The persistence of content-specific memory operations: Priming effects following a 24-h delay

CHRISTOPHER A. WAS

Kent State University, Kent, Ohio

The duration of long-term semantic priming is typically described in minutes. Woltz and Was (2007) found that priming effects following processing in working memory were relatively long-lasting, reporting there was no decrease in priming effects following 32 intervening Stroop-like trials. These findings were interpreted as an increased availability of long-term memory elements, in part due to memory for prior operations, and as not being solely explicable by spreading-of-activation accounts of priming. The present study was designed to test the persistence of these effects following a 24-h delay. In the present study, priming effects were found to be present following a minimum of a 24-h delay between processing of information in working memory and measures of increased availability of long-term memory elements. The results are discussed, in the context of long-term semantic priming, as being the result of persistent memory for prior cognitive operations.

The existence of long-term semantic priming (LTSP) effects would have important implications for cognitive theory. As McNamara (2005) noted, the existence of LTSP effects would pose problems for spreading-of-activation, compound-cuing, and even some distributed network models of priming and, in turn, would provide support for a semantic-connectionist-strengthening model of priming (Becker, Moscovitch, Behrmann, & Joordens, 1997). There is minimal extant evidence for LTSP effects, including effects merely lasting minutes, and theoretical explanations for LTSP effects differ among researchers. Although evidence for LTSP is minimal (see, however, Tse & Neely, 2007a, 2007b), perceptual repetition priming effects have been found to be longer lasting. For example, Tse and Neely (2005) cited studies utilizing lexical decision tasks to measure priming, stating that these studies have demonstrated that perceptual repetition priming can last for minutes (e.g., Dannenbring & Briand, 1982; Duchek & Neely, 1989; Forster & Davis, 1984) and, perhaps, even hours (e.g., Scarborough, Cortese, & Scarborough, 1977).

Evidence for LTSP was found in recent investigations demonstrating long-term facilitation following multiple related primes (Becker et al., 1997). Becker et al. interpreted their findings as reflecting changes in semantic memory representation or incremental learning. Long-term facilitation has also been demonstrated in tasks using single related primes when both the prime and the target were processed at a semantic level (Hughes & Whittlesea, 2003; Joordens & Becker, 1997). Hughes and Whittlesea interpreted these findings in the context of semantic

transfer, or operation-based memory. These findings indicate that processing at a semantic level may be required for long-term priming effects to be demonstrated. However, semantic priming from a single semantically related prime is typically eliminated or at least severely reduced following a minimal time lapse between the prime and target (e.g., Dannenbring & Briand, 1982; Duchek & Neely, 1989).

Recently, Woltz and Was (2006, 2007) demonstrated relatively long-lasting priming following simple working memory (WM) processing. In their experiments, Woltz and Was (2006, 2007) required participants to memorize a short list of words containing two or more exemplars from each of two categories. Following the memory list presentation, the participants were required to identify one or both categories and then, later, perform a task in which they were required to determine whether or not two exemplars were from the same category. The exemplar comparison trials represented memory set exemplars and/or associates (primed trials) or category exemplars from a category not previously encountered (unprimed trials). In all five of the experiments, the participants were faster and more accurate at identifying exemplars from the same category when the exemplars were primed than when they were not. In the first three experiments (Woltz & Was, 2006), category comparisons consisted only of exemplars not previously encountered in the memory list (i.e., memory list associates). Priming effects demonstrated using exemplars not encountered in the memory list represent semantic/associate priming, and not perceptual or repetition priming, because the exemplars have not previously been processed.

C. A. Was, cwas@kent.edu

Woltz and Was (2007) proposed that the priming effects could, in part, be explained by persistent memory for prior operations that were content specific, and not by activation of semantic content as described in spread-of-activation accounts of priming effects (e.g., Collins & Loftus, 1975). Ratcliff and McKoon (1988) found that activation decays rapidly (on the order of 400 msec), and their findings were explainable with both spreading-of-activation and compound-cuing models of priming. Woltz and Was (2007) found that when a minute of intervening tasks transpired (a lag of 32 trials) between the processing in WM of specified content and the measure of priming, the priming effects were still present. These enduring priming effects are not unreasonable for perceptual repetition priming but are on the order of long-term priming effects for conceptual and semantic priming (Becker et al., 1997). Many theorists have proposed a distinction between semantic and procedural memory (e.g., Anderson, 1993; Schacter & Tulving, 1994). It is possible that these enduring effects are indicative of this distinction. In contrast to the momentary activation of semantic content, memory for cognitive operations is assumed to be longer lasting.

Furthermore, Woltz and Was (2007) found that regardless of the content of the comparison trials (category exemplars or category features), priming effects were found as long as the memory set identification content and subsequent comparison trials content were congruent but were not present when the memory set and comparisons were incongruent. In other words, when the priming tasks consisted of category features, facilitation of response to primed targets occurred only when the targets were also category features, and not category exemplars. For example, if the participant was presented with a memory list containing features associated with birds (e.g., *feathers*, *beak*), priming effects were found only if the comparison task required the participant to decide whether two features came from the same category (e.g., *wings*, *nests*), and not when the comparison task required a decision as to whether two exemplars are from the same category (e.g., *robin*, *eagle*). The operation specificity of the facilitation provides evidence against a spreading-of-activation interpretation and supports a persistent-memory-for-prior-operations interpretation.

However, the persistent-memory-for-prior-operations interpretation is perhaps representative of long-term semantic transfer (see McNamara, 2005). Unlike short-term priming effects, long-term semantic transfer does not rely on the spread of activation to increase the availability of long-term memory elements but, instead, relies on the repetition of specific cognitive operations performed previously. McNamara stated, "Long-term semantic transfer effects have a strong episodic component, are specific to the decision being made, and require extensive semantic processing in the prime and test phases" (p. 94). Furthermore, as with other evidence of LTSP, Woltz and Was's (2006, 2007) evidence for LTSP occurred in the context of tasks that required a single experimental session. The priming stimuli were encountered within the same experimental session as the target stimuli. One possible

explanation for these and other single-session demonstrations of LTSP effects is that participants recognize that the information presented as a prime will be needed again in the target operation. Although participants in earlier studies may not have been able to rehearse the prime trial information over intervening tasks, the recognition of task requirements could lead to a form of flagging in episodic memory that the information (even if it is categorical) will be needed again. This might reflect expectancy influences in some priming effects. Neely (1991) explained that expectancy theories of priming assume that, following exposure to a prime, participants use this information to generate a list of expected targets. Potential targets that are generated are responded to more quickly than those that are not. If expectancy partly underlies LTSP, it is not purely a procedural memory strength change.

In an attempt to gather further evidence for the strengthening-of-prior-memory-operations explanation proposed by Woltz and Was (2006, 2007) and to eliminate other explanations, such as the possibility of expectancies underlying LTSP effects, the present study employed an experimental paradigm similar to that found in the Woltz and Was (2006, 2007) studies. Specifically, the task used in Experiment 1 in Woltz and Was (2007) was employed, with one major change. The category comparison trials did not occur following the intervening task but were delayed by 24 h. If previous findings using this experimental paradigm can greatly be accounted for by expectancy theories of priming, it is highly unlikely that priming effects will be detected following a 24-h delay. If facilitation exists when primes are in a separate session from target trials, the expectancy element cannot be a part of the prime trials. However, if the previous effects are dependent on the strengthening of content-specific memory operations, it is quite possible that priming effects may persist over 24 h.

METHOD

Participants

One hundred eight undergraduate students (78% female) participated in the experiment in exchange for course credit. The median age of the sample was 20 years (range = 18–49).

Apparatus

The participants performed the experimental task on personal computers with 17-in. SVGA monitors, standard keyboards, and circumaural sealed headphones. The tasks were programmed using E-Prime software (Schneider, Eschman, & Zuccolotto, 2002).

Experimental Task

Category stimuli were adapted from Woltz and Was (2006, 2007). Twenty-four sets of category triplets organized as sets of recalled, unrecalled, and unprimed categories (this distinction will be explained later in the Method section) were created from 72 categories, each having six exemplars. Figure 1 illustrates the sequence of trial components over the 2-day task with an example. Task components were presented visually, with the exception of the memory set, which was presented aurally via headphones. The auditory presentation of the six-word memory set was necessary because the words would later appear in some of the category comparisons and the change in modality would eliminate facilitation from perceptual priming. The present experiment required two sessions, completed on consecutive days, with a minimum of a 24-h and maximum of a 32-h delay between sessions.

Figure 1. Example of task components.

Day 1. On Day 1, each trial began with a statement indicating that a new word list would be presented (e.g., *Remember the gems*) and designating the category that should be remembered (i.e., the recalled category). Moving forward from this frame was self-paced. There followed an attention frame for 4 sec containing the phrase, *Get ready to memorize words*. This was followed by a low tone for 1 sec, a 1-sec delay, and the aural presentation of six memory set words, three from each of the two memory set categories. Each sound file for the individual memory set words was 2 sec in length, beginning with approximately 500 msec of silence and ending with as much silence as needed to fill the remainder of 2 sec. Each word sound file was preceded by the visual presentation of an asterisk for 500 msec, which remained visible during the auditory file presentation. A 1-sec interstimulus interval separated each word presentation and the subsequent asterisk. The ordering of the exemplars from the two categories was random, with the

constraint that the three words from one category could not be presented contiguously.

There was a 1-sec delay following the final memory set item, followed by 12 number Stroop items (Woltz, Gardner, & Gyll, 2000). The number Stroop frames were preceded by the following instruction for 4 sec: *Get ready to evaluate number strings. . . . Rest four fingers on the number keys 1,2,3,4 at the top left of the keyboard*. Each number Stroop item presented a string of between one and four identical digits (e.g., 444, 33, 2222, 1). The participants were instructed to respond to each string by entering the string length (e.g., 3, 2, 4, 1 for the previous examples). Half of the items had consistent length and digit values (e.g., 22), and half had inconsistent length and digit values (e.g., 444).

After completing the 12 number Stroop items, the participants were prompted to recall the three words of the recalled category in order. There were three recall frames that each asked, *What was*

the <first, second, third> word that you were to remember? The participants were instructed to type the first two letters of each word that they had to remember.

Following the recall of recalled category exemplars and a 1-sec blank frame, a separate frame asked the participants to identify the other category in the memory set. Two category names were presented in the left and in the right sections of the display: the second category in the memory list (unrecalled category) and the unprimed category name. The participants pressed the "1" or "2" key, corresponding to the left and right category name. The position of the unrecalled category name was randomized on each trial. This question was asked in order to ensure that the participants had evaluated the category membership of the unrecalled category during memory set processing.

The number Stroop task followed the memory set in order to ensure that the participants were required to hold the memory set exemplars in WM for an extended period of time. Importantly, Woltz and Was (2006) found that the magnitude of priming effects was not decreased by concurrent attention demands.

Day 2. On Day 2, the participants received directions regarding the category comparison trials. Each of 24 sets of comparison trials began with the 4-sec presentation of the instruction, *Get ready to COMPARE words . . . Rest your fingers on the D and L keys*, followed by a 2-sec blank screen. Each comparison frame began with two asterisks presented for 500 msec, one on top of the other at the location at which the two stimulus words would appear. This cue was followed by a blank screen for 750 msec, and then by the two stimulus words. The stimuli remained on the screen until the participants responded by pressing either the "L" (for *like*) or the "D" (for *different*) key. A 1-sec interval separated the response and the attention cue for the subsequent comparison. During the entire set of comparison frames, the lower left portion of the display contained the reminder *D = Different*, and the lower right portion of the display contained *L = Like*. The participants were instructed to decide whether the two exemplars in each comparison came from the same category (SC; *L* response) or different categories (DC; *D* response).

Sixteen category comparisons were completed during each set of trials: 4 warm-up comparisons (2 SC and 2 DC trials of content unrelated to recalled, unrecalled, and unprimed categories), and 4 comparisons from each of the three content types, 2 SC and 2 DC comparisons. The latter 12 comparisons were presented in randomized order for each participant.

Category comparisons were of three content types: recalled category exemplars (i.e., from the Day 1 memory set category *gems* in the present example), unrecalled category exemplars (*trees* in this example), and unprimed category exemplars (e.g., from a category not presented in the memory set, such as *relatives*). Half of the category comparisons from each content type were of exemplars from DCs (e.g., *oak, tomato*) and the other half of exemplars from the SC. DC comparisons were never formed by combining exemplars from the three content types. Half of all trials of the recalled and unrecalled content were exemplars from the memory set, or *old* exemplars (i.e., *oak, elm*), and half were associates of the memory set or *new* exemplars from the memory set categories but were not in the memory set (i.e., *spruce, maple*). The distinction of old–new exemplars was not pertinent to the unprimed category. Categories and exemplars were taken from norms in Van Overschelde, Rawson, and Dunlosky (2004), but some additional categories and exemplars were generated. Every effort was made to ensure that old and new exemplars were of similar frequency and typicality, on the basis of the norms, in order to avoid confounding the findings. Category comparison frames were organized in trials around the SC triplets within the memory sets from Day 1. Trials and category frames within trials were randomized.

Summary feedback was provided regarding accuracy and average response time. The participants were reminded that they should try to respond as quickly as possible without making errors on the category comparison.

Design and Procedure

Equal numbers of participants ($n = 18$) performed the six counterbalanced versions of the experiment. Counterbalanced across participants, one category from each set was assigned to be the recalled category, the unrecalled category, and an unprimed category unrelated to the memory set. In addition, of the six exemplars in each category, three were assigned to the memory set (and direct priming condition of the comparison phase), and three to the indirect priming condition of the comparison phase. These were not counterbalanced (i.e., words used in the memory set were not used as associates). Six versions of the experiment were created that represented a complete counterbalancing of triplet assignment to priming condition (recalled, unrecalled, and unprimed).

RESULTS

Due to the completely within-subjects design utilized in this study, a repeated measures ANOVA was used to test the hypothesized priming effects. An alpha level of .05 was used in all the statistical tests performed in this experiment.

The participants were relatively accurate in selecting and recalling the recalled category words. Mean accuracy was 92.17% ($SD = 10.78$) for the first word, 91.97% ($SD = 14.14$) for the second word, and 90.86% ($SD = 15.50$) for the third word. The participants were highly accurate at correctly identifying the unrecalled category in the memory set ($M = 97.22\%$, $SD = 6.38$).

Consistent with other measures of the Stroop effect, the participants were more accurate in evaluating consistent numeral strings ($M = 99.36\%$, $SD = 0.01$), as compared with inconsistent strings ($M = 95.03\%$, $SD = 0.10$) [$F(1,107) = 21.85$, $\eta_p^2 = .17$]. They also responded more quickly to consistent strings ($M = 658$ msec, $SD = 177$) than to inconsistent strings ($M = 710$, $SD = 152$) [$F(1,107) = 26.45$, $\eta_p^2 = .20$]. The occurrence of Stroop-type interference supports the assumption that the intervening task was attention demanding for the participants.

Only data from positive match (SC) comparisons were analyzed, on the basis of prior evidence that priming effects are insignificant in negative match (DC) comparisons (Woltz & Was, 2006, 2007). Table 1 displays the response means and standard deviations of the errors and latencies for SC comparisons by condition. As is apparent in Table 1, the expected patterns of priming in the unrecalled and recalled categories, as compared with unprimed comparisons, were evident in both response accuracy and latency. Latency and accuracy effects were significant for primed category versus unprimed category comparisons.

Table 1
Errors and Response Latencies (in Milliseconds) for
Semantically Similar Comparisons, by Priming Condition

Priming Condition	Error		Latency	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Unprimed	8.61	6.99	1,162	305
Old unrecalled	6.73	7.40	1,089	296
Old recalled	5.63	6.46	1,049	275
New unrecalled	7.04	7.72	1,143	315
New recalled	6.59	6.58	1,143	320

Both latency and accuracy effects were significant in the recalled category comparison condition. Only accuracy effects were significant in the unrecalled category comparison condition. However, the trend for latency was in the hypothesized direction and did approach significance (see the Appendix). As in previous studies using the same basic experimental paradigm (Woltz & Was, 2006, 2007), latency and accuracy were combined and transformed. This transformation results in a measure of response speed, because it is the reciprocal of response latency and the speed index is corrected as a function of error rate. Each participant's proportion of correct responses for SC comparisons per condition was divided by the mean of the response time in seconds for that condition and was multiplied by 60, to achieve a metric of correct responses per minute. Because priming effects are evident in both accuracy and latency, this index was computed. The index integrates meaningful variance from both errors and latency and, therefore, provides a more complete description of the size of priming effects than does accuracy or latency alone.

Figure 2 presents the data organized as response speed by priming condition and comparison exemplar type. There was a significant overall speed advantage for primed categories (recalled and unrecalled), as compared with the unprimed categories [$F(1,107) = 69.24, p < .001, \eta_p^2 = .39$]. Furthermore, response speed was greater for all recalled (old and new exemplar) category comparisons than for all unrecalled category comparisons [$F(1,107) = 4.03, p = .047, \eta_p^2 = .04$]. Category comparison mean response speed was much higher for old and new exemplars than for unprimed category comparisons [$F(1,107) = 133.28,$

$p < .001, \eta_p^2 = .56$]. The speed of the unrecalled category comparison was significantly higher than those of the unprimed comparisons [$F(1,107) = 68.77, p < .001, \eta_p^2 = .39$], and old recalled category comparisons were also significantly faster than old unrecalled category comparisons [$F(1,107) = 16.02, p < .001, \eta_p^2 = .13$].

Comparing all primed category comparisons (recalled and unrecalled) using new exemplars with unprimed comparisons revealed a significant difference in speed [$F(1,107) = 9.42, p = .003, \eta_p^2 = .08$]. The contrasts between unprimed and unrecalled category comparisons containing new exemplars was also significant [$F(1,107) = 7.32, p = .008, \eta_p^2 = .06$]. This difference represents LTSP, since the exemplars are new representatives of the unrecalled and recalled category, not exemplars processed on Day 1 in the memory set. The contrast between comparisons containing new recalled and unrecalled categories was not significant ($F < 1$). Finally, a significant speed advantage was found for category comparisons containing old exemplars versus those using new exemplars [$F(1,107) = 88.46, p < .001, \eta_p^2 = .45$].

DISCUSSION

The present study was undertaken to determine whether priming effects following semantic processing demands in WM would remain following a 24-h delay and to provide support for a memory-for-prior-operations explanation of LTSP effects. The results support the hypothesis that processing primes at a semantic level leads to LTSP. Specifically, the results indicated that primed category exemplars (both old and new exemplars) are more available for later processing. The scale of direct priming effects from category comparisons is quite remarkable, considering that the measure of priming was preceded by a 24-h delay. Expressing the priming effect in terms of percentage of savings in response speed in relation to the unprimed trials, responses on comparison trials of recalled category exemplars from the memory set were 12% faster than those on unprimed trials. Representing direct priming of unrecalled category exemplars in the same fashion, there was an 8% savings in response speed. Although this priming effect is based on repetition of the memory set exemplars, it represents conceptual priming, and not perceptual repetition priming, in that the presentation of the memory set and of the category comparisons was cross-modal (auditory presentation of the memory set and visual presentation of the category comparisons).

Savings were also demonstrated in the category comparisons using indirect priming (new exemplars). The savings for recalled and unrecalled category associates combined, as compared with unprimed trials, was approximately 3%. These effects represent strictly semantic priming effects, because the new exemplars represent category exemplars not encountered during the memory load task on Day 1. Although spreading-of-activation and compound-cuing accounts of priming may be tenable explanations for the magnitude of the indirect priming effects (new exemplar comparisons) demonstrated in the present study, these accounts cannot explain the duration of these effects.

Figure 2. Mean correct responses per minute by priming condition and exemplar type. Error bars represent 95% confidence intervals. Unprimed trials are represented in both the old and new exemplar clusters for ease of comparison.

Becker et al. (1997) described LTSP as spanning lags of up to eight items. Becker et al. argued that, for LTSP to occur, a substantial amount of semantic processing must occur. Even more impressive, Hughes and Whittlesea (2003) demonstrated long-term facilitation following lags of, on average, 90 intervening trials. Simulations and human participant experiments supported their hypothesis, that under sufficient semantic-processing demands, priming effects are longer lasting than previously demonstrated. There are, however, some questions regarding the consistency of the long-term priming effects described by Becker and Joordens and their colleagues (Becker et al., 1997; Joordens & Becker, 1997), and the findings of Hughes and Whittlesea are more appropriately described as long-term semantic transfer (McNamara, 2005).

McNamara (2005) explained that distributed network models provide a more tenable explanation than do spread-of-activation accounts for LTSP. McNamara also contended that the findings of Becker and Joordens (Becker et al., 1997; Joordens & Becker, 1997) are perhaps more readily explained by memory for prior cognitive operations. In his explanation, McNamara stated that these long-term priming effects may be similar to the semantic transfer effects demonstrated by Hughes and Whittlesea (2003) and Woltz (1990, 1996), in that these long-term semantic transfer effects require substantial semantic processing in both the priming and testing components of the task, are specific to the decision being made about the stimulus, and have an episodic component.

The duration of the effects demonstrated for direct priming (old exemplar comparisons) in the present investigation may be explained, in part, by an explicit or episodic memory for processing the exemplars during the Day 1 memory load task. It is possible that the participants had an explicit memory for encountering the old exemplars. However, the cross-modal presentation across Day 1 and Day 2 tasks represents conceptual priming, and not the perceptual repetition priming typically associated with episodic accounts of priming (see Tenpenny, 1995, for a review). Also, the significant priming effects, as measured by the speed transformation, demonstrated in relation to the new exemplar comparisons represent an effect of indirect or semantic priming, since these exemplars were not encountered previously, and cannot be explained by an explicit or episodic memory for previous processing.

It would also be difficult to explain the priming effects found in the present study with expectancy theories of priming. The participants in the present study would have had no reason to generate expected targets on Day 1 of the experiment, since they were informed that their task was to remember the primes while completing the number Stroop task. The participants not having generated potential targets, the facilitated response time for primed category comparisons on Day 2 is attributable to the increase in procedural memory strength.

Models of cognition that distinguish between semantic and procedural memory (e.g., Anderson, 1993) assume that memory for cognitive operations is longer lasting than the spread of activation. It is possible that the present find-

ings represent a strengthening of an operation-specific but item-general memory operation. In other words, identifying the categories and exemplars in the memory load task on Day 1 strengthens the procedure of categorizing both old and new exemplars from the processed categories, but not the unprocessed or unprimed categories.

The task involved in the present study requires significant amounts of semantic processing. The priming task reported here and in earlier studies (Liu & Fu, 2007; Woltz & Was, 2006, 2007) required participants not only to rehearse and recall the memory set exemplars, but also to distinguish category membership during and after the memory set presentation and in the category comparison trials (substantial semantic processing). The decisions made during the memory set presentation and the category comparison trials were category membership decisions (specific to the decision being made).

However, due to the separation of priming stimuli and target stimuli into two distinct sessions separated by 24 h, episodic memory or expectancies of targets are not tenable explanations of the results. The results of this experiment provide new evidence that the strengthening of specific prior memory operations is likely the source of some LTSP effects.

AUTHOR NOTE

Thanks to John Dunlosky, Katherine Rawson, and Dan Woltz for helpful comments on earlier drafts of the manuscript. Correspondence concerning this article should be addressed to C. A. Was, Kent State University, Educational Foundations and Special Services, 405 White Hall, Kent, OH 44242 (e-mail: cwas@kent.edu).

REFERENCES

- ANDERSON, J. R. (1993). *Rules of the mind*. Hillsdale, NJ: Erlbaum.
- BECKER, S., MOSCOVITCH, M., BEHRMANN, M., & JOORDENS, S. (1997). Long-term semantic priming: A computational account and empirical evidence. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **23**, 1059-1082. doi:10.1037/0278-7393.23.5.1059
- COLLINS, A. M., & LOFTUS, E. F. (1975). A spreading-activation theory of semantic processing. *Psychological Review*, **82**, 407-428. doi:10.1037/0033-295X.82.6.407
- DANNENBRING, G. L., & BRIAND, K. (1982). Semantic priming and the word repetition effect in a lexical decision task. *Canadian Journal of Psychology*, **36**, 435-444. doi:10.1037/h0080650
- DUCHEK, J. M., & NEELY, J. H. (1989). A dissociative word-frequency $\times$ levels-of-processing interaction in episodic recognition and lexical decision tasks. *Memory & Cognition*, **17**, 148-162.
- FORSTER, K. I., & DAVIS, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **10**, 680-698. doi:10.1037/0278-7393.10.4.680
- HUGHES, A. D., & WHITTLESEA, B. W. A. (2003). Long-term semantic transfer: An overlapping-operations account. *Memory & Cognition*, **31**, 401-411.
- JOORDENS, S., & BECKER, S. (1997). The long and short of semantic priming effects in lexical decision. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **23**, 1083-1105. doi:10.1037/0278-7393.23.5.1083
- LIU, Y., & FU, X. (2007). How does distraction task influence the interaction of working memory and long-term memory? In D. Harris (Ed.), *Engineering psychology and cognitive ergonomics* (pp. 366-374). Berlin: Springer.
- MCMANARA, T. P. (2005). *Semantic priming: Perspectives from memory and word recognition*. New York: Psychology Press.
- NEELY, J. H. (1991). Semantic priming effects in visual word recognition: A selective review of current findings and theories. In D. Besner

- & G. W. Humphreys (Eds.), *Basic processes in reading: Visual word recognition* (pp. 264-336). Hillsdale, NJ: Erlbaum.
- RATCLIFF, R., & MCKOON, G. (1988). A retrieval theory of priming in memory. *Psychological Review*, **95**, 385-408. doi:10.1037/0033-295X.95.3.385
- SCARBOROUGH, D. L., CORTESE, C., & SCARBOROUGH, H. S. (1977). Frequency and repetition effects in lexical memory. *Journal of Experimental Psychology: Human Perception & Performance*, **3**, 1-17. doi:10.1037/0096-1523.3.1.1
- SCHACTER, D. L., & TULVING, E. (1994). What are the memory systems of 1994? In D. L. Schacter & E. Tulving (Eds.), *Memory systems 1994* (pp. 1-38). Cambridge, MA: MIT Press.
- SCHNEIDER, W., ESCHMAN, A., & ZUCCOLOTTO, A. (2002). *E-Prime user's guide* (Version 1.1). Pittsburgh: Psychology Software Tools.
- TENPENNY, P. L. (1995). Abstractionist versus episodic theories of repetition priming and word identification. *Psychonomic Bulletin & Review*, **2**, 339-363.
- TSE, C.-S., & NEELY, J. H. (2005). Assessing activation without source monitoring in the DRM false memory paradigm. *Journal of Memory & Language*, **53**, 532-550. doi:10.1016/j.jml.2005.07.001
- TSE, C.-S., & NEELY, J. H. (2007a). Semantic and repetition priming effects for Deese/Roediger-McDermott (DRM) critical items and associates produced by DRM and unrelated study lists. *Memory & Cognition*, **35**, 1047-1066.
- TSE, C.-S., & NEELY, J. H. (2007b). Semantic priming from letter-searched primes occurs for low- but not high-frequency targets: Automatic semantic access may not be a myth. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **33**, 1143-1161. doi:10.1037/0278-7393.33.6.1143
- VAN OVERSCHELDE, J. P., RAWSON, K. A., & DUNLOSKY, J. (2004). Category norms: An updated and expanded version of the Battig and Montague (1969) norms. *Journal of Memory & Language*, **50**, 289-335. doi:10.1016/j.jml.2003.10.003
- WOLTZ, D. J. (1990). Repetition of semantic comparisons: Temporary and persistent priming effects. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **16**, 392-403. doi:10.1037/0278-7393.16.3.392
- WOLTZ, D. J. (1996). Perceptual and conceptual priming in a semantic reprocessing task. *Memory & Cognition*, **24**, 429-440.
- WOLTZ, D. J., GARDNER, M. K., & GYLL, S. P. (2000). The role of attention processes in near transfer of cognitive skills. *Learning & Individual Differences*, **12**, 209-251. doi:10.1016/S1041-6080(01)00038-3
- WOLTZ, D. J., & WAS, C. A. (2006). Availability of related long-term memory during and after attention focus in working memory. *Memory & Cognition*, **34**, 668-684.
- WOLTZ, D. J., & WAS, C. A. (2007). Available but unattended conceptual information in working memory: Temporarily active semantic content or persistent memory for prior operations? *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **33**, 155-168. doi:10.1037/0278-7393.33.1.155

APPENDIX

Repeated Measures ANOVA of Accuracy and Latency for All Category Comparison Types

Comparison	Accuracy			Latency		
	MS_e	$F(1,107)$	η_p^2	MS_e	$F(1,107)$	η_p^2
Primed (Old and New)						
Primed vs. unprimed	.035	13.51***	.11	333,247	36.25***	.25
Unprimed vs. unrecalled	.026	7.99**	.07	222,079	21.52***	.17
Recalled vs. unrecalled	.002	1.10	.01	44,362	4.82*	.04
Old Exemplars						
Primed vs. unprimed	.064	18.13***	.15	10,171	90.72***	.46
Unprimed vs. unrecalled	.038	8.05**	.07	11,310	48.86***	.31
Recalled vs. unrecalled	.013	3.17	.03	12,326	13.96***	.12
New Exemplars						
Primed vs. unprimed	.004	5.47*	.05	13,660	2.71	.03
Unprimed vs. unrecalled	.005	4.37*	.04	17,885	2.00	.02
Recalled vs. unrecalled	.004	<1	—	26,223	<1	—

* $p < .05$. ** $p < .01$. *** $p < .001$.

(Manuscript received August 11, 2009;
revision accepted for publication December 12, 2009.)