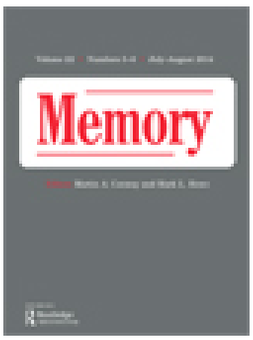

Routledge
Taylor & Francis Group

Memory

ISSN: 0965-8211 (Print) 1464-0686 (Online) Journal homepage: http://www.tandfonline.com/loi/pmem20

Retrieval activates related words more than presentation

Hannah Hausman & Matthew G. Rhodes

To cite this article: Hannah Hausman & Matthew G. Rhodes (2018): Retrieval activates related words more than presentation, Memory, DOI: 10.1080/09658211.2018.1453934

To link to this article: https://doi.org/10.1080/09658211.2018.1453934

Published online: 23 Mar 2018.

MEMORY, 2018
https://doi.org/10.1080/09658211.2018.1453934

Routledge
Taylor & Francis Group

Retrieval activates related words more than presentation

Hannah Hausman and Matthew G. Rhodes

Department of Psychology, Colorado State University, Fort Collins, CO, USA

ABSTRACT

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 hypothesised to activate mediators more than restudying, but existing tests of this hypothesis have had mixed results [Carpenter, S. K. (2011). Semantic information activated during retrieval contributes to later retention: Support for the mediator effectiveness hypothesis of the testing effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(6), 1547–1552. doi:10.1037/a0024140; Lehman, M., & Karpicke, J. D. (2016). Elaborative retrieval: Do semantic mediators improve memory? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *42*(10), 1573–1591. doi:10.1037/xlm0000267]. The present experiments explored an explanation of the conflicting results, testing 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 versus more cues were given during retrieval practice (Experiments 1 and 2), when the target had been studied once versus three times initially (Experiment 3), or when the target could not be recalled versus could be recalled during retrieval practice (Experiments 1–3). A mini meta-analysis of all three experiments revealed a small effect such that retrieval activated mediators more than presentation, but mediator activation was not reliably related to target accessibility. Thus, retrieval may enhance learning by activating mediators, in part, but these results suggest the role of other processes, too.

ARTICLE HISTORY
Received 26 November 2017
Accepted 4 March 2018

KEYWORDS
Testing; mediators; priming; retrieval failure

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 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 concepts 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 retrieval practice attempt. To preview, the present experiments tested a key prediction of the elaborative retrieval hypothesis (we return to the episodic context account in the General Discussion).

Elaborative retrieval hypothesis

According to 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 & Loftus, 1975; Collins & Quillian, 1972). Because of this spreading activation, the cue becomes connected to related semantic information that then connects the cue 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,

CONTACT Hannah Hausman hannah.erin.hausman@gmail.com Department of Psychology, Colorado State University, Fort Collins, CO 80523, USA

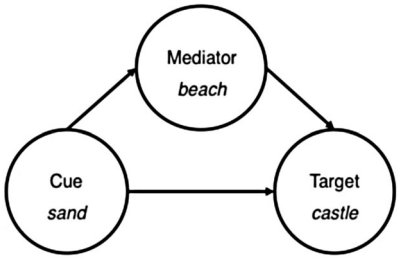

Figure 1. The results of elaborative retrieval. On an initial retrieval attempt, the cue activates related words, which become linked to the target. These mediated paths can facilitate recall on a later test.

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 learners 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 a different 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 non-word. 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. To preview, the present experiments used a similar priming paradigm to further examine mediator activation following presentation and retrieval.

In sum, two measures of activation of semantic mediators (false recognition and lexical decision times) supported different conclusions. However, there may be principled reasons for these divergent findings. Using a similar procedure as Lehman and Karpicke (2016), the present experiments tested the hypothesis that mediator activation, and thus results from prior research, depends on the accessibility of the to-be-recalled information.

Target accessibility

Lehman and Karpicke (2016) found no difference in mediator activation following retrieval versus presentation. However, they 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 beginning 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, and its direct replication, Experiment 2, tested this hypothesis by manipulating whether the first two letters of the target were provided 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, requiring a search of memory. 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 3 tested further 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 accessibility 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 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 & Delosh, 2006; Carpenter, 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 (2015) repeatedly presented or repeatedly 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 that had not been presented earlier in the experiment (see also 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 moderated 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 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 1–3 tested this prediction by comparing semantic priming following unsuccessful retrieval attempts to semantic priming 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 prior studies have not 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 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). Similarly, recalling the target could make the mediator less accessible – a phenomenon referred to as retrieval induced forgetting (Anderson, Bjork, & Bjork, 1994, 2000; see Murayama, Miyatsu, Buchli, & Storm, 2014; Storm & Levy, 2012, for reviews). 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 priming trials that follow successful retrieval attempts.

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 1–3 tested 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 pre-existing semantic associates of the cue and instead, the target is activated directly.

Present experiments

In sum, Experiments 1–3 tested a key prediction of the elaborative retrieval hypothesis, namely, that retrieval activates mediators more than presentation. These experiments also tested a more nuanced hypothesis, which we refer to as the accessibility 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 (Experiments 1 and 2) and the number of study opportunities (Experiment 3) and by comparing successful and unsuccessful retrieval attempts (Experiments 1–3). We tested these hypotheses by examining the level of priming of words related to the cues following (a) presentation vs. retrieval trials when the target had high or low accessibility and (b) successful vs. unsuccessful retrieval attempts.

Experiment 1

Experiment 1 tested the elaborative retrieval hypothesis by comparing mediator priming following retrieval attempts and presentation trials. Half of the participants in

Experiment 1 were given the cue and the first two letters of the target, similar to Lehman and Karpicke (2016). Accordingly, participants 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. The other participants were given only the cue, encouraging a less constrained memory search that should increase the chance of activating related words. Experiment 1 tested a prediction of the accessibility hypothesis, namely, that retrieval would activate mediators more than presentation if participants were not given part of the target.

Methods

Participants

One hundred twenty-five participants from an Introductory Psychology course at Colorado State University received 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 priming 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).

The number of participants was determined based on a power calculation using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). Our primary interest was a within × between-subjects interaction effect (Restudy Type: presentation vs. retrieval × Target Accessibility: high vs. low). The power calculation revealed 90 participants were needed to detect a small (Cohen's $f = .15$) interaction effect with an alpha of .05 and power of .80. The number participants in Experiment 1 slightly exceeded our target of 90 because we collected additional participants to ensure that the number of participants that could be included in the analyses after applying our exclusion criteria would meet the target sample size.

Materials

The materials were two versions of 48 sets of words 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, and an unrelated word (e.g., dusk-sunset-dawn-airplane; see Appendix for full list of materials). The cues and targets were weakly associated, with an average forward association strength (FSG) of .05. For example, when presented with the word *dusk*, roughly 5% of people respond that *sunset* 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 = .60) and weakly associated with the target (avg. mediator–target FSG = .05). For example, when presented with the word *dusk*, roughly 60% of people respond that *dawn* is the first word that comes to mind. 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.

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.

Design and procedure

Experiment 1 had an initial study phase and a restudy + priming phase. During the initial study phase, the 48 cue–target pairs were presented in a random order for 6 s each with a 200 ms inter-stimulus interval. Participants were instructed to learn the pairs for a later test.

The manipulation of restudy condition (presentation or retrieval) and target accessibility (high or low) occurred during the restudy + priming phase (see Figure 2). 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 high target accessibility condition, entailing that the retrieval attempts were constrained by the first 2 letters of the target (Figure 2(A)). The other half of participants were in the low target accessibility condition, entailing that retrieval attempts were unconstrained: Participants were not given any letters of the target on retrieval trials (Figure 2(B)). The presentation trials were identical in the high and low target accessibility conditions.

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 minimise 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 s to type the target on both retrieval and presentation trials.

Immediately after each presentation and retrieval trial came the priming 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 the onset of typing the missing letter. One fourth of the related words and unrelated words were missing either an a, e, i, or o, respectively.

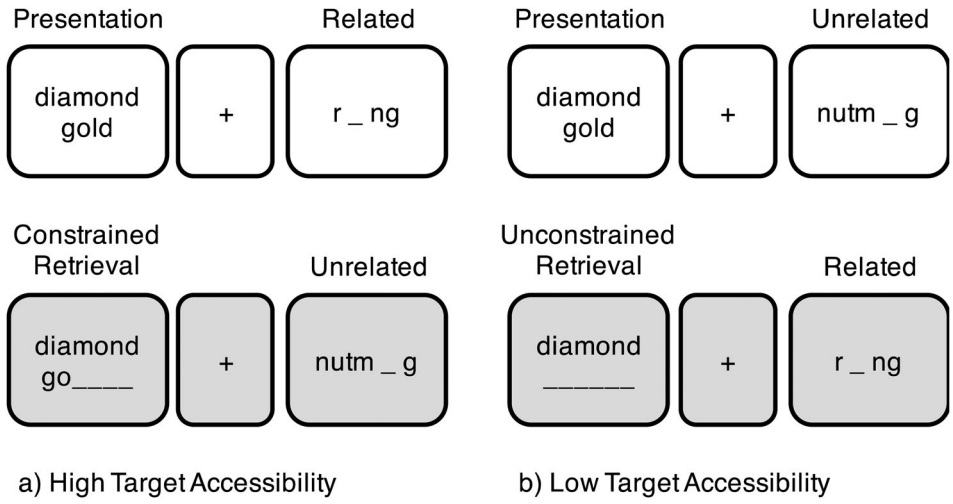

Figure 2. Procedure for restudy + priming phase in Experiments 1 and 2. Half of the participants were randomly assigned to the high target accessibility condition in which the retrieval trials were constrained (a) and the other half to the low target accessibility condition in which the retrieval trials were unconstrained (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 a priming task 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 3, all participants completed unconstrained retrieval trials.

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 + priming trial pairs was randomised across participants. Participants had four practice restudy + priming trial pairs before the phase began in earnest.

Word fragment completion was used in the present experiments 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 additional non-word trials as in a lexical decision task.[1]

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 ($M = .57$, $SD = .23$), $t(102) = 6.83$, $p < .001$, $d = 1.34$.[2] Thus, we effectively made the retrieval attempt easier by providing the first two letters of the target.

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

Table 1 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 that participants were faster to complete related fragments than unrelated fragments. Figure 3 shows semantic priming following presentation and retrieval trials in high and low target accessibility conditions in which the retrieval attempt was constrained or unconstrained, respectively.

A 2 (restudy condition: presentation vs. retrieval) × 2 (target accessibility condition: high vs. low) mixed-effects ANOVA revealed that restudy condition did not significantly affect semantic priming, $F(1, 102) = 2.78$, $p = .10$, $\eta_p^2 = .027$, although the effect was in the predicted direction such that priming was greater, on average, following retrieval than presentation trials. Target accessibility condition did not significantly affect priming, either, $F(1,$

Table 1. Mean reaction times (and SDs) on priming trials in Experiment 1.

	Word type	
Restudy type	Unrelated	Related
High target accessibility condition		
Presentation	1493.88	1323.75
	(421.75)	(298.48)
Retrieval	1533.77	1358.91
	(430.93)	(390.07)
Low target accessibility condition		
Presentation	1347.91	1264.48
	(288.66)	(350.52)
Retrieval	1419.67	1214.14
	(360.66)	(289.00)

Note: Reaction times are in milliseconds and standard deviations are shown in parentheses.

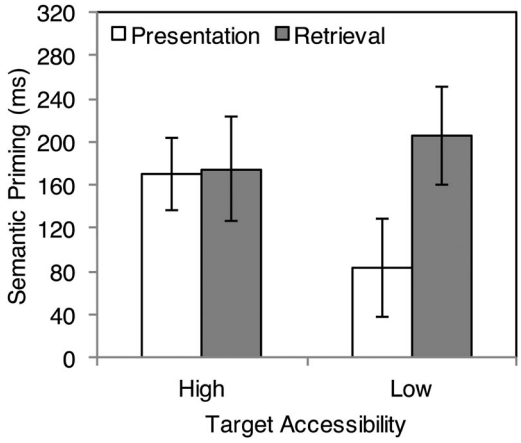

Figure 3. Semantic priming following presentation and retrieval in the high and low target accessibility conditions in Experiment 1. Error bars represent one standard error of the mean.

102) = 0.33, $p = .56$, $\eta_p^2 = .003$. Finally, contrary to the accessibility hypothesis, restudy condition did not interact with target accessibility, $F(1, 102) = 2.38$, $p = .13$, $\eta_p^2 = .023$. However, as predicted, the difference in semantic priming following retrieval and presentation trials was numerically larger in the low than the high target accessibility condition. Planned paired *t*-tests revealed that priming was similar following constrained retrieval attempts ($M = 174.86$, $SD = 349.03$) and presentation trials ($M = 170.13$, $SD = 248.27$) in the high target accessibility condition, $t(51) = 0.09$, $p = .93$, $d = .02$. In contrast, priming was significantly larger following unconstrained retrieval attempts ($M = 205.53$, $SD = 327.53$) than presentation trials ($M = 83.43$, $SD = 322.47$) in the low target accessibility condition, $t(51) = 2.25$, $p = .03$, $d = 0.38$.

We also examined whether retrieval success moderated semantic priming. Figure 4 shows semantic priming following presentation trials, successful retrieval attempts, and unsuccessful retrieval attempts among all eligible participants across the high and low target accessibility conditions combined.[3]

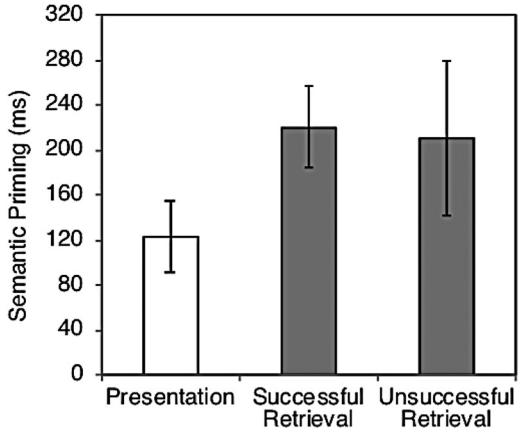

Figure 4. Semantic priming following presentation, successful retrieval attempts, and unsuccessful retrieval attempts, among across target accessibility conditions in Experiment 1. Error bars represent one standard error of the mean.

A one-way repeated measures ANOVA revealed no differences in semantic priming following the three types of trials, $F(2, 96) = 2.33$, $p = .10$, $\eta_p^2 = .046$. Contrary to the accessibility hypothesis, semantic priming was not greatest following unsuccessful retrieval attempts. Instead, planned paired *t*-tests revealed that semantic priming was similar following successful ($M = 221.03$, $SD = 343.61$) and unsuccessful ($M = 210.61$, $SD = 649.67$) retrieval attempts, $t(87) = 0.14$, $p = .89$, $d = 0.02$. Semantic priming was numerically, but not significantly, lower following presentation trials ($M = 123.80$, $SD = 296.65$) than unsuccessful retrieval attempts, $t(87) = 1.33$, $p = .19$, $d = 0.16$, and successful retrieval attempts, $t(87) = 1.89$, $p = .06$, $d = 0.17$.

Discussion

The high target accessibility 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, priming was numerically larger following retrieval attempts, as predicted by the elaborative retrieval hypothesis. 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 retrieval attempts than presentation trials in the low target accessibility condition, but not in the high target accessibility condition (although the interaction between restudy type and target accessibility condition was not statistically significant).

More generally, the accessibility hypothesis predicts that making the target less accessible increases the extent to which memory is searched and mediators are activated. Contrary to this prediction, priming was numerically greatest following successful retrieval attempts, although there were no statistically significant differences in priming following presentation trials, successful retrieval attempts, and unsuccessful retrieval attempts (Figure 4). Thus, the activation of mediators is not necessarily a function of the accessibility of the to-be-recalled information, as defined by retrieval success.

In short, Experiment 1 provided mixed support for the elaborative retrieval hypothesis and accessibility hypothesis. Retrieval may activate mediators slightly more than presentation, but the amount of priming following a retrieval attempt does not reliably depend on target accessibility.

Experiment 2

Given the importance of direct replication (Lishner, 2015; Pashler & Harris, 2012; Simons, 2014), Experiment 2 directly replicated Experiment 1 with sufficient statistical power to

provide an additional test of the elaborative retrieval hypothesis and the accessibility hypothesis. Again, the key questions were whether retrieval activates semantic mediators more than presentation and whether the degree of mediator activation depends on the accessibility of the target information.

Methods

Participants, materials, design and procedure

One hundred ninety-two participants from Introductory Psychology received partial course credit for their participation in this one-hour experiment, which directly replicated Experiment 1. 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 three participants were excluded because they completed fewer than 85% of the fragments on priming trials. Of the remaining 176 participants, 87 (40 females, 40 males reported, median age = 19) were randomly assigned to the high target accessibility condition and 89 participants (40 females, 44 males reported, median age = 19) were randomly assigned to the low target accessibility condition. The sample size was based on a power calculation using the results from Experiment 1 for the effect of the interaction between restudy condition and target accessibility condition on semantic priming. A power calculation using G*Power (Faul et al., 2007) revealed that 172 participants were needed for the within–between-subjects interaction effect with a η_p^2 of .023 (Cohen's $f = .153$) to achieve 90% power with an alpha level of .05.

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 ($M = .79$, $SD = .13$) than when the retrieval attempt was unconstrained ($M = .52$, $SD = .22$), $t(174) = 9.98$, $p < .001$, $d = 1.51$. Thus, we effectively made the retrieval attempt easier by providing the first two letters of the target.

Semantic priming

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 9% of priming 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 high and low target accessibility 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 that participants were faster to complete related fragments than unrelated fragments. Figure 5 shows semantic priming following presentation and retrieval trials in the constrained and unconstrained conditions.

Table 2. Mean reaction times (and SDs) on priming trials in Experiment 2.

	Word type	
Restudy type	Unrelated	Related
High target accessibility condition		
Presentation	1429.25	1276.37
	(414.37)	(335.40)
Retrieval	1491.06	1271.20
	(454.02)	(318.15)
Low target accessibility condition		
Presentation	1302.83	1165.16
	(346.19)	(306.91)
Retrieval	1350.02	1164.80
	(356.41)	(315.66)

Note: Reaction times are in milliseconds and standard deviations are shown in parentheses.

A 2 (restudy condition: presentation vs. retrieval) × 2 (target accessibility condition: high vs. low) mixed-effects ANOVA revealed that restudy condition had a small, but significant effect on semantic priming, $F(1, 174) = 3.81$, $p = .05$, $\eta_p^2 = .021$, whereby priming was greater following retrieval trials than presentation trials. However, target accessibility did not significantly affect priming, $F(1, 174) = 0.47$, $p = .49$, $\eta_p^2 = .003$. Contrary to the accessibility hypothesis, restudy condition did not interact with target accessibility, $F(1, 174) = 0.11$, $p = .74$, $\eta_p^2 = .001$. Planned paired *t*-tests revealed that priming was similar following constrained retrieval attempts ($M = 219.87$, $SD = 385.16$) and presentation trials ($M = 152.88$, $SD = 305.46$), $t(86) = 1.52$, $p = .13$, $d = .19$. Unlike Experiment 1, priming was also similar following unconstrained retrieval attempts ($M = 185.22$, $SD = 244.38$) and presentation trials ($M = 137.67$, $SD = 287.38$), $t(88) = 1.22$, $p = .26$, $d = 0.18$.

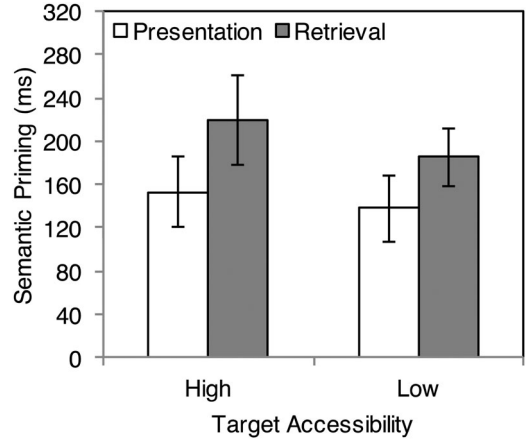

Figure 5. Semantic priming following presentation and retrieval in the high and low target accessibility conditions in Experiment 2. Error bars represent one standard error of the mean.

We also examined whether retrieval success moderated semantic priming, regardless of whether the retrieval attempt was constrained or unconstrained. Figure 6 shows semantic priming following presentation trials, successful retrieval attempts, and unsuccessful retrieval attempts among all eligible participants across the high and low target accessibility conditions (see Note 2).

A one-way repeated measures ANOVA revealed no differences in semantic priming following the three types of trials, $F(2, 262) = 2.80$, $p = .06$, $\eta_p^2 = .021$. Contrary to our prediction, semantic priming was not greatest following unsuccessful retrieval attempts, but rather, successful retrieval attempts. Planned paired *t*-tests revealed that priming was significantly greater following successful retrieval attempts ($M = 252.86$, $SD = 521.43$) than presentation trials ($M = 136.01$, $SD = 304.62$), $t(131) = 2.35$, $p = .02$, $d = 0.27$. Priming was also numerically, but not significantly, greater following successful retrieval attempts than unsuccessful retrieval attempts ($M = 149.06$, $SD = 504.71$), $t(131) = 1.68$, $p = .09$, $d = 0.20$. However, priming was similar following unsuccessful retrieval attempts and presentation trials, $t(131) = 0.26$, $p = .79$, $d = 0.03$.

Discussion

Experiment 2 directly replicated Experiment 1 to examine whether retrieval activates mediators more than presentation and whether target accessibility plays a role. Furthermore, Experiment 2 was conducted with sufficient power to detect the interaction of interest between restudy type (presentation or retrieval) and target accessibility (high or low). The general pattern of results was similar in Experiments 1 and 2: retrieval activated mediators numerically more than presentation and there was no clear effect of target accessibility. However, there were a few notable differences. In Experiment 2, retrieval activated mediators significantly more than presentation, contrary to Lehman and Karpicke (2016) and Experiment 1. Although there were no differences in priming based on whether the retrieval attempt was constrained by the first two letters of the target word, retrieval success affected priming, to a degree. Successful, but not unsuccessful retrieval attempts led to significantly more mediator priming than presentation trials.

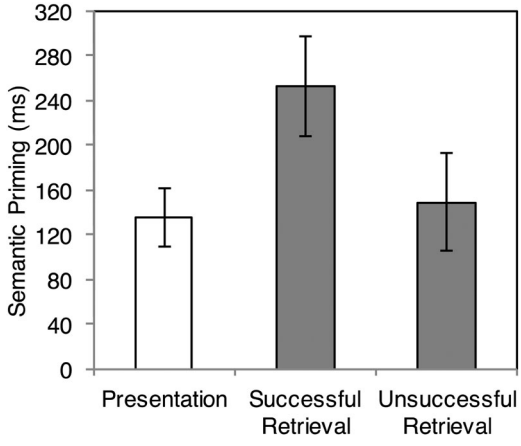

Figure 6. Semantic priming following presentation, successful retrieval attempts, and unsuccessful retrieval attempts, among across target accessibility conditions in Experiment 2. Error bars represent one standard error of the mean.

In short, Experiment 2 supported the elaborative retrieval hypothesis, suggesting retrieval activates mediators more than presentation. However, as in Experiment 1, Experiment 2 provided mixed support for the accessibility hypothesis, with different conclusions emerging based on whether target accessibility was determined based on the nature of the retrieval attempt (constrained vs. unconstrained) or retrieval success.

Experiment 3

The purpose of Experiment 3 was to use a different manipulation to provide a new test of the hypothesis that the less accessible the target is at the time of retrieval, the more 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 3 also directly replicated the low target accessibility condition of Experiments 1 and 2.

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 priming trials.

Among the remaining 101 participants, 49 were randomly assigned to the low target accessibility condition, studying every word pair once initially (34 females, 14 males reported, median age = 19) and 52 were randomly assigned to the high target accessibility condition, studying every word pair three times initially (40 female, 12 male, median age = 19).[4]

Materials, design and procedure

Experiment 3 used the same materials as Experiments 1 and 2 and followed a similar procedure. Participants completed the initial study phase and the restudy + priming phase. However, unlike Experiments 1 and 2, the key manipulation – level of learning – occurred during the initial study phase. Participants in the low target accessibility condition studied each pair once, replicating Experiments 1 and 2. Participants in the high target accessibility condition studied the complete list of 48 pairs three times, with the pairs presented in a random

order for each participant each time through the list. The restudy + priming phase was the same for the low and high-learning conditions and was identical to the restudy + priming phase in Experiments 1 and 2 in which the retrieval attempts were unconstrained (Figure 2(B)).

Results

Initial test performance

During the restudy phase, participants retrieved significantly more targets for pairs they studied three times ($M = .78$, $SD = .17$) than pairs they studied once ($M = .47$, $SD = .21$), $t(99) = 8.05$, $p < .001$, $d = 1.60$. 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 prior experiments, 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 priming 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 target accessibility 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 that participants were faster to complete related fragments than unrelated fragments. Figure 7 shows semantic priming following presentation and retrieval trials in the high and low target accessibility conditions (i.e., when pairs had been studied three times and once, respectively).

A 2 (restudy condition: presentation vs. retrieval) × 2 (target accessibility: high vs. low) mixed-effects ANOVA revealed that restudy condition did not significantly affect semantic priming, $F(1, 99) = 2.32$, $p = .13$, $\eta_p^2 = .023$, but as predicted, semantic priming was numerically greater following retrieval attempts than presentation trials. Target accessibility did not significantly affect priming, either, $F(1, 99) = 0.23$, $p = .63$, $\eta_p^2 = .002$. Finally, contrary to the accessibility hypothesis, restudy condition did not interact with target accessibility, $F(1, 99) = 0.10$, $p = .76$, $\eta_p^2 = .001$.

Planned paired *t*-tests revealed that semantic priming was similar following retrieval ($M = 183.98$, $SD = 291.10$) and presentation trials ($M = 117.37$, $SD = 259.65$), $t(51) = 1.15$, $p = .25$, $d = .24$, when the target was highly accessible because the pairs had been studied three times. Making the target less accessible did not change the pattern of results. Priming was also similar following retrieval ($M = 189.47$, $SD = 252.99$) and presentation trials ($M = 145.62$, $SD = 200.48$), $t(48) = 1.02$, $p = .31$, $d = .19$, when the target had low accessibility because the pairs had only been studied once.

As in Experiments 1 and 2, we examined whether retrieval success moderated semantic priming. Figure 8 shows semantic priming following presentation trials, successful retrieval attempts, and unsuccessful retrieval attempts

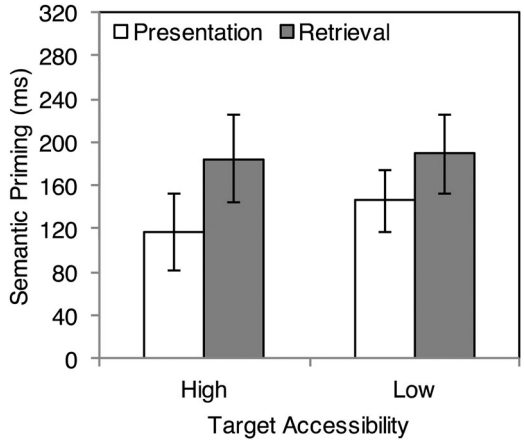

Figure 7. Semantic priming following presentation and retrieval trials Experiment 3. Error bars represent one standard error of the mean.

Table 3. Mean reaction times on priming trials in Experiment 3.

	Word type	
Restudy type	Unrelated	Related
High target accessibility condition		
Presentation	1287.35	1169.98
	(330.44)	(273.61)
Retrieval	1309.64	1125.66
	(347.76)	(247.60)
Low target accessibility condition		
Presentation	1367.23	1221.62
	(355.22)	(281.93)
Retrieval	1362.13	1172.66
	(360.10)	(290.38)

Note: Reaction times are in milliseconds and standard deviations are shown in parentheses.

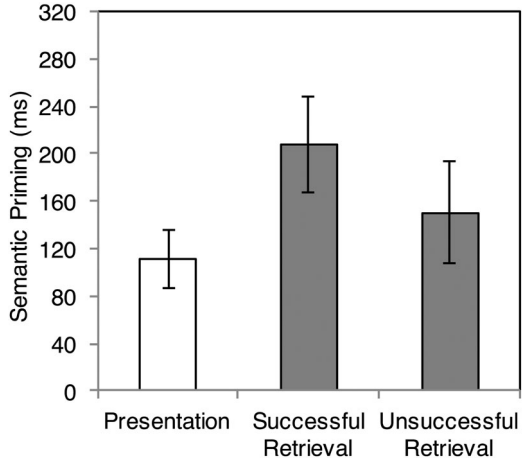

Figure 8. Semantic priming following presentation, successful retrieval attempts, and unsuccessful retrieval attempts, among all participants in Experiment 3. Error bars represent one standard error of the mean.

among all eligible participants in the high and low target accessibility conditions (see also Note 2).

A one-way repeated measures ANOVA revealed no differences in semantic priming following the three types of trials, $F(2, 156) = 1.85$, $p = .16$, $\eta_p^2 = .02$. Contrary to the accessibility hypothesis, priming was greatest following successful, not unsuccessful, retrieval attempts. Planned paired *t*-tests revealed that priming was significantly greater following successful retrieval attempts ($M = 207.62$, $SD = 358.88$) than presentation trials ($M = 111.64$, $SD = 215.64$), $t(78) = 2.07$, $p = .04$, $d = 0.32$. Furthermore, there were no significant differences in priming following successful and unsuccessful retrieval attempts ($M = 150.35$, $SD = 383.42$), $t(78) = 1.08$, $p = .28$, $d = 0.15$, or following unsuccessful retrieval attempts and presentation trials, $t(78) = 0.76$, $p = .45$, $d = 0.13$.

Discussion

Experiment 3 manipulated target accessibility by varying level of initial learning. Although Experiment 3 used a different manipulation than Experiments 1 or 2, a similar pattern of results emerged. Semantic priming was numerically, but not significantly, greater following retrieval than presentation. Consistent with Experiments 1 and 2, target accessibility did not reliably affect semantic priming. Contrary to the accessibility hypothesis, the difference in priming following attempts and presentation trials did not differ when the pairs were initially studied three times or once (Figure 7). Furthermore, priming was numerically greatest following successful retrieval, rather than unsuccessful retrieval attempts. Thus, Experiment 3 provided limited support for the elaborative retrieval hypothesis and did not support the accessibility hypothesis.

Although Experiments 1–3 found a similar pattern of results, there was variability in the size and statistical significance of the effects of interest. Therefore, we conducted a mini meta-analysis to combine the results of Experiments 1–3 in order to better estimate the effects of restudy condition (retrieval vs. presentation) and target accessibility (high vs. low) on semantic priming.

Meta-analysis

A meta-analysis is a tool to quantitatively combine the results of multiple experiments to estimate the size of an effect of interest. For each participant, we calculated semantic priming – i.e., the difference between mean reaction times for unrelated and related words – which we calculated separately for word fragments following pairs that were restudied through retrieval and presentation. The effect size of interest (Cohen's *d*) was the difference between semantic priming following retrieval and presentation divided by the pooled standard deviations, which the elaborative retrieval hypothesis predicts should be greater than 0. Because the present experiments used repeated measures designs, we also took into account the correlation between the two measures, using Cohen's d_{rm} (Lakens, 2013). Each experiment yielded two effect sizes: one for the high target accessibility condition and one for the low target accessibility condition.

Figure 9 displays the effect sizes of interest in Experiments 1–3 and their weighted (by sample size) mean, split by target accessibility condition. The mean weighted effect size was $d = 0.15$, 95% CI [−.03, .33], across the high target accessibility conditions and $d = 0.24$, 95% CI [.054, .432], across the low target accessibility conditions, indicating significantly more semantic priming following retrieval than presentation, but only when the target had low accessibility. However, because the confidence intervals for the two effect sizes largely overlap, the true size of the effects may be the same when the target has high or low accessibility. This finding is consistent with the conclusions from Experiments 1–3 that the interaction of restudy condition and target accessibility did not significantly affect semantic priming.

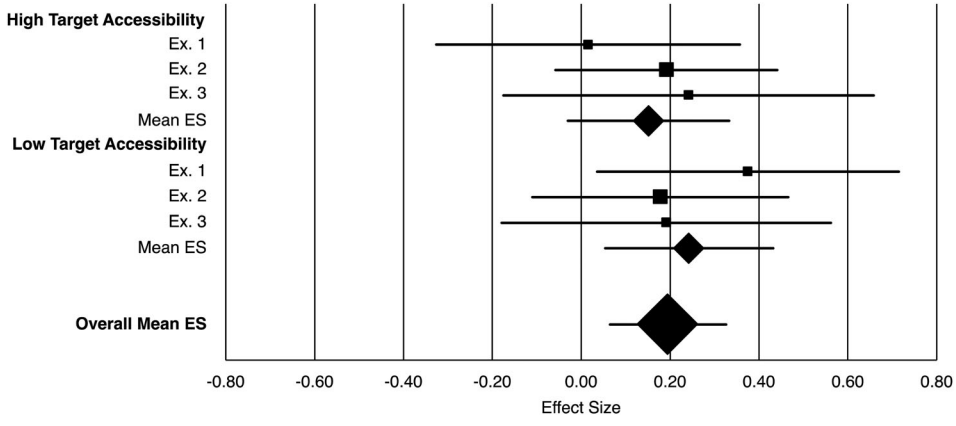

Figure 9. Mean and 95% confidence intervals for the effect sizes of interest in Experiments 1-3. The effect size of interest was Cohen's *d* based on the difference between semantic priming following retrieval and presentation. Values larger than 0 indicate priming was greater following retrieval. The size of the boxes is proportional to the sample size in each experiment. The diamonds indicate the mean weighted effect sizes and 95% confidence intervals from the meta-analyses of the high target accessibility conditions, low target accessibility conditions, and all conditions combined from all three experiments.

Overall – across experiments and target accessibility conditions – the mean weighted effect size was $d = 0.20$, 95% CI [.07, .33], indicating significantly more priming of semantic mediators following retrieval than presentation. Thus, taken together, Experiments 1–3 suggest that retrieval activates mediators more than presentation, but the effect may be small and does not depend on target accessibility.

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 are 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 2006, 2011; Carpenter & Yeung, 2017; Coppens, Verkoeijen, Bouwmeester, & Rikers, 2016; Pyc & Rawson, 2010, 2012). Yet, contrary to the elaborative retrieval hypothesis, Lehman and Karpicke (2016) found that retrieval and presentation activated mediators to a similar degree when measured via semantic priming task. However, Lehman and Karpicke (2016) also provided the first two letters of the target words on retrieval trials, which may have constrained participants' memory search to words that began with those two letters, thereby minimising activation of words semantically related to the cue. More generally, we hypothesised that mediator activation would be inversely related to the ease with which the target information could be retrieved.

Therefore, the present experiments tested a possible refinement to the elaborative retrieval hypothesis that we have termed the *accessibility hypothesis*: 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 & Delosh, 2006; Carpenter, 2009; Karpicke & Roediger, 2007; Pyc & Rawson, 2009), possibly due to greater involvement of mediators (Kole & Healy, 2013; Rawson et al., 2015). Experiment 1 and its direct replication, Experiment 2, manipulated target accessibility by varying whether the first two letters of the target were provided on retrieval trials. Experiment 3 manipulated target accessibility by varying whether the pairs were initially studied three times (high accessibility) or once (low accessibility). We examined whether retrieval activated mediators more than presentation and whether the difference was larger when the target was less accessible on retrieval trials.

Individually, Experiments 1–3 provided mixed support for the elaborative retrieval hypothesis and limited support for the accessibility hypothesis. Consistent with the elaborative retrieval hypothesis, Experiments 1–3 found that semantic priming was greater following retrieval than presentation trials, but the effect was only statistically significant in Experiment 2. Contrary to the accessibility hypothesis, the difference in mediator priming following retrieval and presentation did not differ across the high and low target accessibility conditions in any of the present experiments. Furthermore, we considered a target more accessible when it could be correctly retrieved than when it could not be retrieved. However, mediator priming was numerically greatest following successful, rather than unsuccessful, retrieval attempts (although there were no statistically significant differences in mediator priming following presentation trials, successful retrieval attempts, or unsuccessful retrieval attempts). The only exception was there was significantly more priming following successful retrieval attempts than presentation trials in Experiment 2.

Combining the results of Experiments 1–3, we conducted a meta-analysis to estimate the size of the effect of retrieval versus presentation on mediator activation and the role of target accessibility. Although only one of the individual comparisons of mediator priming following retrieval and presentation revealed a statistically significant effect (the low target accessibility in Experiment 2; Figure 9), the overall mean effect size pointed to a different conclusion. Taken together, Experiments 1–3 provided weak support for the elaborative retrieval hypothesis, suggesting that retrieval activated mediators more than presentation, although the effect was small. It is unclear why Experiments 1–3 found more priming following retrieval than presentation when Lehman and Karpicke (2016) found similar amounts of priming following the two types of restudy trials. One possibility to consider in future research is that Lehman and Karpicke (2016) used a lexical decision task, whereas Experiments 1–3 used a fragment completion task (for a thorough investigation of different implicit memory tasks, see Franks, Bilbrey, Lien, & McNamara, 2000).

The meta-analysis did not support the accessibility hypothesis, however, as the difference in mediator priming following retrieval attempts and presentation trials was similar across the high and low target accessibility conditions. Therefore, the present experiments suggest mediators could play a role in the benefits of retrieval, but the effects of mediators may not depend on how easily the target information can recalled during the retrieval attempt. Thus, it may not be the inaccessibility of the target during the retrieval attempt that drives mediator activation – as the elaborative retrieval hypothesis posits – but some other process involved in trying to recall the target.

Challenges to the elaborative retrieval hypothesis

The present experiments provided modest support for the first assumption of the elaborative retrieval hypothesis,

namely, that retrieval activates related words more than presentation. Although the effect was small, it provides evidence against a major theoretical challenge to the elaborative retrieval hypothesis: retrieval induced forgetting (for more on this critique, see Karpicke et al., 2014). 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). The paradigm used to study retrieval induced forgetting is substantially different than the methods used in this experiment, but it would predict that retrieval should make related words less accessible than presentation, not more accessible. Thus, although the present experiments did not directly examine retrieval induced forgetting, they suggest that elaboration remains a viable mechanism by which retrieval enhances learning.

A second key assumption of the elaborative retrieval hypothesis is that activating related words is not merely a byproduct of retrieval, but that it enhances learning. Given the small effect of retrieval on mediator priming in the present experiments, it is unclear whether mediator activation could account for the robust benefits of retrieval practice (Rowland, 2014). Furthermore, although the second key assumption was not tested in the present experiments, it is inconsistent with the principle of cue overload (see Karpicke et al., 2014 for a detailed review of this criticism). 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 (Goh & Lu, 2012; 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. However, cue overload can be mitigated when the competing information is integrated, or linked (e.g., Myers, O'Brien, Balota, & Toyofuku, 1984). Therefore, mediator activation alone may not facilitate learning. Instead, future research should examine the possibility that retrieval activates mediators more than presentation, but it only enhances learning when the mediators and target are integrated.

Episodic context account

The episodic context account (Karpicke et al., 2014; Lehman et al., 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 mitigating cue overload – a major theoretical challenges of the elaborative retrieval hypothesis.

However, the episodic context account predicts that there should be no difference 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. By this account, any priming of related words should be greater following presentation trials rather than retrieval trials. Therefore, the episodic context account cannot explain the patterns of priming in the present experiments.

Limitations and future directions

Although the meta-analysis revealed 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 organisation of participants' knowledge such that some mediators were more strongly associated with the cue than others. We accounted for this limitation to some degree by counterbalancing an item's status as presented or retrieved across participants.

In addition, although we found 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 Karpicke & Smith, 2012; Lehman et al., 2014). 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 a 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. Taken together, the present experiments provided modest support for the key assumption that retrieval activates mediators more than presentation as the observed effect was small.

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.

Notes

1. Participants completed a final recall test after a 3-minute single-digit arithmetic distractor task at the end of Experiments 1–3. However, the results will not be discussed further because the purpose of the experiments 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. Critically, the final test was not a pure measure of learning of the word pairs. The words presented on the fragment completion trials may have interfered with learning the pairs (e.g., Anderson & Neely, 1996), particularly following retrieval trials (Chan & LaPaglia, 2013; Chan, Thomas, & Bulevich, 2009; Pastötter & Bäuml, 2014).
2. For all analyses based on retrieval accuracy in Experiments 1–3, 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 misspelled but sounded the same as the correct answer.
3. The degrees of freedom are different for the conditional analyses than other analyses. Thirteen participants in the high target accessibility condition and three participants in the low target accessibility condition 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. Forty-four and 22 participants were excluded from conditional analyses in Experiments 2 and 3, respectively, for the same reason.
4. Experiment 3 was designed at the same time as Experiment 1. Therefore, the sample size was determined using the same power calculation described in Experiment 1.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by National Science Foundation Graduate Research Fellowship [grant number DGE-1321845].

References

Anderson, M. C., Bjork, E. L., & Bjork, R. A. (2000). Retrieval-induced forgetting: Evidence for a recall-specific mechanism. *Psychonomic Bulletin & Review*, *7*(3), 522–530. doi:10.3758/BF03214366

Anderson, M. C., Bjork, R. A., & Bjork, E. L. (1994). Remembering can cause forgetting: Retrieval dynamics in long-term memory. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *20*(5), 1063–1087. doi:10.1037/0278-7393.20.5.1063

Anderson, M., & Neely, J. (1996). Interference and inhibition in memory retrieval. *Memory (Hove, England)*, 237–313.*Handbook of Perception and Cognition*. doi:10.1016/B978-012102570-0/50010-0

Carpenter, S. K. (2009). Cue strength as a moderator of the testing effect: The benefits of elaborative retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*(6), 1563–1569. doi:10.1037/a0017021

Carpenter, S. K. (2011). Semantic information activated during retrieval contributes to later retention: Support for the mediator effectiveness hypothesis of the testing effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(6), 1547–1552. doi:10.1037/a0024140

Carpenter, S. K., & Delosh, E. L. (2006). Impoverished cue support enhances subsequent retention: Support for the elaborative retrieval explanation of the testing effect. *Memory & Cognition*, *34*, 268.

Carpenter, S. K., & Yeung, K. L. (2017). The role of mediator strength in learning from retrieval. *Journal of Memory and Language*, *92*, 128–141.

Chan, J. C. K., & LaPaglia, J. A. (2013). Impairing existing declarative memory in humans by disrupting reconsolidation. *Proceedings of the National Academy of Sciences*, *110*(23), 9309–9313. doi:10.1073/pnas.1218472110

Chan, J. C. K., Thomas, A. K., & Bulevich, J. B. (2009). Recalling a witnessed event increases eyewitness suggestibility: The reversed testing effect. *Psychological Science*, *20*(1), 66–73. doi:10.1111/j.1467-9280.2008.02245.x

Collins, A. M., & Loftus, E. F. (1975). A spreading activation theory of semantic processing. *Psychological Review*, *82*, 407–428. doi:10.1037/0033-295X.82.6.407

Collins, A. M., & Quillian, M. R. (1972). How to make a language user. In E. Tulving & W. Donaldson (Eds.), *Organization of memory* (pp. 309–351). New York, NY: Academic Press.

Coppens, L. C., Verkoeijen, P. P., Bouwmeester, S., & Rikers, R. M. (2016). The testing effect for mediator final test cues and related final test cues in online and laboratory experiments. *BMC Psychology*, *4*(1), 443. doi:10.1186/s40359-016-0127-2

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175–191. doi:10.3758/BF03193146

Franks, J. J., Bilbrey, C. W., Lien, K. G., & McNamara, T. P. (2000). Transfer-appropriate processing (TAP) and repetition priming. *Memory & Cognition*, *28*(7), 1140–1151. doi:10.3758/BF03211815

Goh, W. D., & Lu, S. H. (2012). Testing the myth of the encoding–retrieval match. *Memory & Cognition*, *40*(1), 28–39. doi:10.3758/s13421-011-0133-9

Heyman, T., De Deyne, S., Hutchison, K. A., & Storms, G. (2015). Using the speeded word fragment completion task to examine semantic priming. *Behavior Research Methods*, *47*(2), 580–606. doi:10.3758/s13428-014-0496-5

Karpicke, J. D., Lehman, M., & Aue, W. R. (2014). Retrieval-based learning. An episodic context account. *Psychology of Learning and Motivation – Advances in Research and Theory*, *61*, 237–284. doi:10.1016/B978-0-12-800283-4.00007-1

Karpicke, J. D., & Roediger, H. L. (2007). Expanding retrieval practice promotes short-term retention, but equally spaced retrieval enhances long-term retention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*(4), 704–719. doi:10.1037/0278-7393.33.4.704

Karpicke, J. D., & Smith, M. A. (2012). Separate mnemonic effects of retrieval practice and elaborative encoding. *Journal of Memory and Language*, *67*(1), 17–29.

Kole, J. A., & Healy, A. F. (2013). Is retrieval mediated after repeated testing? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 39(2), 462–472. doi:10.1037/a0028880

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*. doi:10.3389/fpsyg.2013.00863

Lehman, M., & Karpicke, J. D. (2016). Elaborative retrieval: Do semantic mediators improve memory? *Journal of experimental psychology . Learning, Memory, and Cognition*, *42*(10), 1573–1591. doi:10.1037/xlm0000267

Lehman, M., Smith, M. A., & Karpicke, J. D. (2014). Toward an episodic context account of retrieval-based learning: Dissociating retrieval practice and elaboration. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *40*(4), 1787–1794. doi:10.1037/xlm0000012

Lishner, D. A. (2015). A concise set of core recommendations to improve the dependability of psychological research. *Review of General Psychology*, *19*(1), 52–68. doi:10.1037/gpr0000028

Moscovitch, M., & Craik, F. I. (1976). Depth of processing, retrieval cues, and uniqueness of encoding as factors in recall. *Journal of Verbal Learning and Verbal Behavior*, *15*(4), 447–458. doi:10.1016/S0022-5371(76)90040-2

Murayama, K., Miyatsu, T., Buchli, D., & Storm, B. C. (2014). Forgetting as a consequence of retrieval: A meta-analytic review of retrieval-induced forgetting. *Psychological Bulletin*, *140*(5), 1383–1409. doi:10.1037/a0037505

Myers, J. L., O'Brien, E. J., Balota, D. A., & Toyofuku, M. L. (1984). Memory search without interference: The role of integration. *Cognitive Psychology*, *16*(2), 217–242. doi:10.1016/0010-0285(84)90008-2

Nairne, J. S. (2002). The myth of the encoding-retrieval match. *Memory (Hove, England)*, *10*(5–6), 389–395. doi:10.1080/09658210244000216

Nelson, D. L., McEvoy, C. L., & Schreiber, T. A. (2004). The university of South Florida free association, rhyme, and word fragment norms. *Behavior Research Methods, Instruments, & Computers*, *36*(3), 402–407. doi:10.3758/BF03195588

Paivio, A., Yuille, J. C., & Madigan, S. A. (1968). Concreteness, imagery, and meaningfulness values for 925 nouns. *Journal of Experimental Psychology*, *76*(1), 1–25. doi:10.1037/h0025327

Pashler, H., & Harris, C. R. (2012). Is the replicability crisis overblown? Three arguments examined. *Perspectives on Psychological Science*, *7*(6), 531–536. doi:10.1177/1745691612463401

Pastötter, B., & Bäuml, K.-H. T. (2014). Retrieval practice enhances new learning: The forward effect of testing. *Frontiers in Psychology*, *5* (April), 286. doi:10.3389/fpsyg.2014.00286

Pyc, M. A., & Rawson, K. A. (2009). Testing the retrieval effort hypothesis: Does greater difficulty correctly recalling information lead to higher levels of memory? *Journal of Memory and Language*, *60*(4), 437–447. doi:10.1016/j.jml.2009.01.004

Pyc, M. A., & Rawson, K. A. (2010). Why testing improves memory: Mediator effectiveness hypothesis. *Science*, *330*(6002), 335–335. doi:10.1126/science.1191465

Pyc, M. A., & Rawson, K. A. (2012). Why is test–restudy practice beneficial for memory? An evaluation of the mediator shift hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(3), 737–746. doi:10.1037/a0026166

Rawson, K. A., Vaughn, K. E., & Carpenter, S. K. (2015). Does the benefit of testing depend on lag, and if so, why? Evaluating the elaborative retrieval hypothesis. *Memory & Cognition*, *43*(1), 619–633. doi:10.3758/s13421-014-0477-z

Roediger, H. L., & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. *Trends in Cognitive Sciences*, *15*(1), 20–27 doi:10.1016/j.tics.2010.09.003

RoedigerIII, H. L., & Karpicke, J. D. (2006). The power of testing memory: Basic research and implications for educational practice. *Perspectives on Psychological Science*, *1*(3), 181–210. doi:10.1111/j.1467-8721.2008.00612.x

Rowland, C. A. (2014). The effect of testing versus restudy on retention: A meta-analytic review of the testing effect. *Psychological Bulletin*, *140*(6), 1432–1463. doi:10.1037/a0037559

Simons, D. J. (2014). The value of direct replication. *Perspectives on Psychological Science*, *9*(1), 76–80. doi:10.1177/1745691613514755

Storm, B. C., & Levy, B. J. (2012). A progress report on the inhibitory account of retrieval-induced forgetting. *Memory & Cognition*, *40* (6), 827–843. doi:10.3758/s13421-012-0211-7

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, *37*(4), 571–590. doi:10.1080/14640748508400920

Tipper, S. P. (2001). Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology*, *54*(2), 321–343. doi:10.1080/02724980042000183

Tipper, S., & Driver, J. (1988). Negative priming between pictures and words in a selective attention task: Evidence for semantic processing of ignored stimuli. *Memory & Cognition*, *16*(1), 64–70. doi:10.3758/BF03197746

Watkins, M. J., & Watkins, O. C. (1976). Cue-overload theory and the method of interpolated attributes. *Bulletin of the Psychonomic Society*, *7*(3), 289–291. doi:10.3758/BF03337192

Appendix. Materials used in Experiments 1–3

Table A1. Word set version one

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

Table A2. Word set version two

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