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The immediate benefits and long-term consequences of briefly presented masked primes on episodic recollection

Geoffrey B. Maddox[a,*], David A. Balota[b], Abhilasha A. Kumar[b], Peter R. Millar[b], Luke Churchill[b]

[a] Department of Psychology, Rhodes College, Memphis, TN 38112, United States
[b] Department of Psychological and Brain Sciences, Washington University, St. Louis, MO 63130, United States

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ABSTRACT

Within-trial priming paradigms have been widely used to measure lexical retrieval and familiarity-based processes in speeded pronunciation, perceptual identification, lexical decision, lexical retrieval, and episodic recognition tasks. Here, we introduce a novel within-trial priming paradigm to examine cued recall, which is considered a more recollection-based task. In each experiment, participants initially studied a list of paired-associates (e.g., BADGE-gold). During each recall test trial, 500 ms after the onset of the stimulus cue (BADGE-??????), a pattern-masked prime was briefly presented for either 48 ms or 125 ms, with the task to recall the word (e.g., gold) paired with the cue (BADGE). Across seven experiments, the primes were identical (gold), semantically related (silver), orthographically related (good), or unrelated (chair) to the to-be-recalled response item (gold). The results consistently indicated that the masked identity primes benefited immediate recall at both the 48 ms and 125 ms durations. There was no benefit from the orthographically related prime condition, suggesting that participants were not using partial letter information as an additional cue for memory retrieval. Semantically related primes only produced a benefit in immediate recall at the 125 ms prime duration. Delayed cued recall performance indicated that the facilitatory priming effects observed in immediate recall were eliminated. In addition, results from conditional analyses suggest that the benefits of retrieval in an immediate recall condition are reversed in the delayed recall condition. We consider multiple interpretations of these delayed recall results and argue that the results are in part due to priming influencing an activation-based mechanism in the immediate recall task, which decreases the retrieval demands for the response item to the paired associate cue, and hence, decreases the long-term benefits of retrieval practice.

Introduction

A critical question in memory research concerns the moment in which the search for a memory triggers a recollective experience. Specifically, as one searches memory for an answer (e.g., what I had for dinner on Tuesday), the targeted trace is likely first activated by multiple cues, and then reaches a response threshold, which provides full and conscious access to the trace, i.e., the recollective experience. Gestalt psychologists called the critical step in which one memory trace (e.g., a retrieval cue) makes contact with a previously stored memory (e.g., the target) the Hoffding step (see Höffding, 1891). Here we explore processes related to this critical step in memory retrieval.

The primary goal of the present study was to examine whether one can increase the activation of stored memory traces for recollection-driven retrieval with brief masked primes presented near the threshold of perception or if a necessary prerequisite is the use of conscious explicit search of episodic memory. Of course, a critical question here is what types of retrieval cues (e.g., identity, semantically related, and/or orthographically related) might facilitate explicit retrieval, compared to an unrelated cue. There is a large literature from word recognition and lexical retrieval studies which clearly demonstrates that both identity (e.g., Forster & Davis, 1984) and semantic cues (see McNamara, 2005, for a review) produce benefits under very short presentation durations. Interestingly, there is also a large literature indicating that explicit retrieval of words that fit low-frequency word definitions benefits from orthographic/phonological primes but not semantic primes (e.g., Meyer & Bock, 1992; Perfect & Hanley, 1992). Thus, it appears that implicit tasks (such as lexical decision and pronunciation) and explicit tasks (such as retrieval of words to low-frequency word definitions) are differentially sensitive to distinct prime types. However, the results from these studies involve tasks that demand retrieval from lexical/semantic memory. A primary goal of the present study is to extend this priming

* Corresponding author.
E-mail address: maddoxg@rhodes.edu (G.B. Maddox).

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literature to tasks that involve *explicit episodic retrieval*.

The topic of partial activation, via priming techniques, has already been explored to some extent in episodic memory contexts. However, as described in detail below, these studies have focused on episodic recognition memory paradigms, wherein, the fluency of the recognition target can be modulated via the presentation of an identity or a related prime. The present study extends this work in a critical manner attempting to push a trace over the Hoffding step for an explicit recollection-based experience in a cued recall paradigm. In addition to this goal, we also examined the long-term consequences of priming retrieval processes, via a delayed memory test.

Near-threshold versus explicit priming in recognition testing

There are a series of episodic recognition studies that are particularly relevant to the present study. In a classic study, Jacoby and Whitehouse (1989) compared the influence of identity versus unrelated primes on recognition test performance when primes were presented near-threshold (50 ms) or supra-threshold (200 ms) immediately before each recognition test probe. In this paradigm, participants first studied a list of single words before completing a recognition test. Each recognition trial was primed with a word matching the test item (i.e., identity prime), a word mismatching the test item (i.e., mismatch prime), or with a neutral prime (i.e., *xoxoxoxo*). Analyses of hit and false alarm rates revealed significant Prime Type × Duration interactions. Specifically, hit and false alarm rates were higher in the match condition than the mismatch conditions when primes were presented near-threshold but this pattern was reversed when primes were presented supra-threshold. Near-threshold and supra-threshold primes were both assumed to increase processing fluency of test items. Jacoby and Whitehouse suggested that near-threshold priming led to increased hit and importantly false alarm rates in the matching condition compared to the mismatching condition, because participants could not attribute the increased fluency of processing the test item to the preceding prime. Hence, the brief presentation of the primes drove the automatic familiarity component of the episodic recognition decisions. In contrast, when primes were presented above threshold, participants could attribute the change in fluency of processing the test item to the preceding prime, and as a result, participants could correct for this fluency when making their recognition decisions.

Taylor and Henson (2012) extended Jacoby and Whitehouse's (1989) work by examining the influence of semantic versus perceptual priming on recognition test performance when primes were presented near- versus supra- threshold. Specifically, Taylor and Henson examined the influence of near-threshold (50 ms) identity primes, semantically related primes, and unrelated primes on recognition performance utilizing a remember/know procedure. Participants studied a list of words and then completed an old/new recognition test. If an item was reported as previously studied, participants then judged whether they based their response on explicitly remembering (R) the item or simply knowing (K) it was familiar. Results revealed a selective increase in R judgments for hits in the semantic priming condition relative to the unrelated priming condition. In contrast, identity priming led to increased K judgments for hits and false alarms relative to the unrelated priming condition. If R judgments are reflective of a recollective experience, these results suggest that semantic, but not identity priming, can influence recollective experiences. However, a second experiment eliminated the identity prime condition and only examined the influence of semantic priming against an unrelated baseline condition, and here the results did not reveal significant differences between prime conditions in the use of R and K judgments for either hits or false alarms. Taylor and Henson interpreted their findings in terms of an attribution account in which participants use Remember and Know judgments differently when different types of fluency are experienced with the list context (i.e., identity prime-related fluency versus semantic prime-related fluency).

Merikle and Joordens (1997) investigated the extent to which "subliminal" primes are necessary to produce the pattern observed in the original Jacoby and Whitehouse experiments. They found that one can obtain the same pattern via attentional, supra-threshold prime durations. Specifically, weakly attended primes produced increased hit and false alarm rates, whereas more strongly attended primes produced decreased hit and false alarm rates. Thus, varying degrees of attention to supraliminal primes produced a similar pattern as perceptual degradation in a primed recognition test.

Huber, Clark, Curran, and Winkielman (2008) addressed whether a fluency attribution strategy was necessary to accommodate the results originally observed by Jacoby and Whitehouse (1989), and subsequent studies. Huber et al. motivated their study by predictions from the Huber and O'Reilly (2003) computational model, which suggests that brief primes will produce facilitation via a preactivation mechanism, whereas, longer duration primes can produce dysfluency via a prime habituation mechanism. This framework does not rely on "strategic" attribution processes to produce the cross-over interaction between prime duration and likelihood of responding "old", or choosing the correct target in a forced-choice paradigm. In a series of experiments, Huber et al. demonstrated that interactive effects of prime duration on recognition accuracy can be accommodated by their automatic activation/habituation model, and do not demand a more strategic attribution process.

It is also noteworthy that primed episodic recognition has been used to investigate the nature of the lexical representations in the first (L1) and second (L2) languages in bilinguals. For example, Jiang and Forster (2001) found that in episodic recognition, one finds greater priming from L2 to L1 translations, but not from L1 to L2, which is opposite of what one finds in lexical decision, i.e., greater priming from L1 to L2, but little priming from L2 to L1. The authors argued that these results are most consistent with the notion that L2 items are more likely to be episodically represented, and hence are more likely tapped by an episodic recognition task and not the lexical decision task. This research nicely demonstrates the power of distinct tasks (i.e., episodic recognition vs lexical decision) in informing the nature of the lexical representations (see also Witzel & Forster, 2012).

Clearly, the literature from primed episodic recognition tasks has generated considerable empirical and theoretical work regarding both the nature of the processes (e.g., automatic familiarity, habituation, attribution processes) and the nature of the representations (e.g., lexical vs episodic representations in L1 and L2). Importantly, this literature converges on the notion that primes can produce increased fluency for a recognition target when they are briefly presented or receive relatively little attention. Because of the importance of fluency/familiarity in performance, this work has naturally focused on recognition test performance. Indeed, in an attempt to isolate the familiarity component of recognition from explicit recollection, Huber et al. (2008) showed that priming effects in recognition memory only occurred on trials that participants did not later recall a paired associate, suggesting that this effect was not due to recollection. However, since the paired associate recall occurred after the recognition decision in this study, one could not address the direct influence of the prime on recollection without the contamination of an earlier recognition decision. In contrast to minimizing the contribution of recollection to recognition, the present study directly targets the influence of distinct types of primes on recollection.

Priming a recollective experience, in contrast to recognition, poses particular challenges which likely have produced a barrier in exploring this issue. In the extreme, consider a free recall task, which is relatively more reliant on a recollection-based retrieval process than recognition testing (Mandler, 1980). While participants are generating items from the recall list, when and how should one present the prime items so that the search of memory is at a particularly sensitive point in time to be influenced by prime items? Obviously, it is difficult to know where in the time-course of retrieval the participant is during a free recall task, i.e., which items are near the threshold of retrieval during memory

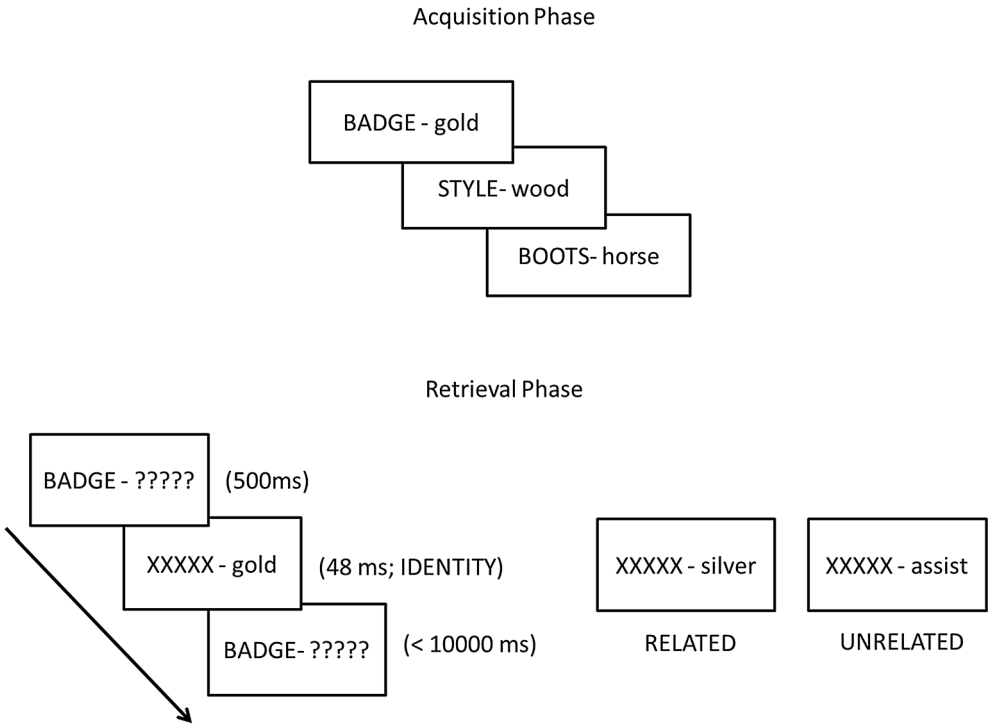

Fig. 1. Schematic of the general procedure.

search. Thus, instead of using a free recall paradigm, we developed a novel primed cued-recall task, which is displayed in Fig. 1. As shown, participants initially studied a list of paired associates. Later, participants were given a cue and a briefly flashed prime that was near the threshold of perception or in some experiments clearly supra-threshold for the target. For example, primes could be the correct paired associate, a related word to the correct paired associate or an unrelated word. If participants studied BADGE-gold, then during test they received BADGE-?????? for 500 ms to ensure that participants were engaged in the retrieval process. At that point, the word *gold* (identity prime), *silver* (related prime) or *assist* (unrelated prime) was briefly presented for 48 ms and pattern masked. It is important to note that, as shown in Fig. 1, there was also a flash of XXXXX for 48 ms embedded within the cue word (e.g., BADGE) at the same time the prime was embedded within the ??????, so that attention would not be exogenously captured by the flash to the prime location on the screen. In this way, one can examine if a briefly presented prime could push a memory representation over the Hoffding step during explicit memory retrieval. Although one might expect facilitation from the identity prime due to preactivation of the target response, the semantically related prime may produce facilitation or inhibition. That is, the prime might produce facilitation due to activation-based processes akin to those occurring in semantic priming in lexical decision or, as discussed later, possibly inhibition due to competition from the related prime and the correct response (e.g., Neely & Durgunoğlu, 1985).

An important additional aspect of the present study is that we included a delayed, unprimed test to examine the consequences of any immediate priming effects on the durability of the memory trace for that item across time. Because there is a strong relationship between successful retrieval at time 1 and successful retrieval at time 2 (e.g., see Roediger & Karpicke, 2006), one may expect any benefits at time 1 to persist in a delayed recall test. However, it is also possible that the any benefits of a prime at time 1 retrieval may not extend to a delayed recall test because such priming might bypass the retrieval demands at time 1. For example, Bjork's (1994) concept of desirable difficulty, as well as the memorial benefits associated with generation versus reading on long-term memory (e.g., Jacoby, 1978; Slamecka & Graf, 1978), suggest that effortful retrieval yields enhanced long-term memory relative to conditions that produce relatively easy retrieval. Thus, to the extent that priming requires active retrieval of a trace, any benefits observed on the initial primed test should also be observed on the delayed, unprimed test. In the current paradigm, the prime will *not* be the correct target on most trials (in most studies 75%); thus, the participant may be careful not to rely on the prime information, even when it may be supportive of the target. Hence, the participant may "check" the briefly presented prime against their memory for the correct answer before recalling it. One might expect this retrieval check to boost the connection between the cue and target, and thereby produce a benefit on a delayed memory test for those same items. In contrast, near-threshold priming might passively reduce the effort required to complete the retrieval process during the immediate memory test due to a boost in activation for the target. In this case, one might expect relatively more forgetting compared to conditions in which more effortful retrieval is required (i.e., in the unrelated/baseline conditions). In sum, the current experiments addressed the following questions: First, to what extent will near-threshold and/or supra-threshold primes push a memory representation over threshold for explicit output? Second, how does the influence of priming during an initial retrieval event influence the durability of that event as reflected in a delayed memory test?

Experiment 1

Although past studies have examined near threshold primes in episodic recognition, we are unaware of any studies that have observed such an effect in explicit retrieval from episodic memory. Because to our knowledge the paradigm explored here is novel, in the first experiment we investigated whether one could observe *any* explicit priming effects in an immediate cued recall test, before further exploring the nature of the effect.

Methods

Participants

Twenty-four Washington University in St. Louis undergraduates

participated in the current experiment for partial fulfillment of a course requirement or $5 remuneration.

Materials

Eighty low-associate word pairs were selected from the USF Free Association Norms (Nelson, McEvoy, & Schreiber, 1998). These pairs were divided into four sets of 20 pairs, such that the target words were rotated across prime conditions, and no word was repeated for a given individual. Stimuli were statistically equated for length, word frequency, orthographic neighborhood, and phonological neighborhood (Balota et al., 2007), *ps* > .10, and across lists the primes were equated on associative strength. Semantically related primes were selected to be moderately related to the targets (M = 63% response rate; Nelson, McEvoy, & Schreiber, 1998). Across lists, semantic primes were statistically equated on associative strength and the aforementioned lexical variables (*ps* > .35). Unrelated primes were the semantic primes from the unused stimulus set.

Design and procedure

There were three prime types during the cued-recall portion of this study (Identity, Semantic, Unrelated) which were randomly intermixed within participants. Participants first completed an acquisition phase in which word pairs (e.g., BADGE - gold) were presented randomly at a rate of one pair every 4.5 s. Following the acquisition phase, participants completed a cued recall test in which the cue and a series of question marks were presented for 500 ms (e.g., BADGE - ??????) before a row of Xs and the prime were presented for 48 ms (e.g., XXXXX – silver) in the same location. As noted, we presented the row of Xs simultaneously with the prime for 48 ms to ensure that there was a flash for both the cue item and the response location, so that attention was not disproportionately cued to the location of the prime stimulus, via a brief flicker. After 48 ms of the XXXXX-prime stimulus, the screen reverted back to the initial stimulus (e.g., BADGE - ??????) until the participant provided a response (up to 10 s). Thus, the prime was both forward and backward masked with a row of question marks to reduce the likelihood that it was explicitly used as a retrieval cue. Prime conditions appeared in a random order at test.

Results

Proportion of correct cued recall is displayed in Fig. 2. Performance was submitted to a within-participants Analysis of Variance (ANOVA) in which Prime Type served as the independent variable, with correct cued recall serving as the dependent variable. Results revealed a main effect of prime type, $F(2, 46) = 10.28$, $p < .001$, $\eta_p^2 = .31$. Follow-up comparisons revealed a significant benefit of identity priming over semantic and unrelated priming ($p = .002$ and $p = .003$, respectively). There was no difference between semantic and unrelated priming conditions ($p > .40$).

Discussion

The results from Experiment 1 are clear. The use of near-threshold identity priming (48 ms; see Jacoby & Whitehouse, 1989; Taylor & Henson, 2012) produced a significant, isolated effect on cued recall performance relative to near-threshold semantic and unrelated priming. These are the first results we are aware of that show a benefit of near-threshold priming in explicit episodic retrieval processes rather than familiarity-driven episodic recognition processes or lexical tasks, such as lexical decision or pronunciation.

Experiment 2

Although facilitation was observed immediately in Experiment 1, it is unclear whether this facilitation has any consequences for the durability of the memory trace in a delayed memory test that requires recollection. Moreover, an assessment of this effect on a delayed test will provide some leverage in examining whether or not the near-threshold prime reduces the effort required for successful retrieval. As discussed in the Introduction, because most primes are incorrect, participants may be careful not to simply rely on the prime information in generating their response. Hence, on trials in which the primes facilitate the retrieval process, participants may engage in a checking process to ensure that any increased fluency in generating the target is not due to the potentially incorrect prime information. This effort should increase the strength of the cue-response connection, and hence any benefit of identity priming should persist in a delayed recall task or possibly even increase. In contrast, if the near-threshold prime preactivates the representation for the target, making it more accessible for generation and decreasing retrieval effort, then the benefit for identity priming over the remaining conditions should be eliminated or even reversed on a delayed test.

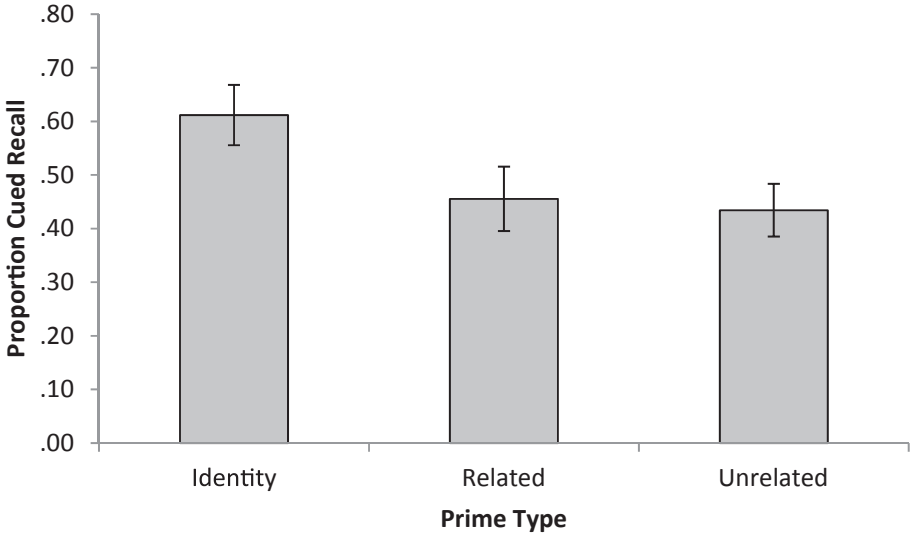

Fig. 2. Proportion correct cued recall as a function of prime type in Experiment 1. Error bars represent ± 1 S.E.M.

Methods

Participants

Twenty-four Washington University in St. Louis undergraduates participated in the current experiment for partial fulfillment of a course requirement or $10 remuneration.

Materials

The materials were the same as those used in Experiment 1.

Design and procedure

The design and procedure were identical to those used in Experiment 1 with one exception. Specifically, participants completed 25 min of filler tasks following the acquisition and primed cued recall phases before completing a delayed cued recall test. The delayed cued recall test differed from the immediate cued recall test in that all retrieval attempts were unprimed. This deviation in procedure allowed us to assess the extent to which the priming effect on the immediate test persisted across the retention interval.

Results

Cued recall

Proportion correct cued recall is displayed in Fig. 3. These data were submitted to a 2 (Retention Interval; RI) × 3 (Prime Condition) within-participants ANOVA. Results revealed main effects of RI, $F(1, 23) = 10.70$, $p = .003$, $\eta_p^2 = .32$, and prime condition, $F(2, 46) = 10.90$, $p < .001$, $\eta_p^2 = .32$. The RI × prime condition interaction was also significant, $F(2, 46) = 9.48$, $p < .001$, $\eta_p^2 = .29$, and is displayed in Fig. 3. Although follow-up analyses revealed a significant effect of prime type on each test ($ps < .005$), t tests revealed a significant decrease in performance across the retention interval in the identity, $t(23) = 3.59$, $p = .002$, and related prime conditions, $t(23) = 2.27$, $p = .033$. There was no effect of delay in the unrelated prime condition, $t(23) = .61$, $p > .50$. To confirm that the decrease in performance across the RI was larger for the identity condition than the related condition, a 2 × 2 ANOVA was conducted which revealed main effects of RI ($p = .001$) and condition ($p < .001$) as well as a significant interaction, $F(1, 23) = 8.78$, $p = .007$, $\eta_p^2 = .28$.

Conditional cued recall

The overall prime type by delay interaction is suggestive of greater forgetting in the identity priming condition compared to the unrelated condition. To further explore this issue, we conducted an item conditional recall analysis. Specifically, if the identity priming condition decreased effort initially, then those specific items that were relatively well-recalled initially (e.g., compared to an unrelated prime condition) should be relatively poorly recalled on a later cued recall test. However, it should also be noted that, assuming all other immediate delayed recall contingencies equal, because there is an effect of prime type on immediate recall, one should expect this pattern since one is dividing by a larger denominator in the identity prime condition compared to the unrelated prime condition. As expected, the results from an ANOVA on the proportion cued recall on the final test for items successfully retrieved on the initial test revealed a main effect of prime type, $F(2, 46) = 7.04$, $p = .002$, $\eta_p^2 = .23$, as is displayed in Fig. 4. Follow-up comparisons revealed significantly *lower* conditional cued recall performance in the identity prime condition relative to the related and unrelated prime conditions ($p = .023$ and $p = .002$, respectively). There was no significant difference in performance across related and unrelated prime conditions ($p = .280$).

Discussion

Results from the immediate, primed retrieval test in Experiment 2 replicated the results observed in Experiment 1. Specifically, briefly presented identity primes produced a benefit in cued recall performance over semantically related and unrelated primes. In contrast to lexical priming studies, there was no hint of an effect from semantically related primes, compared to unrelated primes in this study. The RI × Prime interaction reflected a reduction in the priming effect from the immediate test to the delayed test. Thus, based on these results, it appears there is more forgetting in the identity condition compared to the unrelated condition across the delay. In addition, the effect observed in conditional cued recall suggests that those very same items that benefited in the immediate retrieval from the identity primes were not remembered as well in the delayed cued-recall test, consistent with the notion that these items initially demanded less retrieval effort due to the presence of the identity prime.

Experiment 3

Although the prime duration was 48 ms in the first two experiments, with both a forward and backward mask, it is unclear how much conscious processing of the prime occurred in these experiments. Hence, in Experiment 3 we increased the prime duration (125 ms) to examine the

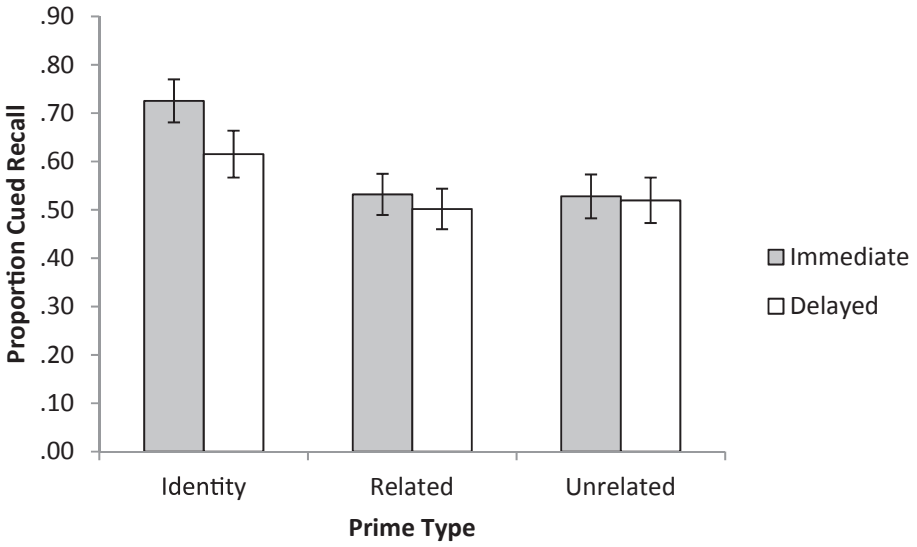

Fig. 3. Proportion correct cued recall on immediate and delayed tests as a function of prime type in Experiment 2. Error bars represent ± 1 S.E.M.

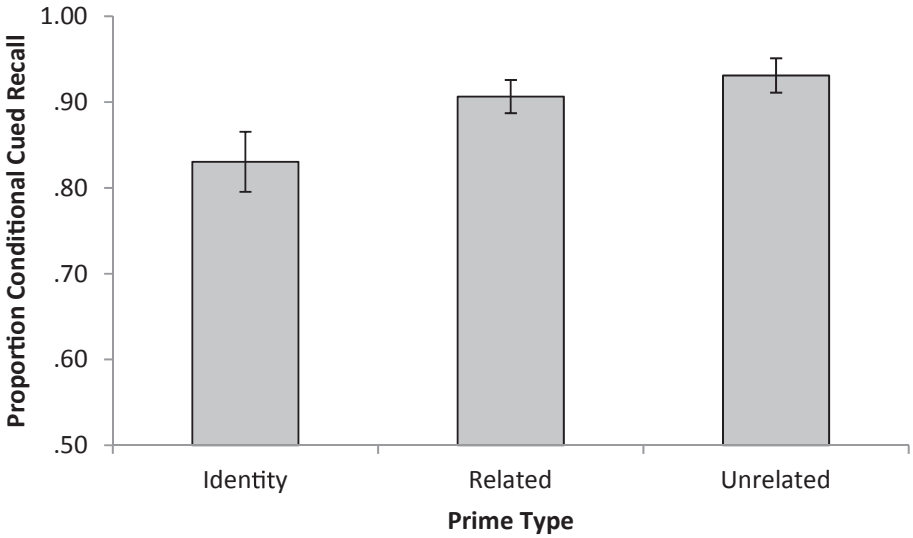

Fig. 4. Conditional cued recall performance in Experiment 2. Error bars represent ± 1 S.E.M.

influence of the current manipulations when the primes were presented sufficiently long such that participants should be likely to recognize most primes. In this way, we could examine if there were any differences when the primes are presented near threshold vs. clearly above threshold, as in Jacoby and Whitehouse's (1989) study. In addition to the longer prime duration, there were two additional modifications in Experiment 3 compared to Experiment 2. First, the retention interval was increased from 25 min to one day. Second, we included a neutral prime condition (XXXXX) to examine if the identity prime condition produced facilitation or if the non-identity primes (related and unrelated conditions) produced inhibition.

Methods

Participants

Thirty Washington University in St. Louis undergraduates participated in the current experiment for partial fulfillment of a course requirement or $10 remuneration.

Materials

Seventy-five of the pairs used in Experiments 1 and 2 were divided into five sets of 15 pairs. Stimuli were again statistically equated for length and word frequency (Balota et al., 2007), and across lists, pairs were equated on backward associative strength (Nelson, McEvoy, & Schreiber, 1998), *p*s > .10. In addition, semantic primes were statistically equated across lists on associative strength with the target and the aforementioned lexical variables (*p*s > .25). Unrelated primes were the semantic primes from the unused stimulus set.

Design and procedure

The design and procedure were the same as those used in Experiment 2 with the exceptions that primes were presented for 125 ms, an increased retention interval of 1 day, and the inclusion of the neutral prime condition.

Results

Cued recall

Proportion of correct cued recall is presented in Fig. 5. As shown, the pattern of priming effects at the longer duration now includes benefits from both the identity and semantic conditions, with the former producing the largest facilitation. Recall performance was submitted to a 2 (RI) × 4 (Prime Type) within-participants ANOVA. Results revealed main effects of RI, $F(1, 29) = 216.15$, $p < .001$, $\eta_p^2 = .88$, and prime type, $F(3, 87) = 19.28$, $p < .001$, $\eta_p^2 = .40$, that were further qualified by a significant RI × Prime Type interaction, $F(3, 87) = 48.07$, $p < .001$, $\eta_p^2 = .62$. Analysis of immediate test performance revealed a main effect of prime type on the immediate test, $F(3, 87) = 49.16$, $p < .001$, $\eta_p^2 = .63$. Follow-up comparisons revealed significant differences between all conditions (*p*s < .001) with the exception of the comparison between unrelated and neutral prime conditions ($p > .50$). The latter comparison suggests that the influences of the identity and related primes are facilitatory relative to the unrelated primes, as opposed to the unrelated primes producing inhibition, assuming the row of Xs is an appropriate baseline prime to measure facilitation and/or inhibition. In contrast, there was no effect of prime type on the delayed test, $F(3, 87) = .55$, $p > .64$, $\eta_p^2 = .02$.

Conditional cued recall

We again examined the item specific effects of prime condition on immediate and delayed recall, via a conditional analysis. The mean proportion of conditional cued recall is displayed in Fig. 6 as a function of prime type. Performance was submitted to a within-participants ANOVA with prime type serving as the independent variable. Results revealed a main effect of prime type, $F(3, 87) = 16.65$, $p < .001$, $\eta_p^2 = .37$. Follow-up comparisons revealed significantly lower performance in the identity condition compared to all other conditions (*p*s < .01). Additionally, performance in the related prime condition was significantly lower than performance in the unrelated and neutral priming conditions (*p*s < .05), while the latter two conditions did not reliably differ, $p = .06$. Hence, it appears that those items primed by identity and semantic primes initially do not survive across the delay as well as those items primed by an unrelated prime initially.

Discussion

Results from the current experiment, which utilized a supra-threshold prime duration, revealed a qualitatively different pattern of performance compared to Experiments 1 and 2, which used 48 ms duration primes. As expected, identity priming conferred the greatest benefit relative to all other prime conditions in immediate test performance, but the use of supra-threshold priming also yielded a benefit in immediate test performance for semantically related primes that was not observed with the use of near-threshold priming. Thus, as opposed to cue competition from the semantically related primes (e.g., Neely & Durgunoğlu, 1985), these primes actually produced facilitation,

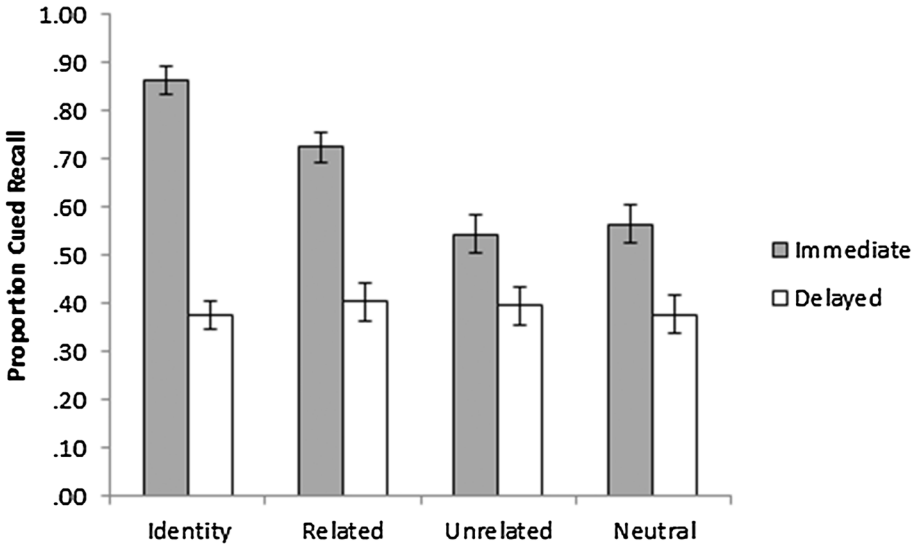

Fig. 5. Proportion correct cued recall on immediate and delayed tests as a function of prime type in Experiment 3. Error bars represent ± 1 S.E.M.

consistent with an activation-based mechanism. In addition, the benefits of these two prime types observed on immediate test performance were eliminated in the delayed test, reflecting the highly reliable delay × condition interaction. Hence, it appears there was more forgetting in the identity and semantic conditions compared to the unrelated and neutral conditions. This was also observed in the conditional recall measures. These results may reflect the consequences of reduced retrieval effort in the identity and semantic conditions to successfully complete the cued recall test, which in turn may contribute to reduced retention for these same items at the longer retention interval.

Experiment 4

The results from the first two experiments indicate that near threshold identity priming benefits cued recall performance. However, the nature of the benefit in the immediate condition is unclear. Specifically, it is possible that the benefit from identity prime condition in immediate recall may involve orthographic and/or phonological cues, as opposed to lexical cues. For example, if the target is gold in response to the cue BADGE, and a brief prime *gold* is presented, then it is possible that participants may perceive a few letters from the prime (e.g., go) and this orthographic information is used to facilitate the search of memory for the correct target *gold*. Indeed, there is a clear benefit of phonological onset primes in speeded naming (e.g., Kinoshita, 2000) and in lexical retrieval to low-frequency definitions (e.g., Kumar, Balota, Habbert, Scaltritti, & Maddox, in press; Meyer & Bock, 1992). Of course, this may not involve activation of the lexical/semantic representation for the word *gold*, but rather activation of prelexical letters that are consistent with that target. Hence, in Experiment 4, we included an orthographic/phonological prime condition, in which the word *gold* would be primed by *good*. If participants use partial letter information to facilitate recall, one would expect facilitation in this condition. On the other hand, if the prime produces activation for the correct lexical/semantic representation, then orthographic/phonological primes may not produce any facilitation.

A second goal of this experiment was to examine the extent to which one can increase the strategic reliance on the prime information. We accomplished this in two ways: First, we eliminated the row of XXXXX that occured simultaneously with the prime word. In this way, participants should be more likely to direct their attention to the brief flash at the ?????? location. In addition, we explicitly told participants that

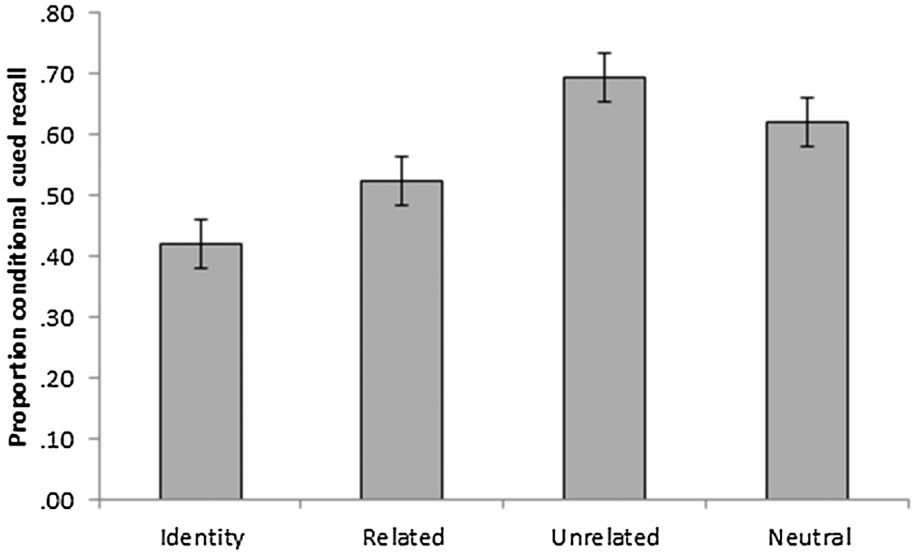

Fig. 6. Conditional cued recall performance in Experiment 3. Error bars represent ± 1 S.E.M.

there would sometimes be flashed words that may or may not help memory performance. We included these instructions to examine if participants use orthographic/phonological primes or semantic primes in a context that encourages participants to strategically use the prime information.

Methods

Participants

Thirty-two Washington University in St. Louis undergraduates participated in the current experiment for partial fulfillment of a course requirement.

Materials

Sixty of the word pairs used in Experiment 3 were used as stimuli in this experiment. Each item had four primes associated with it: identity, semantic, orthographic and unrelated. All orthographic primes overlapped with the target in both the onset and vowel positions, and the semantic primes were the same primes used in Experiment 3. The unrelated primes were chosen from among the semantic and orthographic primes and counterbalanced across eight separate lists. For each participant, each prime type (identity, semantic, orthographic, and unrelated) occurred for 15 pairs, and prime types for each target word were counterbalanced across the eight lists, such that the target words were rotated across prime conditions, and no word was repeated for a given individual.

Design and procedure

The design and procedure were the same as those used in Experiment 3 with the following exceptions: (a) the primes were presented for 48 ms; (b) the retention interval was increased to 2 days; (c) the neutral prime condition was replaced by the orthographic prime condition; (d) in contrast to all other experiments, the participants were instructed that words could be flashed during initial retrieval and that on some trials this could help memory performance; (e) when the prime was presented, the accompanying cue was not replaced by a row of Xs as before, but remained on the screen (e.g., CUE-prime) for 48 ms, after which the screen reverted back to CUE-??????, until the participant made a response. As noted earlier, we included these latter two manipulations to examine if participants could benefit from either the semantic or the partial prime information in the orthographic condition, under conditions which participants are explicitly encouraged to use the prime information.

Results

Cued recall

Proportion of correct cued recall is presented in Fig. 7 as a function of prime type and immediate and delayed test. As shown, it appears that only the identity condition is again producing facilitation in the immediate condition, with no difference among the semantically related, orthographically related or unrelated conditions. In contrast, in the delayed test, there appears to be slightly lower performance in the semantic condition compared to the remaining three conditions. Importantly, there does not appear to be any difference between the orthographically related and unrelated conditions in either the immediate or delayed tests. Cued recall was submitted to a 2 (RI) × 4 (Prime Type) within-participants ANOVA. Results revealed main effects of RI, $F(1, 31) = 166.00$, $p < .001$, $\eta_p^2 = 0.84$, and prime type, $F(3, 93) = 23.13$, $p < .001$, $\eta_p^2 = .43$, that were further qualified by a significant RI × Prime Type interaction, $F(3, 93) = 38.71$, $p < .001$, $\eta_p^2 = .56$. Analysis revealed a main effect of prime type on the immediate test, $F(3, 93) = 45.07$. $p < .001$, $\eta_p^2 = .59$. Follow-up comparisons revealed significant differences between the identity condition and all other all conditions ($ps < .001$). There were no significant differences among the remaining three conditions ($ps > .20$). There was a reliable effect of prime type also in the delayed test, $F(3, 93) = 2.94$, $p = .037$, $\eta_p^2 = .08$, which as shown reflected lower performance in the semantic condition.

Conditional cued recall

The mean proportion of conditional cued recall is displayed in Fig. 8 as a function of prime type. Conditional recall performance was submitted to a within-participants ANOVA with prime type serving as the independent variable. The results from the ANOVA produced a main effect of prime type, $F(3, 93) = 8.87$, $p < .001$, $\eta_p^2 = .22$. As shown in Fig. 8, the identity prime condition was lower than the orthographic, $t(31) = 5.09$, $p < .001$, semantic, $t(31) = 2.25$, $p = .030$, and unrelated conditions, $t(31) = 2.85$, $p = .007$. Performance in the orthographic condition was marginally better than the semantic condition, $t(31) = 1.88$, $p = .07$, and did not differ from the unrelated condition, $t(31) = 0.22$, $p = .83$. There was also no difference in performance between semantic and unrelated primes, $t(31) = 1.59$, $p = .12$.

Discussion

Experiment 4 addressed the question whether the identity priming effect observed in the previous experiments primarily reflects orthographic overlap with the prime and to-be-recalled word or activation of lexical/semantic information for the correct answer from the briefly presented prime. The results are quite clear: Under conditions which encouraged participants to use the prime information, there was only identity priming in immediate cued recall, which was not observed in the delayed recall task. It is also noteworthy that the priming effect for the identity condition was indeed larger than in the previous experiments, suggesting that the manipulations intended to increase use of the prime information were indeed successful. Importantly, even under these conditions, performance was similar with the use of orthographically related primes (e.g., good for gold), semantically related primes, and unrelated primes. The lack of an effect for the orthographically related prime is particularly intriguing because retrieving words to low-frequency word definitions and speeded word naming are both influenced by orthographic/phonological priming (e.g., Meyer & Bock, 1992). Again, this pattern indicates a clear difference between priming recollection in episodic memory compared to other standard priming paradigms. Importantly, these results suggest that the heretofore identity priming effects with briefly presented primes were not due to participants picking up partial letter level information to use as a cue for target retrieval.

Experiment 5

Results from Experiments 1, 2 and 4 suggest that near-threshold identity priming successfully benefits memory retrieval relative to semantically related, orthographically related, unrelated, and baseline priming conditions on an immediate cued recall test. Results also indicate that this benefit is lost in a later delayed, unprimed cued recall test (Experiments 2, 3 and 4). Moreover, comparing the results from Experiments 2 and 3 indicated that different patterns of priming were observed across conditions (i.e., reliable facilitation for semantically related priming) when prime presentation duration was supra-threshold (125 ms), compared to near-threshold (48 ms), which suggests that the nature of the priming effect appears to change as a function of prime processing.

In Experiment 5, we attempted to further examine the nature of the influence of the prime information. Specifically, it is possible that the priming effects observed in the previous experiments reflect a simple boost in familiarity for any target word that was presented during the initial study session (consistent with the earlier experiments that have investigated priming effects on episodic recognition, e.g., Jacoby & Whitehouse, 1989), and hence may not reflect an influence of the prime on the cued episodic retrieval process linking the cue word and the target. Thus, in Experiment 5, we compared intact priming (i.e.,

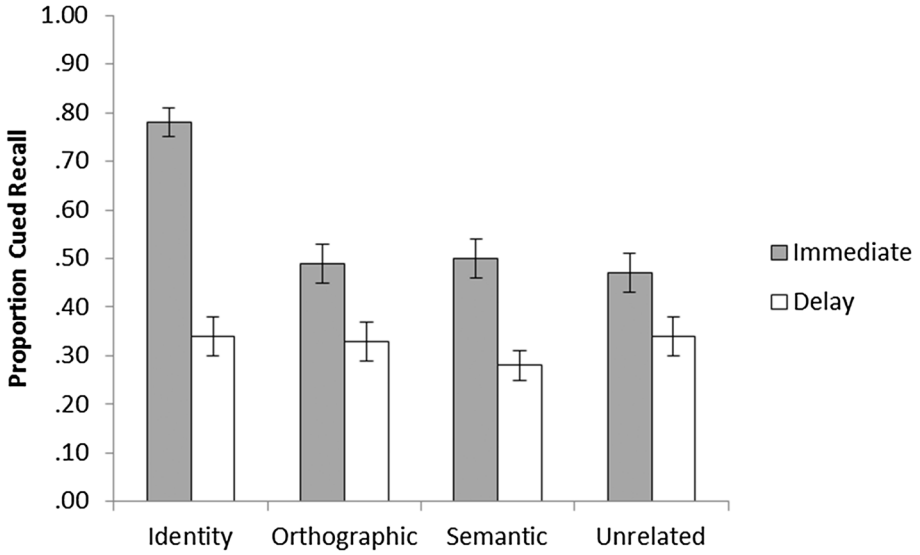

Fig. 7. Proportion correct cued recall on immediate and delayed tests as a function of prime type in Experiment 4. Error bars represent ± 1 S.E.M.

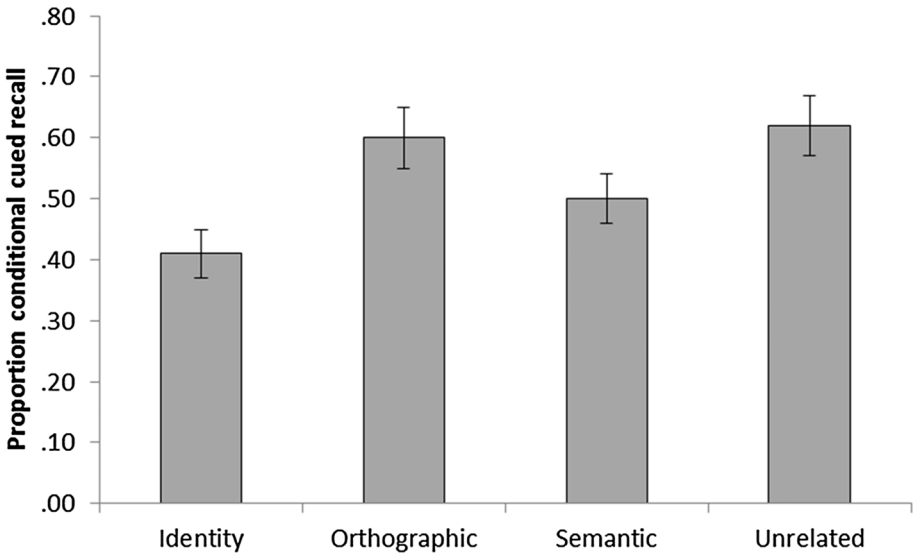

Fig. 8. Conditional cued recall performance in Experiment 4. Error bars represent ± 1 S.E.M.

identity priming) against a rearranged priming condition in which the cued retrieval event was primed with studied, but incorrect, targets. For example, if participants initially studied BADGE-gold and STYLE-wood, then during the cued recall test, BADGE-?????? would be primed with *wood* in the rearranged prime condition. If near-threshold priming influences familiarity-driven retrieval of a previously studied target (independent of its cue), then one should expect that the rearranged condition would lead to overall reduced performance and increased prime intrusions compared to baseline conditions. In contrast, if participants were not primarily relying on fluency of the prime and its match to a previously studied list item, then one might expect the rearranged condition to be similar to the unrelated condition, since the prime does not provide the specific target for a given cue.

Methods

Participants

Forty-five Washington University in St. Louis undergraduates participated in the current experiment for partial fulfillment of a course requirement or $10 remuneration.

Materials

Sixty-four paired associates (60 associates from the previous experiments and four new pairs) were divided into four stimulus sets that were rotated across four prime (identity, semantically related, rearranged, and unrelated) conditions.

Design and procedure

The design and procedure were the same as those used in Experiment 3 with two exceptions. The neutral baseline prime condition (XXXXX) was replaced with a rearranged prime condition in which previously studied targets were used to prime retrieval with the wrong cue. As noted, if participants studied BADGE-gold and STYLE-wood, then during the test phase BADGE-?????? would be primed with *gold* (intact prime), *wood* (rearranged prime), *silver* (related prime) or *assist* (unrelated prime). Participants were dismissed after finishing the immediate primed cued recall test and then completed a delayed test without priming following a 24 h retention interval.

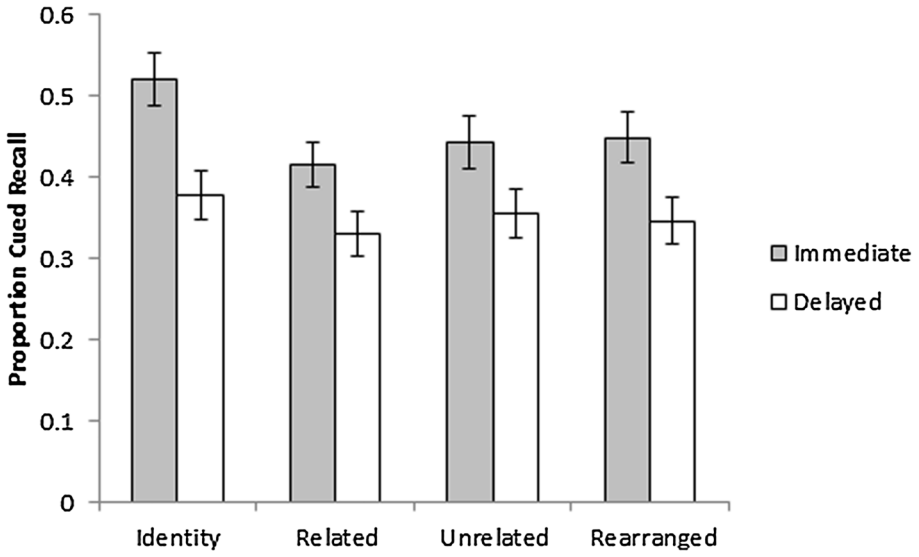

Fig. 9. Proportion correct cued recall on immediate and delayed tests as a function of prime type in Experiment 5. Error bars represent ± 1 S.E.M.

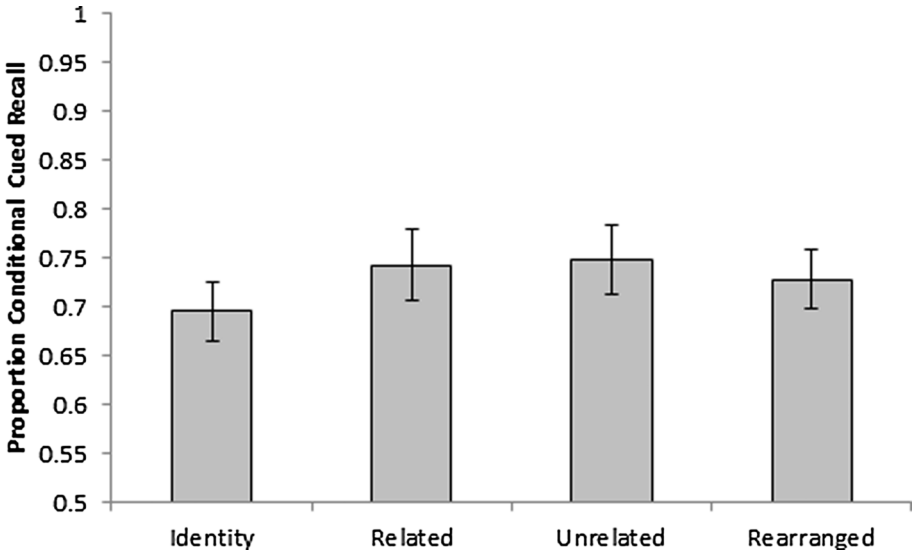

Fig. 10. Conditional cued recall performance in Experiment 5. Error bars represent ± 1 S.E.M.

Results

Cued recall

Proportion of correct cued recall is presented in Fig. 9. As shown, it appears that only the identity condition produced facilitation, with no difference between the unrelated and rearranged conditions. Cued recall was submitted to a 2 (RI) × 4 (Prime Type) within-participants ANOVA. Results revealed main effects of RI, $F(1, 44) = 72.86$, $p < .001$, $\eta_p^2 = .62$, and prime type, $F(3, 132) = 3.60$, $p = .02$, $\eta_p^2 = .08$, that were further qualified by a significant RI × Prime Type interaction, $F(3, 132) = 3.85$, $p = .01$, $\eta_p^2 = .08$. Analysis revealed a main effect of prime type on the immediate test, $F(3, 132) = 5.37$, $p = .002$, $\eta_p^2 = .11$. Follow-up comparisons revealed significant differences between the identity condition and all other all conditions ($ps < .03$). There were no significant differences among the remaining three conditions ($p > .13$). In contrast, there was no effect of prime type on the delayed test, $F(3, 132) = 1.41$, $p = .24$, $\eta_p^2 = .03$.

Conditional cued recall

The mean proportion of conditional cued recall is displayed in Fig. 10 as a function of prime type. Conditional recall performance[1] was submitted to a within-participants ANOVA with prime type serving as the independent variable. Although the identity condition produced slightly lower performance, as found in the previous studies, the results from the ANOVA failed to reveal a main effect of prime type, $F(3, 123) = 0.53$, $p = .66$, $\eta_p^2 = .01$.

Discussion

The use of intact and rearranged primes provided a comparison in which prime accessibility was comparable given that primes in both conditions had been studied as target items during the acquisition phase. Nonetheless, results revealed an isolated benefit in memory on the immediate test for intact (i.e., identity) priming relative to all other

[1] Three participants were excluded from the analysis of conditional cued recall due to missing data in at least one condition. This also occurred for two participants in the analysis of conditional cued recall in Experiment 7. The results did not change in either experiment when the missing data points were imputed.

priming conditions, and notably, performance in the rearranged condition was numerically equivalent to the related and unrelated conditions. Although evidence of equal performance suggests accessibility did not drive performance in the current paradigm, it is also important to note that prime intrusion rates on the immediate recall test were quite low and failed to reveal any significant differences across rearranged (M = .01), related (M = .04), and unrelated prime conditions (M = .01; p = .157). Thus, it does not appear that participants were simply outputting targets that were reactivated by the near threshold primes during the immediate memory test. If this were the case, one would have expected an increased intrusion rate in the rearranged condition. Indeed, the observed pattern of recall intrusions diverges from the pattern of false alarms reported by Jacoby and Whitehouse (1989) in which misattributed familiarity was assumed to drive recognition performance. Of course, this is precisely what one would predict if participants were relying on the episodic link between the cue and the target demanded by the cued-recall task, instead of simple increased familiarity produced by the prime.

Experiment 6

Although there was a reliable prime type by delay interaction suggesting that there was more forgetting in the identity condition across delays than the remaining conditions, this pattern did not translate into a reliable item level effect as reflected by the conditional memory performance measure, although the means were in the predicted direction. This conditional effect was reliably observed in the delayed recall of Experiments 2, 3, and 4. It is possible that the presence of the rearranged prime condition reduced the reliance on prime familiarity information, thereby attenuating the effect on immediate and delayed recall. In Experiment 6, following Experiment 3, we increased the duration of the prime to 125 ms. This manipulation provided a replication of Jacoby and Whitehouse's (1989) procedure as a means to examine the influence of prime conditions when participants are more likely to fully process the primes compared to the briefly presented primes in Experiment 5.

Methods

Participants[2]

Twenty Washington University in St. Louis undergraduates participated in the current experiment for partial fulfillment of a course requirement or $10 remuneration.

Materials

The materials were the same as those used in Experiment 5.

Design and procedure

The design and procedure were the same as those used in Experiment 5 with the exception that primes were presented for 125 ms and the retention interval for the delayed test was increased to 48 h.

[2] Sample size differed somewhat across experiments. This was due to factors including: the specific design and number of conditions, the nature of the hypotheses being tested, i.e., exploratory vs confirmatory, and window used to complete a study during a specific time of year, i.e., during the summer vs during the semester. For example, a smaller sample in Experiment 6 was deemed adequate because the effect size observed in Experiment 3 was larger with the use of the supra-threshold prime duration (125 ms) compared to the effect size observed in Experiment 2 (48 ms prime durations). In contrast, Experiment 5 included a large number of subjects, because a novel hypothesis was being tested (the rearranged condition) and we wanted to ensure that any lack of difference between the rearranged condition and the unrelated condition was not due to lack of power.

Results

Cued recall

Proportion of correct cued recall is presented in Fig. 11. As shown, immediate test performance benefited from both identity and semantically related primes which produced facilitation relative to the rearranged and unrelated conditions, which did not differ. Cued recall performance was submitted to a 2 (RI) × 4 (Prime Type) within-participants ANOVA. Results revealed main effects of RI, $F(1, 19) = 106.88$, $p < .001$, $\eta_p^2 = .85$, and prime type, $F(3, 57) = 11.85$, $p < .001$, $\eta_p^2 = .38$, that were further qualified by a significant RI × Prime Type interaction, $F(3, 57) = 33.46$, $p < .001$, $\eta_p^2 = .64$. Analysis revealed a main effect of prime type on the immediate test, $F(3, 57) = 25.17$, $p < .001$, $\eta_p^2 = .57$. Follow-up comparisons revealed significant differences between all conditions ($ps < .05$) with the exception of the comparison between unrelated and rearranged prime conditions ($p > .50$). Hence, with a 125 ms prime duration, there was reliable semantic facilitation, albeit smaller than in the identity condition. In contrast, there was no main effect of prime type on the delayed test, $F(3, 57) = 0.47$, $p = .70$, $\eta_p^2 = .02$.

Conditional cued recall

The mean proportion of conditional cued recall is displayed in Fig. 12 as a function of prime type. Performance was submitted to a within-participants ANOVA with prime type serving as the independent variable. Results revealed a main effect of prime type, $F(3, 57) = 7.14$, $p < .001$, $\eta_p^2 = .27$. Follow-up comparisons revealed significantly lower performance in the identity condition compared to all other conditions ($ps < .04$). Additionally, performance in the related prime condition was significantly lower than performance in the rearranged priming condition ($p = .03$). Hence, at the longer 125 ms duration, there appears to be more forgetting in the identity condition than in the unrelated condition.

Discussion

Similar to Experiment 3, utilizing a supra-threshold prime duration yielded benefits of intact (i.e., identity) and related priming over unrelated priming. Interestingly, there was again no influence of the rearranged condition, compared to the unrelated condition, either in the immediate or the delayed recall condition, suggesting that simple familiarity of the prime with the previous study list does not modulate performance. Moreover, conditional cued recall performance revealed differential forgetting across prime types such that intact and related priming led to greater forgetting than rearranged and unrelated priming conditions.

Experiment 7

The present series of experiments has consistently indicated that the influence of the identity prime condition (and the semantic prime at the longer durations) is lost in the delayed conditions, and indeed it appears there is greater forgetting across the delay in the identity prime condition compared to the remaining conditions. We have argued that the relationship between immediate and delayed recall may be due to greater forgetting in the identity condition because the retrieval demands decrease initially in the identity prime condition. However, an alternative interpretation[3] is based on the Transfer Appropriate Processing framework (TAP, Morris, Bransford, & Franks, 1977), which suggests that the overlap between the processes engaged during encoding and retrieval is the critical variable that modulates final cued recall performance. According to TAP, it is possible that the reason there appears to be more loss of information in the identity prime

[3] We thank Michael Masson for suggesting the TAP experiment.

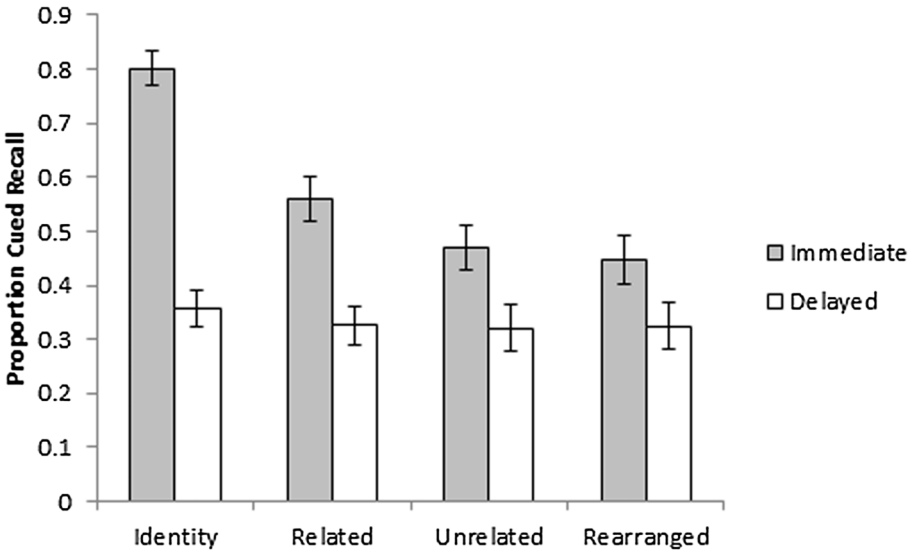

Fig. 11. Proportion correct cued recall on immediate and delayed tests as a function of prime type in Experiment 6. Error bars represent ± 1 S.E.M.

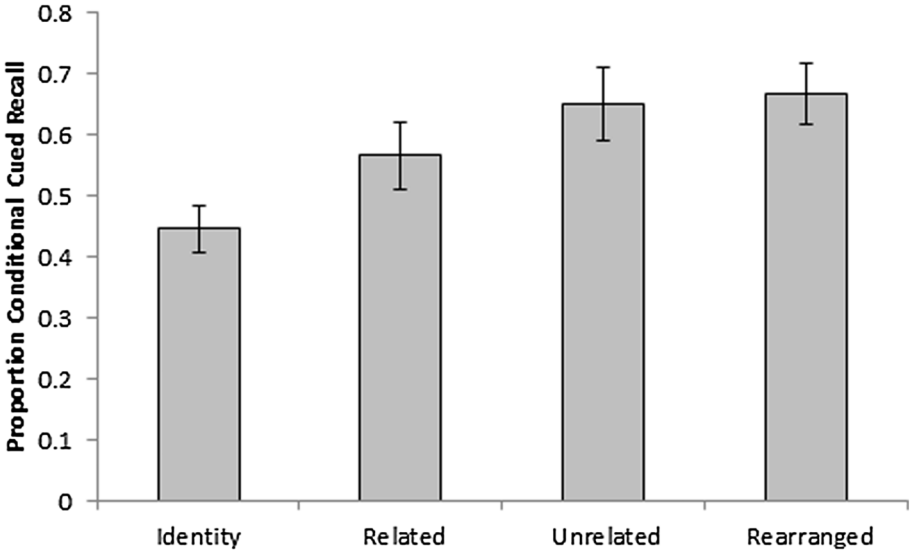

Fig. 12. Conditional cued recall performance in Experiment 6. Error bars represent ± 1 S.E.M.

condition across the delay is due to the fact that there is a change in context between the initial test and the delayed test, i.e., the previously useful identity prime is no longer available. Hence, in the following experiment, we tested this possibility in the following manner. Specifically, as in our earlier experiments, we included three prime types (Identity, Related, and Unrelated) in the initial test with a long 125 ms prime duration. We chose the 125 ms duration to maximize the influence of context and hence increase the influence of TAP. The major difference in this experiment is that we now present two different types of primes during retrieval in the delayed test. These primes were presented briefly for 48 ms. Half of the primes in the delayed test within each condition were identity primes and half were new unrelated primes. In this case, only the identity prime condition will afford a match between encoding and retrieval conditions, and hence this condition (identity primes at immediate test and identity primes at delayed test) should produce the highest delayed recall performance according to TAP. In contrast, if the identity prime condition during the initial test lessens the demands on retrieval, and this leads to a less persistent trace, then one might again expect an influence of prime condition immediately and no influence of the match in identity primes between the immediate and delayed test conditions on performance in the delayed test.

Methods

Participants

Thirty-six Washington University in St. Louis undergraduates participated in the current experiment for partial fulfillment of a course requirement. There was a cluster of 8 individuals, who were eliminated due to a high intrusion rate (> 40%) in the delayed recall condition, which likely reflected attempts to identify the prime instead of retrieving the target from episodic memory, so the final sample included 28 participants. The results from the analyses below do not change when all 36 participants were analyzed.

Materials

The materials used for the acquisition phase and immediate cued recall test were the same as those used in Experiments 1 and 2. Four additional sets of primes equated for length and word frequency were selected from the English Lexicon Project (Balota et al., 2007) for the

unrelated condition in the delayed cued recall test.

Design and procedure

The design and procedure were similar to those used in Experiment 3 with several notable exceptions including the use of within-trial priming on both the immediate and delayed tests. The overall design for Experiment 7 was a 2 (RI: Immediate vs. 48 h Delay) × 3 (Immediate Test Prime condition: Identity, Related, Unrelated) × 2 (Delayed Test Prime Condition: Identity, Unrelated) within-subjects factorial design. Similar to the previous experiments, primes on the immediate test were equally split across identity, related, and unrelated conditions but were presented for 125 ms. Within-trial priming on the delayed test was manipulated such that half of the items in each Immediate Test Prime condition were primed with an identity prime and half of the items were primed with an unrelated prime that was not previously studied or utilized as a prime in the immediate cued recall test. For example, 10 of the 20 target items originally assigned to the related prime condition on the immediate test were primed with identity primes on the delayed test and the remaining 10 items were primed with a new unrelated prime on the delayed test. This same procedure at retrieval for the delayed test was used for the identity and unrelated prime conditions. Primes on the delayed cued recall test were presented for 48 ms.

Results

Cued recall

Proportion of correct cued recall is presented in Fig. 13. For illustrative purposes, we collapsed across Identity and New primes in the immediate condition, since this only reflected a difference between items that would later receive Identity versus New primes in the delayed test and, as expected, there was no difference in performance between these items in the immdediate test (*ts* < 1.0). As shown, immediate test performance benefited from both identity and semantically related primes which produced facilitation relative to the unrelated condition. There was also a clear benefit of identity versus unrelated primes that were presented during the delayed test. Most importantly, however, as shown in the delayed performance, there was very little benefit of a match between encoding and retrieval in the Identity Prime condition, compared to the related and unrelated prime conditions.

Cued recall performance was submitted to a 2 (RI) × 3 (Immediate Test Prime) × 2 (Delayed Test Prime) within-participants ANOVA. Results revealed main effects of immediate test prime type, $F(2, 54) = 13.78$, $p < .001$, $\eta_p^2 = .34$, delayed test prime type, $F(1, 27) = 64.02$, $p < .001$, $\eta_p^2 = .70$, and RI, $F(1, 27) = 14.01$, $p < .001$, $\eta_p^2 = .34$. These main effects were further qualified by significant interactions between immediate test prime type and RI, $F(2, 54) = 20.66$, $p < .001$, $\eta_p^2 = .43$, which reflected the larger effect of immediate prime type (i.e., Identity, Related, and Unrelated) on immediate recall performance than on delayed performance. In addition there was a reliable interaction between delayed prime type and RI, $F(1, 27) = 117.13$, $p < .001$, $\eta_p^2 = .81$, which indicated that there was a large effect of identity primes compared to unrelated primes during retrieval on the delayed test but no difference between conditions on the immediate test, since this was just a difference in items that would later appear be in either the immediate or delayed test.

To more specifically test predictions based on the TAP account, performance for only the items in the identity priming condition on the delayed test was submitted to a 2 (RI) × 3 (Immediate Test Prime Type) within-participants ANOVA. The RI × Prime Type interaction remained highly significant, $F(2, 54) = 10.33$, $p < .001$, $\eta_p^2 = .28$. Follow-up comparisons revealed significant differences in immediate test performance between identity priming and the related and unrelated prime conditions (*ps* < .001) and a marginal difference between unrelated and related prime conditions ($p = .094$). In contrast, there were no differences in delayed test performance as a function of immediate test prime type (*ps* > .19). Thus, the match between encoding and retrieval during the delayed recall test did not confer any additional benefit compared to the remaining related and unrelated prime conditions in overall delayed recall performance.

Conditional recall performance

The mean proportion of conditional cued recall is displayed in Fig. 14 as a function of prime type. Performance was submitted to a within-participants 3 (Immediate Test Prime) × 2 (Delayed Test Prime) ANOVA. Results revealed main effects of immediate prime type, $F(2, 50) = 6.11$, $p = .004$, $\eta_p^2 = .02$, and delayed prime type, $F(1, 25) = 60.48$, $p < .001$, $\eta_p^2 = .71$, as well as a reliable immediate prime type by delayed prime type interaction, $F(2, 50) = 3.99$, $p = .025$, $\eta_p^2 = .14$. As shown, when the unrelated prime was presented during the delayed recall test, this produced the same pattern we observed in the previous experiments indicating a systematic increase in performance across the immediate identity, related, and unrelated conditions. In contrast, when the identity prime condition was presented during retrieval, there was no difference across conditions. Thus, providing a match between the identity prime at encoding and the identity prime during retrieval eliminated any difference in conditional recall performance.

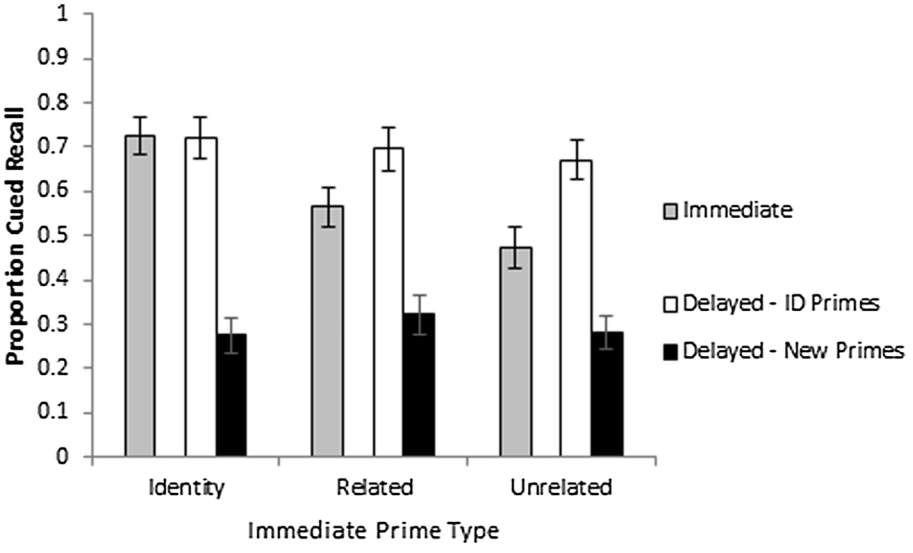

Fig. 13. Proportion correct cued recall on the immediate test as a function of prime type (note immediate performance is collapsed across prime type in the delayed test, since this reflected which items were later assigned to the delayed test, which did not produce any differences, all *ts* < 1.0) and proportion correct cued recall on the delayed test as a function of both immediate prime type and delayed prime type condition in Experiment 7. Error bars represent ± 1 S.E.M.

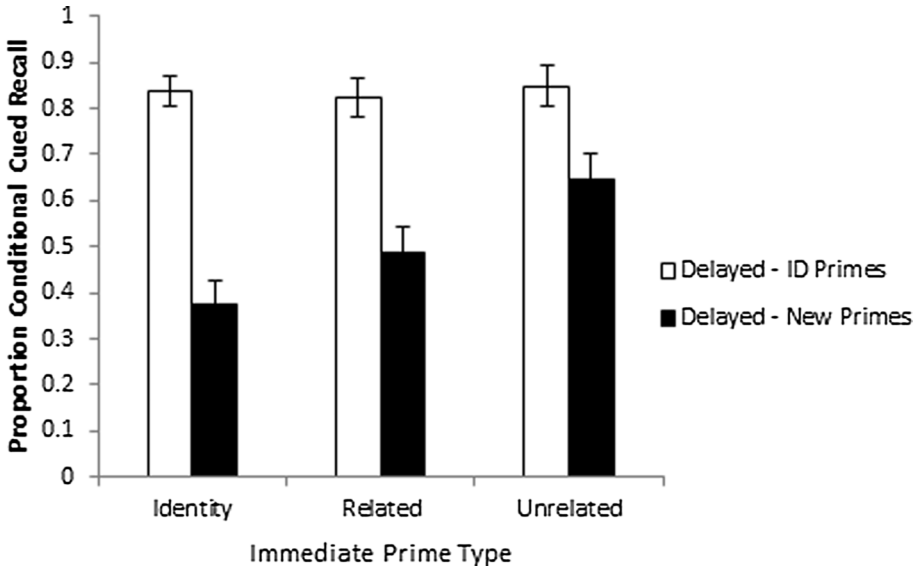

Fig. 14. Conditional cued recall performance in Experiment 7. Error bars represent ± 1 S.E.M.

Discussion

The results from Experiment 7 are quite clear. According to the TAP framework, we expected that delayed recall would be higher in the identity prime condition when there was a match during encoding and retrieval contexts, but this was clearly not found in the correct delayed recall or in the conditional analyses. However, it is also important to note that in contrast to the unrelated primes during delayed recall, the conditional cued recall performance was comparable across immediate prime conditions when delayed retrieval was primed with identity primes. This pattern suggests that the match between encoding and retrieval contexts does appear to modulate the difference in forgetting found in the conditional recall. Hence, although TAP does appear to contribute to the delayed recall effects, because there was no clear *benefit* of a match between encoding and retrieval primes, this cannot accommodate all of the findings from the present experiment.[4]

One intriguing aspect of these results is the strong effect of identity primes during the delayed test compared to the unrelated primes, see Fig. 13 delayed recall performance. We believe this may have occurred due to participants increasing their reliance on the prime information in the delayed recall condition, since during the earlier immediate recall phase they received primes that were clearly visible for 125 ms. Hence, they likely directed their attention to using the primes to help retrieval during the delayed recall test. This is reminiscent of the large benefits of identity primes observed in Experiment 4 when participants were directly instructed that there would be briefly presented 48 ms primes that may or may not help recall. Of course, it is also possible that the benefits of an identity retrieval cue after a long delay are larger due to more items being at a sensitive range of difficulty in the delayed recall condition. The relatively large benefit of masked identity primes during delayed recall deserves further research.

General discussion

The present study examined the influence of near-threshold primes on cued recall performance as a means for assessing whether such a procedure could influence recollection-driven retrieval in a paired associate recall task. We believe that the present novel design provides an important extension to past research, which revealed an influence of near-threshold priming on familiarity-driven episodic recognition performance. In addition, the current study assessed the extent to which any benefit of near-threshold priming observed on an immediate test would persist across a retention interval, as reflected in a delayed recall test. There are four main findings with respect to these issues, which will be discussed before turning to the theoretical implications.

Near-threshold priming influences cued recall performance

Results from all experiments utilizing a 48 ms prime duration revealed an isolated benefit of identity priming on the immediate test. In contrast, an examination of brief but supra-threshold priming (Experiments 3, 6, and 7) also revealed facilitation from a semantically related prime in addition to the benefit of identity priming. Given the distinct patterns of priming in the near (48 ms) and supra-threshold conditions (125 ms)[5], and the total lack of priming from an orthographic/phonological related prime (Experiment 4), these results support the contention that the priming effect observed in the identity priming condition with the 48 ms prime during immediate recall was not simply due to the strategic use of the prime.

It is important to emphasize that although we used presentation

[4] It is possible that the reason one might not find a benefit of the match between Identity primes at encoding and retrieval, compared to unrelated primes at encoding and identity primes at retrieval is because there is a potential ceiling effect. In order to address this possibility, we conducted a median split based on overall performance in the delayed recall condition. The pattern of results was identical for both high performers and low performers, suggesting that our failure to detect a difference was not limited by scaling issues.

[5] Of course, the presence of the semantic priming effect at the longer duration may not reflect an isolated "semantic" effect but may reflect the fact that (a) all priming effects are smaller at the 48 ms than the 125 ms duration, and (b) the semantic effects are in general weaker than identity priming effects, and so can only be detected at the 125 ms duration. In order to statistically examine this, we compared the identity (unrelated minus identity) and semantic (unrelated minus semantically related) priming effects in the experiments that utilized a 48 ms prime duration (Experiments 2 and 5) and those that used the 125 ms prime duration (Experiments 3, 6 and 7). The results of a 2 (Prime Duration) × 2 (Identity vs Semantically Related Priming Effect) yielded a larger priming effect at the longer prime duration than the shorter prime duration ($p < .001$) and a larger identity priming effect than a semantic priming effect ($p < .001$), but the interaction did not approach significance ($p > .20$). Hence, both identity and semantic priming effects increase about the same amount at the long durations, compared to the short prime durations. Thus, it is possible that the lack of semantic priming at the short duration is that this duration is not sufficient to detect a weaker prime-target relationship.

durations that are consistent with past literature on masked priming (e.g., Jacoby & Whitehouse, 1989; Kinoshita & Lupker, 2004), we are not suggesting that the primes in the current study were presented below conscious awareness. Instead, we are suggesting that the 48 ms duration minimizes conscious utilization of the prime to influence retrieval of the paired associate response. Determining an absolute threshold of perception in such studies has been rife with both methodological and theoretical concerns (see Holender, 1986; Joordens & Merikle, 1992; Morey, Rouder, & Speckman, 2008). We believe that the critical issue in the present experiments is that participants' attention was directed towards producing the response item to the current cue, instead of strategically directing attention to identify the briefly presented and patterned masked prime. The latter would be counterproductive since the answer would only be correct 25% of the time in most of the present studies. Moreover, we believe that during the first 500 ms, spatial attention would likely be directed towards reading the supra-threshold cue (e.g., BADGE) and beginning the memory search instead of the ?????? marks. It is also worth reminding the reader that there was a flash in both the cue stimulus (XXXXX) and the question marks to decrease the likelihood that participants were directing attention away from the cue to the ?????? marks due to an unexpected flash at that location. There are two exceptions to this method. First, in Experiment 4 participants were explicitly encouraged to use the briefly presented prime information. Indeed, this experiment increased the size of the identity priming effect to similar levels of the 125 ms durations. Importantly, the results of this experiment also indicated that there was no evidence of semantic priming (but see Footnote 4) or any evidence that participants were using partial information from the orthographic prime to help identify the target. Second, in Experiment 7 participants also produced relatively large benefits from a 48 ms identity prime during delayed recall, after they were exposed to 125 ms primes during immediate recall. We have suggested that participants in Experiment 7 may have attended more to the prime information during retrieval in delayed recall because they were presented clearly supraliminal primes during immediate recall. Thus, we argue that unless participants are encouraged to use the prime information, the identity priming effects in the near threshold conditions of 48 ms were most likely due to automatic increased activation of the response item to the specific paired-associate cue.

Semantic relatedness benefits retrieval in supra-threshold conditions

The facilitatory effects of semantically related primes at the 125 ms duration are noteworthy in light of a previous literature attempting to dissociate semantic from episodic priming effects (e.g., Carroll & Kirsner, 1982; McKoon & Ratcliff, 1979; Neely & Durgunoğlu, 1985). In the most relevant conditions of these earlier studies, participants initially studied unrelated paired-associates, and then were later tested on a speeded yes/no recognition test. During the episodic recognition test, "primes" could be semantically related to the target but not studied (extralist semantic primes), as in the present study. Compared to an unrelated condition, the results from this extralist semantic condition ranged from inhibition (Ratcliff & McKoon, 1982) to facilitation (Carroll & Kirsner, 1982) to no effect (Neely & Durgunoğlu, 1985). Inhibition from a semantically related condition was accommodated by the possibility of cue competition. Although there are a number of differences between these studies and the present work (e.g., including longer prime durations, making decisions on both the primes and targets, and speeded episodic recognition as the criterion task), it is noteworthy that the present results consistently yielded facilitation of the semantically related prime at the short (125 ms), but clearly supra-threshold duration (including forward and backward masks). This pattern supports the contention that the present cued-recall performance likely reflected a more automatic activation-based mechanism supporting retrieval of the target (see further discussion below), as opposed to competition from the semantically related prime and the correct response during retrieval. It is of course possible that at longer prime durations (e.g., 1000 ms) one may find inhibitory competition from semantically related primes.

Masked identity priming influences recollection-driven retrieval

We now consider the extent to which the present paradigm influences recollection-driven rather than familiarity-driven retrieval. Notably, the current study utilized a cued recall test rather than a recognition test that has been used in past studies of near-threshold priming (Jacoby & Whitehouse, 1989; Taylor & Henson, 2012), and clearly the benefit of identity priming was reliably observed across experiments with the use of this more effortful, recollection-driven retrieval test. Importantly, the influence of the prime on more recollection-driven than familiarity-driven processes was further substantiated by the results of Experiments 5 and 6, which compared intact versus rearranged priming. The pattern of false alarms in recognition testing reported by Jacoby and Whitehouse (1989) suggests that familiarity-driven responding in the current cued recall paradigm should have produced significantly lower performance in the rearranged condition than in the related and unrelated conditions due to increased prime intrusions. However, this pattern was not observed in the present experiments. Instead, there was no difference in intrusion rates in the related, unrelated and rearranged conditions. The rearranged condition is particularly informative because the results are inconsistent with a simple increase in accessibility from the earlier study episode, since the rearranged paired associates included targets that were studied earlier, just like the identity primes. Hence, we believe that the present identity priming effects were due to increased accessibility of the target during search of the response to the specific paired-associate cue.

The long-term consequences of the immediate benefits of identity priming

An additional goal of the present experiments was to examine the long-term consequences for those items that initially benefited from prime information. Each experiment produced evidence of a prime condition by retention interval interaction, such that any benefits of a given prime condition on the initial test were lost in the delayed test. As expected, based on this interaction, analyses of conditional cued recall revealed that overall performance was lower in delayed recall for the same items that initially benefited from specific prime conditions (e.g., the identity condition in Experiments 2, 3, 4, 6, and 7, and the related condition in Experiments 3, 6 and 7). The only exception to this pattern was the result from Experiment 5, in which the conditional recall performance did not produce a reliable effect. However, it is noteworthy that the means were indeed in the predicted direction, and so one should be cautious in accepting the null hypothesis from this experiment, given the results from the remaining experiments. It is also interesting to note that the results from the longer 125 ms durations used in Experiments 3, 6 and 7 indicated that not only did the identity prime condition produce lower conditional performance but also the semantically related condition produced lower performance than the unrelated conditions in the delayed recall condition. Clearly, the act of retrieving items in the identity priming condition was not sufficient to yield a sustained long-term benefit of equal magnitude.

Implications for models of retrieval and paired associate recall

In contrast to models of recognition-based retrieval which often incorporate a global matching process (i.e., the test probe is compared in parallel against all items stored in memory), models of cued recall typically posit a generation or specification process to initiate the search of memory for the target item. Although models of cued recall differ in the extent to which the retrieval process following the initial generation of a target candidate is serial and iterative (e.g., Diller, Nobel, & Shiffrin, 2001; Nobel & Shiffrin, 2001) or parallel (e.g., CHARM; Metcalfe Eich, 1982), these distinctions are not of critical

importance for the current discussion, and our data clearly do not adjudicate amongst these accounts. Rather it is important to consider how the initial target candidate is generated and how near-threshold priming may influence the generation process.

Consider the ARC-REM model of cued recall (Diller et al., 2001; Nobel & Shiffrin, 2001) which represents each studied word as an episodic vector of 20 feature values copied with varying degrees of success from the corresponding semantic vector representing the word. For paired associate memory, it is assumed that associative encoding will yield a concatenated vector of 40 features in which the two words will be stored. The associative link between the cue and response word is stored within the vector by tagging a subset of the 40 features as "associative" (Shiffrin & Steyvers, 1997; pg. 160). At the start of the retrieval process, a threshold is established for sampling a set of information from long term memory, called an *image* (Raaijmakers & Shiffrin, 1981), such that a sufficient number of features comprising the 20-feature vector of the retrieval cue must overlap with the 40-feature vector of the encoded paired-associate image. The sampling process yields an image with incomplete information (i.e., a subset of the 40 features is generated), from which the individual must decide to reject or accept the image. If the image is rejected, the individual may resample or give up the search process. If the image is accepted, the individual will attempt to reconstruct the remainder of the image through a recovery process which results in output of the item or a failed retrieval attempt based on the number of features that were or were not recovered. The success of the sampling and recovery processes depends on the strength of the association between the cue and the target item established during encoding and the use of vector features that were marked as associative during the encoding process.

In the context of the ARC-REM model of cued recall, consider how near-threshold priming might influence the sampling and recovery stages of retrieval. With regard to the sampling process, the retrieval cue and any episodic context cues will provide equal support of sampling across prime conditions; moreover, it is assumed that associative features do not play a role in the sampling process (Shiffrin & Steyvers, 1997). Thus, one would assume that the prime should have its influence on recovery of features for the target image. Data from the current set of experiments suggests that near-threshold priming may have two effects on the recovery process. First, near-threshold priming may increase the number of successfully retrieved features that are associated with the target item. In turn, one may expect that an increase in recovered features of the target item would yield high levels of prime intrusion rates across experiments. This pattern would be exaggerated in the rearranged prime condition included in Experiments 5 and 6. However, this pattern was not observed. Instead, cued recall rates were similar across rearranged and unrelated prime conditions. The second effect near-threshold priming may have on the recovery process is to facilitate recovery of the "associative" features tagged during the acquisition phase and later used to facilitate retrieval. Indeed, this account can accommodate the consistently low intrusion rates as well as the pattern of cued recall observed in our comparison of intact versus rearranged priming. Of course, this is not to deny the possibility that near-threshold priming exerts some influence on recovery of non-associated target features also; however, it appears that recovery of target features must be accompanied by priming the recovery of associatively marked features to accommodate the current results.

Although this model is useful in accounting for the influence of the primes on immediate retrieval, it is unclear how such a framework would accommodate the reduced magnitude of this effect on conditional recall performance in the delayed condition. Hence, we now turn to a few alternative accounts of the influence of immediate prime condition on delayed recall.

The consequences of immediate priming on the delayed memory test

The results from the delayed recall performance consistently yielded little effect of the immediate prime condition on overall delayed recall performance. Given there is a consistent benefit of the identity prime on immediate recall (and the semantic prime at the 125 ms duration) it appears that there is greater forgetting for these conditions across delays. There are multiple accounts for this pattern. First, it is possible that the effect of the prime is fleeting, and the relation between immediate recall and delayed recall in the conditional analyses simply reflects a possible item selection effect.[6] Of course, this would easily explain the effect on immediate recall and no effect on the delayed recall. For example, consider the possibility that the identity primes are particularly useful in pushing the *difficult* items over threshold initially. This effect might be only fleeting during the initial retrieval event. However, during the delayed recall test, these very same difficult items will be relatively poorly recalled since there is no longer any benefit of the identity prime to push these items over threshold. We attempted to address this specific item selection issue by reanalyzing the data from each experiment as a function of item difficulty for each experiment, via a median split on item difficulty. The results were quite clear. None of the experiments produced the predicted item difficulty by prime type interaction in conditional recall performance (all $ps > .5$). Only Experiment 3 produced a reliable effect, which was in the opposite direction, showing a larger reduction in the identity priming effect for easy items compared to difficult items. Therefore, this type of item selection problem does not appear to be underlying the present results. Of course, it should also be noted that there is limited support for the possibility that easier items benefit more from priming, since only Experiment 3 provided any evidence for this possibility. Nonetheless, there may be other item selection effects that could contribute to the conditional analyses, and so we clearly cannot eliminate the possibility that the present results simply reflect a fleeting influence of the prime in immediate recall, which is lost during delayed recall.[7]

We believe that there are two additional accounts of the present delayed recall data, which rest on the extant literature indicating there is a benefit of an initial retrieval on delayed memory performance. As noted earlier, there is clear evidence that retrieval at time 1 is strongly related to retrieval at time 2. This is likely due to two factors: (a) some items are simply easier to recall than other items on both occasions; (b) there is a benefit of retrieval practice, i.e., the mere act of retrieval at time 1 affords a benefit for long term retention (see for example Roediger & Karpicke, 2006). Notably, there are several accounts of the retrieval practice effect including TAP (e.g., Veltre, Cho, & Neely, 2015) and the desirable difficulty account (Bjork, 1994). Although the goal of the current set of experiments was not to exhaustively test each of these accounts, we explicitly examined the TAP account in Experiment 7 as an explanation of the differential long-term effects of immediate priming across prime conditions. Our results provided some support for the contribution of TAP to the present results. On one hand, the delayed test performance was no better when encoding and retrieval contexts matched (i.e., identity priming on both the immediate and delayed tests) than when they mismatched, which is inconsistent with a clear prediction from the TAP account. On the other hand, increasing the similarity between encoding and retrieval contexts in the identity priming condition yielded comparable levels of conditional cued recall across prime conditions, which stands in contrast with lower conditional cued recall for identity priming relative to related and unrelated

[6] We thank David Huber for presenting the fleeting influence of the prime account of our results.

[7] As one might expect, one finds converging evidence from proportional forgetting analyses. Specifically, a common procedure used to measure forgetting is simply the difference between immediate and delayed recall condition divided by the proportion correct in the immediate recall condition (see, for example, Roediger & Karpicke, 2006). The results from these analyses were very similar to the conditional analyses, indicating a main effect of immediate prime condition, which reflected more forgetting in the Identity condition compared to the Unrelated condition. The only exception to this was Experiment 5 which also did not produce a main effect in the conditional analyses.

priming that was observed in the earlier experiments. Thus, it appears that TAP does contribute to the present delayed conditional recall performance, but cannot fully account for the results. Hence, it is also important to consider additional mechanisms that may influence the relationship between immediate retrieval and delayed memory performance.

An additional account of the lower conditional performance in the identity condition compared to the remaining conditions is due to the decreased retrieval demands during the immediate condition when the identity prime is presented. This is consistent with Bjork's (1994) notion of desirable difficulties, i.e., variables that produce benefits initially do not necessarily extend to long term memory and indeed can sometimes produce a cost. Specifically, Bjork (pg. 192) suggested that "in responding to the difficulties and challenges induced by [encoding and/or retrieval operations] the learner is forced into more elaborate encoding processes." Of course, if threshold identity priming increases the activation of associative features, then the subsequent generation and retrieval of the target may be more fluent for these items compared to a pair that does not have its associative features preactivated by the prime. Hence, an increase in accessibility of these features may lead to reduced processing during retrieval on the immediate test, thereby less elaborate processes to support subsequent performance on the delayed test.

In a similar vein, one could consider these results within a generate-recognize model of cued recall. Here the notion is that the identity prime facilitates the generation process, and hence decreases the time and/or effort engaged during initial retrieval. Assuming the amount of retrieval engaged in encoding is related to long-term retention, one would expect any variable that decreases retrieval would produce a relative decrement in retrieval on a delayed cued recall test. Interestingly, Hopper and Huber (2018) have recently developed a model that suggests the benefit of retrieval practice underlying the well-established testing effect (i.e., the benefit of testing, compared to restudy, on long-term memory, e.g., see Roediger & Karpicke, 2006) may reflect the amount of time the participant is engaged during retrieval. Thus, the identity prime condition in the present study may serve to short-circuit the benefits of the retrieval processes that are important in improving long-term memory and likely contribute to the testing effect.

Conclusions

The current experiments extend past studies of near-threshold priming on episodic memory by using a cued recall test rather than a recognition test and by examining the persistence of immediate near-threshold priming on the durability of a memory trace across time. Results indicated that the use of a 48 ms identity prime (and a 125 ms identity or semantic prime) effectively enhanced immediate cued recall performance, but this effect did not persist during delayed recall performance. This pattern could reflect a fleeting influence of the prime on immediate performance, changes in the match between encoding and retrieval contexts, and/or a short circuiting of retrieval processes that lead to more forgetting in conditions which facilitate immediate recall. We believe that this pattern likely reflects the latter two mechanisms, but we cannot eliminate the former interpretation with the present results.

Of course, this is simply an initial set of studies with this novel paradigm. We believe that there are many issues yet to be explored including different types of prime information (e.g., forward vs backward associates, transposed letters within words, associative vs semantic relatedness) that have produced clear effects in pronunciation, lexical decision, and/or category verification tasks (e.g., Kinoshita & Lupker, 2004; McNamara, 2005). In addition, it will be important to map out the time-course of retrieval operations via manipulations of both cue to prime onset time, and durations of the primes, which have been successfully used in the semantic priming literature (e.g., Neely, 1977). Moreover, one may expect that different types of primes (e.g., identity, semantic, and orthographic) may exert distinct influences during retrieval at different time points (e.g., Starreveld & Van Heij, 1996). Finally, it is possible that individuals with episodic memory deficits (e.g., older adults compared to younger adults) may disproportionately benefit from identity and/or semantic prime information, since these individuals often show disproportionate deficits in recollection-based retrieval. In this light, the present studies are an important first step using this paradigm to explore the important transition between activation and recollection.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jml.2019.02.003.

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