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The Persistence of Procedural Memory for Content-Specific Prior Memory Operations

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Abstract

Woltz and Was (2006, 2007) demonstrated persistent and sizable priming effects following simple processing of information in working memory. The results of these previous studies were interpreted as the demonstration of the strengthening of prior memory operations. In the current study, these priming effects were found to be present following minimum of a 24-hour delay between processing of information in working memory and measures of increased availability of long-term memory elements.

Keywords: Working memory; long-term working memory; priming

Introduction

In the results of several experiments, Woltz and Was (2006, 2007) demonstrated increased availability of long-term memory (LTM) elements following simple working memory (WM) processing. An impetus for the first Woltz and Was (2006) investigation was recent proposals regarding the content and nature of WM (e.g. Cowan, 1995, 1999; Ericsson & Kintsch, 1995; Oberaurer, 2002). Many of these models include activated or highly accessible components of LTM as part of WM. Cowan (1995, 1999) proposed an embedded processes model of WM. In this model, the contents of WM consist of LTM, a subset of LTM elements that are in an active state, and a subset of those activated LTM elements that are currently in the focus of attention. Woltz and Was (2006, 2007) had hoped to demonstrate, as Cowan and others have proposed, that processing in WM activates LTM elements associated with the contents of the focus of attention.

In their experiments, Woltz and Was (2006, 2007) required participants to remember a short list of words containing two or more exemplars from each of two categories. Following the memory list presentation, participants were required to identify one or both categories and then later perform a category comparison task. The category comparison task required participants to determine if two words were of the same or different category. The category 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 it was found that participants were faster and more accurate at identifying exemplars from the same category when the exemplars were primed than when they were not.

Woltz and Was (2006, 2007) interpreted the results within the context of models of WM that include instant and direct access to LTM elements that are available for processing, but not actively kept in the focus of attention (e.g. Cowan, 1995, 1999; Ericsson & Kintsch, 1995; Oberaurer, 2002). More importantly, Woltz and Was (2007) proposed that the priming effects related to available long-term memory (ALTM) could be in part explained by persistent memory for prior operations and not by activation of semantic content as describe in spreading of activation accounts of priming effects (e.g., Collins & Loftus, 1975). This explanation was in part based on the finding 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 and subsequent comparison trials were congruent, but were not present when the memory set and comparisons were incongruent.

This interpretation is perhaps representative of Ericsson and Kintsch's (1995) conceptualization of long-term working memory (LT-WM) as immediate and effortless access to LTM within highly familiar tasks or knowledge domains. This access to LTM is described as "specific control processes used to encode heeded information in LTM in a retrievable form" (p. 211). If one conceptualizes the task employed by Woltz and Was (2006, 2007) in terms of repeated operations, then the increased availability of elements within LTM occurs due to the strengthening of those memory operations through repetition.

It may also be that the findings of previous studies of ALTM represent long-term semantic transfer (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.

A second reason for these possible interpretations is the duration of the available LTM effects. Woltz and Was (2007) found that when a minute of intervening tasks transpired (a lag of 32 trials) between the processing in working memory of specified content and the measure of increased availability of LTM, the priming effects were still present. These enduring priming effects are not unreasonable for perceptual or repetition priming, but are on the order of long-term priming effects for conceptual and semantic priming (Becker, Moscovitch, Behrman, and Joordens, 1997). Many models of memory make a clear 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.

In an attempt to gather further evidence for the strengthening of specific memory operations explanation the current study employed a similar experimental paradigm as found in the Woltz and Was (2006, 2007) studies. Specifically the task used in Experiment 1 from 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 hours. To foreshadow, results of the current experiment are similar to those previously demonstrated. Again, the interpretation of the data is that of strengthening of specific memory operations following processing in WM.

Method

Participants. A total of 108 undergraduate students (78% female) participated in the experiment in exchange for course credit in a college of education course. The median age of the sample was 20 (range = 18-49).

Apparatus. Participants performed the experiments on personal computers with 17" SVGA monitors, standard keyboards, and circumaural sealed headphones. The tasks were programmed using E-Prime software (Schnieder, Eschman, &Zucclotto, 2002).

Experimental Task. Category stimuli were adapted from earlier research (Woltz & Was, 2007, 2006). Order and procedure of the current task were similar to that of Experiment 1 in Woltz and Was (2007). Figure 1 illustrates the sequence of trial components over the two-day task. All task components were presented visually via the computer display, 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. It was assumed that the change in modality would eliminate facilitation from perceptual priming.

Figure 1 presents and example of the experimental task. The current experiment required two sessions to complete. The two sessions were completed on consecutive days with a minimum of a 24-hour and maximum of 32-hour delay between sessions. On day one, each trial began with a statement indicating that a new word list would be presented, and designating the category that should be remembered (i.e., the focus category name). Moving forward from this frame was self-paced, followed by a frame for 4 s containing the words, *Get ready to memorize words*. This was followed by a low tone for 1 s, a 1 s 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 s in length, beginning with approximately 500 ms of silence and ending with as much silence as needed to fill the remainder of 2 s. Each word sound file was preceded with the visual presentation of an asterisk for 500 ms, and which remained visible during the auditory file presentation. A 1 s inter-stimulus 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 s delay following the final memory set item followed by 12 Number Stroop items (Morton, 1969; Woltz, Gardner & Gyll, 2000). The Number Stroop frames were preceded by the following instruction for 4 s: *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 1 and 4 identical digits (e.g., *222, 44, 3333, 1*). Participants were instructed to respond to each string by entering the string length (e.g., *3, 2, 4, 1* for the previous examples). Prior research has shown a Stroop-like interference effect when the numbers in the string differ from the length evaluation, and a facilitation effect when the numbers agree with the length evaluation. A feedback frame presented the accuracy and average response latency for the number string evaluations of each trial.

After completing the 12 Number Stroop items, participants were then prompted to recall the three words of the focus category in order. There were three recall frames that each asked, *What was the <first, second, third> word that you were to remember?* Participants were instructed to type the first two letters of each word they were remembering. Following the recall of focus category exemplars and a 1 s blank frame, a separate frame asked participants to identify the other category in the memory set.

Two category names were presented one the left and one on the right sections of the display: the ignored category name and the unprimed category name. Participants pressed the 1 or 2 key corresponding to the left and right category name. The position of the ignored category name was randomized on each trial. This question was asked to make sure that participants evaluated the category membership of the ignored category during memory set processing.

Woltz and Was (2007) incorporated the Number Stroop items before the recall frames in their first experiment. In the current study, this order of task components was reversed to ensure that participants were required to maintain the focus category memory load items, as well as the identity of the ignored category, active for a sustained period of time. It was hypothesized that the magnitude of priming may be diminished had the participants completed immediate recall of the focused category exemplars and made the ignored category determination immediately following the memory load. Importantly, Woltz and Was (2006) found that the magnitude of increased ALTM effects were not decreased by a concurrent attention demands.

The day two session began with participants receiving directions regarding the category comparison trials. Each trial began with the instruction, *Get ready to COMPARE words... Rest your fingers on the D and L keys*. This instruction was presented for 4 s followed by a 2 s blank screen to allow participants to prepare for the comparison frames. Each comparison frame began with two asterisks presented for 500 ms, one on top of the other in the location that the two stimulus words would appear. This cue was
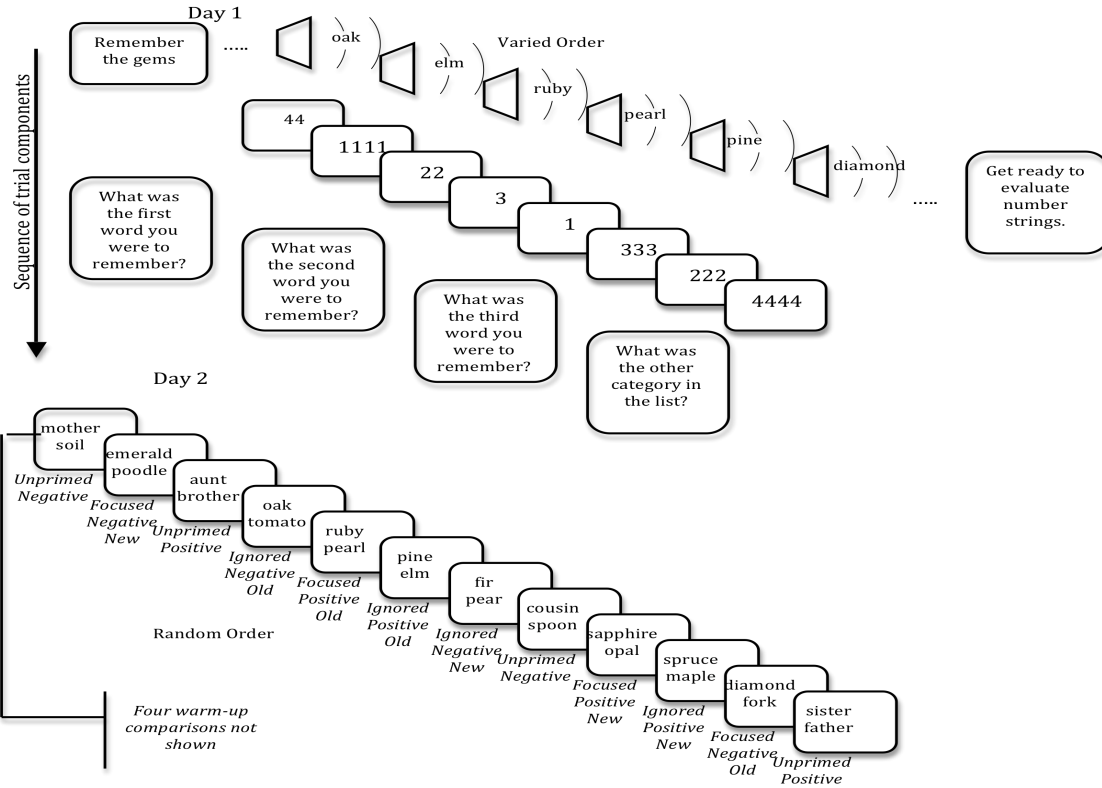
Figure 1. Example of Task Components

followed by a blank screen for 750 ms, and then the two stimulus words. The stimuli remained on the screen until the participant responded by pressing either the L (for like) or D (for different) key. A 1 s 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*. Participants were instructed to decide if the two exemplars in each comparison came from the same category (*L* response) or different categories (*D* response).

A total of 16 category comparisons were completed per trial; four warm-up comparisons (two positive and two negative comprised of content unrelated to focused, ignored, and unprimed categories), and four comparisons from each of the three content types. Categories comparisons were comprised of three content types: focus category exemplars (i.e., from the memory load category *gems* in the current example), ignored category exemplars (i.e., from the memory load category, *trees* in this example), and unprimed category exemplars (e.g., from a category not presented in the memory load such as *relatives*). Half of the category comparisons from each content type were negative matches (e.g., *oak tomato*) Negative match comparisons were never formed by combining exemplars from the three content types. Half of all trials of the focused and ignored content were exemplars from the memory set, or *old* exemplars (i.e.,

oak elm), and half were new exemplars from the memory set categories but not in the memory set (i.e., *spruce maple*). The distinction of old-new exemplar was not pertinent to the unprimed category. As in previous experiments (Woltz & Was, 2007, 2006), 24 sets of category triplets were created from 72 categories each having six exemplars.

Following the category comparison frames, summary feedback was provided for the entire trial. Participants were informed of their overall accuracy for the recall frames and their accuracy and average response time for the category comparison frames. Prior to the next trial, participants were reminded that they should try to obtain perfect accuracy on the recall frames and try to respond as quickly as possible without making errors on the category comparison. The feedback and goal reminder frames were self-paced.

Procedure. Participants performed the experimental task in two 1-hr sessions. They performed the experiment in groups of 1-4 subjects, with each participant seated in a computer carrel separated by sound-deadening panels. Equal numbers of participants (n=18) performed the 6 counterbalanced versions of the experiment.

Category comparison frames were organized in trials around the same category triplets within the memory sets from Day 1. Trials and category frames within trials were randomized. As stated previously, a total of 16 category comparison frames were complete per trial; four warm-up comparisons (two positive and two negative comprised of

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content unrelated to focused, ignored, and unprimed categories), and four comparisons from each of the three content types. That latter 12 comparisons in randomized order for each participant.

The category triplets were organized in order to minimize conceptual overlap between categories. Counter-balanced across participants, one category from each set was assigned to be the focused category in the memory set, one was assigned to be the ignored category in the memory set, and the remaining one represented a category unrelated to the memory set. Additionally, 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. Six versions of the experiment were created that represented a complete counterbalancing of triplet assignment to priming condition (focused, ignored, and unprimed).

Results

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

Participants were relatively accurate in selecting and recalling the focus category words following the Number Stroop trials. 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. Participants were highly accurate at correctly identifying the ignored category in the memory set ($M = 97.22\%$, $SD = 6.38$.).

Consistent with other measures of the Stroop effect, participants were more accurate in evaluating consistent numeral strings ($M = 99.36\%$, $SD = .01$) compared to inconsistent strings ($M = 95.03\%$, $SD = .10$), $F(1,07) = 21.85$, partial $\eta^2 = .17$. They also responded more quickly to consistent ($M = 658$ ms, $SD = 177$) compared to inconsistent strings ($M = 710$, $SD = 152$), $F(1,107) = 26.45$, partial $\eta^2 = .20$ The occurrence of Stroop-type interference supports the assumption that the intervening task was attention demanding for participants.

Only data from positive match category comparisons were analyzed on the basis of prior evidence that priming effects are insignificant in negative match comparisons (Woltz & Was, 2006, 2007). Table 1 displays the response means and standard deviations of error and latency for positive match comparisons by condition. As can be seen in this table, the expected patterns of priming in the ignored and focused categories compared to unprimed comparisons were evident in both response accuracy and latency. As in previous studies using the same basic experimental paradigm (Woltz & Was, 2007, 2006) latency and accuracy were combined and transformed. Each participant's number of correct responses per condition was divided by the sum of the response latency for all comparisons in that condition (both correct and incorrect) and then divided by 60,000. This transformation results in a measure of response speed because it is the reciprocal of response latency and the speed

Table 1. Mean Error Rate (Percentage) and Response Latency (Milliseconds) for Positive Match Comparisons by Priming Condition

Priming Condition	Error		Latency	
	M	*SD*	*M*	*SD*
Unprimed	8.61	6.99	1162	305
Old ignored	6.73	7.40	1089	296
Old focused	5.63	6.46	1049	275
New ignored	7.35	7.72	1143	315
New focused	7.55	6.58	1143	320

index is corrected as a function of error rate. This transformation is interpreted as the number of correct responses per minute in the current analysis. The index incorporates meaningful variance from both errors and latency and therefore provides a more complete descriptive of the size of priming effects in a single metric.

Figure 2 presents the mean response speed for positive match category comparisons. As can be seen in the figure, there was a significant overall speed advantage for primed categories (focused and ignored) compared to the unprimed categories, $F(1,107) = 69.24$, partial $\eta^2 = .39$. Furthermore, response speed was greater for the focused category as compared to the ignored category, $F(1,107) = 4.03$, partial $\eta^2 = .04$.

Figure 3 presents category comparison mean response speed comparing exemplars from the memory load and new exemplars to unprimed category comparisons. Not surprisingly, category comparison speed for memory load exemplars was much higher than for unprimed category comparisons, $F(1,107) = 133.28$, partial $\eta^2 = .56$. The speed of the ignored category comparison was significantly higher than unprimed comparisons, $F(1,107) = 68.77$, partial $\eta^2 = .39$, and focused category comparison from the memory load were also significantly faster than ignored category comparisons with memory load exemplars, $F(1,107) = 16.02$, partial $\eta^2 = .13$.

Of greater interest to the current research is the contrast between category comparisons based on new exemplars and unprimed category comparisons. Comparing all primed category comparisons (focused and ignored categories) with new exemplars to unprimed comparisons revealed a significant difference in speed, $F(1,107) = 9.42$ partial $\eta^2 = .07$. As with memory load comparisons, the contrasts between unprimed and ignored category comparisons containing new exemplars was also significant, $F(1,107) = 7.32$, partial $\eta^2 = .36$. The contrast between comparisons containing new focused and ignored comparisons was in opposite direction of they hypothesized results, but not significant ($F < 1$).
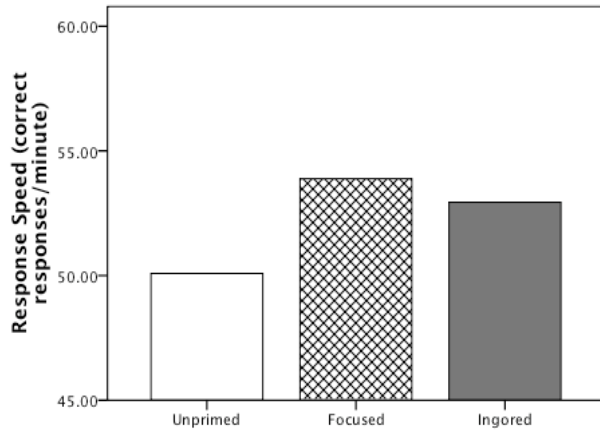
Figure 2. Response speed by priming condition

These findings closely resemble those of Experiment 1 of Woltz and Was (2007) with a delay of at least 24 hours between the memory load presentation and category comparison trials, thus indicating that the increased availability of LTM is present following a 24-hour delay.

Another important goal of this experiment was to test the long-lasting priming effects of direct priming, as measured by the old exemplars from the memory set, versus the long-lasting effects of indirect priming as measured by the new exemplars not in the memory set. A significant speed advantage was found for category comparisons containing old exemplars versus those using new exemplars $F(1,107) = 88.46$, partial $\eta^2 = .45$. Most models of ALTM make the assumption that prior attention processes play a principal role in determining the levels of LTM availability. Although not a surprising finding, these results do reflect that assumption.

Discussion

The current study was undertaken to determine if the increased availability of LTM elements following simple processing in WM, would remain following a 24-delay. The results of this study indicate that primed category exemplars (both from the memory set and associated exemplars) are more available for later processing.

The scale of direct priming effects from category comparisons is quite remarkable considering the measure of increased availability of LTM was preceded by a 24-hour delay. Expressing the priming effect in terms of percent savings in response speed, comparison trials comprised of focus category exemplars from the memory load were 12% faster than unprimed trials. Representing direct priming of ignored category exemplars in the same fashion, it is found that there was an 8% savings in response speed. Although this priming effect is based on repetition of the memory load exemplars, it represents conceptual priming and not perceptual repetition priming in that the memory load and category comparisons was cross-modal presentation of(auditory presentation of the memory load and visual presentation of the category comparisons).
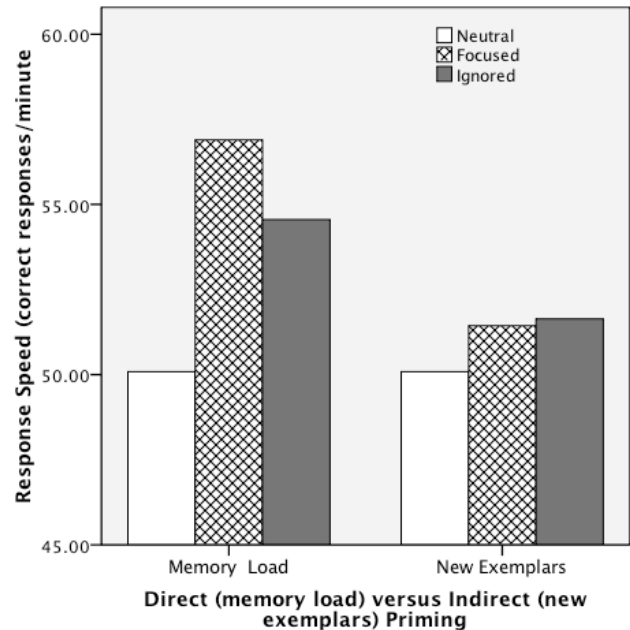

Figure 3. Response speed by priming condition and exemplar type.

The savings demonstrated in the category comparisons using indirect priming (category exemplars not in the memory load) was also substantial. The savings for focused and ignored category associates combined as compared to unprimed trials was approximately 3%. These effects represent strictly semantic priming effects

Most important in the current findings is the duration of the priming effects. Becker, et al. (1997) described long-term semantic priming as spanning lags of up to 8 items. Even more impressive, Hughes and Whittlesea (2007) demonstrated long-term priming following lags on average of 90 intervening trials. Becker, et al make the argument that for long-term semantic priming to occur a substantial amount of semantic processing must occur. Becker, et al. demonstrated these long-term priming effects within the context of an attractor neural network. Simulations and human participant experiments supported their hypothesis that under sufficient semantic processing demands, priming effects are longer lasting than previously demonstrated priming effects. 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).

McNamara (2005) explained that distributed network models provide a more tenable explanation than spread of activation accounts for long-term semantic priming. McNamara also contended that perhaps the findings of Becker and Joordens (Becker, et al., 1997; Joordens & Becker, 1997) are more readily explained by memory for prior cognitive operations. In his explanation, McNamara states 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, rely on an episodic component, and are specific to the decision being made about the stimulus.

The ALTM task reported here and in earlier studies (Liu & Fu, 2007; Woltz & Was, 2006, 2007) required participants to not only rehearse and recall the memory set exemplars, but to distinguish category membership during and after the memory set presentation and in the category comparison trials (substantial semantic processing). The decisions being made during the memory set presentation and the category comparison trials are category membership decisions (specific to the decision being made) and require and episodic component.

One interpretation of the current findings is that the priming effects demonstrated here represent a learning process. The processing of the memory set, requires the participant to make category membership decisions. These decisions are for specific categories. When faced with the category comparison trials on the second day, participants have previously established the memory operation of deciding whether exemplars are representative of the specific categories.

It is clear that the findings of the current study are not explainable by spread of activation accounts of priming effects. It is the author's opinion that the results represent the strengthening of specific prior memory operations. This process may reflect the creation of LT-WM as proposed by Ericsson and Kintsch (1995) or perhaps long-term semantic transfer as described by McNamara (2005). In either case, as Was and Woltz (2007) stated, the effects found using the ALTM task represent "persistent procedural memory for content-specific memory operations" (p. 100).

The current data have a wide range of implications for cognition and learning. Was and Woltz (2007) found that individual differences in performance of a variant of the ALTM task not only predicted individual differences in a listening comprehension task, but also mediated the effect of WM on comprehension. Perhaps individual differences in priming effects over longer delays would predict learning. This is an interesting hypothesis that will require a great deal of empirical research.

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