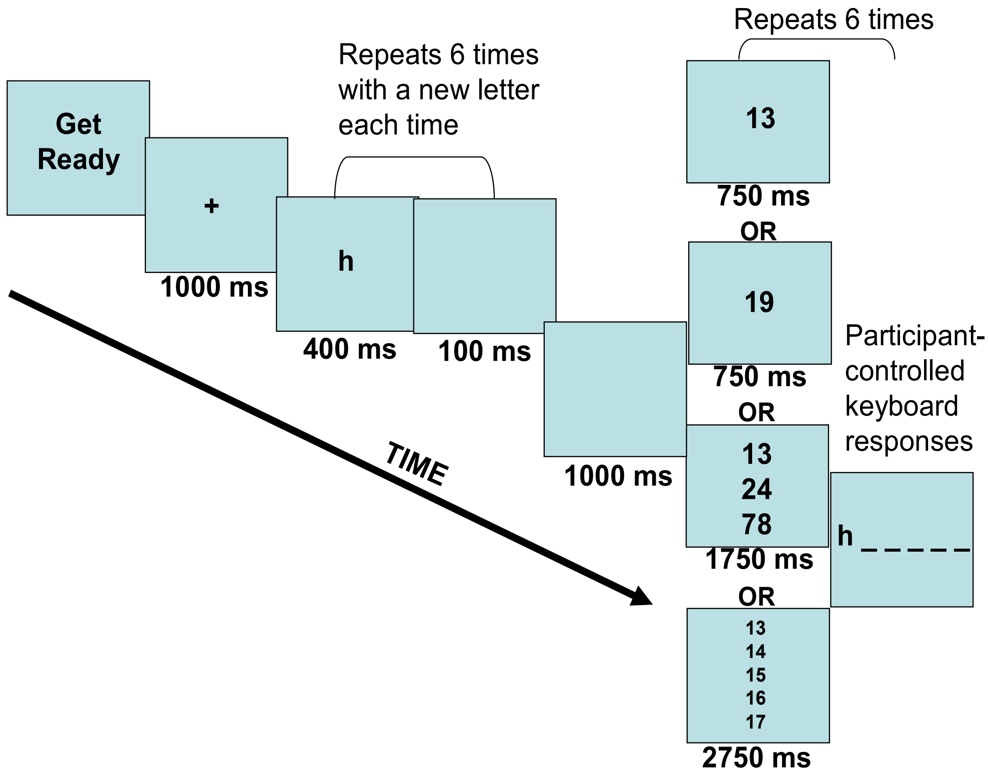

Figure 6: Experiment 1 RT Results

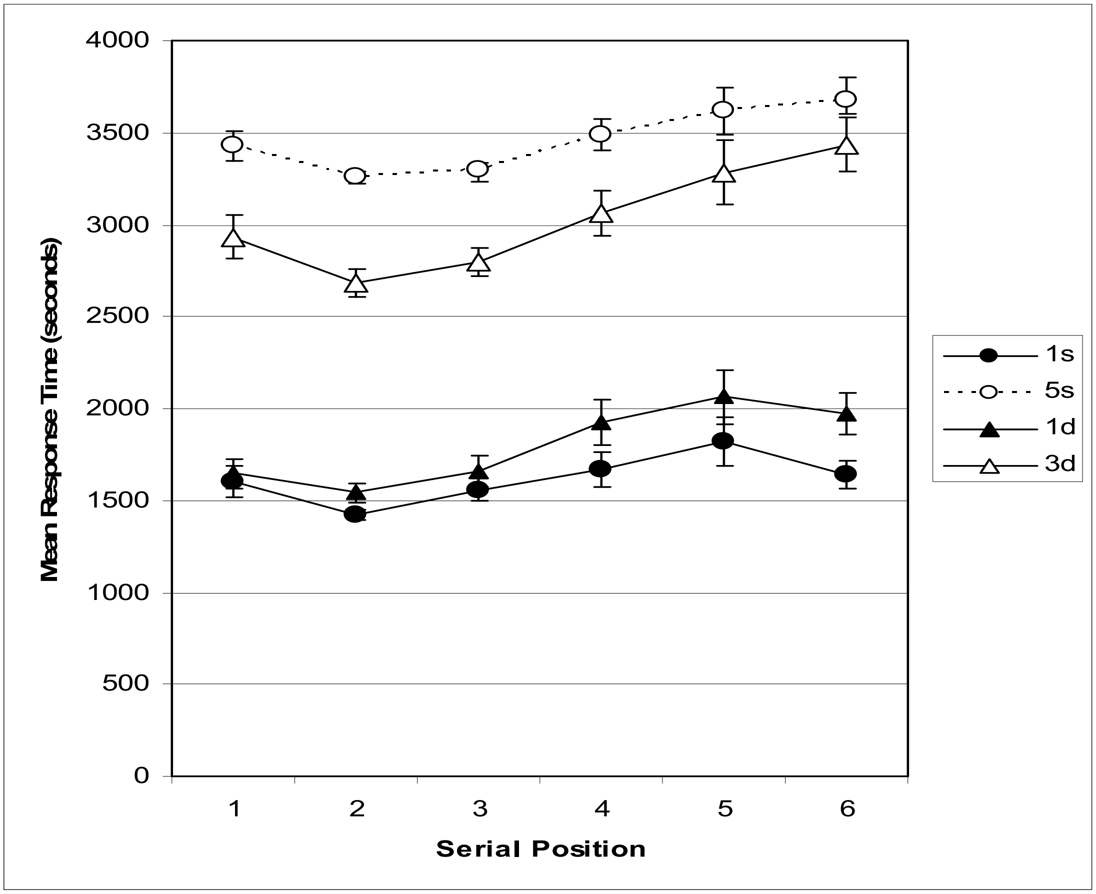

Figure 7: Experiment 1 Serial Recall Accuracy Results

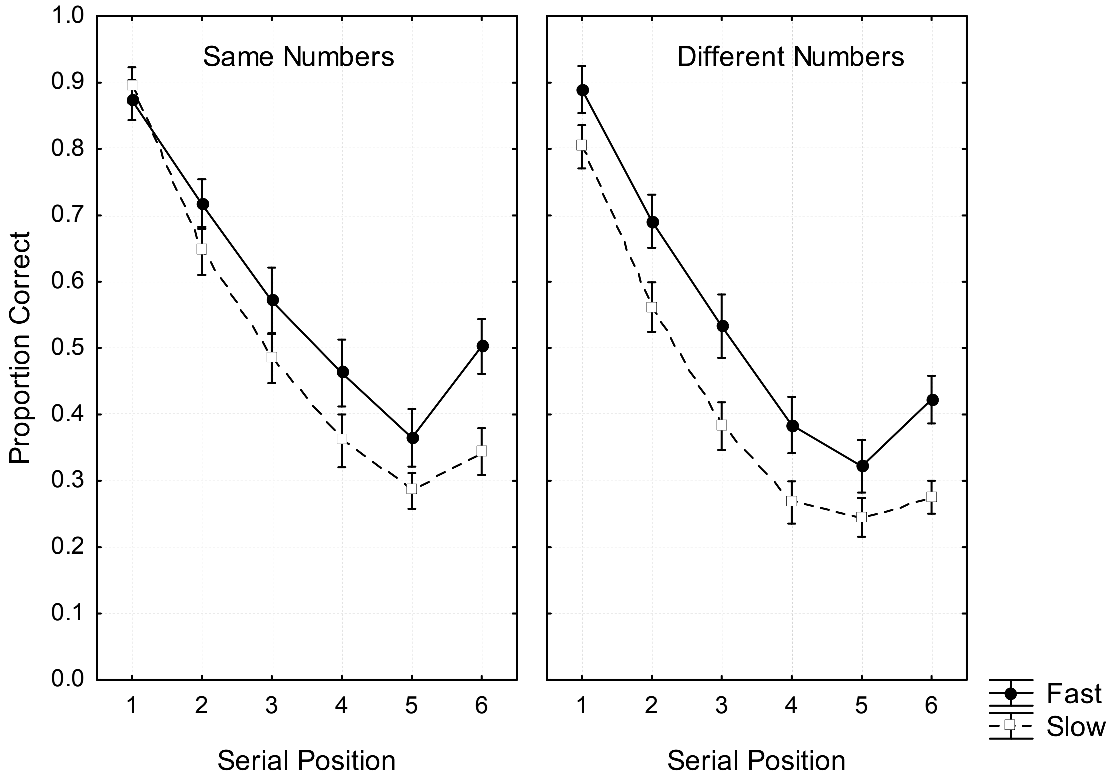

Figure 8: Experiment 2 Design

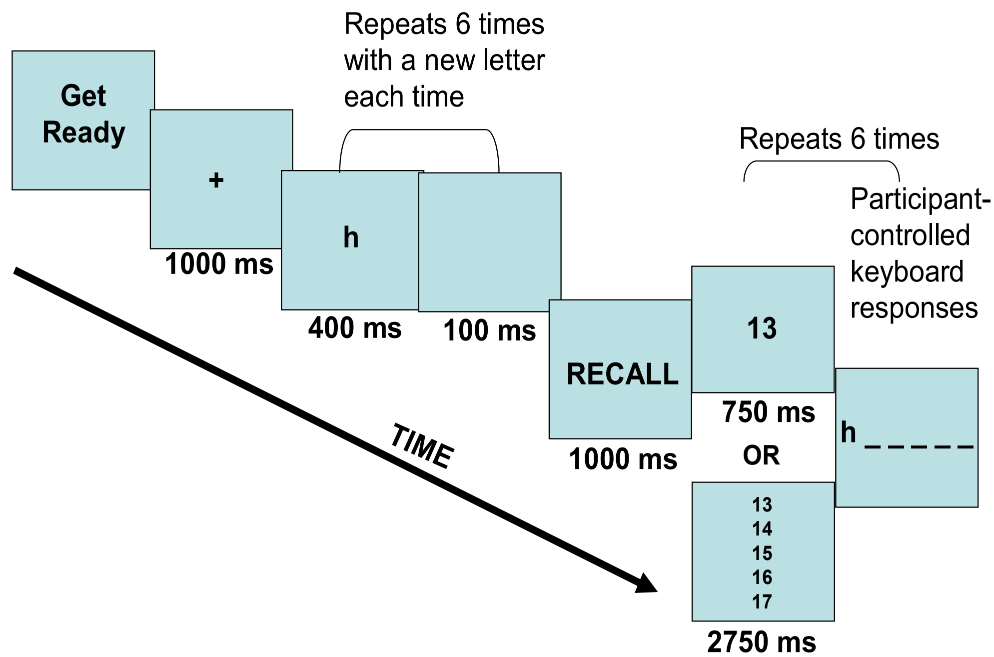

Figure 9: Experiment 2 Serial Recall Accuracy Results

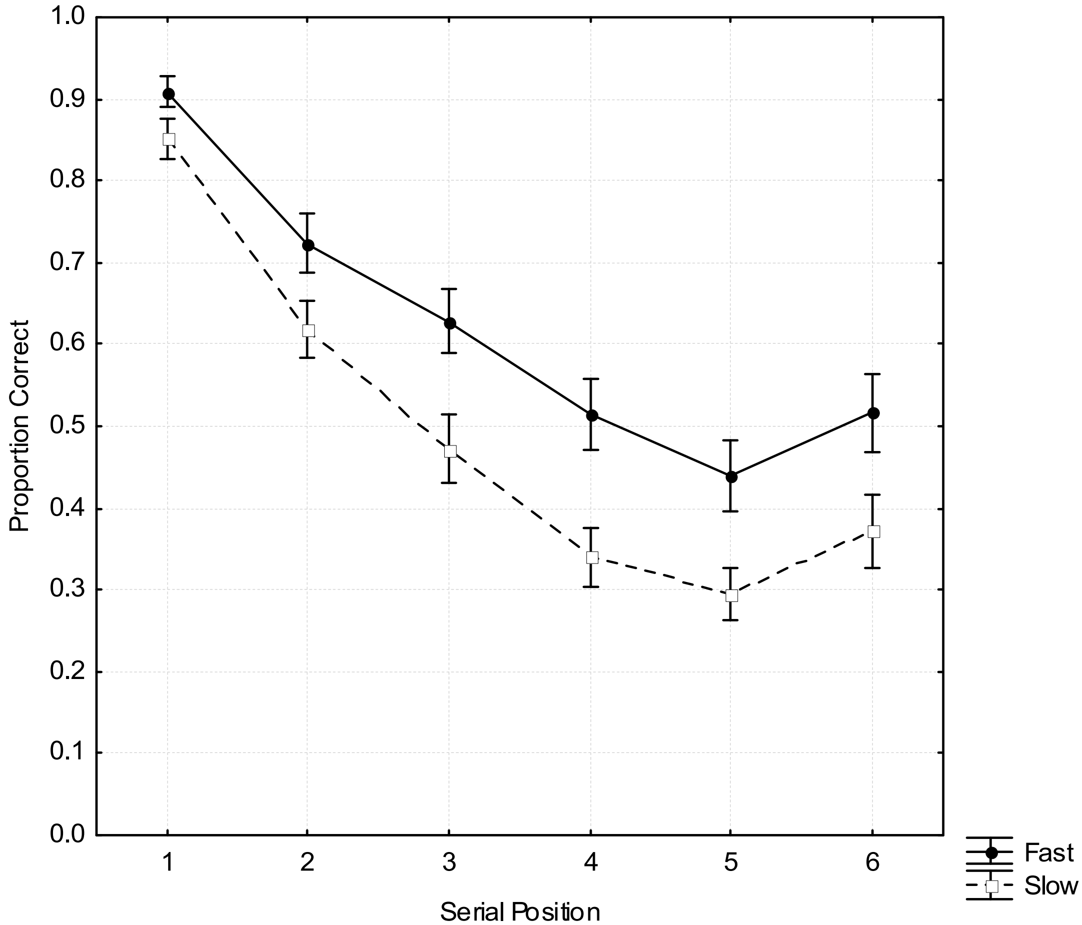

Figure 10: Experiment 2 RT Results

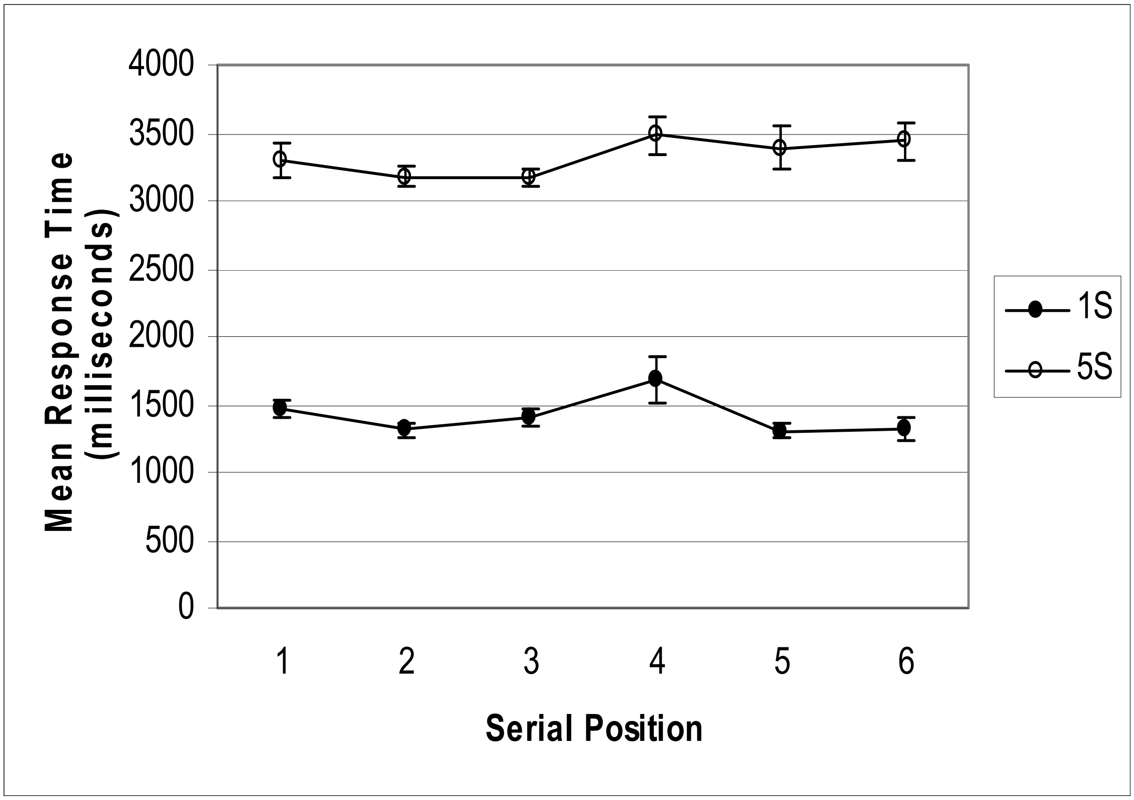

Figure 11: Experiment 3 Conditions

	0 Fast 750 ms	0 Slow 2750 ms	1 Fast 750 ms	5 Slow 2750 ms	3 or 4 Slow 2750 ms
SP1			13	13 13 13 13 13	13 _ 13 _ 13
SP2			13	13 13 13 13 13	13 _ _ 13 13
SP3			13	13 13 13 13 13	13 13 _ _ 13
SP4			13	13 13 13 13 13	13 _ 13 13 13
SP5			13	13 13 13 13 13	13 13 13 _ 13

Figure 12: Experiment 3 Design

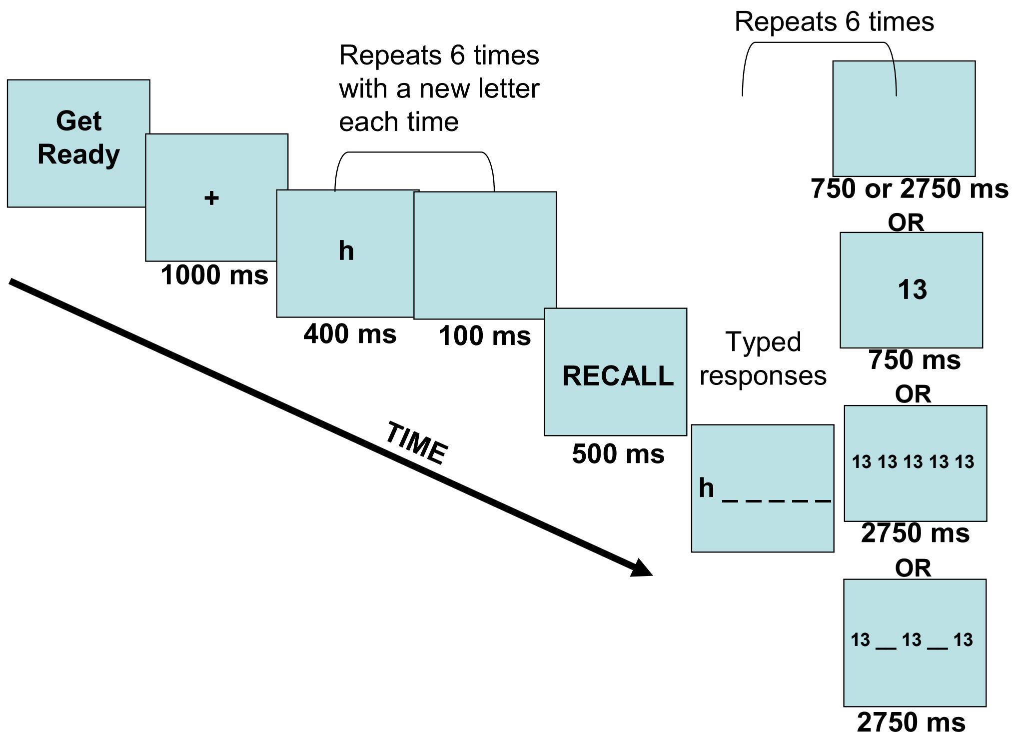

Figure 13: Experiment 3 Serial Recall Accuracy Results

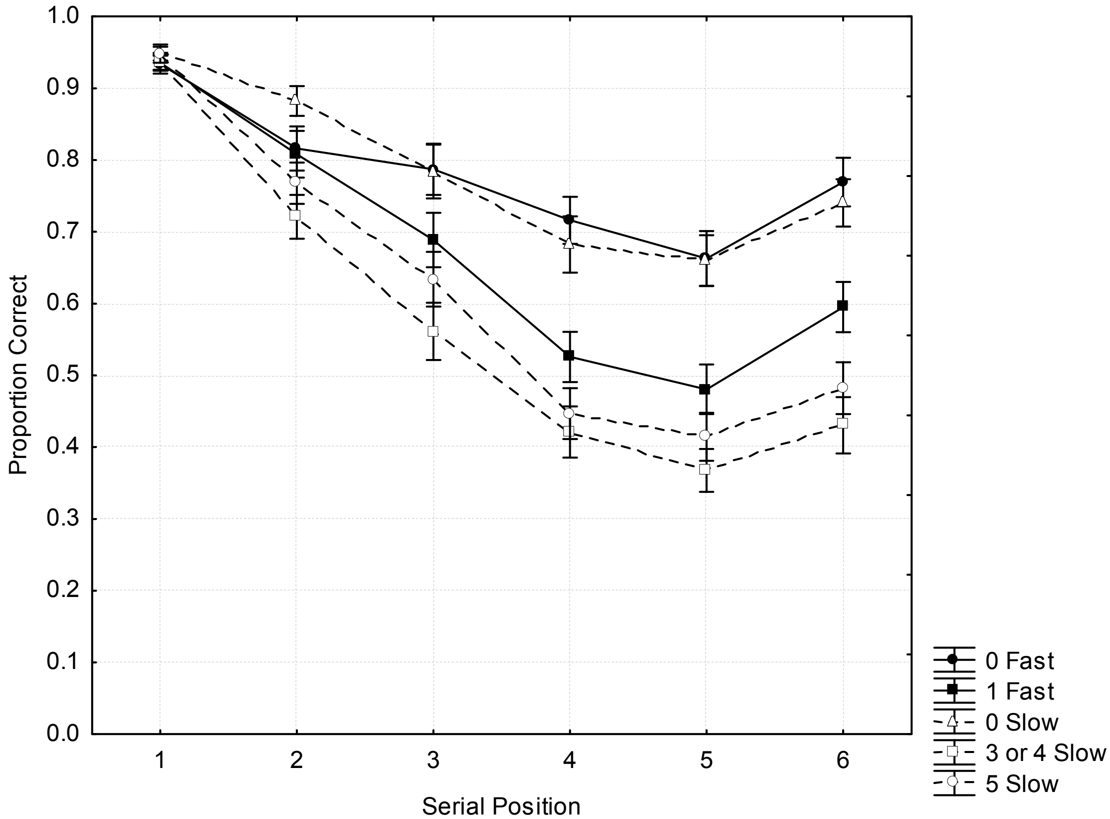

Figure 14: Experiment 3 Serial Recall Accuracy Results

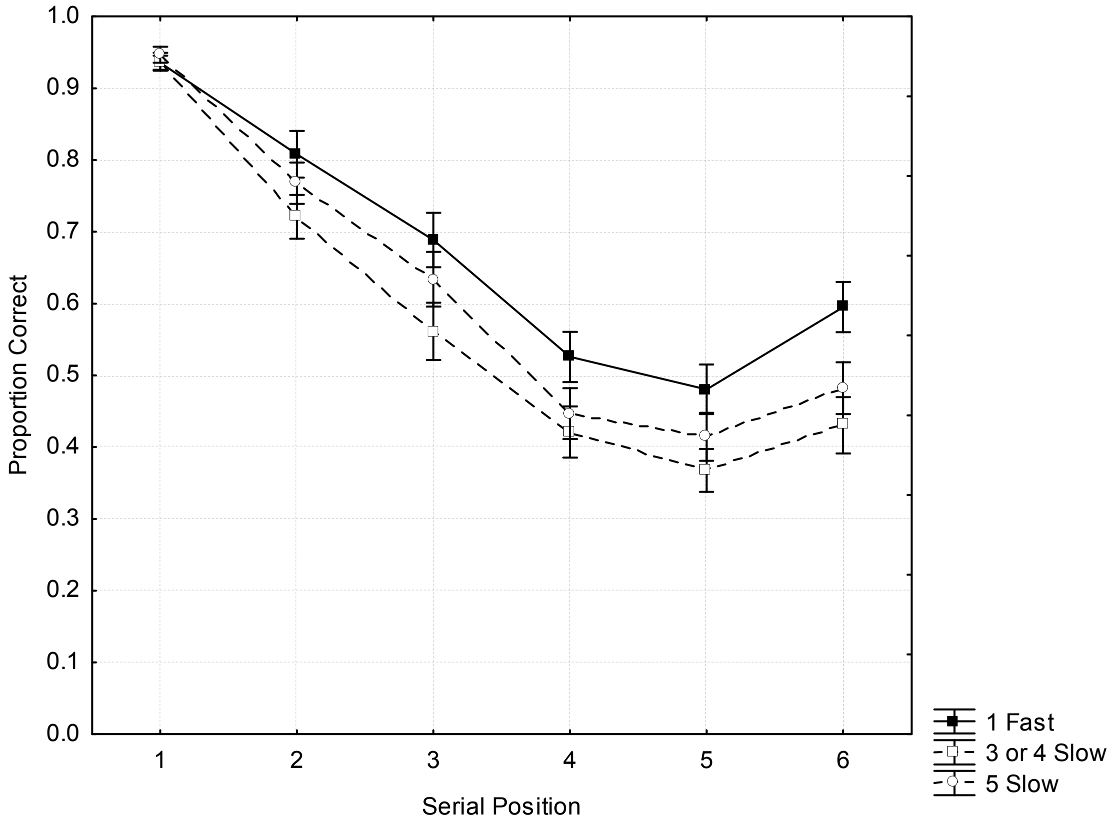

Figure 15: Experiment 3 RT Results

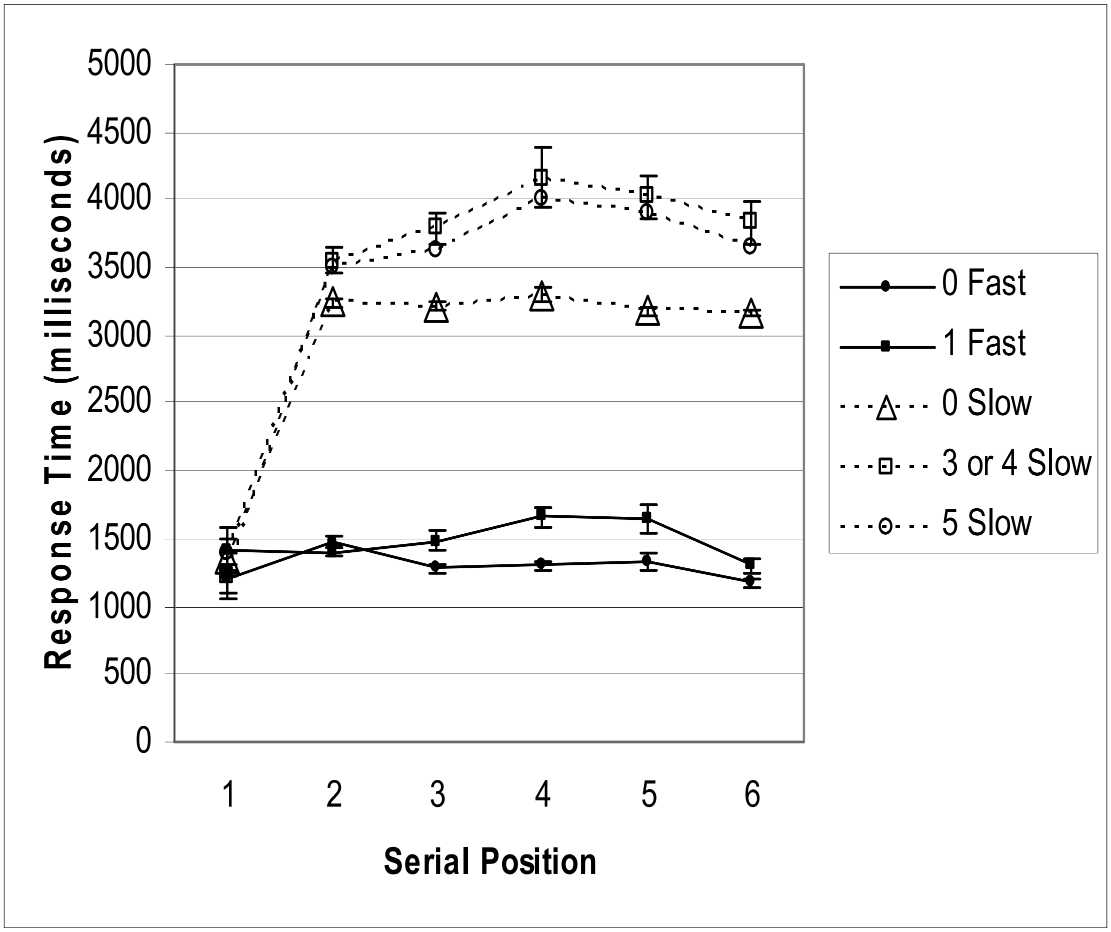

Figure 16: Experiment 4 Design

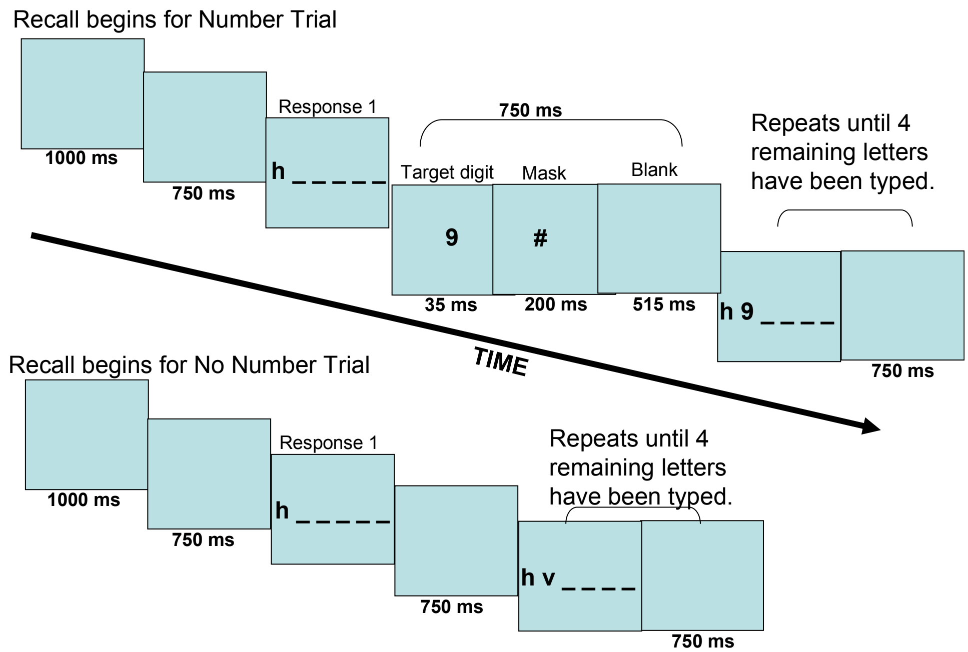

Figure 17: Experiment 4 Serial Recall Accuracy Results for Trials with No Target Digits

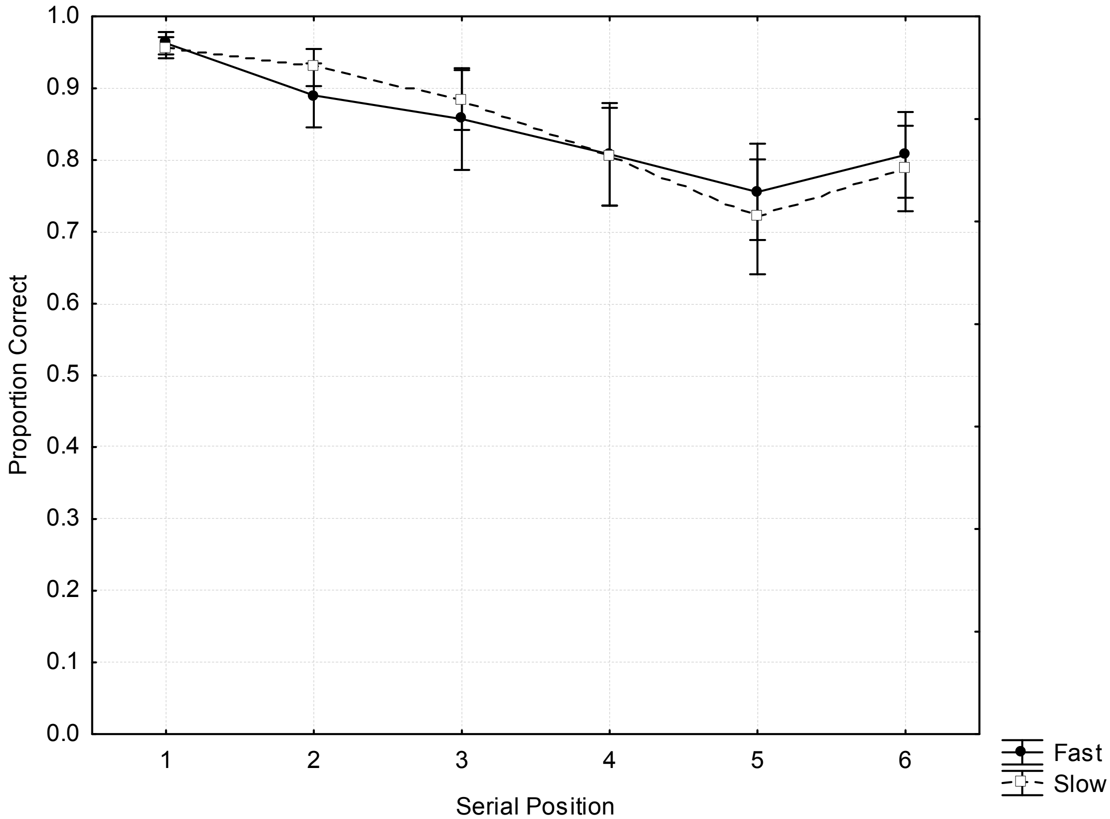

Figure 18: Experiment 4 RT Results

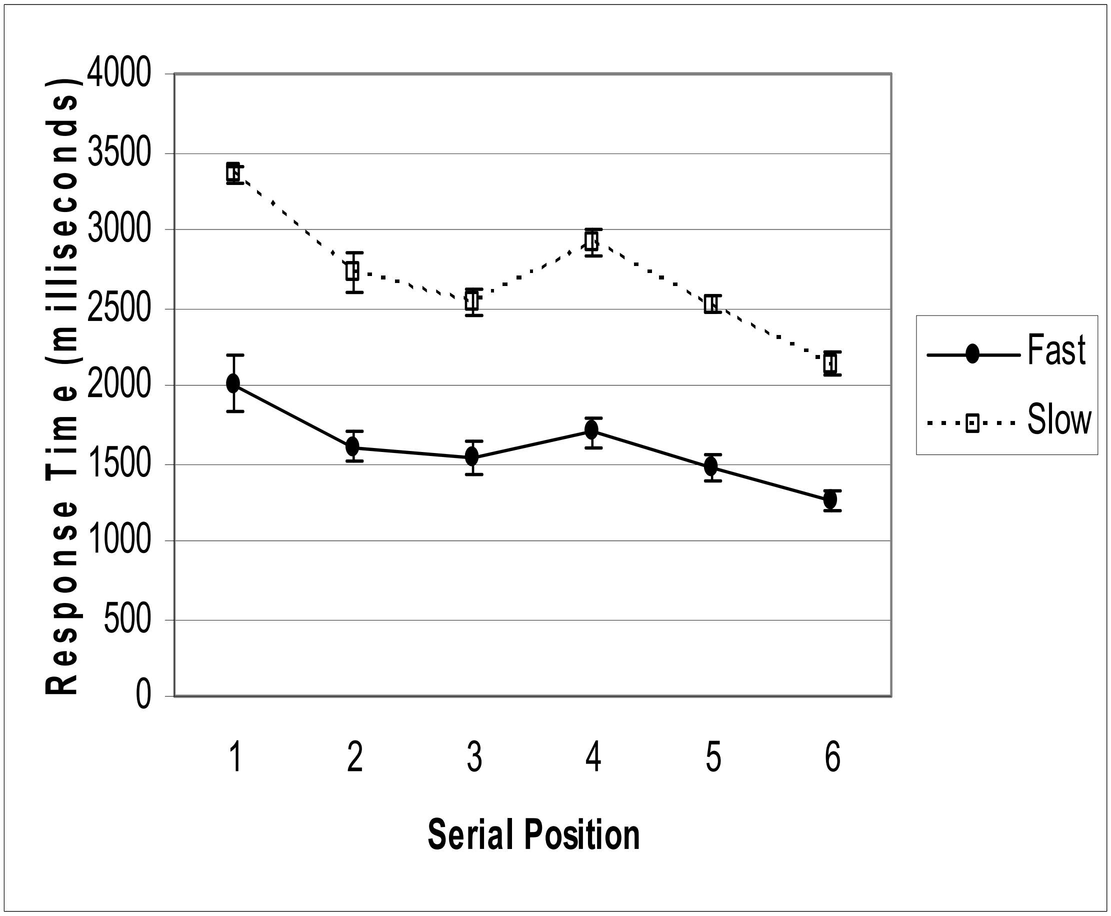

Figure 19: Experiment 5 Design

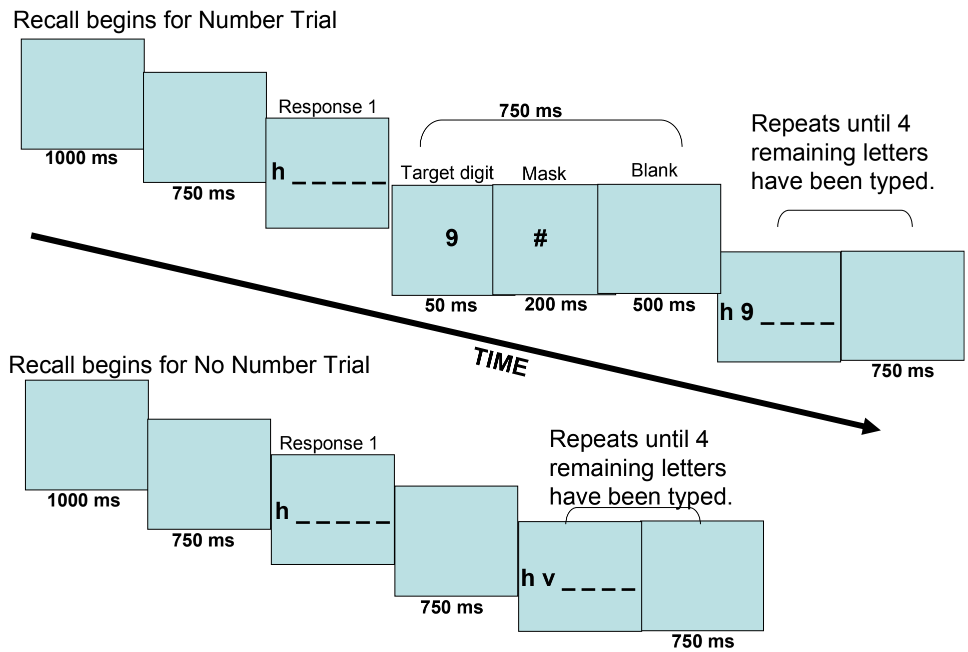

Figure 20: Experiment 5 Serial Recall Accuracy Results for All Trial Types

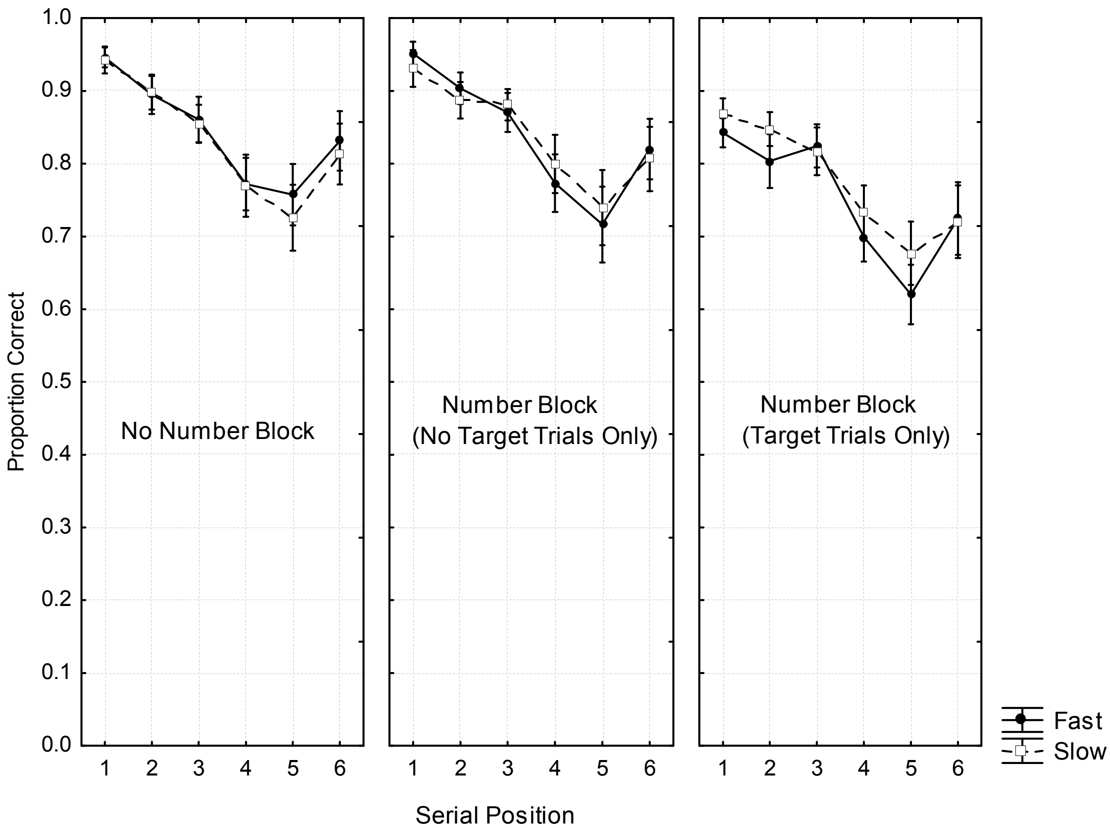

Figure 21: Experiment 5 Serial Recall Accuracy Results for No Target Trials Only

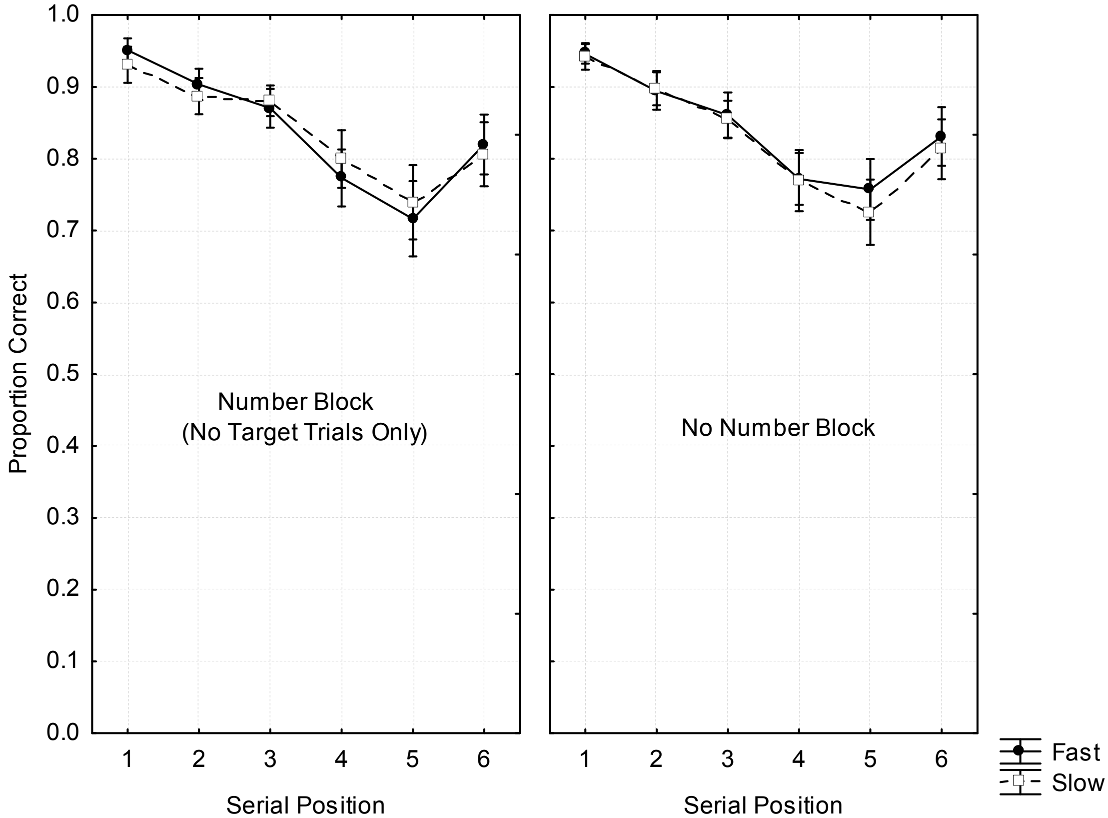

Figure 22: Experiment 5 RT Results

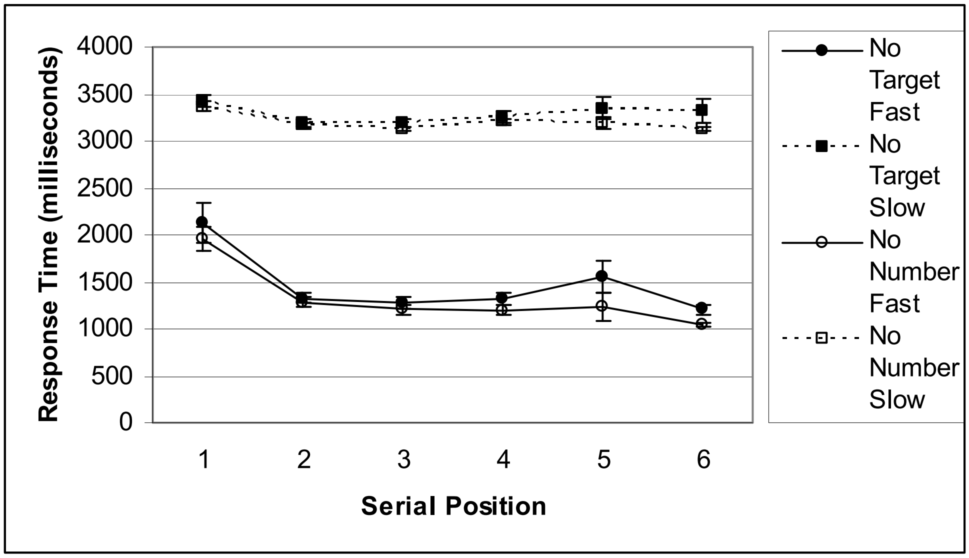

Figure 23: Experiment 6 Design

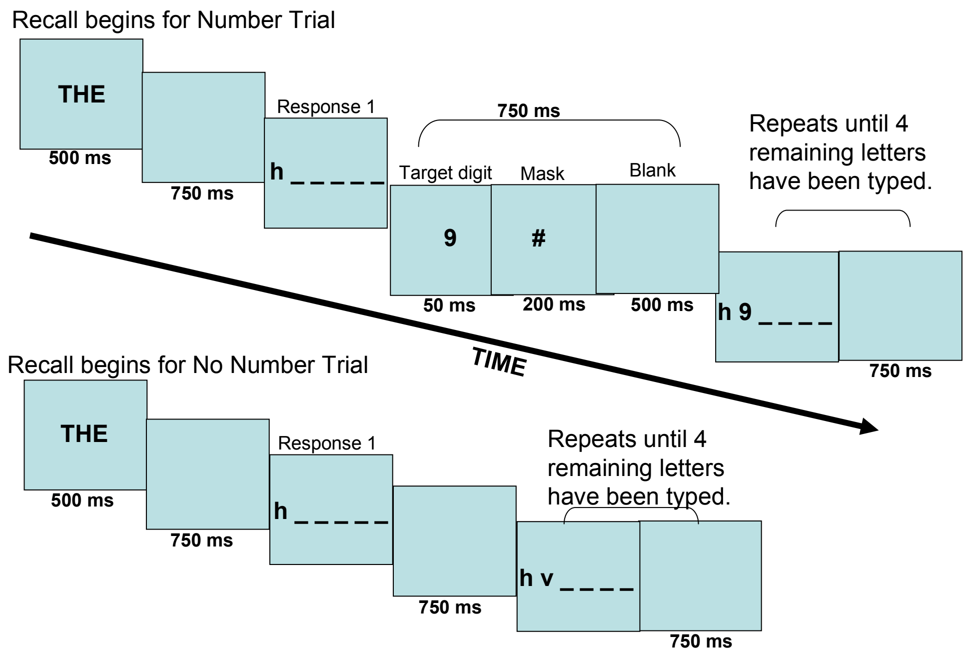

Figure 24: Experiment 6 Serial Recall Accuracy Results for All Trial Types

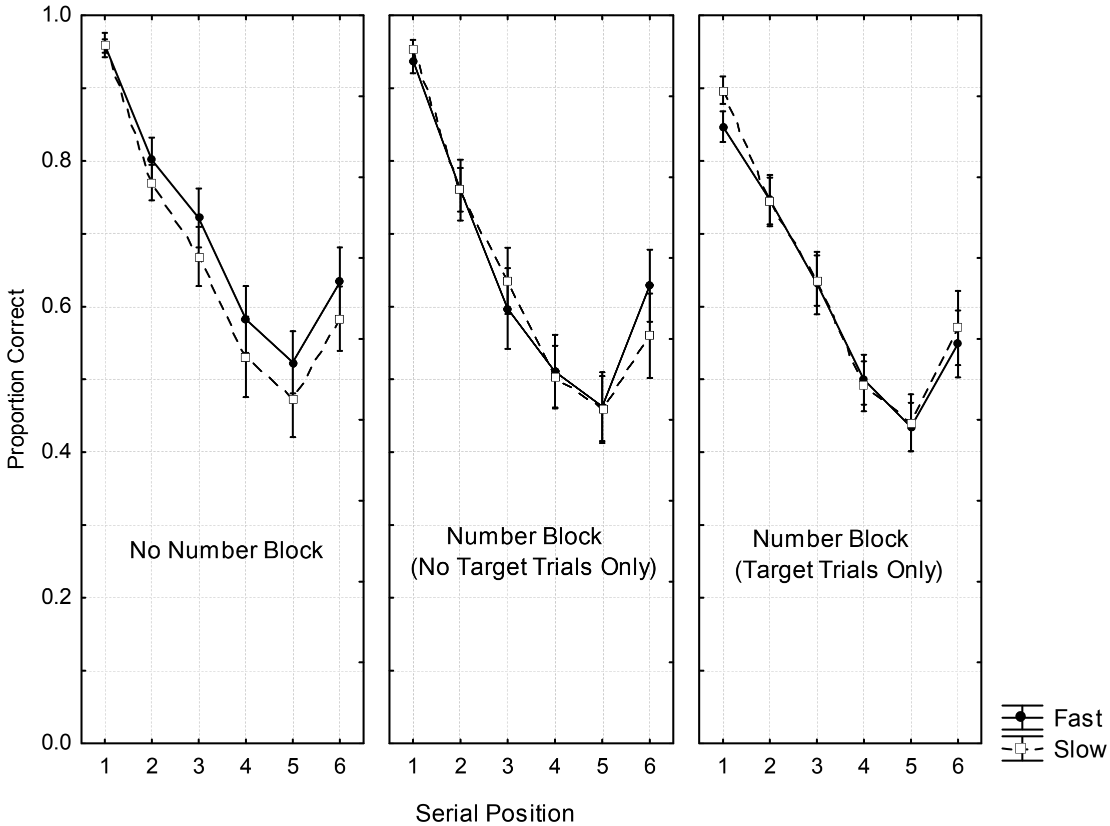

Figure 25: Experiment 6 Serial Recall Accuracy Results for No Target Trials Only

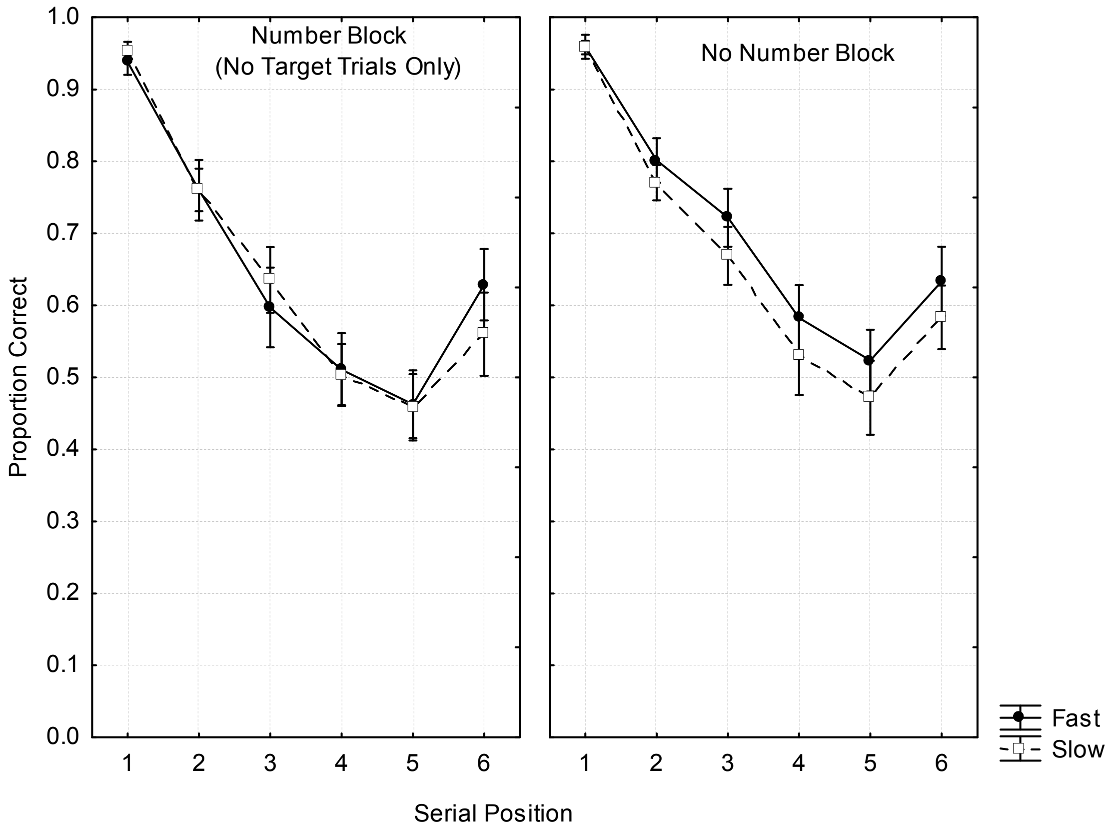

Figure 26: Experiment 6 RT Results