THESIS

DOES RETRIEVAL ACTIVATE RELATED WORDS MORE THAN PRESENTATION?

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ABSTRACT

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Retrieving information enhances learning more than restudying. One explanation of this effect is based on the role of mediators (e.g., *sand-castle* can be mediated by *beach*). Retrieval is hypothesized to activate mediators more than restudying, but existing tests of this hypothesis have had mixed results (Carpenter, 2011; Lehman & Karpicke, 2016). The present experiments explored different explanations of the conflicting results. The pilot experiment tested—and found no evidence—that the results depended on whether a conceptual or perceptual measure of mediator activation was used. Experiments 1 and 2 tested whether mediator activation during a retrieval attempt depends on the accessibility of the target information. A target was considered less versus more accessible when fewer retrieval versus more cues were given during retrieval practice (Experiment 1), when the target had been studied once versus three times initially (Experiment 2), or when the target could not be recalled versus could be recalled during retrieval practice (Experiments 1 and 2). Although there was a trend for retrieval to activate mediators more than presentation, mediator activation was not reliably related to target accessibility. Thus, Experiments 1 and 2 neither strongly supported, nor disconfirmed, the role of mediators in enhancing learning from retrieval.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

A wealth of research has demonstrated that retrieving previously studied information enhances memory for that information relative to restudying it, a phenomenon referred to as the *testing effect* (for recent reviews see Roediger & Butler, 2011; Roediger & Karpicke, 2006; Rowland, 2014). The mnemonic benefits of retrieval over restudying have been demonstrated with different types of materials (e.g., single word lists, word pairs, face-name pairs, foreign language vocabulary definitions, maps, educational text passages) and different types of tests (e.g., recognition, cued recall, free recall) (see Roediger & Butler, 2011; Rowland, 2014, for reviews).

Despite the extensive evidence that retrieval enhances learning, there is no consensus on how retrieval enhances learning. Multiple theories have been proposed, but only two specify an underlying mechanism: the *elaborative retrieval hypothesis* (Carpenter, 2009, 2011; Pyc & Rawson, 2010, 2012) and the *episodic context account* (Karpicke, Lehman, & Aue, 2014; Lehman, Smith, & Karpicke, 2014). Both theories suggest that, relative to restudying, individuals form more effective cues for to-be-remembered information following retrieval. However, the theories differ on the exact nature of these cues. The elaborative retrieval hypothesis proposes that the cues are words and ideas that are semantically related to the to-be-remembered information. The episodic context account proposes that the cues are contextual features from the initial learning episode and subsequent initial retrieval attempt. To preview, the goal of this thesis is to test a key prediction of the elaborative retrieval hypothesis. The episodic context account will only be addressed in the General Discussion because the present experiments have no direct implications for it.

Elaborative Retrieval Hypothesis

According the elaborative retrieval hypothesis (Carpenter, 2009, 2011; Carpenter & Yeung, 2017; Pyc & Rawson, 2010, 2012), when people are given a cue and asked to retrieve the target, activation automatically spreads throughout the cue's semantic network (Collins & Quillian, 1972, Collins & Loftus, 1975). Because of this spreading activation, the cue becomes connected to related semantic information that then connects it to the target. This process is illustrated in Figure 1. For example, when a cue is presented (e.g., *sand*) and participants are asked to retrieve a previously studied target (e.g., *castle*), activation spreads from the cue and activates related words or concepts, which can be referred to as mediators (e.g., *beach*). When the pair is restudied, the target is immediately available; therefore, the contents of memory do not need to be searched and less activation spreads from the cue. Thus, restudying leads to weaker mediator pathways from the cue to the target. On a later test, the target is more likely to be recalled following retrieval practice than restudying because the additional mediated pathways facilitate retrieval.

Consistent with this account, Carpenter (2011) demonstrated that retrieval leads the learner to form cue-mediator-target connections. Participants studied word pairs (e.g., coffee-table) and then either restudied the pairs or took a cued recall test on them (e.g, coffee-????). A third word was considered to be a mediator of a cue-target pair if there was a strong pre-existing semantic association between the cue and the mediator (e.g., tea). On a final recognition test for the cues and targets, taking an initial test led to higher levels of false alarms for semantic mediators than restudying, suggesting that mediators are more activated by retrieval.

However, recent research has reached the opposite conclusion. Lehman and Karpicke (2016) had participants study related word pairs after which half of the pairs were presented again and half were tested. (Henceforth, *restudying* will refer to studying a pair more than once, which could involve pairs being presented or tested.) Immediately after each presentation or retrieval trial, participants engaged in a lexical decision task in which they judged whether the presented string of letters was a valid English word or not. Participants were shown a word strongly related to the cue (referred to as the *mediator* for the remainder of this article), an unrelated word, or a nonword. The key measure of interest was semantic priming: the difference in average reaction times on mediator trials and unrelated trials. If retrieval activates words and concepts in the cue's semantic network more than presentation, then priming (i.e., access to the mediator relative to the unrelated word) should be greater following retrieval trials than presentation trials. A significant semantic priming effect was found: Participants' lexical decision times were faster for mediators than unrelated words. Critically, however, the size of the priming effect was equivalent following retrieval and presentation trials and numerically greater following presentation trials. Thus, Lehman and Karpicke suggested that retrieval does not enhance learning by involving mediators.

In sum, two measures of activation of semantic mediators (false recognition and lexical decision reaction times) reached different conclusions. However, there may be principled reasons for these divergent findings. Two possibilities are that 1) the results depend on the way that mediator activation is measured (i.e., transfer appropriate processing) or 2) the results depend on the accessibility of the to-be-recalled information. The present experiments test these two hypotheses using a similar procedure as Lehman and Karpicke (2016).

Transfer Appropriate Processing in Priming

A major theme of memory research is that the way memory is tested affects performance. Specifically, memory performance is often best when the type of processing required on the test matches the type of processing at encoding, a phenomenon referred to as transfer appropriate processing (Morris, Bransford, & Franks, 1977). This has been demonstrated with *explicit* memory tests—i.e., when participants are told to use their memories—and more importantly for present purposes, with *implicit* memory tests (Blaxton, 1989; Franks, Bilbrey, Lien, & McNamara, 2000; Graf & Ryan, 1990; Jacoby, 1983; Jacoby & Dallas, 1981; Rajaram, Srinivas, & Roediger, 1998; Roediger & Blaxtona, 1987; Weldon, 1991). Implicit memory tests require participants to complete a task without explicitly telling them to consciously access a prior study episode. Some examples include lexical decision, reading a briefly flashed word, and word stem/fragment completion (for a review of all these tasks see Roediger & McDermott, 1993). A signature of implicit memory tests is that they show repetition priming effects, such that participants are faster to react to a given stimulus when they were previously exposed to that stimulus. For example, participants will be faster to complete the word fragment *d_c_o_* or judge the word *doctor* as a valid English word if they previously saw the word *doctor* (e.g., Duchek & Neely, 1989; Graf, Mandler, & Haden, 1982; Srivinas & Roediger, 1990; Tulving & Schacter, 1990; Tulving, Schacter, & Stark, 1982).

There is an important caveat to this pattern of repetition priming. The existence and magnitude of repetition priming effects depend on the degree of match between how the critical information is processed earlier in the experiment and the type of processing required on the implicit memory test. For example, Franks et al. (2000) demonstrated that participants were faster to make animacy judgments for words that they had previously encountered in the experiment as compared to new words (the classic repetition priming effect). However, repetition priming only emerged when the first time participants encountered a word also involved an animacy judgment and not a lexical decision. Critically, lexical decisions require primarily perceptual processing while animacy judgments require primarily conceptual processing (for reviews of this distinction see Roediger, 1990; 2003; Roediger & Blaxton, 1987a; Roediger & McDermott, 1993; Roediger, Srinivas, & Weldon, 1989; Roediger, Weldon, & Challis, 1989). Tasks such as lexical decision and perceptual identification (i.e., recognizing a word that was flashed very briefly) are considered primarily perceptual because completing them relies on processing physical features of the letters presented. Conceptual implicit memory tasks, in contrast, rely on meaning and concepts (e.g., what a doctor is, what it is related to), such as providing the first word that comes to mind in response to a cue (i.e., free association) or answering general knowledge questions.

Encoding manipulations that affect perceptual processing affect performance on perceptual implicit memory tests, but tend to have little or no effect on conceptual tests (Blaxton, 1989; Franks et al., 2000; Roediger & Blaxton, 1987b; Weldon, 1991; Weldon, Roediger, & Challis, 1989). For example, Blaxton (1989) reported that participants were faster to complete a word fragment of a word they had previously seen as opposed to heard. However, manipulating whether participants saw or heard a word had no effect on how likely they were to later answer a general knowledge question with that word. Most important for this research is the finding that the converse is also true. Conceptual encoding manipulations affect performance on conceptual tests, but have little or no effect on perceptual tests (Blaxton, 1989; Jacoby, 1983; Jacoby & Dallas, 1981; Rajaram et al., 1998, Vaidya et al., 1997; Weldon, 1991). One common way of manipulating conceptual encoding is to manipulate whether participants encode information deeply (e.g., by answering whether a presented word represent something tangible or intangible) versus shallowly (e.g., by answering whether a presented word contains a vowel). Vaidya and colleagues (1997) showed that participants were more likely to generate a target word (*tooth*) from a new cue (*tusk*) if the target word was encoded deeply, rather than shallowly, in the study phase of the experiment. However, deep versus shallow encoding does not affect perceptual identification (Jacoby & Dallas, 1981).

If mediators are activated, it is likely the result of conceptual, meaning-based processing of the cue. Therefore, because lexical decision is a perceptually based task, it may not be sufficiently sensitive to detect differences in mediator activation following retrieval versus presentation. However, there is one major difference between measuring mediator activation and the repetition priming literature reviewed previously. Measuring mediator activation is an example of semantic priming, which is the extent to which responses are faster to a critical word (*doctor*), not because participants studied it earlier in the experiment, but because they studied a semantically related word (*nurse*). Although lexical decision is one of the most common ways to measure semantic priming, to my knowledge, there is no research that has examined the extent to which semantic priming depends on the perceptual versus conceptual nature of the priming task (see MacNamara, 2005, for a thorough review of semantic priming).

Nevertheless, the results of a few similar experiments hint that transfer appropriate processing is also relevant for priming of words that were not previously studied (Blaxton, 1989; Graf & Ryan, 1990; Jacoby, 1983; Masson & MacLeod, 1992; Weldon, 1991). For example, Blaxton (1989) presented semantically related word pairs. Participants either read both words in the pair (*hawk*-*eagle*) or generated the second word based on the first word (*hawk*-*e*_____). Relative to reading the pair, generating the second word requires more conceptual processing and less perceptual processing (because the second word in the pair was not shown). Accordingly, generation led to greater priming of the second word than reading on conceptual tests and less priming than reading on perceptual tests. Thus, conceptual processing had opposite effects depending on the nature of the implicit memory test, even when the critical words were not directly presented in the experiment.

In light of this research on transfer appropriate processing and implicit memory, it is perhaps not surprising that Lehman and Karpicke (2016) did not find differences in mediator priming following retrieval and presentation on a lexical decision task. In what follows, I report a pilot experiment that was designed to test whether differences would emerge on a conceptual implicit memory task. To preview, there was no evidence that the nature of the priming task affected the pattern of priming results.

Pilot Experiment

The purpose of the pilot experiment was to provide converging evidence on whether retrieval activates semantic mediators more than presentation using a perceptual measure and a conceptual measure of mediator activation. Participants studied word pairs and then were presented with the pairs again or were tested on the pairs. Immediately after each presentation or test trial, participants engaged in a lexical decision task or a relatedness judgment task. Both tasks assessed participants' access to words strongly related to the cue (i.e., mediators) and unrelated words. The pilot experiment tested the hypothesis that if retrieval activates words and concepts in the cue's semantic network more than presentation, then priming (i.e., access to the mediator relative to the unrelated word) should be greater following test trials than presentation trials.

Methods

Participants. Forty-three participants completed the pilot experiment and received 1 hour of course credit for their participation. Twenty-two were randomly assigned to the lexical decision condition (5 females, mean age = 19) and 21 were randomly assigned to the relatedness condition (9 females, mean age = 19).

Materials. The materials were 60 sets of words (see Appendix A), 41 of which were used in Lehman and Karpicke (2016), while the remaining 19 were constructed using the same principles based on the Nelson, McEvoy, and Schreiber (2004) word association norms and the Paivio, Yuille, and Madigan (1968) norms.

Each word set consisted of a cue, a target, a related word, an unrelated word, and a pronounceable non-word (e.g., petals-tulip-flower-key-brepth). The cues and targets were weakly associated, with an average forward association strength (FSG) of .05. For example, when presented with the word *petal*, roughly 5% of people respond that *tulip* is the first word that comes to mind. The related word was a word that was strongly associated with the cue (avg. cue-mediator FSG = .70) or weakly associated with the target (avg. mediator target FSG = .05). The unrelated word was not related to any other words in the same set or any other word sets and was equated with the related words in terms of length and concreteness. Finally, the pronounceable non-words were also matched with the related words in terms of length (Rastle, Harrington, & Coltheart, 2002).

Design and procedure. The experiment had 3 phases: initial study, restudy+implicit memory, and final test. The three manipulations happened during the restudy+implicit memory phase (see Figure 2). Restudy condition (presentation vs. retrieval) was manipulated within-subjects as was the type of word used on implicit memory trials (related, unrelated, and non-word [lexical decision only]). The type of priming task (lexical decision vs. relatedness) was manipulated between-subjects.

Initial study. During the initial study phase, each of the 60 cue-target pairs was presented in a random order for 6 seconds with a 500 ms blank screen between each pair. Participants were instructed to learn these pairs for a later test.

Restudy+implicit memory. The restudy+implicit memory phase consisted of pairs of trials: a restudy opportunity followed by an implicit memory test designed to measure semantic priming (Figure 2). Thirty cue-target pairs were randomly assigned to the presentation condition in which the cue and target were presented again for 6 seconds. The other 30 pairs were assigned to the retrieval condition, in which the cue and the first 2 letters of the target were presented for 6 seconds. Participants were instructed to recall the second word in the pair, although they did not type their answer (leaving no record of their answers or their accuracy). The purpose of using a covert retrieval task was to minimize task switching between typing the target word and pressing the decision key in the priming task, especially since presentation trials did not require any overt response from the participants. Previous research has shown that covertly retrieving information enhances memory as much as overtly retrieving that information (Smith, Roediger, & Karpicke, 2013) and that using covert versus overt retrieval does not change the pattern of results in a lexical decision task (Lehman & Karpicke, 2016). Corrective feedback was not provided after retrieval trials in order to minimize the number of different, intermixed trial types in a single experimental phase. The purpose of corrective feedback would be to help participants learn the cue-target pairs better, which was not the primary focus of the experiment.

An implicit memory test followed each presentation or retrieval trial. A fixation point was presented on the screen for 500ms. Then, in the lexical decision condition, a related word, unrelated word, or non-word was presented and participants decided whether the presented word was a valid English word as quickly and accurately as possible. One third of presentation and retrieval trials were randomly assigned to be followed by related word, an unrelated word, or a non-word, respectively. In the relatedness condition, the cue was shown again, but paired with either a related word or an unrelated word. Participants judged whether the pair was related or unrelated as quickly and accurately as possible. Half of the presentation and retrieval trials were randomly assigned to be followed by a related pair and the other half by an unrelated pair. The 30 presentation+implicit memory trial pairs and 30 retrieval+implicit memory trial pairs were presented in a random order. Participants had three practice trials prior to beginning the restudy+implicit memory phase of the experiment in earnest.

Final test. After a 3-minute single-digit arithmetic distractor task, there was a cued recall test for all 60 pairs. The cue and the first 2 letters of the target were presented and participants had as long as they needed to recall and type the full second word in the pair. Final test performance in the pilot experiment will not be discussed further. The purpose of the pilot experiment and Experiments 1 and 2 was not to test whether retrieval enhances learning relative to presentation, but to examine the type of processing that happens during these two types of restudy opportunities. There are reasons to suspect that retrieval may not enhance learning relative to presentation in the present experiments, given their design. First, participants were not given feedback in the pilot experiment (and will not be in the Experiments 1 or 2) so as to minimize the number of different trial types in a single experimental phase. Retrieval does not consistently enhance learning relative to presentation when feedback is not provided (Rowland, 2014). Furthermore, the words presented on the implicit memory trials may have interfered with learning the pairs (e.g., Anderson & Neely, 1996), particularly following retrieval trials (Chan & LaPaglia, 2013; Chan, Thomas, & Bulevich, 2009; Pastotter & Bauml, 2014).

Results

Three participants in the lexical decision condition and two in the relatedness condition were excluded because their overall decision accuracy on implicit memory trials was below 85%. Among the remaining participants, individual trials were excluded if the implicit memory test answer was incorrect. Finally, trials were excluded if the implicit memory test reaction time was 2.5 standard deviations below or above that participant's mean reaction time. As a result, 5% of trials in the lexical decision condition and 6% of trials in the relatedness condition were excluded. Table 1 shows the mean reaction times for the remaining trials in each experimental condition.

Lexical decisions. The primary measure of interest was semantic priming, calculated as the difference between reaction times for lexical decisions for related words and unrelated words. Consistent with prior research, there was a robust semantic priming effect. Participants were significantly faster to respond when the word presented on the implicit memory was related (*ring*) to the previous trial (*diamond-gold*) compared to when it was unrelated (*nutmeg*). This was true following presentation trials, $t(18) = 3.48$, $p = .003$, $d = 0.78$, and retrieval trials, $t(18) = 2.90$, $p = .01$, $d = 0.54$. Critically, the size of the semantic priming effect was similar, albeit numerically larger, following presentation trials ($M = 85.24$ ms, $SD = 108.93$) than retrieval trials ($M = 63.67$ ms, $SD = 95.74$), $t(18) = 0.62$, $p = .54$, $d = 0.2$.

Another way to measure semantic priming is to compare reaction times on related trials to non-word trials. This measure also showed no significant difference in semantic priming following presentation versus retrieval trials, $t(18) = 1.21$, $p = .24$, $d = 0.30$, although priming was numerically larger following retrieval ($M = 404.35$ ms, $SD = 280.63$) than presentation ($M = 334.90$ ms, $SD = 239.52$). In short, these results suggest that retrieval does not activate semantic mediators more than presentation.

Relatedness judgments. Just as in the lexical decision condition, semantic priming was calculated as the difference between relatedness judgment reaction times for related words and unrelated words. Again, there was a robust semantic priming effect following both presentation trials, $t(18) = 5.93$, $p < .0001$, $d = 1.36$, and retrieval trials, $t(18) = 6.40$, $p < .0001$, $d = 1.47$. However, the size of the semantic priming effect was numerically, but not significantly, larger following retrieval trials ($M = 276.14$ ms, $SD = 188.03$) than presentation trials ($M = 261.67$ ms, $SD = 192.20$), $t(18) = 0.61$, $p = .61$, $d = .12$. Thus, regardless of the nature of priming task used, there was no evidence that retrieval activates mediators more than presentation.

Discussion

The pilot experiment examined whether retrieval practice activates semantic mediators (i.e., words strongly related to the cue) more than being presented with the intact cue-target pair and whether the results depend on how mediator activation is measured. There was a reliable semantic priming effect: lexical decisions and relatedness judgments were faster for related words than unrelated words. However, in contrast to the elaborative retrieval hypothesis, semantic priming was not greater following retrieval than presentation. This was true when semantic priming was measured using lexical decisions (replicating Lehman & Karpicke, 2016), and critically, when semantic priming was measured using relatedness judgments. Thus, transfer appropriate processing and the distinction between perceptual and conceptual processing cannot account for why retrieval does not appear to activate mediators more than presentation. Instead, the pilot experiment suggests that mediators may not play as large of a role in the benefits of testing as previously thought.

Introduction to Experiments 1 and 2

Target Accessibility

There is a possible explanation for why the pilot experiment replicated Lehman and Karpicke (2016) and found no difference in mediator activation following retrieval versus presentation. The pilot experiment used the same procedure as Lehman and Karpicke; both experiments provided participants the first two letters of the target word on retrieval trials (e.g., diamond – ri____). Doing so may have constrained participants' memory searches to words that begin with the first two letters of the target, which would not have included the mediator (Carpenter & Yeung, 2017, also made this suggestion but did not test it). Experiment 1 tested this hypothesis by manipulating whether the first two letters of the target were given on retrieval trials and measured mediator activation immediately afterwards using a word fragment completion task.

More generally, withholding the first two letters of the target is one way to make the to-be-recalled information less accessible. A key premise of the elaborative retrieval hypothesis is that retrieval activates mediators more than restudying because the target is not available, so memory must be searched. Accordingly, "…rendering target information less accessible at the time of initial retrieval would presumably increase the likelihood of activating semantically related information" (Carpenter, 2011, p. 5). Experiment 2 tested this accessibility hypothesis by manipulating the level of learning; some items were studied once in the learning phase and others were studied three times. The elaborative retrieval hypothesis predicts that mediators will be activated more by attempts to retrieve less well-learned information than better-learned information. In contrast, the level of learning should not affect the activation of semantic mediators on presentation trials because the target is already available. Thus, the difference in semantic priming between retrieval and presentation should be greater in the low-learning condition than the high-learning condition.

Consistent with the target accessibility hypothesis, previous research has shown that the benefits of retrieval over presentation are greater when the retrieval attempt is made more effortful by weaker cues on the initial retrieval attempt (Carpenter 2006, 2009) and a longer delay between encoding and the initial retrieval attempt (Karpicke & Roediger, 2007; Pyc & Rawson, 2009; but see Rowland, 2014). However, few studies have directly measured the role of mediators. Rawson, Vaughn, and Carpenter (2014) repeatedly presented or tested participants on weakly associated cue-target pairs and manipulated the lag between repetitions of a given item. Increasing the lag made the retrieval attempts more difficult. Repeated testing led to better performance on the final cued recall test than repeated presentation and the benefit of testing was greater at longer lags. Critically, this was also true when participants had to recall the targets from mediators, which had not been presented earlier in the experiment (also see Carpenter & Yeung, 2017). The results of this experiment suggest that making the target less accessible on retrieval attempts leads to more learning and creates a stronger link between the semantic mediator and the target as a result.

Kole and Healy (2013) also investigated the extent to which target accessibility moderates mediator activation. Participants learned French vocabulary (*pomme-apple*) and were given a keyword that sounded like the French word (*palm*) to help them remember the translations (*pomme*→*palm*→*apple*). Some participants learned the vocabulary better than others because they were given more study opportunities. The results suggested that participants were more likely to use the keyword to facilitate retrieval at lower levels of learning than at higher levels of learning. Although a keyword is akin to a mediator because it links the cue to the target, the elaborative retrieval hypothesis is based on the idea that the mediator is a semantic, not phonetic, associate of the cue. Furthermore, participants were given the keyword and practiced using it to help them translate the vocabulary in the initial learning phase. Thus, Kole and Healy's results hint that mediators may be activated more by more difficult retrieval attempts, but this finding needs to be replicated under more standard retrieval conditions.

Retrieval Success

Taken together, the existing research predicts that a less accessible target leads to a more extensive memory search and greater mediator activation. Targets that cannot be recalled are, by definition, less accessible than targets that can be successfully recalled. Thus, unsuccessful retrieval attempts should activate mediators more than successful retrieval attempts and more than when the target is presented. Experiments 1 and 2 tested this prediction by comparing semantic priming following unsuccessful retrieval attempts to semantic priming and following successful retrieval attempts and presentation trials. The hypothesis that target accessibility affects mediator activation during retrieval attempts necessitates distinguishing between successful and unsuccessful retrieval attempts, which none of the studies reviewed have done.

It is less clear what the prediction should be for the comparison between mediator activation following successful retrieval attempts and a presentation. Successful retrieval attempts may show *less* mediator priming than presentation. In fact, it is possible there will be no priming, or even negative priming, of mediators following successful retrieval attempts. Previous research has shown that ignoring a stimulus on one trial can inhibit responding to that stimulus on a subsequent trial (Tipper, 1985, 2001; Tipper & Driver, 1988). Perhaps participants will have to inhibit their tendency to respond with the mediator (the strongest associate of the cue) in order to correctly recall the target (a weak associate of the cue) in Experiments 1 and 2. Similarly, recalling the target could make the mediator less accessible—a phenomenon referred to as retrieval induced forgetting (Anderson, Bjork, & Bjork, 1994, 2000; Murayama, Miyatsu, Buchli, & Storm, 2014; Storm & Levy, 2012). Regardless of the exact mechanism, such negative priming would be evident in the present experiments if participants' responses were slower to the mediator than to the unrelated word on implicit memory trials that follow successful retrieval attempts.

Present Experiments

In its current form, the elaborative retrieval hypothesis does not distinguish between successful and unsuccessful retrieval attempts, but suggests that any retrieval attempt involves searching memory and activating semantic mediators. Experiments 1 and 2 will test the possibility, which we refer to as the *accessibility hypothesis*, that unsuccessful and successful retrieval attempts involve qualitatively different processing. Unsuccessful retrieval attempts may involve an exploratory memory search that results in greater, more varied activation of words in the cue's semantic network. In contrast, successful retrieval may involve narrowing, or focusing, the memory search such that less activation spreads to the preexisting semantic associates of the cue and instead, the target is activated directly.

In sum, the pilot experiment used two different measures to test the hypothesis that retrieval activates mediators more than presentation. Experiments 1 and 2 tested a more nuanced version of this hypothesis: Retrieval activates mediators more than presentation when the target is not easily accessible. Target accessibility was manipulated by varying the number of retrieval cues (Experiment 1) and study opportunities (Experiment 2) and by comparing successful and unsuccessful retrieval attempts.

Experiment 1

Participants in Experiment 1 were given the cue and the first two letters of the target. Accordingly, they could constrain their memory search for words that started with the same two letters as the target, which would not include a related word that could serve as a mediator. Experiment 1 tested the hypothesis that retrieval activates mediators more than presentation if participants are not given part of the target.

Methods

Participants. One hundred twenty-five participants from Introductory Psychology received course credit for their participation in this one-hour experiment. Thirteen were excluded because they did not follow instructions to type the presented targets on presentation trials. Specifically, they copied fewer than 85% of the targets correctly on presentation trials. Another eight participants were excluded because they completed fewer than 85% of the fragments on implicit memory trials. Among the remaining 104 participants, 52 were randomly assigned to the constrained condition (33 females, median age = 18 years) and 52 were randomly assigned to the unconstrained condition (35 females, median age = 18 years).

Materials. The materials were two versions of 48 cues, targets, related words, and unrelated words (Appendix B) that were created in the same manner as the pilot materials. Each participant only learned one version of the materials and the version was counterbalanced across conditions. The two versions were constructed such that the related words of one set acted as the unrelated words of the other set. That is, whether a given word fragment was considered related to the cue or unrelated to the cue was counterbalanced across participants and conditions. Therefore, any differences in times to complete related and unrelated fragments cannot be explained by differences in the words themselves. As in the pilot experiment, some of the cues and targets were weakly related (average FSG = .05 in both versions) and some were strongly related (version one: average FSG = .59; version two: average FSG = .57) to the related word.

Design and procedure. Experiment 1 had an initial study phase and a restudy+implicit memory phase. During the initial study phase, the 48 cue-target pair were presented in a random order for 6 seconds each and participants were instructed to learn the pairs for a later test.

The manipulations happened during the restudy+implicit memory phase (see Figure 3). For each participant, half of the items were randomly assigned to be restudied through presentation and the other half through retrieval practice, but the format of retrieval trials differed across participants. Half of the participants were randomly assigned to the constrained retrieval condition, meaning that they were given the first 2 letters of the target on retrieval trials (Figure 3A). The other half of participants were in the unconstrained retrieval condition, meaning that they were not given any letters of the target on retrieval trials (Figure 3B).

On retrieval trials, participants were shown the cue and were instructed to type the target word that had been paired with that cue in the initial study phase. The presentation trials were as similar to the retrieval trials as possible to minimize the number of different task instructions participants would have to remember and follow. Participants were presented the cue and the target and were instructed to type the target word. Participants were given 7 seconds to type the target on both retrieval and presentation trials.

Immediately after each presentation and retrieval trial came the implicit memory test trial, which was a fragment completion task. A fixation point was shown for 500 ms, then either the related word or unrelated word was presented, missing one vowel. Participants were instructed to type the missing vowel as quickly and accurately as possible. Priming was measured based on how quickly participants typed the missing letter. A quarter of the related words and unrelated words were missing either an a, e, i, or o, respectively. There was only one valid way to complete each word fragment. Half of each of the presentation and retrieval trials were randomly assigned to be followed by a related fragment and the other half were followed by an unrelated fragment. The order of the restudy+implicit memory trial pairs was randomized across participants. Participants had four practice restudy+implicit memory trial pairs before the phase began in earnest.

Word fragment completion was used in Experiments 1 and 2 because it can reliably capture semantic priming and is more sensitive than lexical decision for high frequency words (Heyman, De Deyne, Hutchison, & Storms, 2015). Another advantage is that it does not require non-word trials as in a lexical decision task.

Results

Initial test performance. During the restudy phase, participants retrieved significantly more targets when the retrieval attempt was constrained by the first two letters of the targets (M = .81, SD = .12) than when the retrieval attempt was unconstrained (M = .57, SD = .23), $t(102)$ = 6.83, p < .001, d = 1.43.[1] Thus, the manipulation to make the retrieval attempt easier by providing the first two letters of the target was effective.

Semantic priming. The primary measure of interest was reaction time on word fragment completion trials. A trial was excluded if the fragment was completed incorrectly or if the

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[1] For all analyses based on retrieval accuracy, a retrieval response was considered correct if it was typed correctly, was misspelled but sounded the same as the correct answer, was a plural of the correct answer (e.g., *nails* instead of *nail*), or was correct, except for the suffix (e.g., *writing* instead of *write*). In addition, we considered constrained retrieval responses correct if participants correctly typed the remaining letters of the presented target fragment (e.g., rm instead of farm when presented fa____). However, the pattern of results did not change for any analyses when responses were only considered correct if they were spelled correctly or were

reaction time was 2.5 standard deviations below or above each participant's personal mean reaction time. Approximately 8% of implicit memory trials were excluded based on these criteria.

Table 2 shows average reaction times for unrelated and related word fragments, following presentation and retrieval trials in both the unconstrained and constrained conditions.

Semantic priming was calculated for each participant as the difference between word fragment completion times for unrelated and related words. A positive priming value indicates participants were faster to complete related fragments than unrelated fragments. Figure 4 shows semantic priming following presentation and retrieval trials in the constrained and unconstrained conditions.

A 2 (restudy condition: presentation vs. retrieval) x 2 (retrieval type: constrained vs. unconstrained) mixed-effects ANOVA revealed that restudy condition did not significantly affect semantic priming, $F(1, 102) = 2.78$, $p = .10$, $\eta_p^2 = .03$, and neither did retrieval type, $F(1, 102) = 0.33$, $p = .56$, $\eta_p^2 = .003$. Furthermore, there was not a significant interaction effect of restudy condition and retrieval type, $F(1,102) = 2.38$, $p = .13$, $\eta_p^2 = .02$. Planned paired *t*-tests revealed that priming was similar following constrained retrieval attempts ($M = 174.86$, $SD = 349.03$) and presentation trials ($M = 170.13$, $SD = 248.27$), $t(51) = 0.09$, $p = .93$, $d = .01$. In contrast, priming was significantly larger following unconstrained retrieval attempts ($M = 205.53$, $SD = 327.53$) than presentation trials ($M = 83.43$, $SD = 322.47$), $t(51) = 2.25$, $p = .03$, $d = 0.3$.

We also examined whether retrieval success moderated semantic priming. Figure 5 shows semantic priming following presentation trials, successful retrieval attempts, and unsuccessful retrieval attempts among participants in the unconstrained retrieval condition.[2] Participants in the constrained retrieval condition were not considered because they had many more successes (81% of retrieval trials) than failures (19% of retrieval trials) and conditional analyses would have involved calculating priming based on too few trials.

A one-way repeated measures ANOVA revealed no differences in semantic priming following the three types of trials, $F(2,96) = 2.32$, $p = .10$, $\eta_p^2 = .05$. However, planned paired *t*-tests revealed that priming was significantly greater following successful retrieval attempts (M = 240.40, SD = 358.16) than presentation trials (M = 68.94, SD = 325.97), $t(48) = 2.33$, $p = .02$, d = 0.33. In contrast, there were no significant differences in priming following successful and unsuccessful retrieval attempts (M = 182.44, SD = 581.55), $t(48) = 0.63$, $p = .54$, $d = 0.09$, or following unsuccessful retrieval attempts and presentation trials, $t(48) = 1.51$, $p = .14$, $d = 0.24$.

Discussion

The constrained condition of Experiment 1 conceptually replicated Lehman and Karpicke (2016) and found the same result: There were no significant differences in priming following retrieval attempts and presentation trials. However, Experiment 1 also tested the hypothesis that providing the first two letters of the target word would constrain memory search and reduce the degree to which semantically related words and concepts would be activated. Consistent with this hypothesis, priming was significantly greater following unconstrained retrieval attempts than presentation trials (although the interaction between restudy type and retrieval condition was not

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[2] The degrees of freedom are different for the conditional analyses than other analyses. Three participants were excluded for not having at least one of each of the four trial types necessary to calculate priming separated by retrieval success: successful retrieval followed by a related word fragment, successful retrieval followed by an unrelated word fragment, unsuccessful retrieval followed by a related word fragment, and unsuccessful retrieval followed by an unrelated word fragment. Twenty-two participants were excluded from conditional analyses in Experiment 2 for the same reason.

statistically significant). More generally, the elaborative retrieval hypothesis predicts that making the target less accessible increases the extent to which memory is searched and mediators are activated. Contrary to the accessibility hypothesis, priming was greatest following successful retrieval attempts. There were no differences in priming following unsuccessful retrieval attempts and successful retrieval attempts or implicit memory trials (Figure 5).

Taken together, Experiment 1 provided mixed support for the elaborative retrieval hypothesis. Critically, it revealed that retrieval can activate mediators more than presentation, contrary to the conclusions of Lehman and Karpicke (2016). However, Experiment 1 also revealed that the activation of mediators is not only a function of the accessibility of the to-be-recalled information.

Experiment 2

The purpose of Experiment 2 was to provide a second test of the hypothesis that the more accessible the target is at the time of retrieval, the less the retrieval attempt will activate related words and concepts. Target accessibility was manipulated by varying the number of times an item was studied initially. Experiment 2 also replicated the unconstrained condition of Experiment 1.

Methods

Participants. One hundred twenty-one participants from Introductory Psychology received one-hour course credit for their participation. Fifteen were excluded because they did not follow instructions to type the presented targets on presentation trials. Specifically, they copied fewer than 85% of the targets correctly on presentation trials. Another five participants were excluded because they completed fewer than 85% of the fragments on implicit memory trials.

Among the remaining 101 participants, 49 were randomly assigned to study every word pair once initially (34 females, 14 males reported, median age = 19) and 52 were randomly assigned to study every word pair three times initially (40 female, 12 male, median age = 19).

Materials, design and procedure. Experiment 2 used the same materials as Experiment 1 and followed a similar procedure. Participants completed the initial study phase and the restudy+implicit memory phase. However, unlike Experiment 1, the key manipulation—level of learning—occurred during the initial study phase. Participants in the low-learning condition studied each pair once, replicating Experiment 1. Participants in the high-learning condition studied each pair three times. The restudy+implicit memory phase was identical to the unconstrained retrieval condition in Experiment 1 (Figure 3B) and was identical for the low and high-learning conditions.

Results

Initial test performance. During the restudy phase, participants retrieved significantly more targets of pairs they studied three times (M = .78, SD = .17) than pairs they studied once (M = .47, SD = .21), $t(102) = 8.05$, $p < .001$, $d = 1.60$. Thus, the manipulation to make the target more accessible by increasing number of study opportunities was effective.

Semantic priming. Again, the primary measure of interest was reaction time on word fragment completion trials. As in Experiment 1, a trial was excluded if the fragment was completed incorrectly or if the reaction time was 2.5 standard deviations below or above each participant's personal mean reaction time. Approximately 8% of implicit memory trials were excluded based on these criteria.

Table 3 shows average reaction times for unrelated and related word fragments, following presentation and retrieval trials in both the low and high-learning conditions.

Semantic priming was calculated for each participant as the difference between word fragment completion times for unrelated and related words. A positive priming value indicates participants were faster to complete related fragments than unrelated fragments. Figure 6 shows semantic priming following presentation and retrieval trials in the low and high-learning conditions (i.e., when pairs had been studied once or three times, respectively).

A 2 (restudy condition: presentation vs. retrieval) x 2 (learning level: low vs. high) mixed-effects ANOVA revealed that restudy condition did not significantly affect semantic priming, $F(1, 99) = 2.32$, $p = .13$, $\eta_p^2 = .02$, and neither did learning level, $F(1, 99) = 0.23$, $p = .63$, $\eta_p^2 = .002$. Furthermore, there was not a significant interaction effect of restudy condition and retrieval type, $F(1,99) = 0.10$, $p = .76$, $\eta_p^2 = .001$. Planned paired *t*-tests revealed that when pairs were studied once, priming was similar following retrieval (*M* = 189.47, *SD* = 252.99) and presentation trials (*M* = 145.62, *SD* = 200.48), $t(48) = 1.02$, $p = .31$, $d = .15$. There were also no significant difference in priming following retrieval (*M* = 183.98, *SD* = 291.10) and presentation trials (*M* = 117.37, *SD* = 259.65) when pairs were studied three times, $t(51) = 1.15$, $p = .25$, $d = .16$.

As in Experiment 1, we examined whether retrieval success moderated semantic priming. Figure 7 shows semantic priming following presentation trials, successful retrieval attempts, and unsuccessful retrieval attempts among all participants, regardless of learning level condition.[2]

A one-way repeated measures ANOVA revealed no differences in semantic priming following the three types of trials, $F(2,156) = 1.85$, $p = .16$, $\eta_p^2 = .02$. However, planned paired *t*-tests revealed that priming was significantly greater following successful retrieval attempts (*M* = 207.62, *SD* = 358.88) than presentation trials (*M* = 111.64, *SD* = 215.64), $t(78) = 2.07$, $p = .04$, $d = 0.24$. In contrast, there were no significant differences in priming following successful and unsuccessful retrieval attempts (*M* = 150.35, *SD* = 383.42), $t(78) = 1.08$, $p = .28$, $d = 0.12$, or following unsuccessful retrieval attempts and presentation trials, $t(78) = 0.76$, $p = .45$, $d = 0.09$.

Discussion

The low-learning condition of Experiment 2 replicated Experiment 1 and revealed the same pattern of results: Semantic priming was greater follow retrieval attempts than presentation trials, although the effect was only statistically significant in Experiment 1. However, contrary to the accessibility hypothesis, making the target less accessible in memory did not increase the amount of priming. Specifically, the extent to which priming was greater following retrieval trials than presentation trials differ whether pairs were initially studied once or three times

(Figure 6). Furthermore, priming was greatest following successful retrieval attempts compared to unsuccessful retrieval attempts and presentation trials (Figure 7), as in Experiment 1.

General Discussion

Elaborative retrieval has been offered as a mechanism by which retrieval enhances learning more than restudying. The theory is that being presented with a cue and trying to retrieve the target involves activating words and concepts in the cue's semantic network, which then get linked to the target and can mediate later retrieval. In contrast, when the cue and target are presented together, there is no need to search memory so possible mediators are less likely to be activated (Carpenter 200, 2011; Carpenter & Yeung, 2017; Coppens et al., 2016; Pyc & Rawson 2010, 2012).

The pilot experiment directly tested the hypothesis that retrieval activates mediators more than presentation, but found no evidence that this was the case using either a perceptual measure of mediator activation (lexical decisions) or a conceptual measure of mediator activation (relatedness judgments). This finding replicated and extended results reported by Lehman and Karpicke (2016). Taken together, these results contradict the elaborative retrieval hypothesis in its simplest form and suggest that it needs further refinement.

Experiments 1 and 2 tested a possible refinement: Retrieval activates semantic mediators more than restudying when the to-be-remembered information is not readily accessible. This refinement is supported by previous research showing that the benefits of retrieval over restudying are greater when the retrieval attempt is more difficult (Carpenter 2006, 2009; Karpicke & Roediger, 2007; Pyc & Rawson, 2009), possibly due to greater involvement of mediators (Kole & Healy, 2014; Rawson et al., 2014).

Experiment 1 varied target accessibility by manipulating whether participants were given the first two letters of the target word on the retrieval attempt. Consistent with the accessibility hypothesis, there were no differences in priming following retrieval attempts and presentation trials when the retrieval attempts were constrained by the first two letters of the target word. In contrast, priming was significantly greater following retrieval attempts than presentation trials when the retrieval attempt was unconstrained.

However, target accessibility cannot fully account for the results of Experiments 1 and 2. In Experiment 2, target accessibility was manipulated by manipulating the level of learning. Participants either initially studied pairs once or three times. Although priming was numerically greater following retrieval attempts than presentation trials, the size of the effect did not depend on the level of learning. Furthermore, Experiments 1 and 2 revealed priming was significantly greater following successful retrieval attempts than presentation trials, even though the target was accessible in both cases. The experiments also revealed that priming did not differ significantly following successful and unsuccessful retrieval attempts or following unsuccessful retrieval attempts and presentation trials.

In short, Experiments 1 and 2 provided mixed evidence for the elaborative retrieval hypothesis. Retrieval led to greater activation of mediators than presentation. However, the effects were small and were driven by successful retrieval attempts, rather than unsuccessful retrieval attempts as the accessibility hypothesis predicted. Therefore, the present experiments do not rule out the role of mediators in retrieval, but the elaborative retrieval hypothesis in its current form cannot explain the complete pattern of results. The present experiments do not suggest a clear alternative theoretical explanation.

Challenges to the Elaborative Retrieval Hypothesis

The present experiments provided mixed support for the first assumption of the elaborative retrieval hypothesis, namely, that retrieval activates related words more than presentation. More generally, this assumption is at odds with retrieval induced forgetting. Retrieval induced forgetting is the finding that retrieving some words (e.g., retrieving *banana* from *fruit*: *ba*____) can make related words (e.g., *apple*) less memorable on a later test (for a meta-analysis, see Murayama et al., 2014). Although Murayama and colleagues (2014) found significant variability in the size of the retrieval induced forgetting effect, it is a robust phenomenon, suggesting retrieval should make related words less accessible than presentation, not more accessible.

A second key assumption of the elaborative retrieval hypothesis is that the activation of related words is not merely a byproduct of retrieval, but that it enhances learning. Although this assumption was not tested in the present experiments, it is inconsistent with the principle of cue overload. Specifically, the cue overload hypothesis holds that memory is best when a retrieval cue uniquely specifies the target. In contrast, when a retrieval cue is associated with many pieces of information, the probability of recalling the target information decreases (Moscovitch & Craik, 1976; Nairne, 2002; Watkins & Watkins, 1976). Thus, if retrieval activates related words more than presentation, the related words should interfere with—and not facilitate—recall of the target on future memory tests. Karpicke and colleagues (2014) identified the theoretical challenges of the elaborative retrieval hypothesis and offered the episodic context account as an alternative.

Episodic Context Account

The episodic context account (Karpicke, et al., 2014; Lehman, Smith, & Karpicke, 2014) is the only other specific mechanism that has been proposed for how retrieval enhances learning relative to restudying. The hypothesis is that attempting to retrieve a target—but not restudying it—involves reinstating the context in which the target was learned. This process is presumed to strengthen the association between target and the contextual features such that the contextual features can facilitate retrieval on a later test. Contextual features are thought to help hone the memory search to the target word, while excluding non-target information. Thus, contextual features help the retrieval cue uniquely specify the target information, thereby solving cue overload—a major theoretical challenges of the elaborative retrieval hypothesis.

However, the episodic context account predicts that there should be no differences in priming following presentation or retrieval trials because reinstating the initial study phase context does not involve activating words and concepts related to the cue. Indeed, the episodic context account suggests that when a target is successfully retrieved, the cue word and associated contextual cues effectively specified the target word, while excluding non-target words. Thus, if priming of related words should be *smaller* following successful retrieval attempts, if there were any differences with presentation trials. Therefore, the episodic context account cannot explain the patterns of priming in the present experiments.

Limitations and Future Directions

Although we found numerically greater priming following retrieval than presentation, the effects were small relative to the variability in the priming measures. The variability in priming could be related to how we defined mediators. Strong associates of the cues (e.g., *ring* is a strong associate of *diamond*) were selected as mediators based on word association norms (Nelson et al., 2004). According to the norms, we would expect that approximately 60% of participants would report the mediator as the first word that comes to mind when prompted with a cue from Experiments 1 or 2, on average. Therefore, for any given cue, we would expect that the selected mediator would not be the strongest associate of the cue for approximately 40% of the participants. Theories of spreading activation suggest that when the cue is more strongly associated with the mediator, reaction times to the mediator should be faster (Collins & Loftus, 1975). Thus, variability in priming could be due to idiosyncrasies in the organization of participants' knowledge such that some mediators were more strongly associated with the cue than others.

One caveat is that although we found some evidence that retrieval activates mediators more than presentation, our results do not necessarily imply that retrieval enhances learning more than presentation *because* of mediator activation. It is possible that words related to the cue are activated as a byproduct of making a retrieval attempt, but that the activated words do not enhance learning by facilitating future retrieval (Karpicke et al., 2014). Consistent with this possibility, Lehman and Karpicke (2016) found that requiring participants to explicitly generate words associated with a cue did not enhance learning of the targets (Experiments 3-5; see also Lehman et al., 2014; Karpicke & Smith, 2012). Thus, although we cannot conclude that retrieval enhances memory because of mediators, the present experiments also do not rule out the role of mediators altogether.

Similarly, although the episodic context account cannot fully account for the results we observed, our experiments were not designed to test, and thus cannot rule out, that episodic contextual cues play some role in enhancing learning from retrieval. Just as we tested whether retrieval activates related words more than presentation, future research should test whether retrieval activates contextual cues associated with the initial study phase more than presentation.

Conclusion

A wealth of research has demonstrated that retrieving information enhances memory for that information and these experiments focused on elaborative retrieval as an explanation of this phenomenon. The results were ambiguous and neither fully support nor contradict the key assumption that retrieval activates mediators more than presentation. However, the episodic context account also cannot account for the pattern of results observed.

Ultimately, it is important to focus on the larger question of how retrieval enhances learning across a variety of material and types of tests. It seems implausible that a single mechanism will be able to account for the benefits of retrieval in so many different circumstances. For example, the elaborative retrieval hypothesis (and the results of this experiment) only applies to paired-associate learning and cued recall tests. It is hard to imagine how semantic mediators could support free recall of target words or enhance learning of face-name pairs. Thus, different types of materials and tests may necessitate different types of processing during retrieval, all of which can enhance learning relative to passively processing the material during restudy. One possibility is that learners rely more on episodic context cues when effective semantic cues are not available (e.g., when learning unrelated word pairs for which mediators would be irrelevant). The elaborative retrieval and episodic context accounts are not necessarily mutually exclusive and future research should examine whether episodic context and semantic mediators complement each other to facilitate learning from retrieval across a range of materials and at various levels of learning.

Table 1. Mean reaction times (and SDs) on implicit memory trials in the pilot experiment.

Lexical Decisions			
	Word Type		
Restudy Type	Unrelated	Related	Non-Words
Presentation	888.99	803.75	1138.66
	(209.77)	(219.48)	(293.63)
Retrieval	921.55	857.88	1262.23
	(216.69)	(207.10)	(391.38)
Relatedness Judgments			
	Word Type		
Restudy Type	Unrelated	Related	Non-Words
Presentation	1499.65	1237.98	--
	(443.86)	(401.08)	
Retrieval	1587.75	1311.61	--
	(481.56)	(451.93)	

Note. Reaction times are in milliseconds.

Table 2. Mean reaction times (and SDs) on implicit memory trials in Experiment 1.

Constrained Retrieval Condition		
	Word Type	
Restudy Type	Unrelated	Related
Presentation	1493.88	1323.75
	(421.75)	(298.48)
Retrieval	1533.77	1358.91
	(430.93)	(390.07)
Unconstrained Retrieval Condition		
	Word Type	
Restudy Type	Unrelated	Related
Presentation	1347.91	1264.48
	(288.66)	(347.21)
Retrieval	1419.67	1214.14
	(360.66)	(289.00)

Note. Reaction times are in milliseconds.

Table 3. Mean reaction times (and SDs) on implicit memory trials in Experiment 2.

Low Learning Condition		
	Word Type	
Restudy Type	Unrelated	Related
Presentation	1367.23	1221.62
	(355.22)	(281.93)
Retrieval	1362.13	1172.66
	(360.10)	(290.38)
High Learning Condition		
	Word Type	
Restudy Type	Unrelated	Related
Presentation	1287.35	1169.98
	(330.44)	(273.61)
Retrieval	1309.64	1125.66
	(347.76)	(247.60)

Note. Reaction times are in milliseconds.

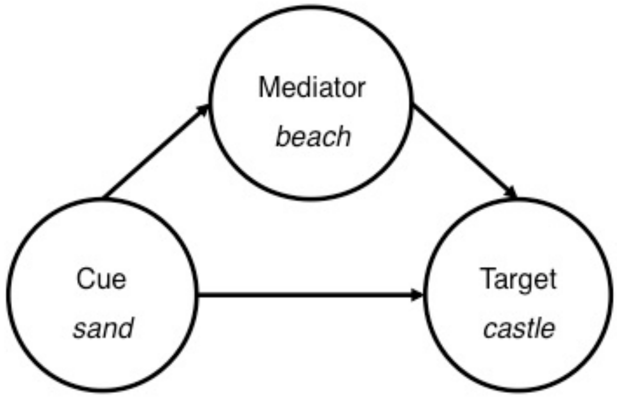

Figure 1. The results of elaborative retrieval. On an initial retrieval attempt, the cue activates related words, which become linked to the target. These mediated paths can facilitate recall on a later test.

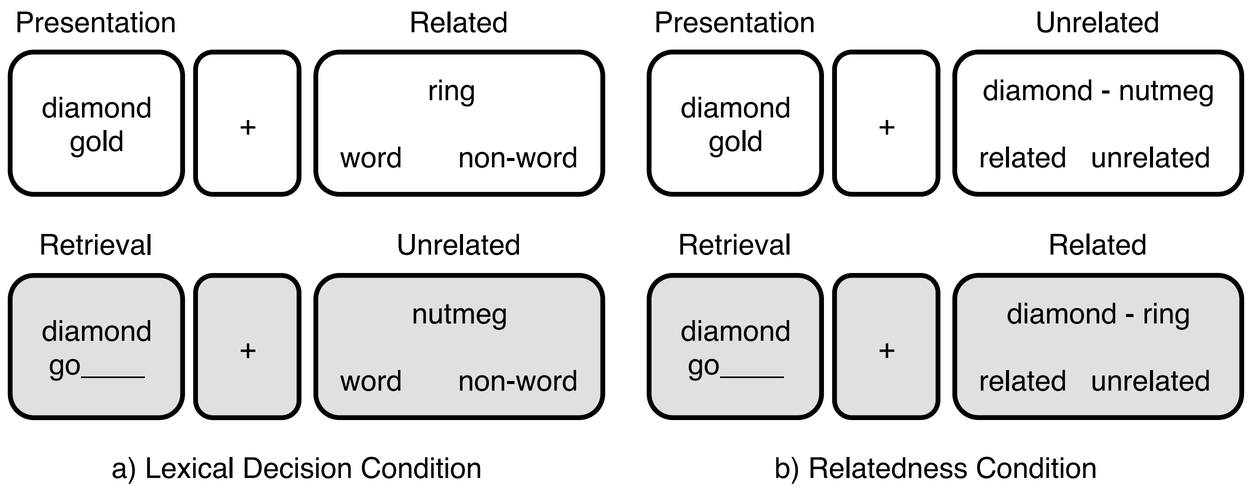

Figure 2. Restudy+implicit memory phase procedure in the pilot experiment. Half of the participants were randomly assigned to the lexical decision condition (a) and the other half to the relatedness condition (b). For each participant, half of the word pairs were randomly assigned to be restudied through presentation trials (white boxes) and the other half through retrieval trials (grey boxes). After a fixation point was presented briefly, participants completed an implicit memory test involving a lexical decision or relatedness judgment about a word that was related to cue, unrelated to the cue, or—only in the lexical decision condition—a pronounceable non-word.

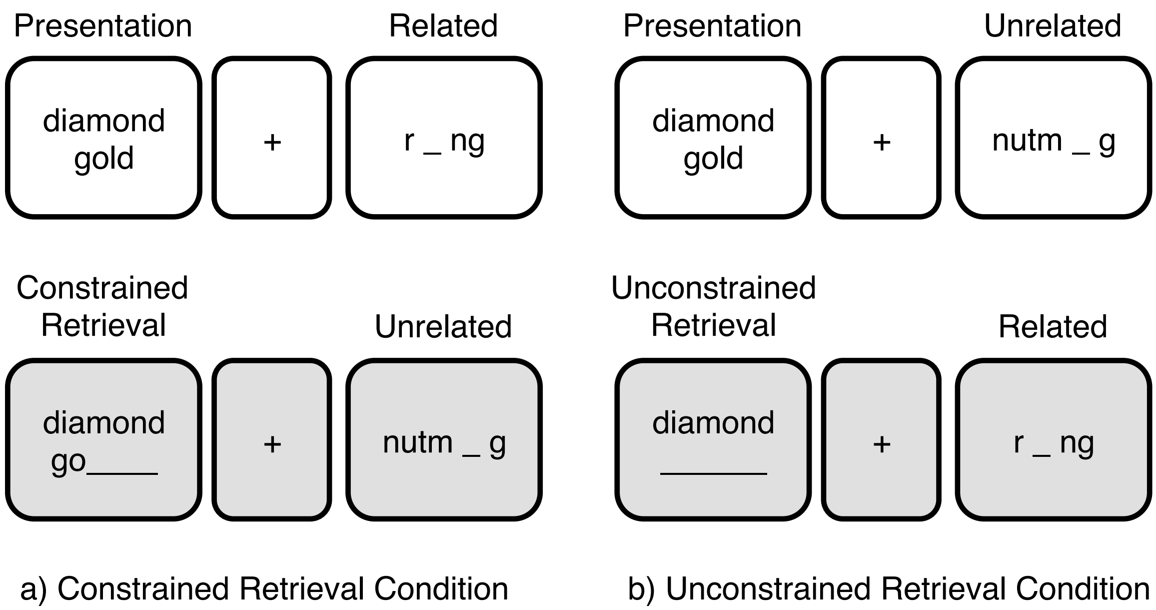

Figure 3. Procedure for restudy+implicit memory phase in Experiments 1. Half of the participants were randomly assigned to the constrained retrieval condition (a) and the other half to the unconstrained retrieval condition (b). For each participant, half of the word pairs were randomly assigned to be restudied through presentation trials (white boxes) and the other half through retrieval trials (grey boxes). After a fixation point was briefly shown, participants completed an implicit memory test in which they completed a word fragment that was related to the cue or unrelated to the cue. Half of the presentation and retrieval trials were followed by a related fragment and the other half by an unrelated fragment. In Experiment 2, all participants were in the unconstrained retrieval condition.

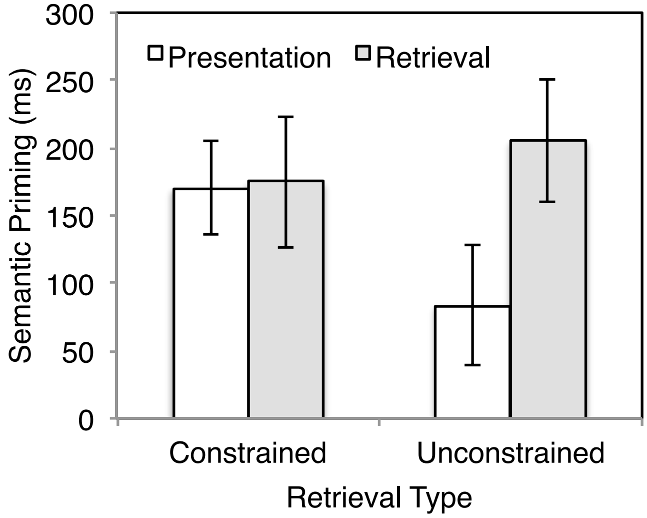

Figure 4. Semantic priming following presentation, constrained retrieval, and unconstrained retrieval trials Experiment 1. Error bars represent one standard error of the mean.

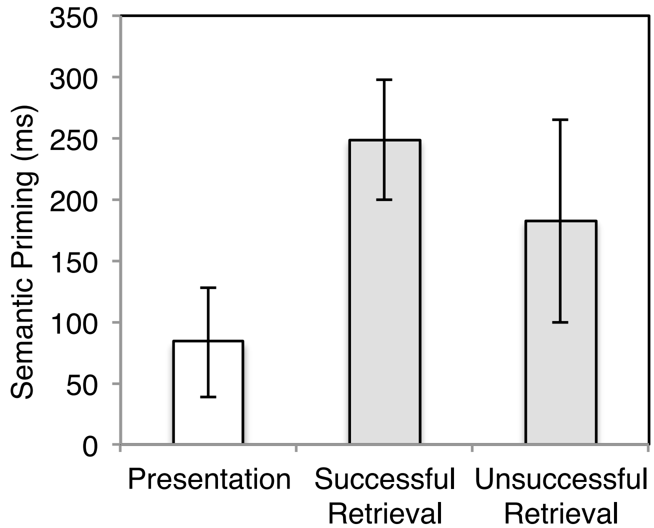

Figure 5. Semantic priming following presentation, successful retrieval attempts, and unsuccessful retrieval attempts, among participants in the unconstrained retrieval condition in Experiment 1. Error bars represent one standard error of the mean.

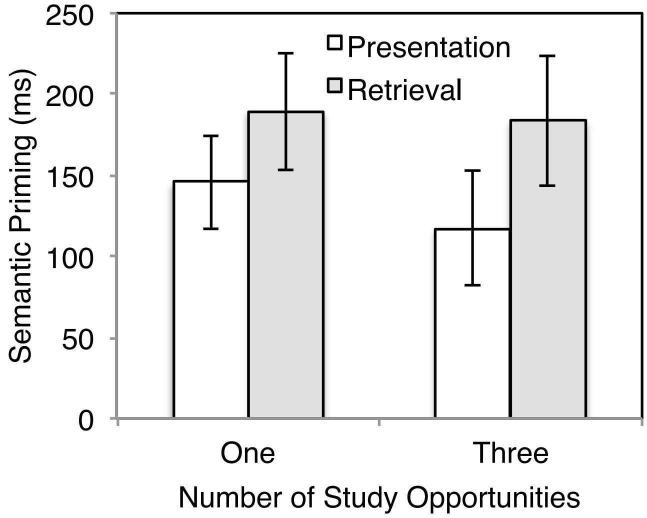

Figure 6. Semantic priming following presentation and retrieval trials Experiment 2. Error bars represent one standard error of the mean.

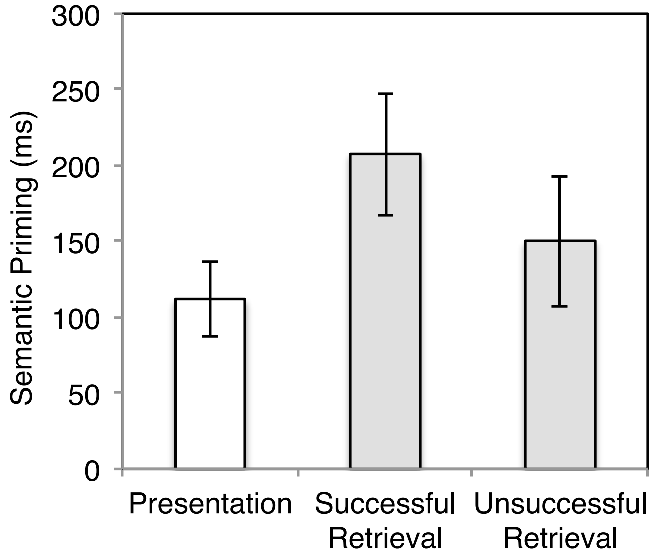

Figure 7. Semantic priming following presentation, successful retrieval attempts, and unsuccessful retrieval attempts, among all participants in Experiment 2. Error bars represent one standard error of the mean.

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Appendix A

Pilot Experiment Materials

Cue	Target	Related	Unrelated	Nonwords
antler	fawn	deer	garden	shrumped
arm	thigh	leg	mosquito	shround
atlas	globe	map	bandit	ide
bulb	lamp	light	morning	rop
calculus	equation	math	liver	grourn
calf	bull	cow	game	clett
cash	bank	money	noodle	snurfs
cathedral	steeple	church	circle	steaves
chalk	bulletin	board	floor	twarked
cob	husk	corn	frog	phrinsed
cod	trout	fish	journal	swaught
crib	diaper	baby	banquet	shroons
diamond	gold	ring	nutmeg	hais
donor	plasma	blood	winter	phleague
drapes	house	curtains	insect	sckrapps
exam	quiz	test	walk	blowns
film	cinema	movie	poetry	stroobs
flame	match	fire	jury	muld
frame	portrait	picture	shingle	wofts
gums	braces	teeth	volcano	whols
handbag	pocketbook	purse	teeth	flince
hanger	wardrobe	clothes	foam	spirped
hive	buzz	bee	birth	stilch
hog	pork	pig	tank	shourned
icing	frosting	cake	dance	clulched

instructor	professor	teacher	train	fusk
jacket	mink	coat	forest	phrup
juice	tangerine	orange	rabbit	vapse
keg	party	beer	bloom	seus
knob	hinge	door	hospital	fenth
leaf	green	tree	retailer	toed
marrow	skeleton	bone	continent	trebe
nest	canary	bird	bottle	tarb
nurse	physician	doctor	hall	crolt
occupation	career	job	letter	croiced
pal	buddy	friend	knife	gwoints
pen	eraser	pencil	salad	soys
pepper	spice	salt	colony	slax
petals	tulip	flower	key	brepth
pistol	trigger	gun	lace	flane
planet	space	earth	residue	fluks
pony	saddle	horse	ladder	plail
rake	grass	leaves	episode	cripte
rectangle	triangle	square	link	spaist
rye	wheat	bread	alligator	rhand
sail	yacht	boat	clock	skoal
saucer	bowl	cup	artist	dex
scale	pound	weight	graduation	gnakks
slither	serpent	snake	tower	micked
sock	sneaker	shoe	tobacco	ghumped
soil	ground	dirt	master	rycs
stewardess	pilot	airplane	inn	phrumpse
stone	boulder	rock	text	phlands
suds	bath	soap	circuit	mapt

table	seat	chair	flood	swoists
throne	crown	king	oxygen	boid
thunder	rain	lightning	dreamer	sckripse
tin	opener	can	fence	yusks
yolk	omelet	egg	ink	wumps
zoo	lion	animal	leader	speist

Appendix B

Word Set Version One for Experiments 1 and 2

Cue	Target	Related	Unrelated	Related Fragment	Unrelated Fragment
garbage	junk	trash	hands	tr _ sh	h _ nds
jacket	tie	coat	animal	co _ t	anim _ l
tent	woods	camp	cigarette	c _ mp	cig _ rette
juice	fruit	orange	shark	or _ nge	sh _ rk
sprain	break	ankle	bread	_ nkle	bre _ d
marsh	water	swamp	curtains	sw _ mp	curt _ ins
wife	spouse	husband	square	husb _ nd	squ _ re
stewardess	pilot	airplane	dawn	airpl _ ne	d _ wn
helium	air	balloon	thread	b _ lloon	thre _ d
clorox	clean	bleach	baby	ble _ ch	b _ by
democrat	politics	republican	earth	republic _ n	e _ rth
whiskers	hair	beard	maze	be _ rd	m _ ze
keg	party	beer	present	b _ er	pr _ sent
sonnet	english	poem	ocean	po _ m	oc _ an
yolk	white	egg	penny	_ gg	p _ nny
funeral	black	death	secretary	d _ ath	s _ cretary
noun	adjective	verb	baseball	v _ rb	bas _ ball
rake	grass	leaves	temperature	l _ aves	t _ mperature
cash	dollar	money	test	mon _ y	t _ st
roast	turkey	beef	area	b _ ef	ar _ a
brook	creek	stream	letter	str _ am	lett _ r
lime	sour	lemon	pencil	l _ mon	p _ ncil
nephew	cousin	niece	neutron	ni _ ce	n _ utron
instructor	professor	teacher	orchestra	t _ acher	orch _ stra

film	cinema	movie	dirt	mov _ e	d _ rt
dagger	stab	knife	light	kn _ fe	l _ ght
throne	crown	king	fright	k _ng	fr _ ght
scale	pound	weight	fire	we _ ght	f _ re
steps	ladder	stairs	milk	sta _ rs	m _ lk
yawn	bored	tired	highway	t _ red	h _ ghway
kilometer	distance	mile	building	m _ le	bu _ lding
ache	back	pain	rabbit	pa _ n	rabb _ t
crook	criminal	thief	child	th _ ef	ch _ ld
caboose	engine	train	mistake	tra _ n	m _ stake
sparrow	robin	bird	police	b _ rd	pol _ ce
thunder	rain	lightning	fight	lightn _ ng	f _ ght
orchid	plant	flower	dolphin	fl _ wer	d _ lphin
bouillon	broth	soup	old	s _ up	_ ld
noisy	music	loud	cow	l _ ud	c _ w
lord	bible	god	doctor	g _ d	doct _ r
dustpan	mop	broom	atom	bro _ m	at _ m
library	study	book	monk	b _ ok	m _ nk
knight	soldier	armor	crocodile	arm _ r	cr _ codile
suds	bath	soap	couch	s _ ap	c _ uch
chimpanzee	ape	monkey	ghost	m _ nkey	gh _ st
crowd	group	people	tooth	pe _ ple	t _ oth
fudge	candy	chocolate	bomb	ch _ colate	b _ mb
pliers	wrench	tool	food	t _ ol	fo _ d

Word Set Version Two for Experiments 1 and 2

Cue	Target	Related	Unrelated	Related Fragment	Unrelated Fragment
fingers	nails	hands	trash	h _ nds	tr _ sh
zoo	lion	animal	coat	anim _ l	co _ t
ashtray	butt	cigarette	camp	cig _ rette	c _ mp
jaws	fish	shark	orange	sh _ rk	or _ nge
rye	wheat	bread	ankle	bre _ d	_ nkle
drapes	house	curtains	swamp	curt _ ins	sw _ mp
rectangle	triangle	square	husband	squ _ re	husb _ nd
dusk	sunset	dawn	airplane	d _ wn	airpl _ ne
spool	string	thread	balloon	thre _ d	b _ lloon
cradle	crib	baby	bleach	b _ by	ble _ ch
planet	space	earth	republican	e _ rth	republic _ n
labyrinth	puzzle	maze	beard	m _ ze	be _ rd
gift	christmas	present	beer	pr _ sent	b _ er
sea	beach	ocean	poem	oc _ an	po _ m
cent	dime	penny	egg	p _ nny	_ gg
receptionist	desk	secretary	death	s _ cretary	d _ ath
league	team	baseball	verb	bas _ ball	v _ rb
thermometer	fever	temperature	leaves	t _ mperature	l _ aves
quiz	grade	test	money	t _ st	mon _ y
region	land	area	beef	ar _ a	b _ ef
envelope	stamp	letter	stream	lett _ r	str _ am
pen	write	pencil	lemon	p _ ncil	l _ mon
proton	chemistry	neutron	niece	n _ utron	ni _ ce
symphony	violin	orchestra	teacher	orch _ stra	t _ acher
soil	ground	dirt	movie	d _ rt	mov _ e
bulb	lamp	light	knife	l _ ght	kn _ fe
scare	horror	fright	king	fr _ ght	k _ng

flame	match	fire	weight	f _ re	we _ ght
dairy	cheese	milk	stairs	m _ lk	sta _ rs
interstate	car	highway	tired	h _ ghway	t _ red
architecture	structure	building	mile	bu _ lding	m _ le
hare	bunny	rabbit	pain	rabb _ t	pa _ n
adult	kid	child	thief	ch _ ld	th _ ef
error	correct	mistake	train	m _ stake	tra _ n
officer	law	police	bird	pol _ ce	b _ rd
feud	war	fight	lightning	f _ ght	lightn _ ng
flipper	swim	dolphin	flower	d _ lphin	fl _ wer
elders	wise	old	soup	_ ld	s _ up
pasture	farm	cow	loud	c _ w	l _ ud
nurse	medicine	doctor	god	doct _ r	g _ d
molecule	cell	atom	broom	at _ m	bro _ m
monastery	nun	monk	book	m _ nk	b _ ok
alligator	reptile	crocodile	armor	cr _ codile	arm _ r
sofa	sleep	couch	soap	c _ uch	s _ ap
ghoul	goblin	ghost	monkey	gh _ st	m _ nkey
cavity	dentist	tooth	people	t _ oth	pe _ ple
atomic	nuclear	bomb	chocolate	b _ mb	ch _ colate
meal	lunch	food	tool	fo _ d	t _ ol