Running head: MEMORY BLOCKING

Honors Thesis In Neuroscience:

Origins And Mechanisms Of Semantic Memory Retrieval Inhibition

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Abstract

Retrieval blocks can be induced in semantic memory by a variety of methods, including part-list cuing or priming with information semantically related to a target. Mechanisms underlying retrieval blocks may involve automatic spreading inhibition, but other interfering cognitive processes seem to play a role in this phenomenon as well. The first study attempted to evoke memory retrieval blocks using an indirect means of priming. Subjects studied a part list of United States with their capitols and were asked to recall the capitol of a given state after being primed with a studied or non-studied state. Results showed that studied primes inhibited retrieval more than non-studied primes, indicating that significant retrieval blocks may indeed be induced by indirect means. A new model was devised using a connectionist approach to illustrate one possible means of such retrieval inhibition. In the second study, studied and non-studied capitols were included as the possible primes. The results showed that state primes tended to inhibit retrieval more than capitol primes. To explain this finding, the concept of immediate memory was proposed to explain a possible mechanism underlying the cognitive process of memory retrieval.

ORIGINS AND MECHANISMS OF SEMANTIC MEMORY RETRIEVAL INHIBITION

Imagine that you are walking down the street during your lunch hour in a very familiar part of town, not far from the workplace. As you stroll along peacefully, your eye catches the face of a man who looks vaguely familiar. He makes eye contact and greets you by name. You return his greeting with a distant smile as you search frantically through your mind, trying to recall his name. You feel a sense of obligation to remember his name, since he knew yours. However, you certainly do not want to guess, for fear that you would be wrong. Also, it would allow you to save face by simply not using his name, instead of revealing your error of memory. As your mind races, you can remember having met him at a company picnic a few months ago, and you manage to place him as an employee in a separate department within your company. What could his name be? Matt? Mark? Mike? You feel as though his name is on the tip of your tongue. You are certain that you know his name, but no matter what you do, you simply cannot draw it into your conscious memory – how frustrating! You are experiencing a memory block.

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According to the traditional concept of cognitive memory networks, automatic spreading activation should occur between associated nodes in memory. Therefore, when a person retrieves one item from memory, his or her ability to retrieve related pieces of information should be facilitated, since those associated memory nodes will be activated when a related memory node becomes active. If this were true, then memory enhancement should occur when the nodes related to a certain target become activated. However, research has been conducted to question the concept of automatic spreading activation in memory, and researchers have shown consistently that retrieval blocking can occur in both episodic and semantic memory, forcing psychologists to reassess their concept of the memory retrieval process.

Semantic memory retrieval blocking occurs when an individual's ability to recall a target item from memory is impaired by recent presentation of material semantically related to, yet distinct from, the target information. This phenomenon may occur by a variety of possible mechanisms. Moreover, retrieval blocking has been produced experimentally in a variety of domains, including recall tasks, categorization tasks, and perceptual tasks. Among these areas of study, recall tasks were selected as the focus of the present study. Moreover, due to the volatile nature of short term memory, it experiences temporal decay which might make observation of the desired effect more difficult. In order to reduce the possibility of confounding, cued recall tasks oriented to involve long term memory were chosen for this experiment.

McGeoch (1942) was an early scientist to propose that interference in memory retrieval might occur due to competition of stored information. He hypothesized that memory blocking occurred due to retrieval inhibition caused by this competition, not due to loss of information from memory storage. Therefore, according to his ideas, the problems with retrieval blocking might be due to certain aspects of the mechanism of memory retrieval itself.

R. Brown and McNeill (1966) popularized the term most frequently used to refer to this all-too-familiar occurrence – the "tip-of-the-tongue" phenomenon. They defined this condition as "a state in which one cannot quite recall a familiar word but can recall words of similar form and meaning." The experience of the tip-of-the-tongue state, with which perhaps everyone is well-acquainted from firsthand experience, also subjectively seems to indicate that retrieval inhibition may be due to a mechanistic process of memory retrieval.

Empirical lines of evidence to support this idea have been relatively recent, and the first experiment involving semantic memory blocking using a recall task was conducted by J. Brown (1968). He divided a set of English citizens into two groups, and allowed one group to study a randomly selected list of half of the English counties, while the control group did not study anything relevant to the experiment. Next, he asked each subject to recall as many of the counties as possible. He found that the experimental group recalled more of the counties from the study list than did the control group, while the control group recalled more of the non-studied counties as compared to the experimental group. Karchmer and Winograd (1971) repeated the same experiment in the United States, requiring one experimental group to recall the states from the studied list before proceeding to recall the non-studied states. Their results mirrored those made by Brown, adding further support to the idea that the action of studying a subset of list elements interfered with recall of items outside of that set.

Later, A. S. Brown (1979) primed subjects with a word representing one of four different prime types, immediately after which he presented the subject with a word definition and asked them to respond with the proper word to match that definition. Some of his primes were identical to the correct response, some primes were semantically related to the answer, some were words orthographically related to the correct response, while some were unrelated to the target response. One example set would include "gobble", the correct prime; "cram", the semantically related prime; "goggle", the orthographically related prime; and "feud", the unrelated prime. He found that recall seemed to be facilitated by primes orthographically related to the correct answer, but subjects were slowest and least likely to respond correctly after having been primed with a word semantically related to the target response.

Roediger and his colleagues (1983) reevaluated A. S. Brown's (1979) conclusions, studying two groups of subjects. All subjects were presented with a word or phrase to act as a prime, followed by a general knowledge question such as “What precious stone comes from oysters?” One group of subjects received four types of primes: identical to the correct response (“pearl”), semantically related to the correct response (“opal”), unrelated to the correct response (“marijuana”), and neutral (“ready”). The other group of subjects received the same priming treatment, except that they never received the prime which was identical to the correct response. The experimenters found that for the first group, memory retrieval was inhibited by a semantically related prime, whereas for the second group, target retrieval was facilitated by this prime instead. They concluded that the retrieval delay that Brown had encountered was not caused by automatic spreading inhibition, but instead due to the cognitive process of deciding whether the prime was identical to the correct answer.

A. S. Brown (1981) also attempted to analyze the cumulative effects of consecutive memory retrievals on subsequent retrieval efforts. He primed subjects with a category and with the first letter of the desired item from that category, such as “fruit-a” when the target response was “apple”. After performing multiple trials within the same category for each subject, he found that the mean response time tended to be lowest at the beginning of a stimulus set and highest near the end of the set. However, he conducted an additional experiment which administered multiple consecutive stimuli from different categories, finding that the response time did not show a similar increase as in the previous experiments. Based upon this, he concluded that the observed memory retrieval blocks were not solely due to increasing fatigue.

Blaxton and Neely (1983) further questioned the conclusions of the paper published by A. S. Brown (1981). They instructed subjects to either read primes or to retrieve them before beginning target trials in which they were required to generate an answer based on a category and a letter, as Brown did in his prior study. Their results showed that subjects who were actively required to retrieve targets during the priming phase performed more poorly in the subsequent trials than did the subjects who were required to merely read the priming stimuli. They concluded that the action of retrieval itself, and not necessarily the simple presentation of stimuli, exerted the greatest inhibitory effect on memory retrieval.

Nickerson (1984) published a comprehensive review of memory blocks evoked by part-set cuing, in which subjects were required to retrieve as many items as possible from a well-known category after receiving a small subset of category items as cues. He focused on tasks whereby subjects were instructed to recall as many words or other set elements within a given amount of time, under varying conditions. He reviews a number of potential hypotheses to explain the retrieval blocks observed in such experiments, two of which hold relevance to this study. The Competition-at-Retrieval hypothesis, proposed by several different investigators, suggests that the effect of cuing causes items from that list to be activated, and therefore the probability of recalling an item from the cue list would increase. Thus, the average probability that the subject would recall an item outside of the cue list would decrease. The Search of Associative Memory hypothesis (SAM), also termed the Associative Sampling-Bias hypothesis, put forth by Raaijmakers and Shiffrin (1981), was considered by Nickerson to be the most comprehensive and accurate explanation for retrieval blocking. This model suggests that items form clusters in memory, with each cluster containing a few items. Activation of any cluster will likely lead to retrieval of all items from that cluster due to the associations between related items. Subjects were therefore likely to experience retrieval blocking, because they are more likely to oversample clusters containing a recently stimulated item, reducing the likelihood of sampling from a cluster that does not contain such items. One should note that both of these hypotheses share a common feature: the associations between items in memory become important in effecting retrieval inhibition.

D'Agostino and Elmes (1987) tested the effects of prior mobilization of knowledge on recall. Using category sets such as countries of the world or United States presidents, they asked subjects to generate as many instances from that set as possible. A list was then prepared of generated and non-generated items, asking subjects either to recall the items from that list or to simply recognize list elements. In contrast to a prior study by Peeck (1982), they found that such mobilization of knowledge fails to facilitate recall. Moreover, retrieval of items from the non-generated set was inhibited. In their concluding remarks, they hypothesized that this inhibition occurred using a mechanism similar to the Competition-at-Retrieval or SAM hypotheses, whereby "the retrieval of highly accessible generated study list items blocks the retrieval of less accessible nongenerated items."

In more recent research, Carr and Dagenbach (1990) used a lexical decision task to study the effect of semantic and repetitive priming on the ability of subjects to retrieve the meaning of a word. They found that when subjects were unsuccessful in retrieving the meaning of a prime word, their subsequent lexical decisions were significantly slower than if they successfully retrieved the meaning of the prime. They hypothesized that the increased, fruitless effort exerted by subjects when they failed to retrieve the meaning of a prime caused them to focus their attention too strongly on that word, so that they were unable to devote adequate mental processing power to deal with the subsequent trial. In other words, the stronger that the activation of one item in memory is, the more strongly inhibited the semantically related items in memory will be. Based upon their results, they proposed the interesting idea that stores of memory could exhibit a system of semantic lateral inhibition remarkably similar to the center-surround paradigm found in other areas of the nervous system, such as the visual system.

The goal of the current study was to reconcile seemingly inconsistent findings in the field of memory retrieval blocking, while simultaneously providing direction for future research in the area. To test long-term memory retrieval specifically, recall of state capitols was used as a domain for study, because most American students memorize all 50 capitols at some point while growing up. Therefore, even if subjects had trouble recalling certain state capitols, the experimental setup ensured that this was not attributable to an absence of that information in memory, but instead due to difficulty in retrieving that information from memory. Every subject was tested following a prime-cue paradigm, whereby subjects were presented two stimuli for each question in the experiment. The first stimulus was termed the “prime”, and subjects merely needed to read this item aloud. For the second stimulus – called the “cue”, which was always the name of a state in this study – subjects were instructed to respond with the capitol of that state. Subjects studied a partial list of states with their capitols, so the hypothesis behind this research states that a subject should have more difficulty recalling a state capitol after being primed with an element from the studied list than if they were primed with an element from the non-studied set. Therefore, it was expected that subjects would demonstrate increased response times when primed with studied states, compared to their response times when primed with non-studied states. In Experiment 1, only studied and non-studied state primes were used, while in Experiment 2, studied and non-studied capitol primes were added as well. These testing conditions were used in an effort to fulfill the goals of this study: to examine the extent to which automatic spreading inhibition could occur, to test the previous hypotheses that offer explanations of retrieval blocking, and to elucidate the mechanisms by which memory retrieval occurs.

EXPERIMENT 1

Methods

Subjects

This experiment involved 37 male and female undergraduate students from Washington and Lee University who volunteered to participate in the experiment. All subjects confirmed that they had memorized all 50 state capitols during their academic careers. The data collected from 14 of the subjects were discarded for reasons to be discussed shortly.

Materials

All data collection occurred using a Power Macintosh G4 computer connected to a microphone. The audio editing program Felt Tip Sound Studio for Macintosh was used to perform sound recordings of each trial. In addition to this commercial software, a custom computer program was implemented using REALbasic for the Macintosh. This program generated a random list of 25 of the United States for the subject to study. Next, the program pseudo-randomly created 25 experimental questions, adhering to the following criteria. Each question consisted of two states, so five types of questions were presented during the course of experiment. Some questions presented two different states from the studied list (SS), while some used two different states from the list of 25 non-studied states (NN). Other questions involved a studied state followed by a non-studied state (SN), and some reversed this order (NS). Lastly, some questions presented a duplicate state (D), so that the same state was used twice within that question. The frequency with which a D question used a studied state or a non-studied state varied randomly. With the exception of D questions, no state was used more than once in this set of 25 questions. This program saved the study list and experimental questions for each subject in separate text files, aiding in later data analysis.

Design

The experiment was conducted using a within-subjects factorial design. For the purposes of this study, the first stimulus presented in each question was termed the “prime”, and the second stimulus was the “cue”. Two independent variables were used, each with two levels – Prime (studied or non-studied) and Cue (studied or non-studied). For the purposes of data analysis, D questions were not scored; they served as a control in the experiment, so that the subjects could never assume that the cue would differ from the prime. Also, since all subjects had memorized the 50 state capitols before, both levels of the Cue independent variable tested one and only one possible condition to eliminate confounding – for studied cues, the subject knew the capitol and had been recently exposed to it as well, while for non-studied cues, the subject knew the capitol, even though they may have had difficulty recalling it since they had not been exposed to that information in a long time.

The dependent variable for this experiment was the response time, which was measured at a ratio level of measurement. Since the audio recording software used for this experiment enabled direct viewing of recorded waveforms, response time could be measured very accurately, to the nearest hundredth of a second. Response times were measured from the beginning of the computer beep to the beginning of the waveform for the subject’s correct response, as illustrated in Figure 1.

Procedure

To facilitate audio recording, each subject participated in the experiment individually in a quiet room. During the experiment, the subjects were first presented with their list of 25 states matched with the corresponding capitols on the computer screen. They were given unlimited time to study the list, with instructions to study it until they felt able to correctly recall the capitol when presented with any state from that list. When they notified the experimenter that they were finished, the experimenter quizzed them verbally on every state from the list, naming a state to the subjects and asking them to respond with the state capitol. Next, the experimenter read directions aloud to the subjects, and these directions are duplicated in Appendix C. After the subjects clearly understood the directions, they were quizzed again on each state from their study list, maximizing their exposure to the states from the study list.

Next, a slide show began on the computer screen, in which one state name at a time was shown in large letters on the middle of the screen, and the experimenter advanced each slide using the mouse input. There was no pause between presenting the prime and cue of one question, while a pause of approximately three seconds was inserted between different questions. Each subject completed two example problems prior to beginning the experiment proper, and all four states for the example problems were chosen randomly from the subject's study list, thus avoiding interference from non-studied states. Finally, the audio recording was started, and the subjects completed 5 questions in each of the SS, SN, NS, NN, and D categories. The order in which the questions were presented was randomized. The subjects simply repeated the name of the prime state, while they responded with the capitol of the cue state. A brief audible beep presented simultaneously with the cue served as a reminder for the subject to give the capitol, and also as a reference point in the data recording to allow accurate measurement of response times. At the conclusion of the experiment, subjects were debriefed on the goals of the study.

Results

Of the 37 subjects who participated in the experiment, the data from 11 were discarded because they responded incorrectly to all of the questions in any single category. Next, since response times tend to be positively skewed, the median was selected as the best representative descriptive statistic, so the median response time was selected from the correct responses to the SS, SN, NS, and NN questions for each subject. The difference in response time between the SS and NS categories was used as a benchmark for data reliability, since this difference was the most relevant information to the hypothesis being studied. Using the difference between these two medians, Dixon tests (Dixon, 1953) were conducted at an alpha level of 0.05, and an additional 3 data points were discarded as statistical outliers via this means. The median response times in each category for all 23 remaining subjects were recorded as shown in Appendix A. In addition, using these median latencies, the mean (*M*) and standard deviation (*SD*) for each category were calculated as indicated in Table 1, and as portrayed visually in Figure 2. The *M* response time was 1.01 seconds for SS questions, 0.89 seconds for NS questions, 2.23 seconds for SN questions, and 1.92 for NN questions.

Using the data shown in Appendix A, a within-subjects two-way analysis of variance was conducted to determine the overall effects of Prime, Cue, and Prime by Cue interaction. The effect of Cue was found to be highly significant ($F(1,22) = 60.293$, $MSe = 0.484$, $p < 0.0001$, $\eta = 0.856$). However, no significant effect for Prime was found ($F(1,22) = 2.265$, $MSe = 0.471$, $p > 0.05$, $\eta = 0.305$), nor was any significant interaction between Prime and Cue found ($F(1,22) = 0.499$, $MSe = 0.401$, $p > 0.05$, $\eta = 0.149$). Next, a within-subjects t test was conducted to analyze the difference in response times between SS and NS questions. The results of this test showed that there was indeed a significant difference between the response times for these two categories of questions ($t(22) = 2.389$, $SEM = 0.051$, $p < 0.05$, $r_{pb} = 0.454$). Finally, a within-subjects t test was conducted between response times for the SN and NN questions, although this test did not achieve statistical significance ($t(22) = 1.141$, $SEM = 0.271$, $p > 0.05$, $r_{pb} = 0.236$).

The results of this study illustrated several key points. First, one should note the descriptive statistics presented in Table 1. As expected, the mean response time for NS questions was faster than for SS questions, while the mean latencies for SN and NN questions were both greater than the latencies for SS and NS questions. Moreover, response times to SS and NS questions were both tightly distributed as shown by their relatively small standard deviation, whereas the much larger standard deviation for SN and NN questions indicated great variability in response time.

In addition, a main effect for Cue was found with a large effect size, which merely highlighted the concept that subjects tended to perform better recalling capitols of states that they had studied than they did with states they had not studied, although this was hardly a groundbreaking discovery. However, the most important result found was the significant difference between recall of SS and NS items, showing that priming indeed had a significant effect on recall for states that the subject had studied. This finding was consistent with those of prior research, showing that the presentation of semantically related information resulted in retrieval blocking for cognitive recall tasks. As a last note regarding the inferential statistics presented, the effect sizes for the insignificant statistical tests were all found to be relatively small, so even if this experiment were repeated with a larger sample size, these effects would be unlikely to become significant.

The next experiment sought to expand upon this one, studying the effects of using state capitols as primes. The hypothesis of this experiment states that the observed studied/non-studied effect should be confirmed under these new conditions. Moreover, if automatic spreading inhibition plays the most significant role in retrieval inhibition, priming with capitols should cause greater inhibition than priming with states, since that prime would belong to the same set in memory as the target information.

Experiment 2

Methods

Subjects

The study involved 53 undergraduate students – 13 male and 40 female – from Washington and Lee University who volunteered to participate in the experiment. All subjects were born and raised in the United States. The data collected from 18 of the subjects were later discarded according to rules which will be discussed shortly.

Materials

All data collection occurred using a Power Macintosh G4 computer connected to a microphone. The software used for this experiment was designed and implemented by the experimenter, using REALbasic for the Macintosh. Every time the program was executed, it generated a random list of 25 of the United States. The software then pseudo-randomly created 24 experimental questions, adhering to the following criteria. Each question consisted of two states, and seven types of questions were presented during the course of experiment. Some questions presented two different states from the studied list with a state prime (SS), while some used two different states from the studied list with a capitol prime (SSc). Other questions involved a non-studied state prime with a studied cue (NS), while others used a non-studied capitol prime with a studied cue (NSc). Moreover, some questions involving two states from the non-studied list were inserted, with either state or capitol primes (NN and NNc). Lastly, some questions presented a duplicate state (D), so that the same non-studied state was used twice within that question. The frequency with which a D question used a state or capitol prime varied randomly. With the exception of D questions, no state was used more than once in this set of 25 questions. This program saved the study list and experimental questions for each subject in separate text files, aiding in later data analysis. The software was also designed to permit audio waveform visualization and integration to aid and increase precision in scoring data.

Design

The experiment was conducted using a within-subjects factorial design. Two independent variables were used, each with two levels – prime Type (state or capitol) and prime Study (studied or non-studied). For the purposes of data analysis, D questions were not scored; they served as a control to prevent subjects from assuming that the cue would differ from the prime. Similarly, NN and NNc questions were not scored, but were instead used as a benchmark for data reliability. A subject's ability to respond correctly to non-studied states was considered to be an indicator of the extent of their prior exposure to states and state capitols, and subjects who had little prior exposure tended to give more widely-dispersed response times.

The dependent variable for this experiment was the response time, which was measured at a ratio level of measurement. Since the audio recording software created for this experiment enabled automatic processing and viewing of recorded waveforms, response time could be measured very accurately, to the nearest millisecond. Response times were measured from the cue stimulus timestamp to the beginning of the correct integrated voice response, similar to the method as illustrated in Figure 1.

Procedure

To facilitate audio recording, each subject participated in the experiment individually in a quiet room. Subjects were then presented with a list of 25 states matched with the corresponding capitols on the computer screen. They were given unlimited time to study the list, with instructions to study it until they felt able to recall the capitol when presented with any state from that list. When they notified the experimenter that they were ready, the experimenter read directions aloud to the subjects, and these directions are reproduced in Appendix D. After the subjects clearly understood the directions, the experimenter quizzed them verbally on every state from the list, naming a state to the subjects and asking them to answer with the state capitol. Verbal quizzing was repeated indefinitely until the subject was able to proceed through the entire list twice in a row with no errors.

Next, a slide show began on the computer screen, in which the stimuli were presented sequentially on the screen. The experimenter manually advanced each slide using the mouse input to ensure that all stimuli were presented with the appropriate timing. Each subject completed two example problems prior to beginning the experiment proper, and the two cue states for the example problems were always Virginia and the subject's home state, thus avoiding interference from other states in the experiment. Finally, the audio recording was started, and the subjects completed 4 questions in each of the SS, SSc, NS, NSc, and D categories. Subjects also completed 2 questions in each of the NN and NNc categories. The order in which the questions were presented was randomized for the sake of counterbalancing. Between every question, subjects completed a simple math problem between every prime/cue set which served as a distracting task, thus minimizing the carryover effect between questions. The subjects simply repeated the name of the prime stimulus, while they responded with the capitol of the cue. The computer program made a brief audible beep while simultaneously presenting the cue, thus reminding the subject to give the capitol, while also serving a reference point in the data recording to allow visualization of the cue timestamp. At the conclusion of the experiment, subjects were debriefed on the goals of the study.

Results

Of the 53 subjects who participated in the experiment, the data from 18 were discarded because they responded incorrectly to all of the questions in the NN and NNc categories. Next, since response times tend to be positively skewed, and since most responses in this experiment ranged from 0.8 seconds to 1.5 seconds, any individual responses greater than 2.0 seconds were eliminated from consideration. The median from the remaining data was selected as the best representative descriptive statistic to offset the tendency for skewed data, so the median response time was selected from the remaining correct responses to the SS, SSc, NS, and NSc questions for each subject. The median response times in each category for all of the subjects were recorded as shown in Appendix B. In addition, using these median latencies, the mean (*M*) and standard deviation (*SD*) for each category were calculated as indicated in Table 2, and as illustrated in Figure 3. The *M* response time was 1.242 seconds for SS questions, 1.164 seconds for SSc questions, 1.166 seconds for NS questions, and 1.113 for NSc questions.

Using the data shown in Appendix B, a within-subjects two-way analysis of variance was conducted to determine the overall effects of Study, Type, and Study by Type interaction. The effect of Study was found to be significant ($F(1,34) = 4.351$, $MSe = 0.032$, $p < 0.05$, $\eta = 0.337$). A significant effect for Type was also found ($F(1,34) = 4.466$, $MSe = 0.034$, $p < 0.05$, $\eta = 0.341$), but no significant interaction between Study and Type was found ($F(1,34) = 0.175$, $MSe = 0.031$, $p > 0.05$, $\eta =$

0.072).

The results of this experiment again show some unusual effects, which may allow strong explanations to be proposed for this retrieval inhibition. The descriptive statistics presented in Table 2 illustrate that, as expected, the mean response time for NS questions was faster than that for SS questions, and the mean response time for NSc questions was similarly faster when compared to the latency for SSc questions. Unexpectedly, however, the mean response time for questions using a state prime was slower than for the questions using a capitol prime in the corresponding categories of studied and non-studied primes. Lastly, the standard deviation was relatively consistent for all questions, indicating that response times were fairly tightly dispersed for all of the questions when subjects were required to recall capitols of states from their studied list.

The main effect found for Study replicated the finding shown in the first experiment, whereby presentation of a studied prime causes more of an inhibitory effect than a non-studied prime. Thus, the response times following studied primes were longer than response times following non-studied primes, regardless of whether the prime was a state or a capitol. Now, the significant effect for Type was the most interesting result, because this had been completely unanticipated. This indicates that, regardless of whether the prime was studied or non-studied, the response latencies following capitol primes were faster than the corresponding response times for state primes. The effect sizes for both of these inferential statistics were moderate, indicating that important underpinnings of the mechanism behind memory retrieval may be revealed from this information.

GENERAL DISCUSSION

The design of the first experiment did not attempt to distinguish between the potential causes of retrieval blocking, since Roediger and his colleagues (1983) already demonstrated that more factors than simply automatic spreading inhibition were likely to be involved. However, the present study expanded upon the findings made by Brown (1979) and Roediger, because a new mechanism for interfering with semantic memory retrieval was discovered in the present research. In both of those studies, the experimenters primed their subjects with potential answers to a question in order to achieve memory blocking, while the present research primed subjects with potential questions to create the memory blocking effect when the subject subsequently attempted to retrieve the answer to the following question.

Carr and Dagenbach (1990) observed that memory blocking could occur by an inhibitory mechanism highly analogous to lateral inhibition, with what they termed a "center-surround attentional mechanism". If a similar sort of automatic spreading inhibition played a role in the retrieval blocking found in this experiment, this method of inducing retrieval blocks presumably exerted its effect by an indirect route. That is, when the subjects were primed with a state from the study list, activation of the memory node for that state occurred, and since the subject had recently studied the capitol of that state, the pathway between that state and its capitol was relatively sensitive to activation, causing stimulation of the node associated with that state capitol. In this way, retrieval of semantically related nodes – that is, nodes associated with other state capitols – was inhibited. By this model, the inhibition effect would not be seen when subjects were primed with a state that they had not studied, since the pathway connecting a non-studied state to its capitol was far less prone to activation than a pathway that had been recently aroused by studying. For an illustration of this mechanism for indirect semantic memory retrieval, see the connectionist model outlined in Figure 4.

Note that for the SS questions, because the activation of the node for a state leads to subsequent activation of the corresponding capitol, the activation of the node for the capitol inhibits nodes semantically related to it – that is, this node inhibits the nodes for other capitols so that they are relatively more difficult to retrieve on the subsequent cue. By contrast, the connection between the prime state and its capitol is weak and relatively insensitive to activation. Therefore, the node for the capitol corresponding to the prime state is less likely to be activated, so inhibition of semantically related nodes does not occur, and little interference takes place during retrieval of other state capitols on the following cue.

J. Brown's (1968) study supported the concept of automatic spreading activation among associated memory nodes, and some observations such as those by A. S. Brown (1979) may be attributed almost entirely to automatic spreading inhibition. However, Roediger et al. (1983) showed that retrieval inhibition was not necessarily due to such an effect, but other cognitive processes may cause the delay. While the difference between these findings may be a result of the different procedures used by each, the reader must note that the precise cognitive mechanism underlying retrieval blocking remains conjectural. Experiment 2 accomplished more to further reveal the mechanistic underpinnings in this phenomenon which, along with automatic spreading inhibition, may contribute to memory blocking.

Due to the more precise methods, relative to Experiment 1, the second experiment should be considered a confirmation of the indirect memory blocking initially observed. The software integration of waveform data allowed responses to be measured much more precisely, and eliminated the possibility of inadvertent experimenter bias in data scoring. As illustrated in the first experiment, memory blocking may occur, at least in part, via automatic spreading inhibition, and this inhibition would occur directly with the horizontal connection between two states, or indirectly using the vertical connection between a state and the capitol set.

The Type effect from the second experiment, while initially unexpected, may prove to reveal more about the mechanism of memory blocking than first anticipated. One might question why, in light of the model for indirect automatic spreading inhibition proposed in Experiment 1, there should be an effect between studied and non-studied capitol primes. The strength of the connection between that state and its capitol is obviously not important in this priming effect, and it seems logical that one capitol, even if it had not been studied, would still be semantically related to other capitols and therefore should have a blocking effect via automatic spreading inhibition. This leads to the notion that more than automatic spreading inhibition may be involved, and that the relative degree of activation of various nodes in memory plays an important role in retrieval inhibition.

Before explaining this effect, one should note that subjects only studied from state to capitol, and not vice versa. This issue may play a partial role in the Type effect, but more is likely to be involved. Memory retrieval appears to involve a mechanism whereby long-term memory is temporarily loaded, in a sense, into the more volatile immediate memory, which is that memory that is currently cognitively active. In order to load any given item into immediate memory, it must be first cleared of its current contents. This action of wiping the contents of immediate memory takes a non-trivial amount of processing time, and the amount of processing time required for this operation is influenced by two factors – the amount of information, and the strength of information in immediate memory.

When a subject recalls a given capitol, less concomitant information is likely to be retrieved than when a subject recalls a given state. In other words, a given capitol may hold little significance aside from its status as the capitol city of a state. However, a given state is likely to hold far more significance aside from being the home state of its capitol. For example, the stimulus of "Albany" is likely to cause subconscious memory retrieval of little information, but the stimulus of "New York" is likely to cause subjects to think of New York City, Long Island, Wall Street, the Giants football team, the Catskill mountains, and so forth. Note that this may vary from state to state, because some states have more prominent capitols than others. Also, individual subjects may have important ties to a given city, such as having family in Sacramento or having attended college in Denver. However, the confounding effects of these less likely instances would achieve a statistical average of unimportance over the course of the experiment. In light of this, more information is retrieved into immediate memory when a subject is primed with a state than when primed with a capitol, thus raising the overhead required in processing time to retrieve the subsequent capitol.

Also, studying results in heightened activation of the studied states and studied capitols, apparently increasing their inhibitory effect on memory retrieval. Monaco (2000) sought to explain this by drawing an analogy with computer science. As he pointed out, according to the computer science model of Strongest Association First Out stacks, items in memory may be stored in a vertical stack, with most highly activated set elements near the top. Thus, any recently stimulated item is more likely to be retrieved, since items are always removed from the top of the stack. This particular means of memory blocking seems to correlate with the hypotheses mentioned earlier from the Nickerson (1984) paper, which indicate that items compete for immediate memory at retrieval time, and more strongly activated items are more likely to be retrieved. Because a studied prime will likely remain in immediate memory more stubbornly than a non-studied prime, subsequent retrieval takes longer, and inhibition is observed.

It is worth noting that, if the degree of activation in memory of an item influences its ability to inhibit retrieval of other information, then Blaxton and Neely (1983) may not be entirely justified in their conclusions. Subjects who were required only to read a given prime did not necessarily have to perform a great deal of mental computation to do so. Because retrieval of an item is a cognitively involved process relative to simply reading that prime, it follows that prime retrieval would activate that prime more highly than reading it. This heightened activation and its subsequent effects on future memory retrieval, rather than inherent aspects of the initial retrieval itself, may be the source of their experimental findings.

By consolidating these potential contributors to retrieval inhibition, a new model must be proposed to explain the cognitive mechanism underlying memory retrieval, and thus account for the effects that have been experimentally observed. The retrieval model for the Immediate Memory hypothesis, outlined in Figure 5, should be considered a consolidated algorithm containing interdependent processes, which are separated into discrete components merely for the sake of understanding. Since neural processing occurs in a massively parallel fashion, instead of serially as computers process information, flow diagrams – while they may be accurate on a macroscopic level – should not be assumed to be an exact representation of the processing which occurs on a more minute level in the brain.

Immediate memory is defined as a focused area of memory in which data may be operated upon directly. One may consider immediate memory to be a designated segment of memory or consciousness, or one may think of it as a multifaceted cursor which may be moved about in long- or short-term memory to point to one or more specific items at a time. The latter is likely to be more accurate on a neural basis, while the former illustration may be easier to understand due to its conceptual similarity to the processor registers of a computer. Regardless of how one prefers to understand immediate memory, the point remains the same – items stored in memory must be assembled into structures of immediate memory before they can be consciously manipulated or retrieved.

Baddeley (1986) developed the most influential definition of immediate memory. To explain the place of immediate memory in relation to other types of memory, short-term memory is generally considered to be a faculty of limited size, although it may concurrently contain bits of information of unrelated types. Short-term memory shows volatile tendencies, because its contents tend to experience rapid temporal decay. However, the contents of short-term memory may be consolidated into long-term memory if they become sufficiently activated. Long-term memory, by contrast, is an informational container of apparently unlimited size which is not as prone to temporal decay as short-term memory. Information retrieval from long-term memory, however, may sometimes prove more difficult than information retrieval from short-term memory. Now, immediate memory is an extremely volatile memory facility, with its contents decaying in less than one second, only to be continually replaced by new information. The size of immediate memory is limited by the fact that it is a highly focused type of memory, and thus can only contain bits of information that are closely related at any given time. Furthermore, if information in immediate memory undergoes cognitive processing, it may become incorporated into short-term memory. The most important distinction is that while immediate memory may be filled with information from the environment, from short-term, or from long-term memory, any information which must be operated upon must first be loaded into immediate memory.

Information is constantly being loaded into immediate memory by a variety of means. This may occur subconsciously as a result of an outside stimulus, as foreign information from the environment may be brought into immediate memory via the senses. Loading of information into immediate memory may also occur intentionally as the subject makes a conscious effort to operate upon a desired item from memory storage, in either short-term or long-term memory. Regardless of how information is loaded into immediate memory, other items which are strongly associated with items in immediate memory may be automatically loaded as well.

As information is loaded into immediate memory, a person must deliberately scan through available items to see if any of the items in immediate memory represents the desired target. The amount of time required to scan through the items in immediate memory increases in relation to the amount of information available in immediate memory. If the desired information is found after scanning the contents of immediate memory, then the target is retrieved and the task is completed.

If the target item is not found in immediate memory, then the contents of immediate memory must be cleared in order to load new information. Alternatively, if one prefers the pointer interpretation of immediate memory, this attentional arrow must be shifted away from its current mark to point toward other items in memory. The amount of processing time required to remove items from immediate memory increases with the degree of activation of any given item. An unimportant item may be removed from immediate memory very easily, while a significant item is likely to remain a stubborn resident of immediate memory for much longer.

As mentioned before, one should not consider the step of clearing immediate memory to be entirely distinct from the subsequent step of loading new information into immediate memory. It may be more helpful and accurate to think of new information being loaded and therefore forcing old information out of immediate memory. Note that this process does not involve a conscious effort to avoid thinking about an undesired item; instead, it is the effort to load new and desirable information into immediate memory that causes the old residents of immediate memory to decay.

Other models have been proposed to try to illustrate the mechanistic source of memory blocking, so a comparative analysis must be undertaken. The Competition-at-Retrieval hypothesis embraces a very similar idea to that of the Immediate Memory hypothesis, in that intercompetition between related nodes of memory can lead to difficulty in memory retrieval, and that the degree of activation of these memory nodes leads to increased competition between them. The greatest difference between the two hypotheses is that the Immediate Memory hypothesis seeks to expand upon the Competition-at-Retrieval hypothesis and find a more detailed explanation of why such competition leads to retrieval blocking, and it accomplishes this by providing a possible cognitive mechanism behind retrieval itself. Regardless, the Competition-at-Retrieval hypothesis serves adequately to explain the studied/non-studied effect observed. However, it fails to account for the effect between state and capitol primes that was found. To make up for this, one additional idea that the Immediate Memory model proposes is the possibility that sheer quantity of information can lead to memory blocking, just as heightened activation can. While this thought would make sense under the Competition-at-Retrieval paradigm, it is not explicitly stated.

The SAM hypothesis of Raaijmakers and Shiffrin (1981) is not incompatible with the Immediate Memory hypothesis, but it takes a very different approach to solving the same problem. This hypothesis describes the temporary rearrangement of memory nodes into volatile structures that results from studying, while the Immediate Memory hypothesis describes the mechanism of retrieval from pre-existing structures. The SAM hypothesis seems to account for the state/capitol prime effect quite well. If list items are separated into clusters of states and capitols, and if individuals are most likely to oversample clusters containing recently stimulated items, then priming people with a capitol would make them likely to sample from the cluster of capitols, thus finding the target information more quickly than if they oversampled from the state cluster. However, this idea of memory clustering seems to predict the opposite of the Study effect, because if memory nodes were divided into studied and non-studied clusters, it seems that subjects would be most likely to resample from the studied cluster after having been primed with a studied item. In essence, the Immediate Memory hypothesis does not contradict the SAM hypothesis, but it may instead serve as a complement, helping it to account for observations that it was previously unable to explain.

The Immediate Memory hypothesis appears to be fairly robust, because it seems to account well for previous experimental findings in this field which could not be explained by automatic spreading inhibition, and it seems to be compatible with the previous hypotheses proposed in the field of retrieval inhibition. Additionally, the Immediate Memory hypothesis seems to explain a classical psychological phenomenon which is not directly related to memory retrieval inhibition – the Stroop effect. This phenomenon can be evoked in a variety of fashions, one of which involves subjects reading through a list of color names printed in colored ink, but the color name and ink color do not correspond. Subject take significantly longer to complete this task than to read through a list of black words describing color names or solid boxes illustrating a color. According to the Immediate Memory hypothesis, each time a subject sees an item from the list, two nodes will be loaded into immediate memory – the color described by the word and the color described by the ink. Thus, additional processing time is required to decide which of the elements in immediate memory represents the correct answer. This task differs from memory retrieval tasks because, of the items in immediate memory, one will always be the target answer, so no clearing of immediate memory is required until proceeding to the next item in the list. Regardless, the processing model illustrated in Figure 5 shows how the operations of immediate memory would lead to an increase in processing time. The Competition-at-Retrieval hypothesis seems to account for the Stroop effect as well, suggesting that competition between the two colors would lead to the time increase. However, the SAM hypothesis fails to explain the Stroop effect, because no clustering of information appears to be occurring.

Based upon this comparative study of models, the Immediate Memory hypothesis appears to hold substantial merit in deepening our understanding of the process underlying memory retrieval. In an argument inspired by Occam's Razor, it seems to be the simplest hypothesis which shows the most versatility of applications. Like all models, there are likely to be some conditions under which it would break down, and as required by science, it is prone to falsification by future research. However, it corresponds very well with our feeling of having to focus our attention in order to process material. With all of these justifications put together, one should accept the Immediate Memory paradigm as a potential explanation for memory retrieval.

In closing, it may be unnecessary to reject one model to further qualify another, because these varying ideas may serve to complement one another instead of contradicting one another. Scientists must always be open-minded to the mutual compatibility of their ideas. To illustrate, we should consult the fabled four blind men who all inquired into the nature of an elephant. The first one felt its leg and said, "An elephant is like a tree." One of them felt its trunk and said, "An elephant is like a snake." Still another felt its ear and said, "An elephant is like a piece of leather." The last one felt its tail and said, "An elephant is like a rope." If they could combine the differing ideas instead of rejecting them, they would form a much more complete picture of the true nature of the elephant.

Conclusion

Considering the two experiments together, there appear to be three potential causes of the retrieval blocking observed. Processing time is required to clear the contents of immediate memory, and a studied prime requires more time to be removed from memory than a non-studied prime. Also, competition at retrieval causes those items which are strongly highly activated to be most prone to retrieval from memory. Lastly, automatic spreading inhibition may or may not play a role in this phenomenon, and it cannot be ruled out on the basis of current experimental findings. Current models that have been proposed seemed inadequate to account for the effect seen between state and state capitol primes. However, important aspects of retrieval inhibition may be explained within a model for memory retrieval using the concept of immediate memory, as illustrated.

Additional research based upon the current study could be improved by replicating the findings of this study using a different set of information for primes and cues. Using American presidents and their corresponding vice presidents would serve this purpose well. Furthermore, later experiments should examine the effects of priming subjects with nonsense words versus real words, while measuring subsequent response times in tasks. According to the idea that immediate memory would be more difficult to clear if its contents hold significance, one would expect that inhibition would be greater when subjects are primed with real words than with nonsense words. Experiments comparing the effects of using studied or non-studied, state or capitol primes with the effects of unrelated words, real or nonsense. This inquiry should lead either to further support for the Immediate Memory model, or to the exposure of its need for revision or rejection.

Regardless of the precise mechanism underlying the effects discovered in this experiment, the present research remains consistent with observations made by Posner (1973), which represent the central theme in research of memory retrieval processes: "The tendency of thought to follow paths similar to ones that have recently been activated is an important and pervasive one."

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Table 1.

Means and Standard Deviations of Median Response Times in Experiment 1.

	SS	SN	NS	NN
M	1.01	2.23	0.89	1.92
SD	0.32	1.14	0.16	0.79

Note. All times are in seconds.

Table 2.

Means and Standard Deviations of Median Response Times in Experiment 2.

	SS	SSc	NS	NSc
M	1.242	1.164	1.166	1.113
SD	0.260	0.230	0.235	0.213

Note. All times are in seconds.

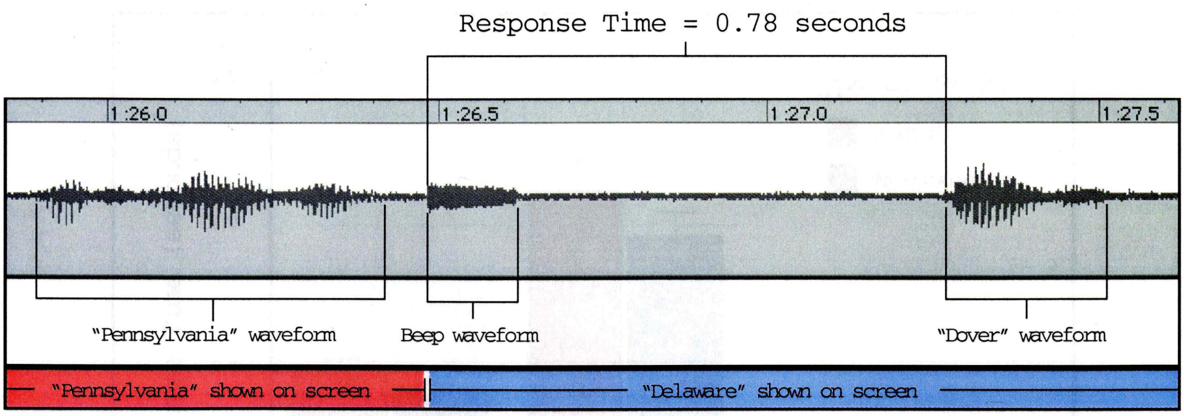

Figure 1. Sample waveform from Subject 13 in Experiment 1, illustrating the technique used to measure response times. The red segment of time represents the prime, while the blue segment of time represents the cue. Note that the image was scaled down to fit the page, while actual measurement took place using a higher level of magnification to allow greater precision. Experiment 2 measured response times according to the same rules, but the actual measurements were performed by the computer instead of by the experimenter.

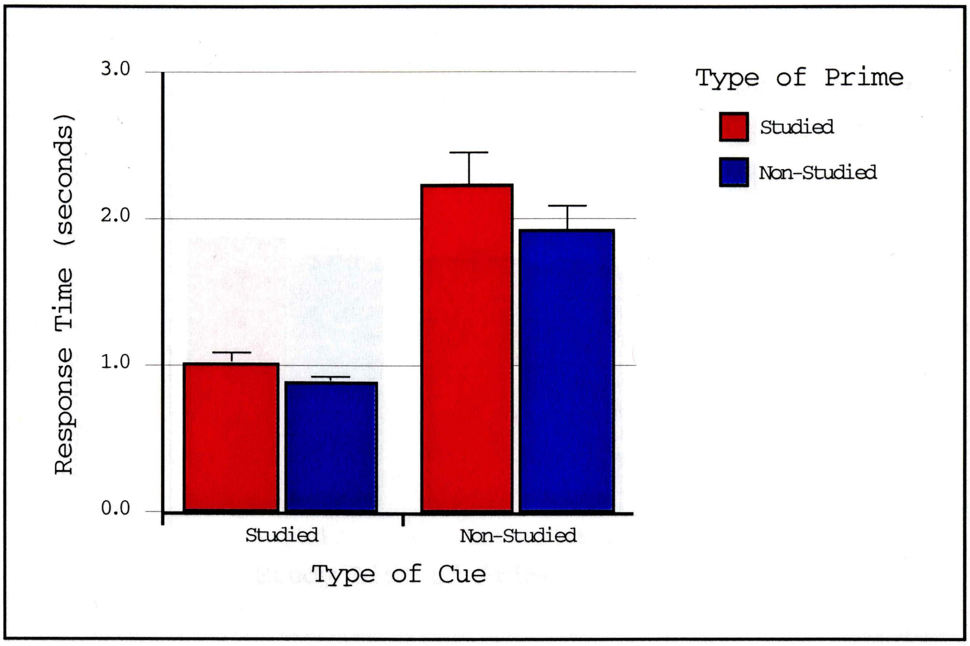

Figure 2. Graph of means and standard errors of the mean for response times in each category of question in Experiment 1. All times are in seconds.

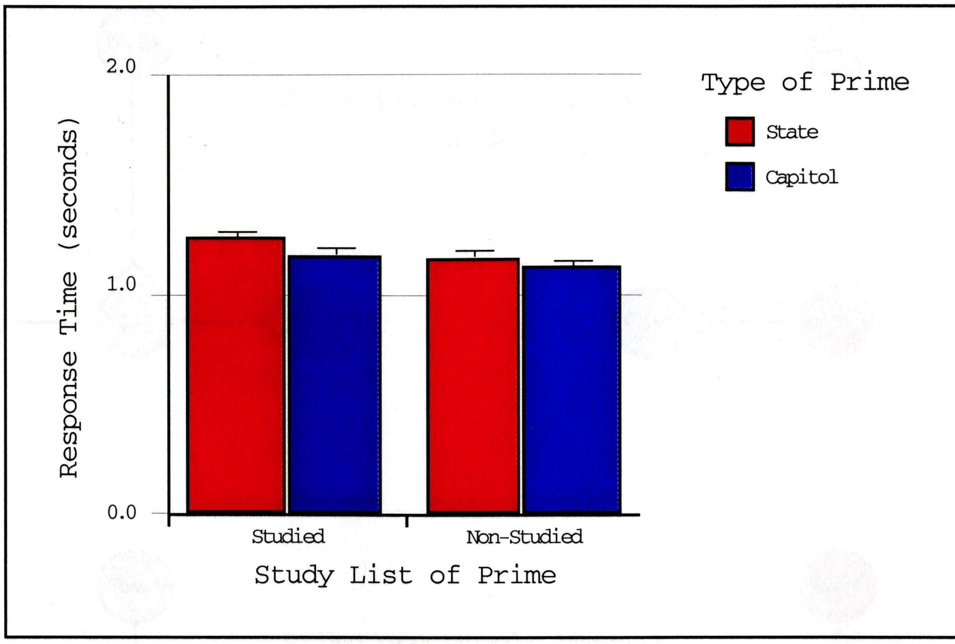

Figure 3. Graph of means and standard errors of the mean for response times in each measured category of question in Experiment 2. All times are in seconds.

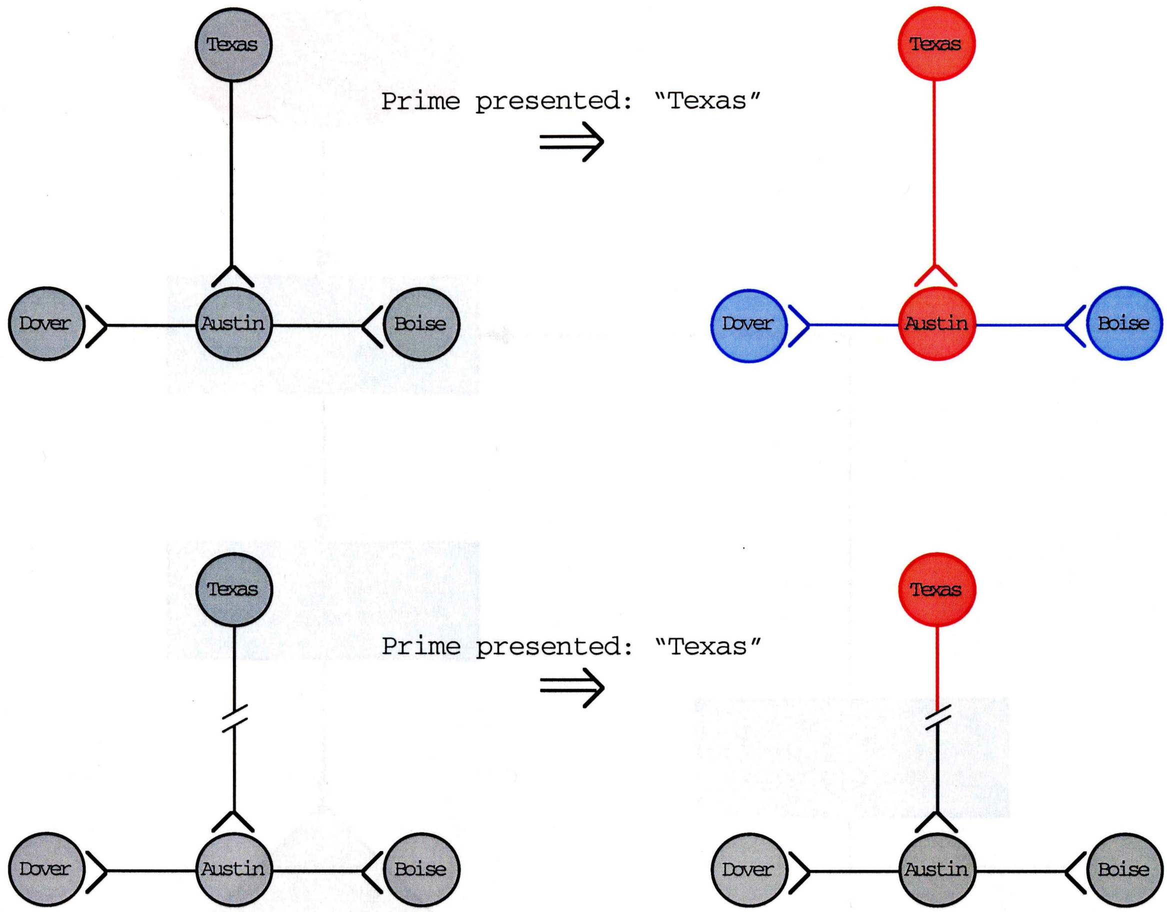

Figure 4. Model to represent observed the indirect retrieval blocking seen in Experiment 1. All gray nodes and connections represent the resting state. Red nodes and connections represent an activated condition, whereas those in blue represent an inhibited condition. The top diagram illustrates the inhibition observed in the SS question category, as the connection between the studied state and its capitol is relatively prone to activation. The bottom diagram is identical, but it represents the NS question category, wherein the connection between the non-studied prime state and its capitol is weak and relatively insensitive to activation.

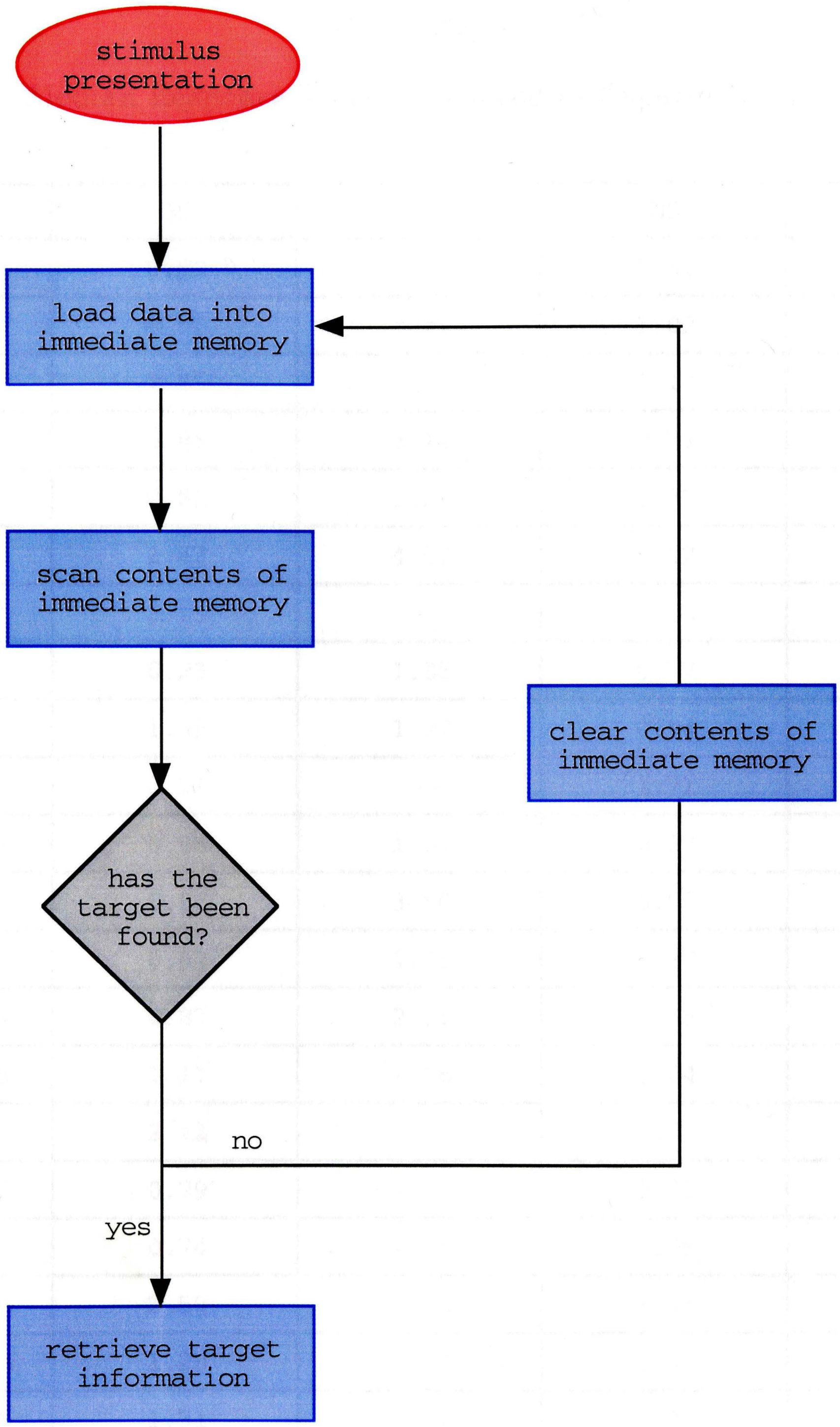

Figure 5. Flowchart diagram to illustrate the processes involved in the proposed Immediate Memory model for memory retrieval.

Appendix A

Median Response Times Measured in Experiment 1.

	SS	SN	NS	NN
Subject 1	0.89	1.11	0.80	1.04
Subject 2	0.92	1.79	1.02	2.53
Subject 3*	1.25	---	1.13	2.39
Subject 4	0.85	3.14	0.77	1.64
Subject 5	0.81	1.25	0.77	4.13
Subject 6	1.42	4.52	1.02	2.56
Subject 7*	2.15	---	1.98	---
Subject 8	0.73	1.85	0.77	1.50
Subject 9	1.35	1.97	0.94	1.36
Subject 10*	0.82	---	1.71	2.04
Subject 11	0.86	1.37	0.87	2.10
Subject 12	0.86	3.50	0.82	1.22
Subject 13	0.82	1.75	0.89	1.73
Subject 14	0.87	2.11	0.65	1.01
Subject 15	1.11	1.16	1.04	2.76
Subject 16*	2.12	---	0.97	2.29
Subject 17	0.79	1.70	0.75	0.98
Subject 18*	0.74	1.85	0.99	---
Subject 19†	2.50	2.05	1.13	8.74
Subject 20†	1.28	1.82	3.46	1.08
Subject 21	1.31	1.52	0.97	3.01
Subject 22†	0.94	3.15	2.37	2.76
Subject 23	0.71	4.88	0.86	2.95

Appendix A Continued

	S/S	S/N	N/S	N/N
Subject 24	0.70	2.35	0.69	1.23
Subject 25*	0.83	1.42	0.89	---
Subject 26	0.82	1.82	0.77	1.51
Subject 27*	0.94	---	1.12	---
Subject 28	1.00	1.41	0.93	1.34
Subject 29*	0.96	---	1.07	2.24
Subject 30	1.80	3.44	0.84	1.85
Subject 31	1.73	2.11	1.31	1.66
Subject 32*	0.89	---	0.76	---
Subject 33*	0.75	1.34	0.99	---
Subject 34	0.73	1.06	0.79	1.61
Subject 35*	0.93	2.67	1.23	---
Subject 36	0.92	1.37	0.95	2.08
Subject 37	1.28	4.16	1.25	2.44

Note. All times are in seconds. Data points shown in red were discarded. An asterisk (*) indicates that the subjects responded incorrectly to all five questions in one or more categories, so these points could not be scored. Data from subjects marked by a cross (†) were discarded as extreme outliers via the Dixon test.

Appendix B

Median Response Times Measured in Experiment 2.

	SS	SSc	NS	NSc
Subject 1	0.839	0.891	0.875	1.068
Subject 2	1.044	1.390	1.038	0.880
Subject 3	0.961	0.996	1.175	0.850
Subject 4	1.542	1.152	1.243	0.886
Subject 5	1.294	1.080	1.077	0.938
Subject 6	1.095	1.235	1.578	0.892
Subject 7	0.891	1.085	1.219	1.021
Subject 8	1.596	1.396	1.570	1.292
Subject 9	1.168	1.628	0.940	0.984
Subject 10	1.111	0.880	0.958	1.417
Subject 11	1.130	1.088	1.098	1.684
Subject 12	1.076	1.139	1.452	1.050
Subject 13	0.793	0.902	0.963	0.845
Subject 14	1.061	1.002	0.990	0.978
Subject 15	1.295	1.491	1.406	1.192
Subject 16	0.906	0.860	1.150	1.065
Subject 17	0.938	1.237	1.048	1.404
Subject 18	1.642	1.214	1.173	0.999
Subject 19	0.857	1.389	0.822	0.820
Subject 20	0.868	0.879	1.163	0.991
Subject 21	1.192	1.145	0.953	1.132
Subject 22	1.056	1.489	1.291	1.569
Subject 23	1.181	1.168	1.368	1.233

Appendix B Continued

	SS	SSc	NS	NSc
Subject 24	1.093	1.567	1.006	1.318
Subject 25	1.398	1.421	0.998	1.304
Subject 26	1.259	1.125	1.087	1.078
Subject 27	1.509	1.574	1.219	1.064
Subject 28	1.383	1.163	1.526	1.397
Subject 29	1.314	1.122	1.238	1.312
Subject 30	1.004	1.189	1.440	1.290
Subject 31	1.524	1.505	1.594	1.423
Subject 32	1.602	1.752	1.384	1.615
Subject 33	1.493	1.464	1.875	1.179
Subject 34	1.994	1.432	1.583	1.088
Subject 35	1.554	1.160	1.216	1.532
Subject 36	1.302	1.108	1.015	0.981
Subject 37	0.954	1.068	1.068	0.972
Subject 38	1.315	1.399	0.969	1.221
Subject 39	1.254	0.922	1.178	1.008
Subject 40	1.531	0.986	1.256	1.291
Subject 41	1.080	1.095	1.402	1.271
Subject 42	1.261	1.531	1.391	1.012
Subject 43	1.438	0.901	0.885	1.226
Subject 44	1.179	0.898	0.925	0.864
Subject 45	1.169	1.068	1.092	1.067
Subject 46	1.161	1.164	1.204	1.399
Subject 47	0.939	1.437	1.197	1.441

Appendix B Continued

	SS	SSc	NS	NSc
Subject 48	1.078	1.314	1.167	1.937
Subject 49	1.270	1.380	1.283	1.784
Subject 50	1.459	1.396	1.124	1.461
Subject 51	1.351	1.376	1.468	1.438
Subject 52	1.094	0.879	1.109	1.107
Subject 53	1.246	0.828	0.967	0.966

Note. All times are in seconds. Medians were calculated after eliminating all individual responses greater than 2.0 seconds. Data points shown in red were discarded because subjects missed all four of the questions between the NN and NNc categories.

Appendix C

Directions Given to Subjects in Experiment 1.

This experiment will consist of 25 questions, and each question will have two parts. First, the name of a state will be presented to you on the computer screen, and you simply need to repeat the name of the state aloud. Next, the name of a second state will be presented to you, and you need to respond with the capitol of that state. This process will be repeated 25 times in the next few minutes, after which the experiment will be finished. In order to help you remember when to give the capitol of each state, the computer will beep audibly to remind you. This experiment may involve states that you have not studied, and it may also use the same state twice in the same question, so do not let this surprise you. This experiment tests your response time, so if you know the capitol of a state, try to answer as quickly as possible. If you do not know the capitol of a state, do not worry about it, and you may simply say "Pass." Lastly, you will not be told whether you are right or wrong in your responses; the experiment will continue regardless.

Appendix D

Directions Given to Subjects in Experiment 2.

This experiment will consist of 24 questions, and each question will have two parts. First, a word – either the name of a state or a state capitol – will be presented to you on the computer screen, and you simply need to repeat aloud whatever you see on the screen. Next, the name of a second state will be presented to you, and you need to respond with the capitol of that state. In between each question, a simple math problem will appear on the screen which you will need to solve before proceeding to the next question. This process will be repeated 24 times in the next few minutes, after which the experiment will be finished. In order to help you remember when to give the capitol of each state, the computer will beep audibly to remind you. This experiment may involve states that you have not studied, and it may also use the same state twice in the same question, so do not let this surprise you. This experiment tests your response time, so if you know the capitol of a state, try to answer as quickly as possible. If you do not know the capitol of a state, do not worry about it, and you may simply say "Pass." Lastly, you will not be told whether you are right or wrong in your responses; the experiment will continue regardless.