

MASKED ANTIPRIMING: A BEHAVIORAL AND EVENT-RELATED
POTENTIAL EXAMINATION OF SHORT-TERM
ANTIPRIMING EFFECTS

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Abstract

Antipriming is a new implicit-memory effect of prior processing of stimuli measured as *impaired* identification of objects following recent encoding of *other* objects (e.g., identifying a piano is impaired by having recently viewed objects that are not pianos; Marsolek et al., 2006). Antipriming effects have been established in several behavioral experiments (with young adults, amnesic patients, and age-matched controls), neurocomputational models, and studies measuring neural activity. In this series of studies, I extended the prior findings by establishing a new masked antipriming paradigm. This new paradigm allowed examination of the antipriming effect in a task where the prime and target are only separated by milliseconds (a short-term memory task) as opposed to the minutes of separation between prime and target in the original task (measuring long-term memory). Experiment 1 demonstrated both repetition priming (faster response times for repetition primed objects compared to objects in a baseline condition) and antipriming (decreased accuracy as compared to baseline identification). In Experiment 2, speed was emphasized in an effort to detect both priming and antipriming in one measure. Experiment 3 was the first experiment to directly examine the role of visual similarity in antipriming and it demonstrated that high visual similarity between objects could result in increased antipriming. An ERP masked antipriming task revealed two main effects. There were no very early effects and the first effect occurred around 500-600 ms as a positive deflection for antiprimed objects compared to baseline and repetition primed items. The second effect began

around 1100 ms also as a positive deflection for antiprimed objects compared to baseline (and sometimes repetition primed items). This effect extends out through 1600 ms and has both a posterior and a frontal location. These effects could be explained by the same theory applied to the long-term memory effects, or they could be due to more immediate effects of competition between object representations.

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Introduction

Priming is one of the most fascinating and well-studied aspects of learning and memory (Tulving & Schacter, 1990). Identification of an item can be improved by prior experience with that particular item (repetition priming), or a related item (conceptual or semantic priming). For example, visually identifying a piano typically is facilitated by having recently viewed a piano. This facilitation does not require deliberate retrieval (explicit memory) of the original stimulus presentation, which is supported by evidence of preserved priming in severely amnesic patients (Warrington & Weiskrantz, 1974; for a review, see Schacter, Chiu, & Ochsner, 1993). Since it does not require awareness, priming is considered an important example of implicit or non-conscious memory (for a review, see Schacter & Buckner, 1998). Recent work in our lab is the first to uncover another implicit memory effect of prior processing of stimuli, namely what we have termed “antipriming” (Marsolek, Schnyer, Deason, Ritchey, & Verfaellie, 2006). This is measured as *impaired* identification of objects following recent encoding of *other* objects (e.g., identifying a piano is impaired by having recently viewed objects that are not pianos).

The neural correlates of antipriming and repetition priming have been investigated using functional magnetic resonance imaging (fMRI) and event-related potentials (ERPs). Interestingly, when a critical new baseline condition is included, fMRI results indicate that the typical repetition-related decreases (less activation for

primed than “unprimed” items) usually found in priming studies can be due to increased activation for the unprimed (or antiprimed) items (compared against baseline) rather than less activation for the repetition primed items (compared against baseline; Marsolek et al., 2007; Marsolek et al., submitted). A late ERP effect (around 1200 – 1600 ms) in left posterior electrodes showed a similar pattern to the fMRI results (a positive deflection in the waveform for antiprimed items compared to baseline and primed items). The inclusion of a baseline condition affords separate measurement of priming and antipriming, two effects that cannot be teased apart when only comparing primed versus unprimed/antiprimed performance. Our behavioral and imaging results emphasize the importance of separating these two effects in correctly conceptualizing long-term memory repetition priming.

In the current series of experiments, I further examine priming and antipriming effects first by extending the antipriming effect to a short-term memory paradigm using a masked procedure in which the target object is preceded by a heavily masked prime object (Experiments 1 and 2). One of the most interesting reasons to use this short-term masked antipriming paradigm is that it enables us to investigate the role of visual similarity in the antipriming effect (Experiment 3). Finally, ERPs were collected using the masked antipriming paradigm (Experiment 4) to investigate the time course of these effects.

Antipriming

Antipriming is a predicted negative consequence of ongoing adjustments that are continually made to superimposed representations of different object shapes (Marsolek, 2003; Marsolek et al., 2006). Superimposed representations afford important benefits (e.g., efficient storage, generalization abilities), but their maintenance in the face of learning new shapes and gaining expertise with old shapes requires ongoing adjustments. The representation of an object is strengthened via small representational changes after the object is identified—the visual representations actually change. These changes are responsible for facilitating subsequent identification for that object (repetition priming), but they also are responsible for impaired identification of other objects when those objects are represented in a manner that is superimposed with the representation of the primed object (antipriming).

The antipriming effect has been demonstrated in young adults, amnesic patients, and neural-network models (Marsolek et al., 2006). In these experiments, we first obtained a measure of familiar object identification unaffected by priming or antipriming (baseline object identification) by having participants identify briefly presented objects following a period of viewing a blank computer display while responding to auditory object names (see Figure 1). Then participants viewed and rated visual objects in an encoding phase. Subsequently, they performed a second

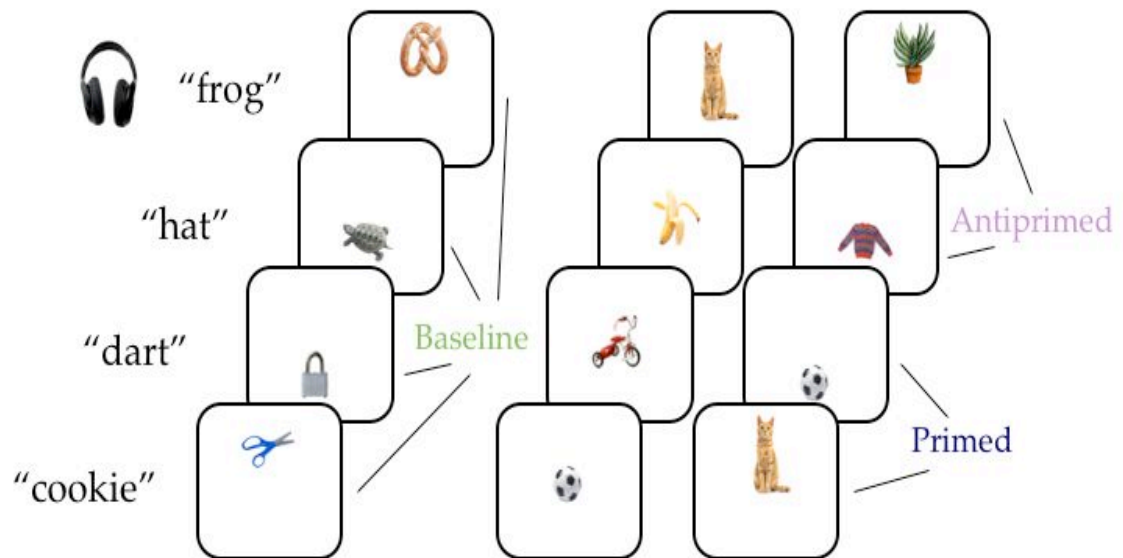


Figure 1 – Antipriming paradigm (figure adapted from Marsolek, Schnyer, Deason, Ritchey, & Verfaellie, 2006). Antipriming and priming effects are measured in comparison to baseline identification.

identification task in which half of the objects were the same as the visual objects just seen in the encoding phase (to measure repetition priming) and the other half were objects that were different from any objects presented previously (to measure antipriming; note that this condition is usually labeled “unprimed” in many experiments). In these experiments, both priming and antipriming were measured in comparison with the baseline condition. Consistently we have demonstrated both priming (higher accuracy for primed versus baseline trials) and antipriming (decreased accuracy for antiprimed versus baseline trials) across several different experiments (see

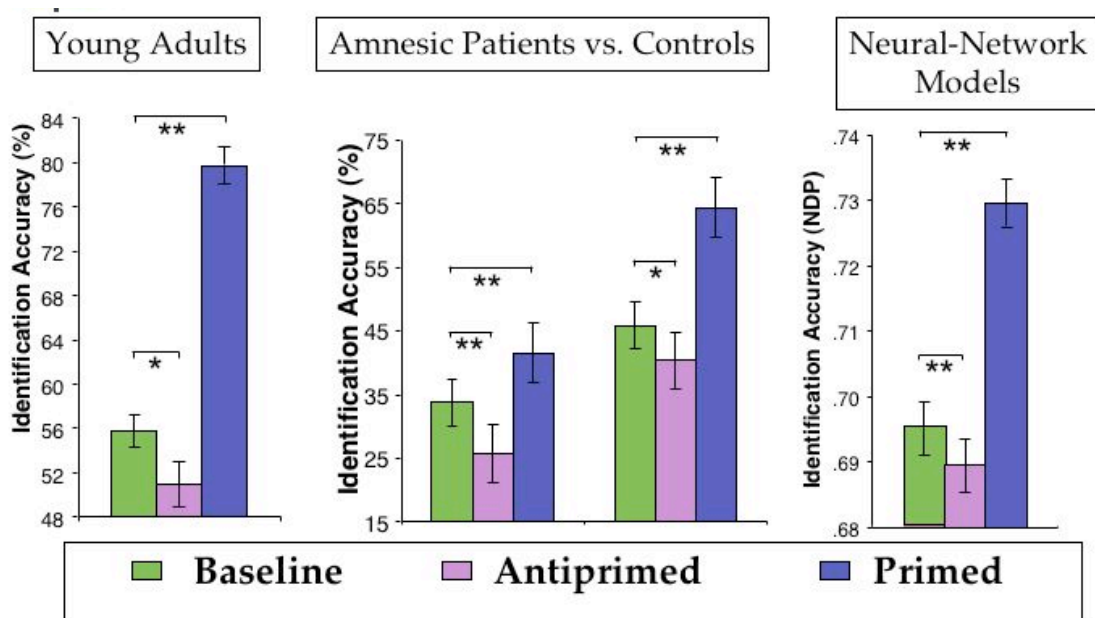


Figure 2 – Results demonstrating repetition priming and antipriming in young adults, amnesic patients, and neural-network models (figure adapted from Marsolek, Schnyer, Deason, Ritchey, & Verfaellie, 2006). Antipriming and priming effects are measured in comparison to baseline identification.

Figure 2). These two effects have been conflated in prior priming experiments, as our “antiprimed” condition would have served as the unprimed condition. The baseline condition is critical for being able to separately measure repetition-priming and antipriming effects.

Typical fMRI and ERP Repetition Effects

With functional magnetic resonance imaging, one can use a blood oxygenation level dependent (BOLD) measure to track neural activity. This technique maps the hemodynamic response in different areas of the brain. Changes in local hemodynamics

(the ratio of oxygenated-to-deoxygenated hemoglobin) are observed as an indirect measure of activity in the brain (Bandettini, Wong, Hinks, Tikofsky, & Hyde, 1992; Bandettini & Ungerleider, 2001; Heeger & Ress, 2002; Kwong et al., 1992; Ogawa et al., 1992). The typical finding with fMRI during repetition-priming tasks is a decrease in BOLD signal elicited by repeated items compared against BOLD signal elicited by new or unprimed items (for reviews, see Henson, 2003; Schacter, Buckner, & Koutstaal, 1998; but for interesting exceptions see Eger, Henson, Driver, & Dolan, 2004; Henson, Shallice, & Dolan, 2000; Schacter et al., 1995; Turk-Browne, Yi, Leber, & Chun, 2007; Yi & Chun, 2005). This decrease has been shown in regions of the ventral temporal cortex, medial temporal cortex, and areas of frontal cortex.

In one study, Buckner et al. (1998) used rapid presentation event-related functional neuroimaging to examine the neural correlates of object priming. Participants were first presented with a set of objects in a study phase outside of the scanner. Each object was presented six times in the study phase to enhance the repetition priming. In both the study phase and the following test phase, participants had to decide whether objects could move of their own accord. Novel (i.e., unprimed) object classification, when compared against fixation trials, activated areas including striate, extrastriate, and left dorsal prefrontal cortices as well as several other regions (see Figure 3). As in most repetition priming studies, the repetition-related deactivation was not found in earlier visual areas. Repetition-related reductions were observed in the

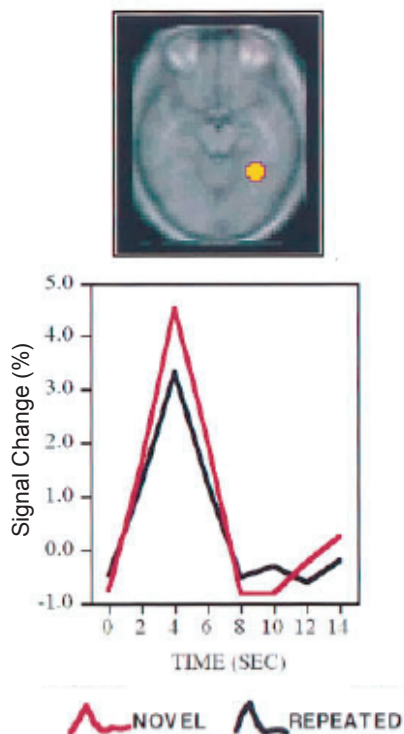


Figure 3 – Typical fMRI repetition effect as demonstrated in Buckner et al. (1998). (Reprinted from *Neuron*, 20, Buckner et al., Functional-anatomic correlates of object priming in humans revealed by rapid presentation event-related fMRI, pg 285-296, copyright (1998), with permission from Elsevier)

higher-level visual processing stream from extrastriate cortex extending to the inferior temporal cortex.

Several theories have been proposed to explain the fMRI repetition effects (for a review, see Grill-Spector, Henson, & Martin, 2006). The most influential theory posits that priming is caused by sharpening, or tuning, of representations (Desimone, 1996; Wiggs & Martin, 1998). The first presentation of a stimulus results in firing of many neurons involved in the distributed representation of the stimulus. On the second

presentation of a stimulus, only a subset of those original neurons fires – presumably those representing the important and diagnostic features of the stimulus. With each repetition, sharpening results in sparser object-specific representations allowing for more efficient, faster processing since fewer neurons are firing. Fewer neurons firing in response to repeated stimuli results in the measured decrease in BOLD signal.

Another theory proposes that priming is caused by fatigue. All of the neurons that initially respond to a stimulus are less able to respond when the stimulus is presented again due to fatigue (Miller & Desimone, 1994). Thus, these neurons do fire to the repeated stimulus but at a reduced rate. The overall decrease in neuronal firing is responsible for repetition-related deactivations in fMRI. This theory differs from the sharpening theory in that the repetition-related decreases should be most prominent in cells that are important for representing the stimulus, while in the sharpening theory repetition-related decreases are most evident in neurons that are not necessary for representing the stimulus. Studies examining “fMRI adaptation” rely on such fMRI repetition effects (Grill-Spector, Kushnir, Hendler, & Malach, 2000; Grill-Spector & Malach, 2001; for a review see Kourtzi & Grill-Spector, 2005).

A third possibility, the facilitation/accumulation theory (Henson & Rugg, 2003; James et al., 2000; James & Gauthier, 2006), proposes that with repetition, stimulus-related activation is of a shorter duration or shorter latency. One explanation is that stimulus information is accumulated more rapidly with repetitions (James & Gauthier, 2006). The same neurons initially firing are still active, but duration of neuronal

activity is shorter for repeated stimuli than for the first presentation. Since the hemodynamic response is averaged over seconds, a shorter duration or latency could result in a decrease in the BOLD signal as seen in repetition deactivations.

While functional neuroimaging can provide excellent spatial resolution, electrophysiological measures can offer more precise temporal resolution. Event-related brain potentials reflect scalp-recorded changes in brain electrical activity time-locked to a specific event (Coles & Rugg, 1995; Kutas & Dale, 1997; Rugg & Allen, 2000). When these changes in electrical activity are averaged across trials representing single conditions, ERP waveforms reflect time-locked neural activity that can be used to examine millisecond differences between experimental conditions. Typically, the repetition of a stimulus evokes a positive deflection in the ERP waveform compared with the waveform evoked by the first stimulus presentation, and this effect occurs across widely distributed electrode sites (Rugg, 1995; e.g., see Figure 4). This positive deflection is present from 250-600 ms post-stimulus in many studies (Badgaiyan & Posner, 1997; Benten, Moscovitch, & Heth, 1992; Doyle, Rugg, & Wells, 1996; Paller & Gross, 1998; Rugg, 1987; Rugg, Doyle, & Melan, 1993). Interestingly, a few studies also have demonstrated an earlier (before 200 ms post-stimulus) negative deflection for repeated items (Rugg, 1987; Doniger et al., 2001; Penney, Mecklinger, & Nessler, 2001; Rugg, Soardi, & Doyle, 1995).

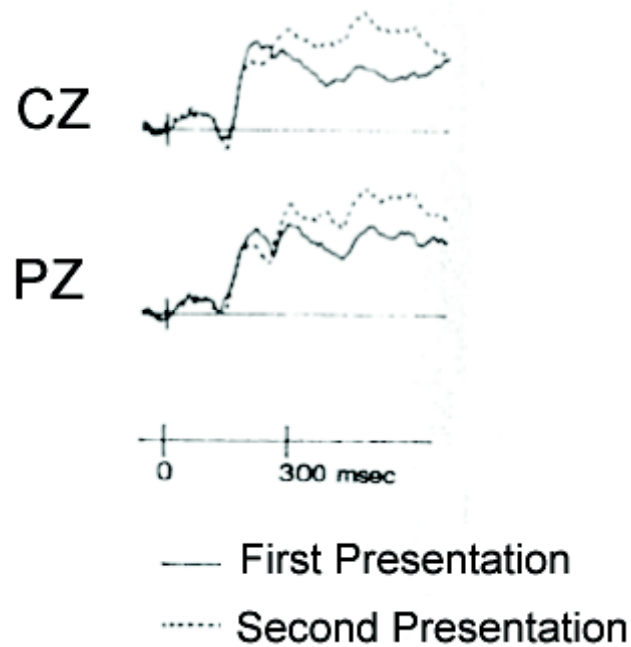


Figure 4 –Typical ERP repetition effect as demonstrated in Rugg (1987). There is a widespread positive deflection in the waveform around 300 ms for repeated words compared to the first presentation of a word shown at a central (CZ) and a posterior (PZ) electrode. (Reprinted with permission of Psychology Press (Informa-Healthcare Journals) from *The Quarterly Journal of Experimental Psychology*, 39A, Rugg, M. D., Dissociation of semantic priming, word and non-word repetition effects by event-related potentials, pg 123-148, copyright (1987); permission conveyed through Copyright Clearance Center, Inc)

The ERP repetition-related effect beginning around 250 ms is often interpreted as reflecting the same kind of efficiency or habituation hypothesized for fMRI findings (Gruber, Malinowski, & Muller, 2004; Gruber & Muller, 2005; Penney et al., 2001; Rugg et al., 1995).

fMRI and ERP Antipriming Effects

In typical priming experiments, there is no separate baseline condition and priming effects are measured in comparison with an “unprimed” condition, which is analogous to our antiprimed condition. The usual finding with fMRI during repetition-priming tasks is a decrease in fMRI signal elicited by repeated items compared against the signal elicited by new or unprimed items. To examine the neural correlates of the antipriming effect, we conducted an fMRI experiment using the paradigm described above (Marsolek et al., 2007). We observed the typical decreased activation in left occipito-temporal cortex for repeated items when compared to antiprimed items (unprimed items in standard procedures). Most important, primed items elicited no difference in activation compared with baseline items, but antiprimed items elicited greater activation than baseline items (See Figure 5).

We also examined biologically plausible neural network models of object identification and the priming and antipriming effects that occur in these models with ongoing learning/re-learning of objects. These computational models were trained to identify the same objects used in the fMRI experiment by using small changes in the weights on the connections to accomplish learning and by using partially overlapping representations of the object shapes. Once trained, the models were put through simulations of the antipriming experiment. Since relearning of objects takes place after every identification, these models can be used to simulate visual object priming (Stark & McClelland, 2000) and antipriming (Marsolek et al., 2006) effects in brain regions

involved in visual object identification. We found that the fMRI findings are not predicted by patterns of activations of processing units (simulating neuronal spiking activity), but instead are better predicted by the magnitudes of errors in object identification that are used to guide subsequent changes in weights between units for learning/re-learning (simulating synaptic modifications; Marsolek et al., 2007; Marsolek et al., submitted). These errors are used after identification has been made to strengthen or weaken weights on connections for maintenance relearning. Greater error occurs in the antiprimed condition than in either the baseline or primed condition, which might correspond with the increase in the fMRI signal. This interpretation is in contradiction to the current popular view that repetition-related findings in fMRI are due to greater efficiency of processing primed objects than unprimed objects or to a habituation effect.

The typical repetition-related reduction is thought to be analogous to “repetition suppression effects” demonstrated in single-cell recording data (Desimone, 1996; Wiggs & Martin, 1998). In single-cell recordings of neurons in the inferior temporal cortex area of rhesus monkeys, firing rates often but not always are smaller when elicited by repeated stimuli compared with the first presentation of the stimuli (Li, Miller, & Desimone, 1993). The magnitude of this reduction can continue to grow with each stimulus repetition until activity stabilizes after 6-8 presentations. Around 100 ms post-stimulus, the responses of populations of cells can distinguish a novel stimulus from a stimulus presented once before. Fast processing times of neurons in inferior temporal cortex suggest priming is an automatic process and top-down effects are

unlikely to be responsible for this effect (Xiang & Brown, 1998). Although it is not clear that the results of these studies reflect the same mechanism that is being measured in the fMRI repetition effects (Henson & Rugg, 2003). Supporting this suggestion, our computational models suggest that the patterns in the fMRI data might be reflective of synaptic modifications (represented by the magnitude of errors leading to weight changes on connections after identification) in visual object identification areas. The neuronal spiking activity measured in the single cell recordings would be more related to the magnitude of processing unit activations in the model, which did not serve as a good predictor of the fMRI pattern. The antipriming fMRI and computational model findings suggest a re-conceptualization of what is underlying the fMRI priming effects. Potentially, the lower magnitude activation typically found for repeated items in priming studies is more related to increased activation in the antipriming/unprimed condition rather than decreased activation in primed conditions.

To complement and extend the fMRI investigations of antipriming, a parallel experiment was performed measuring ERPs (Deason, Steele, Bernat, Patrick, & Marsolek, 2006, 2007; Marsolek et al., submitted; see Figure 6). In typical ERP reports, little attention is paid to later time windows, and more focus is given to the positive ERP deflection in waveforms around 250 ms after stimulus onset for primed items compared against unprimed items (Rugg, 1995).

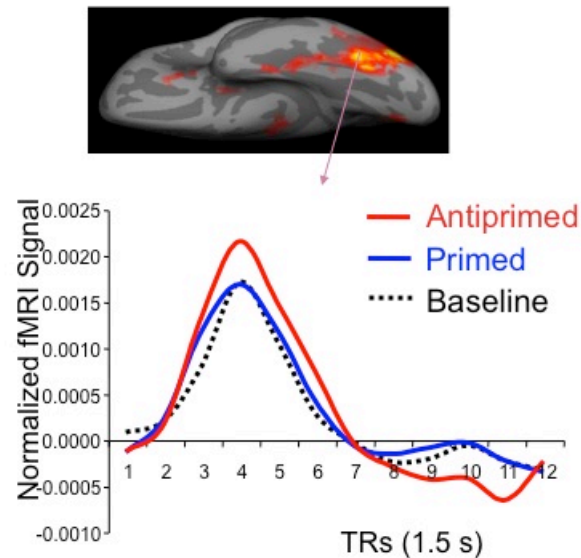


Figure 5 –Antipriming fMRI results showing comparison between primed, antiprimed, and new baseline conditions (Marsolek et al., 2007; Marsolek et al., submitted).

We found this widely distributed early ERP effect in our data as well, but this effect may reflect a different process from what underlies the fMRI results, given that the pattern of early ERP results and the pattern of fMRI results are different. The typical early ERP effect may be related to one of the efficiency of processing theories described above or to explicit memory for the repeated stimuli.

The correspondence between the fMRI pattern and the computational models suggest that the increased activity for antiprimed items is a result of post-identification weight changes. This hypothesis was directly tested in the ERP experiment by focusing on later time windows. When examining later time windows in the ERP data, a similar pattern to the fMRI results was observed. There was a later effect (roughly 1200-1600

ms) in left posterior electrodes in which the antiprimed waveform is more positive than both the primed and baseline waveforms (which did not differ). The mean response time was 855 ms, which confirms that the later effect definitely reflected post-identification processes. This finding could reflect the same processes that are reflected in the fMRI activation patterns (which are averaged over several seconds).

Masked Antipriming

To extend antipriming effects to short-term memory and to investigate the role of visual similarity, I developed a masked antipriming paradigm. Masked priming is a technique in which there is a heavily masked prime briefly presented before a target item (Forster, 1998; Forster & Davis, 1984; for a recent review see Kouider & Dehaene, 2007). This sequence occurs in such a manner that the prime is not consciously perceived by the participant. Even though it is not consciously processed, the prime has a demonstrated effect on the target. In behavioral studies, repetition-priming effects have been demonstrated by showing that response times to primed targets are faster than to unprimed targets. This paradigm could easily be adapted to contain primed and antiprimed conditions, as well as the baseline condition critical to distinguishing between priming and antipriming effects.

Masked priming also has the benefit of limiting the use of explicit-memory processes and therefore helping to isolate automatic, implicit-memory mechanisms of priming. Forster and colleagues argue that masking is necessary to examine priming

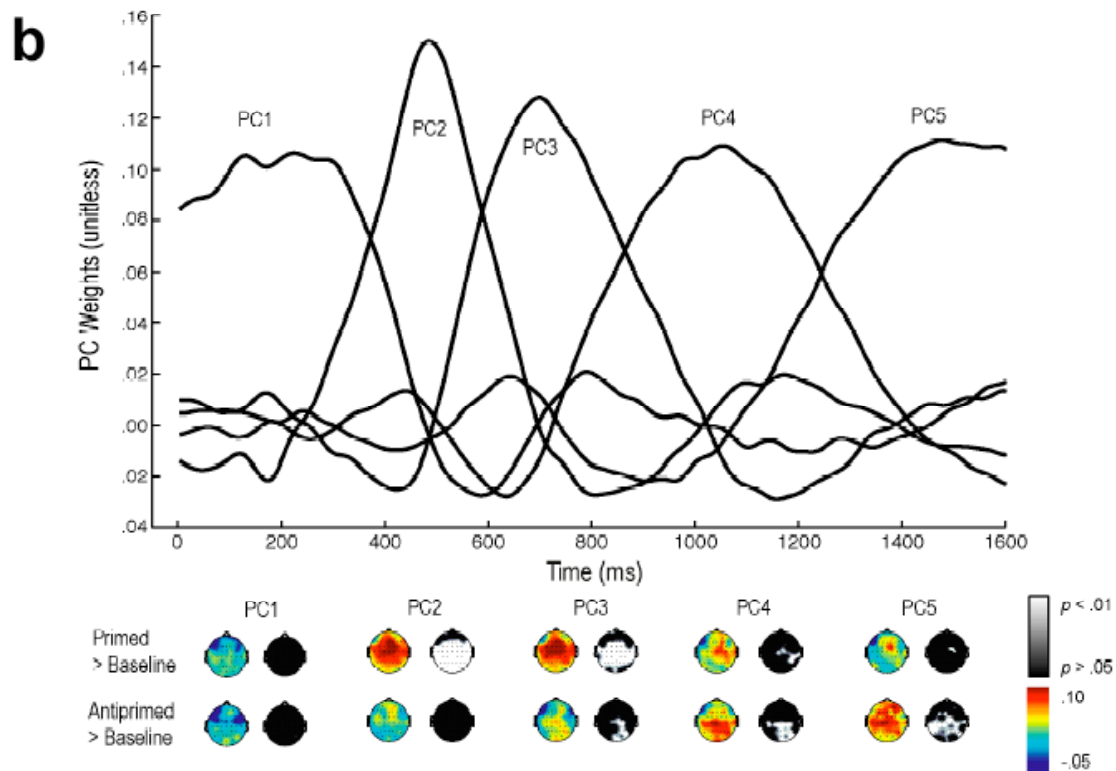
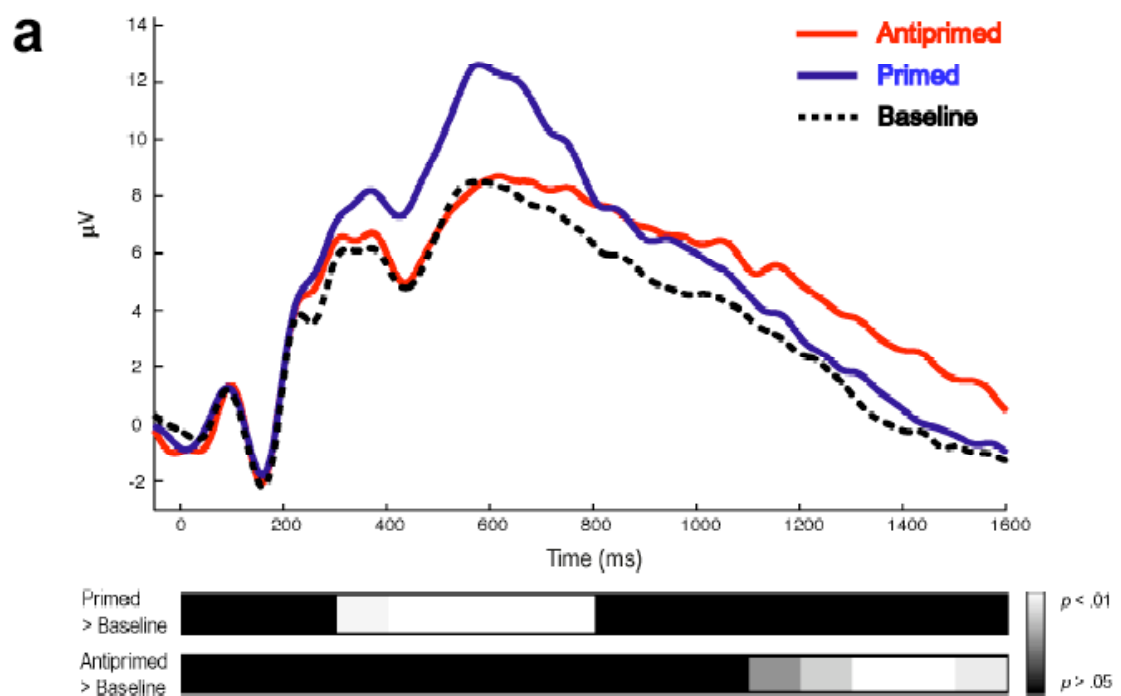


Figure 6 - ERP results from Marsolek et al. (submitted). (a) ERP waveforms from the five electrodes closest to the left lateral occipital-temporal fMRI area, for baseline, primed, and antiprimed conditions. Levels of gray reflect the significance of primed > baseline and antiprimed > baseline tests every 100 ms poststimulus. (b) Principal components analysis (PCA) decomposition of waveforms from all electrodes. Topographic amplitude and significance head maps reflect priming > baseline and antiprimed > baseline condition differences for each component. Both analyses indicate that the pattern of fMRI results (Figure 5) occurs only relatively late after object presentations.

without explicit memory contamination (Forster, 1998; Forster & Davis, 1984).

Masked priming is also thought to reflect more feedforward processes rather than contributions from top-down feedback processes (Dehaene et al., 2001; Lamme, Zipser, & Spekreijse, 2002).

Masked priming has been successfully used in ERP studies with words (Dehaene et al., 2001; Holcomb, Reder, Misra, & Grainger, 2005; Holcomb & Grainger, 2006; Misra & Holcomb, 2003; Petit, Midgley, Holcomb, & Grainger, 2006; Schnyer, Allen, & Forster, 1997) and in one recent study with objects (Eddy, Schmid, & Holcomb, 2006). In particular, ERP masked priming studies have been used to further explore the time course of word and object recognition as well as priming. Using a variation of this paradigm to examine the time course of short-term antipriming seems a necessary next step in better understanding the processes underlying antipriming.

Since the presentation of the prime and the target are very close in time, this technique is measuring short-term memory repetition effects (on the order of milliseconds) unlike in the previous antipriming paradigm in which repetitions occur

over many minutes. If antipriming is observed using masked priming, then the antipriming effect can be extended to short-term memory processes. Potentially, this may reflect different underlying mechanisms than long-term priming.

A masked antipriming paradigm could be used to answer one of the most important questions about the nature of the antipriming effect. One outstanding question is whether visual similarity underlies antipriming. The theory currently used to explain the antipriming effect requires that an antiprimed object have a visual form representation that is superimposed with the representation of an object that was previously processed and therefore strengthened and primed. This implies that the two objects must share some type of common visual feature(s). Therefore predictions can be made about levels of antipriming resulting from differing levels of visual similarity. Increased visual similarity between objects should result in higher levels of antipriming. Using masked antipriming, the researcher is in control of which stimulus antiprimes another within a trial, and a particular prime-target pairing could be set up to directly test this question by experimentally manipulating the level of visual similarity (though there might also be uncontrolled across-trial cumulative antipriming effects that could contribute to performance).

The establishment of a masked antipriming effect can potentially help better understand aspects of priming and antipriming effects. First, I tested whether antipriming is limited to a long-term memory effect or whether it can be measured in a short-term task. Second, I examined the role of visual similarity in the antipriming

effect. By using the masked antipriming effect, I tested both of these questions as well as investigated the distinct contributions of priming and antipriming to repetition effects in ERPs.

Experiment 1: Establishment of the Masked Antipriming Paradigm

The first step in investigating short-term priming and antipriming effects was to develop a new behavioral paradigm. Experiment 1 established a masked priming paradigm that included not only a repetition priming condition, but also a measure of antipriming.

Method

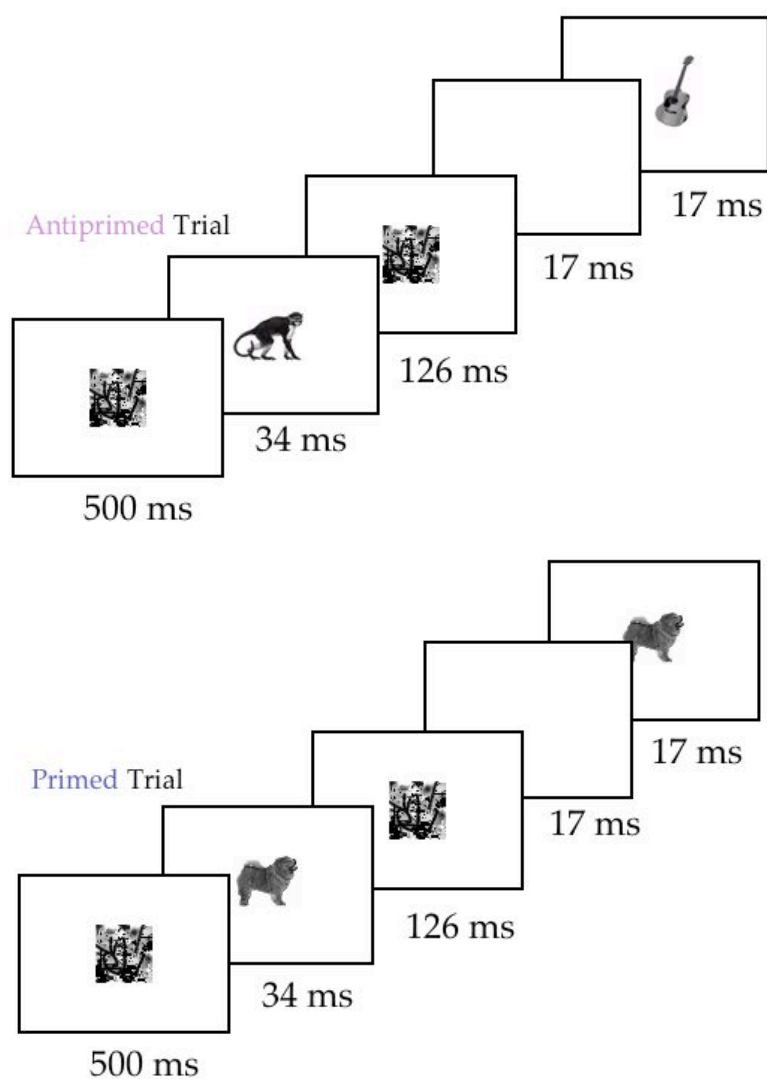
Participants

Participants were 40 University of Minnesota undergraduate students (half male, half female) participating either for research credit or payment. All participants had normal or corrected-to-normal vision. All participants gave written, informed consent in accordance with procedures and protocols approved by the human subjects review committee of the University of Minnesota.

Materials

The stimuli were 250 grayscale photographs and line drawings of familiar visual objects (5.4 degrees in height). An additional 10 objects were used for practice and buffer trials at the beginning of the session. The objects were a subset of stimuli developed for another study of object priming (Koutstaal et al., 2001). The stimuli were divided into 5 lists of 50 objects counterbalanced on several variables including object frequency, object name word frequency, object typicality, and semantic category of the

object. None of the objects were highly similar to another in the set, and all had different entry-level names (Jolicoeur, Gluck, & Kosslyn, 1984). Across subjects, the five lists were rotated through target and prime conditions to ensure full counterbalancing.



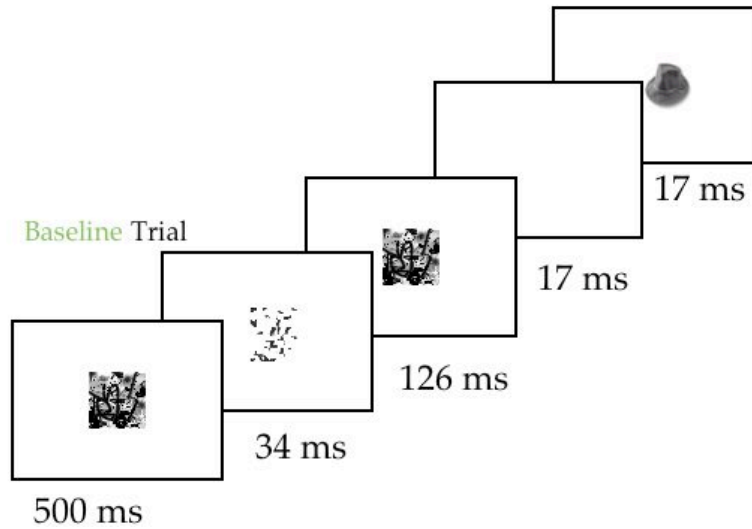


Figure 7 – Sequence of events for trials in Experiment 1, depicting examples of the three main conditions (antiprimed, primed, and baseline).

Procedure

The procedure was loosely based on another masked priming study that used objects as stimuli (Eddy et al., 2006). There were 150 trials consisting of 50 primed, 50 antiprimed, and 50 baseline trials pseudorandomly intermixed so that no more than three of the same trial type appeared consecutively. First, the participant was presented with a 500 ms forward mask, a 34 ms prime, and a 126 ms backward mask. At the end of this sequence and following 17 ms of a blank screen, a target object was presented for 17 ms (see Figure 7). The participant was instructed to verbally identify the target object as quickly and accurately as possible and name it aloud into a microphone (see the Appendix for instructions). There was a one second interval after the response was

initiated before the next trial commenced. Acceptable identifications were the entry-level names for the objects, with close synonyms also counting as correct responses.

In the repetition-primed condition, the prime and the target were the same object. In the antiprimed condition, the prime and the target were different objects (and not of the same general category). In the baseline condition, the prime was a scrambled version of an object not used in any other condition for that participant and the target was another object. The same mask was used in all conditions as both the forward and backward mask.

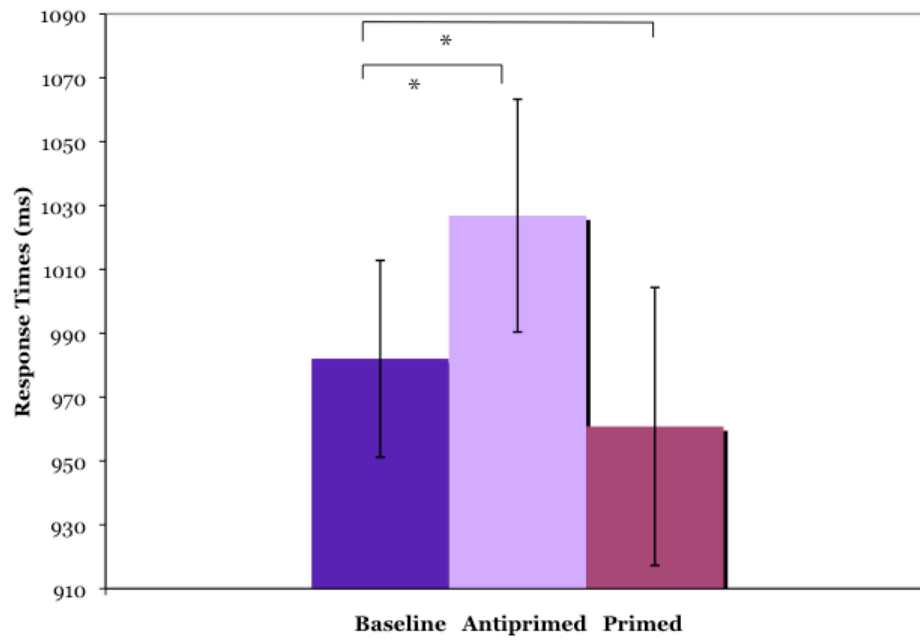
Results

Two repeated-measures analyses of variance (ANOVAs) were conducted using type of prime (primed, antiprimed, or baseline) as the within-subject independent variable, and using mean error rates and mean response times for correct identifications as the dependent measures. The counterbalanced assignment of object lists to conditions was also included as a between-subjects variable to pull out variance due to assignments of particular objects to particular conditions (Pollatsek & Well, 1995). One participant was removed from analyses after determining they were an outlier in overall response times (overall response time mean was more than 2.5 standard deviations above the general average).

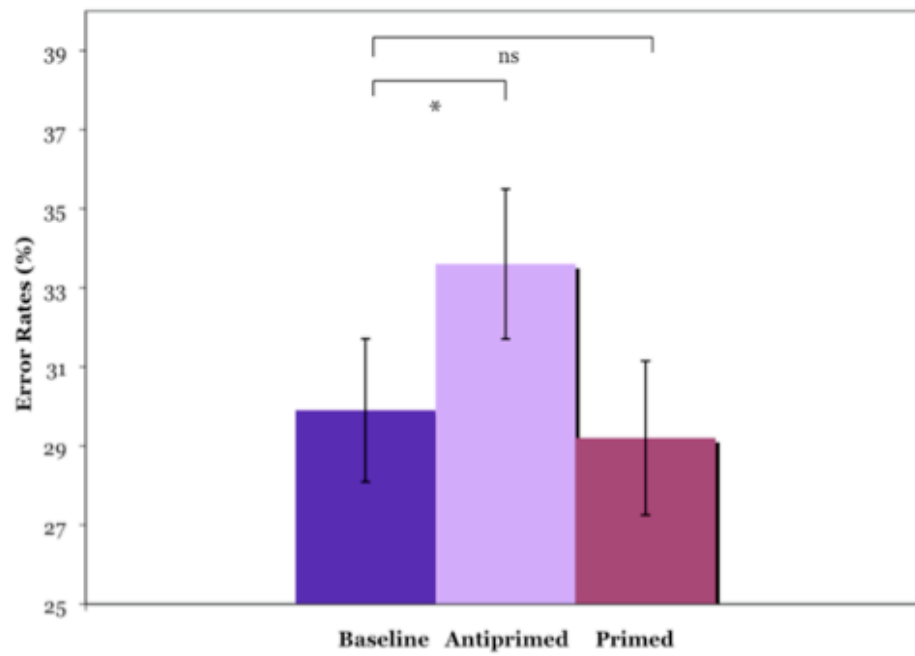
The response time distribution was positively skewed (skew = 1.9, kurtosis = 4.7) and therefore the response data for each subject was logarithmically transformed

before statistical analyses (untransformed response time data are presented in the text and figures for ease of interpretation). The main effect of type of prime was significant for mean response times of correctly identified objects ($F(2,68) = 25.5$, $MS_e = .051$, $p < .001$; see Figure 8a). Primed objects were identified faster (961 ms¹) than objects in the baseline condition (982 ms; $F(1,68) = 21.93$, $MS_e = .044$, $p < .001$) and also in the antiprimed condition (1026 ms; $F(1,68) = 49.16$, $MS_e = .099$, $p < .001$). There was also a significant difference between the antiprimed (1026 ms) and baseline (982 ms) conditions ($F(1,68) = 5.42$, $MS_e = .011$, $p < .05$). There was a significant interaction with type of prime and counterbalancing list ($F(8,68) = 3.34$, $MS_e = .0067$, $p < .05$). Counterbalancing lists 2, 3, 4 and 5 appeared to be driving the main effect of prime type (List 2: $F(2,12) = 7.38$, $MS_e = .018$, $p < .01$; List 3: $F(2,12) = 7.93$, $MS_e = .015$, $p < .01$; List 4: $F(2,12) = 7.80$, $MS_e = .013$, $p < .01$; List 5: $F(2,12) = 10.45$, $MS_e = .028$, $p < .01$). For lists 4 and 5, objects in the antiprimed condition (List 4: 1162 ms; List 5: 1184 ms) were identified slower than objects in the baseline condition (List 4: 1119 ms, $F(1,12) = 6.63$, $MS_e = .011$, $p < .05$; List 5: 1008 ms, $F(1,12) = 8.81$, $MS_e = .023$, $p < .05$). For list 3, objects in the primed condition (942 ms) were identified faster than the objects in the baseline condition (963 ms; $F(1,12) = 15.1$, $MS_e = .028$, $p < .01$).

The main effect of type of prime was also significant for mean identification error rates ($F(2,68) = 3.95$, $MS_e = .022$, $p < .05$; see Figure 8b). Most importantly, antiprimed objects were identified less accurately with higher error rates (33.6%) than objects in the baseline condition (29.9%; $F(1,68) = 4.93$, $MS_e = .027$, $p < .05$).



a)



b)

Figure 8 – a) Mean response times (untransformed) for Experiment 1 by condition. b) Mean error rates for Experiment 1 by condition. Error bars reflect standard error of the mean. (* $p < .05$)

Antiprimed objects also had higher error rates than primed objects (29.2%; $F(1,68) = 6.77$, $MS_e = .038$, $p < .05$). With error rates, there was no significant difference between the primed (29.2%) and baseline (29.9%) conditions ($F < 1$).

Discussion

In previous priming experiments, researchers compared the primed condition with an “unprimed” condition, which according to our theory should be understood as an antiprimed condition. In this experiment, there were significant differences between the antiprimed and primed conditions in both error rates and response times. This is a replication of typical repetition priming effects.

Primed objects were identified more quickly than baseline and antiprimed objects in the masked priming experiment. Only three other studies have attempted to investigate masked priming with objects (rather than words). Two studies have found the typical priming effect (primed objects responded to quicker than unprimed/”antiprimed” objects; Dell’Acqua & Grainger, 1999; Harris, Dux, Benito, & Leek, 2008). The only ERP masked object priming study did not have a behavioral measure of priming (Eddy et al., 2006). The current study offered more evidence that a

behavioral effect of repetition priming can be measured successfully in error rates as well as in response times.

Most importantly, the results showed that an antipriming effect could be found in a masked priming paradigm. A significant antipriming effect was demonstrated in error rates with antiprimed objects identified less accurately (higher error rates) than baseline or primed objects. Antiprimed objects also took longer to identify than primed or baseline objects. This is the first investigation of the antipriming effect outside the long-term effect found in the paradigm developed by Marsolek et al. (2006). Antipriming effects can be found in a short-term memory experiment – with prime and target only separated by milliseconds rather than the many minutes in the long-term tests. These results also suggest that a masked priming paradigm can be successfully used to explore different aspects of the antipriming effect that cannot readily be explored via the long-term memory paradigm that has been used in prior experiments.

It is unclear whether there is an interesting reason that the antipriming effect emerges strongly in error rates while repetition priming effects are significant in response times. The trade-off between accuracy and response times can be described by a speed-accuracy trade-off function, with different experimental conditions exhibiting slightly different functions (Wickelgren & Corbett, 1977). In this masked priming experiment, the three different conditions may be associated with slightly different speed-accuracy tradeoff curves (see Figure 9), which were not measured because the experiment afforded only one mean accuracy rate and one mean response time per

condition per subject. The mean accuracy rate and the mean response time in this experiment may have landed on the points depicted in the hypothetical curves illustrated in Figure 9. In this way, a significant repetition priming effect was found only in response times and a significant antipriming effect was found in both error rates and response times. Potentially, a change in instructions could result in mean accuracy rates and mean response times that land on different points on these curves. In the next experiment, I tested this possibility in an attempt to elicit both effects in both dependent measures.

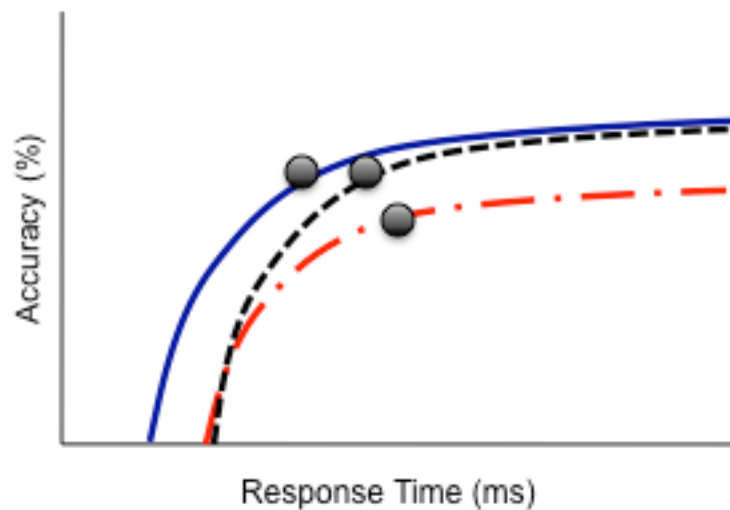


Figure 9 - Hypothetical speed-accuracy trade-off curves for the three conditions (antipriming = dash, baseline = dotted, priming = solid).

Experiment 2: Refining the Masked Antipriming Paradigm

The findings from Experiment 1 suggested that the masked antipriming paradigm was successful in isolating the separate effects of repetition priming and antipriming in a short-term memory test.

One curious aspect of the results of Experiment 1 is that the antipriming effect was strong in both error rates and response times but the priming effect was strong only in response times. It is possible that the conditions may be associated with slightly different speed-accuracy trade-off curves (see Figure 9). In Experiment 2, I tested whether a change in instructions would cause the mean accuracy rates and the mean response times to land on different points (to the left) on their tradeoff curves that are more amenable to finding significant priming and significant antipriming effects in the same dependent measure (see Figure 10). Because the baseline condition may have a steeper slope at the appropriate part of its tradeoff function compared with the primed and antiprimed conditions, an emphasis on speeded responses could have the intended effect. Emphasizing quick response times over accuracy might enable both significant priming and significant antipriming to be measurable in the both dependent measures in the masked antipriming paradigm. By slightly varying the instructions given to the participants, I sought in this experiment to replicate and strengthen effects found in Experiment 1.

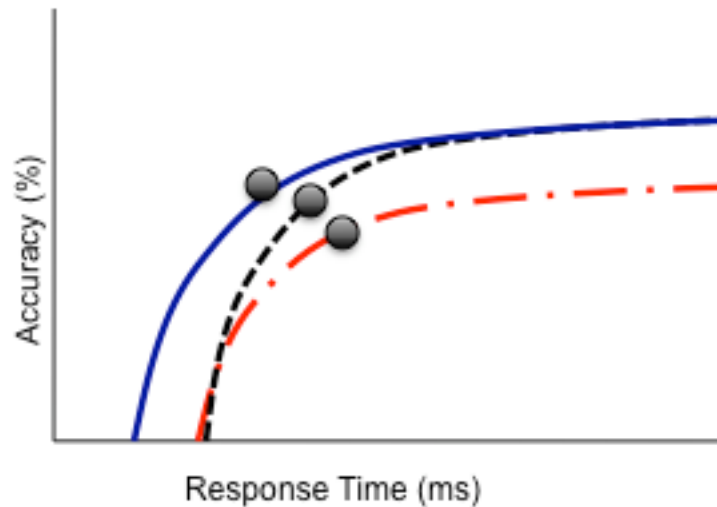


Figure 10 - This depicts the results of a leftward shift in positions of the condition means on the hypothetical speed-accuracy trade-off curve due to emphasizing quick response times (antipriming = dash, baseline = dotted, priming = solid).

Method

Participants

Participants were 40 University of Minnesota undergraduate students (half male, half female) participating either for research credit or payment. All participants had normal or corrected-to-normal vision. Participants gave written, informed consent in accordance with procedures and protocols approved by the human subjects review committee of the University of Minnesota.

Materials and Procedure

The stimuli and procedure were identical to those used in Experiment 1. The only difference was that participants were instructed to respond as quickly as possible with no emphasis on accuracy (see the Appendix for the exact instructions).

Results

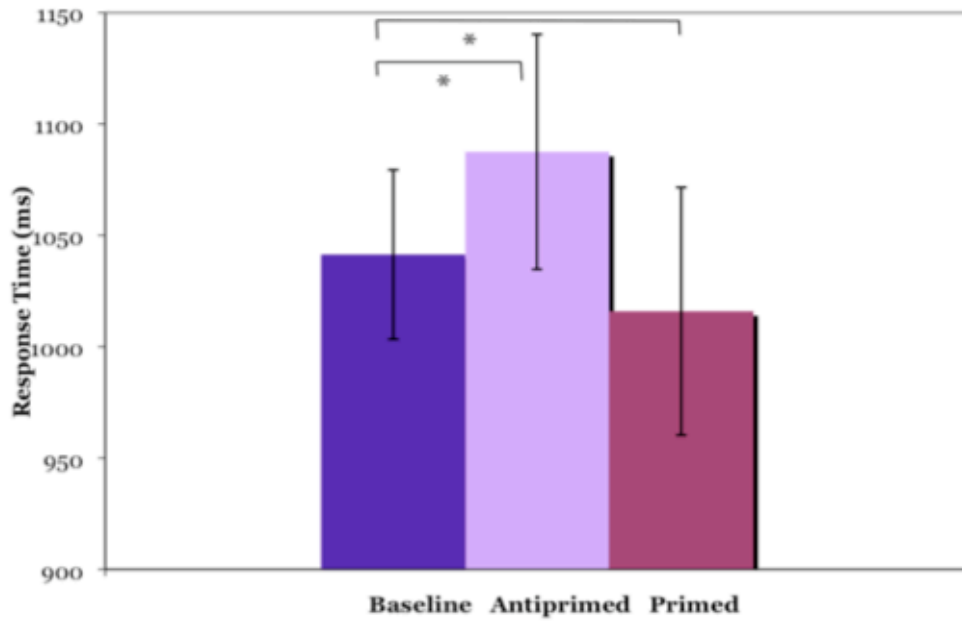
Two repeated-measures analyses of variance (ANOVAs) were conducted using type of prime (primed, antiprimed, or baseline) as the within-subject independent variable, and with dependent measures of error rates and response times for correct identifications. The counterbalanced assignment of object lists to conditions was also included as a between-subjects variable to pull out variance (Pollatsek & Well, 1995).

The response time distribution was positively skewed and therefore the response data for each subject was logarithmically transformed before statistical analyses (untransformed response time data are presented in the text and figures for ease of interpretation). The main effect of type of prime was significant for logarithmically transformed response times of correctly identified objects ($F(2,70) = 12.47$, $MS_e = .0396$, $p < .001$; See Figure 11a). Primed objects were identified faster (1016 ms) than objects in the baseline condition (1041.4 ms; $F(1,70) = 5.25$, $MS_e = .0167$, $p < .05$) and objects in the antiprimed condition (1089.5 ms; $F(1,70) = 24.88$, $MS_e = .0792$, $p < .001$). Most importantly, there was also a significant difference between the antiprimed

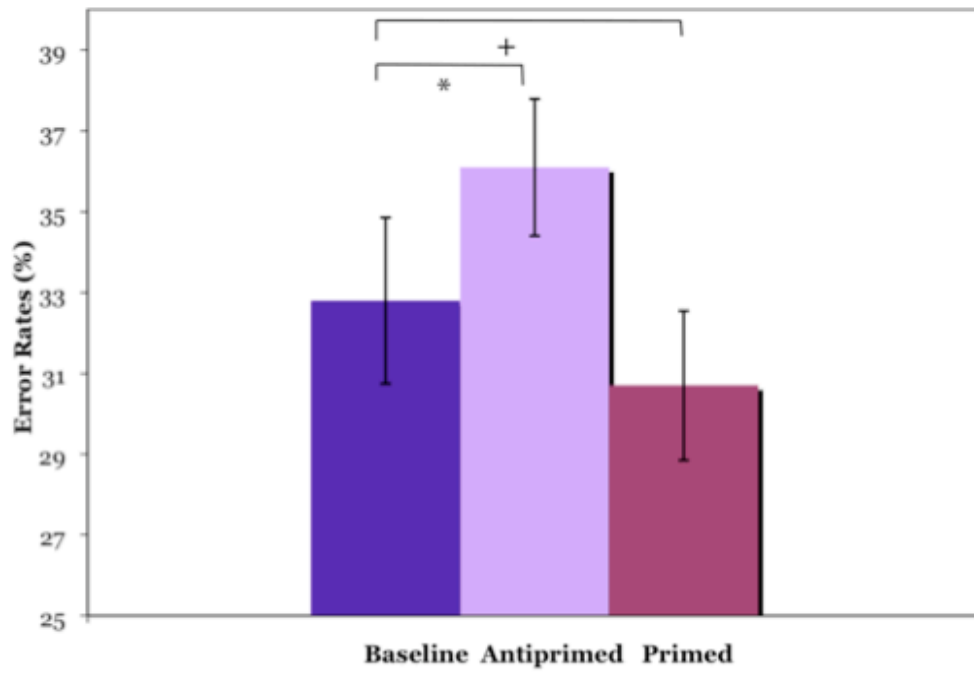
(1087.5 ms) and baseline (1041.4 ms) conditions with the baseline condition identified faster than the antiprimed condition ($F(1,70) = 7.27$, $MS_e = .0231$, $p < .01$).

The main effect of type of prime was also significant for mean error rates ($F(2,70) = 8.46$, $MS_e = .02715$, $p < .001$; See Figure 11b). Most importantly, antiprimed objects were identified with more errors (36.1%) than objects in the baseline condition (32.8%; $F(1,70) = 5.74$, $MS_e = .01842$, $p < .05$) and also more errors than primed items (69.3%; $F(1,70) = 16.76$, $MS_e = .0538$, $p < .001$). With error rates, there was no significant difference between the primed (30.7%) and baseline (32.8%) conditions although the numerical trend is in the expected direction ($F(1,70) = 2.88$, $MS_e = .009$, $p < .10$). There was a significant interaction with type of prime and counterbalancing list ($F(8,70) = 2.31$, $MS_e = .007413$, $p < .05$). Counterbalancing lists 4 and 5 appeared to be driving the main effect of prime type (List 4: $F(2,14) = 20.34$, $MS_e = .035$, $p < .001$; List 5: $F(2,14) = 12.24$, $MS_e = .023$, $p < .001$). For list 4, objects in the antiprimed condition had a higher error rate (45.8%) than objects in the baseline condition (35%; $F(1,14) = 27.0$, $MS_e = .046$, $p < .001$). For list 5, objects in the primed condition (24.7%) had fewer errors than the objects in the baseline condition (31.5%; $F(1,14) = 9.85$, $MS_e = .018$, $p < .001$).

Figure 11 – a) Mean response times (untransformed) from Experiment 2 by condition. b) Mean error rates from Experiment 2 by condition. Error bars are the standard error of the untransformed means. ($p < .05$; + $p < .10$)*



a)



b)

Discussion

This experiment replicated the findings from Experiment 1. With the slight variation in instructions to the participants, these results also demonstrated both the priming and antipriming effects in the both dependent measures. Primed objects were identified faster than both baseline and antiprimed objects. In error rates, primed objects were identified with fewer errors than baseline (marginally significant) and antiprimed objects. In addition, antiprimed objects were identified slower and less accurately than objects in the baseline condition.

Experiment 3: Exploring the Role of Visual Similarity in Masked Antipriming

The results of Experiment 1 and 2 established a masked antipriming paradigm demonstrating both priming and antipriming effects. One of the exciting potential uses of this paradigm is to explore the role of visual similarity in antipriming. This study is the first to experimentally manipulate visual similarity to determine whether antipriming is indeed related to this variable.

The current theory offered for long-term priming and antipriming effects requires superimposed and overlapping visual object representations. In this theory, weight changes to superimposed visual object representations lead to both positive effects (repetition priming) and negative effects (antipriming; Marsolek, 2003; Marsolek et al., 2006). In particular, for the antipriming effect to occur two objects must share some type of common visual feature(s). Therefore predictions can be made about levels of antipriming resulting from differing levels of visual similarity. Increased visual similarity between objects should result in higher levels of antipriming (see Figure 12 for a schematic of the potential effects of high and low visual similarity).

The masked antipriming paradigm developed in Experiments 1 and 2 is uniquely suited for investigating this question because of the close pairing of the prime and target. In the long-term memory antipriming experiments, visual similarity between the objects in the encoding and test phases can be manipulated, but there is no control over which exact object may be antipriming another. Since the target and prime are directly

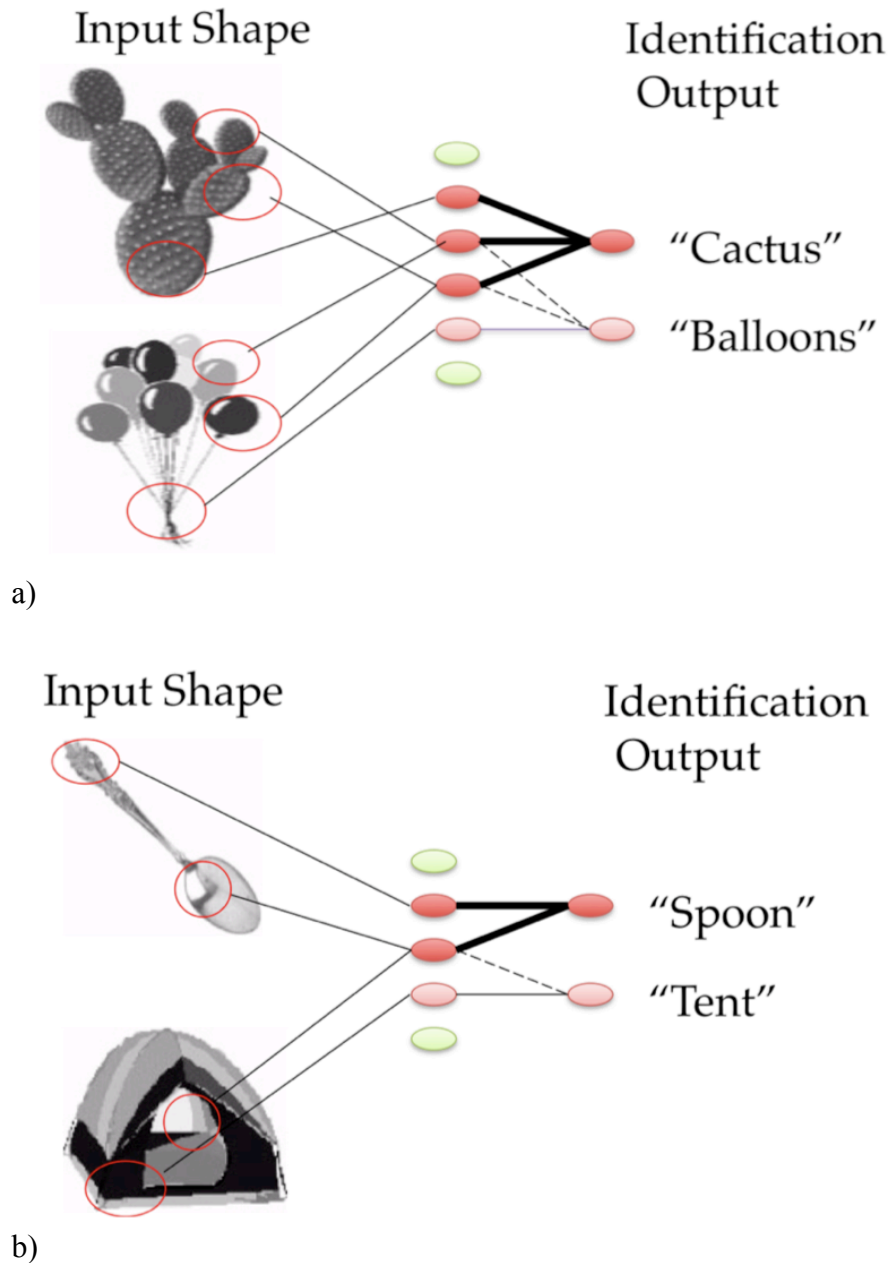


Figure 12 – Representation of superimposed objects. A) In this schematic, the balloons and the cactus share the two rounded features. Further, this shows the connections between the features of the cactus and the output of “cactus” being strengthened (after viewing of the cactus) while the connection between the overlapping features and the output of “balloons” is simultaneously being weakened. These changes will result in priming of the cactus if it is presented again and strong antipriming of the balloons if it

is presented due to the high overlap of the representations. B) This schematic demonstrates the same processes as in part A, but with two objects that do not have much overlap. The decreased overlap of representations should result in less antipriming.

matched within a trial in the masked priming experiments, pairings can be predetermined based on the amount of visual similarity between the two objects. In Experiment 3, two types of antipriming pairs were used: one type with a high level of visual similarity between the two objects and the other with a low level of visual similarity between the two objects.

Method

Participants

Participants were 40 University of Minnesota students (half male, half female) participating either for research extra credit or payment. All participants had normal or corrected-to-normal vision. Participants gave written, informed consent in accordance with procedures and protocols approved by the human subjects review committee of the University of Minnesota.

Creation of Prime/Target Pairings

The stimuli were the same as the 250 grayscale objects used in Experiment 1 and 2, but with different prime/target pairings. The visual objects were first transformed using a series of Gabor filters as described in Lades et al. (1993). This

Gabor filtering generated 1000-element vectors representing information on the spatial frequencies and orientations of the objects. This transformation represented the type of processes occurring in early visual areas.

A correlation matrix was created between the 1000-element vectors of each of the objects with every other object. The average correlation amongst all objects was determined and then each correlation was subtracted from the overall average to give a measure of how much above or below average the pairing was in terms of visual similarity.

These similarity measures were used to select pairings within the counterbalanced lists of objects to maximize or minimize similarity. The five counterbalancing lists of 50 objects used in Experiment 1 and 2 were each divided into two sub-lists of 25 objects, which were also counterbalanced on the relevant attributes described in the preceding experiments. These sub-lists were paired twice – once to create a low visual similarity antiprimed condition and once to create a high visual similarity antiprimed condition. This ensured that each object served in both the high and low visual similarity antiprimed condition across subjects (e.g., for one subject items from list 4a were paired with items in 5a in the low visual similarity antiprimed condition while in another subject items from list 4a were paired with items from 3b in the high visual similarity antiprimed condition).

One restriction placed upon the pairings was that the two objects could not be of the same general category (e.g., two animals could not be paired together). This

restriction limited the ability to maximize visual similarity, but helped to prevent semantic or categorical priming effects.

Once these pairings were generated, a preliminary rating study was conducted to examine whether human judgments of similarity would correspond with the high/low similarity pairings based on the Gabor filtering. Participants were 16 (half male, half female) University of Minnesota students participating either for research extra credit or payment. All participants had normal or corrected-to-normal vision and none had participated in any prior version of the experiment. Participants gave written, informed consent in accordance with procedures and protocols approved by the human subjects review committee of the University of Minnesota. Participants were asked to examine two objects presented simultaneously in the center of the screen for 500 ms and rate how visually similar the two objects were to each other based on a 1-7 scale (1 = very dissimilar, 7 = very similar; see the Appendix for visual similarity instructions).

The average visual similarity rating for all pairings for all sixteen subjects was 2.93. The ratings in this pilot experiment demonstrated that the average visual similarity ratings for each pairing by human participants correlated with the similarity ratings from the filtering process ($r = .40, p < .001$) and the ratings of the high visual similarity (3.28) and low visual similarity pairings (2.58) were significantly different

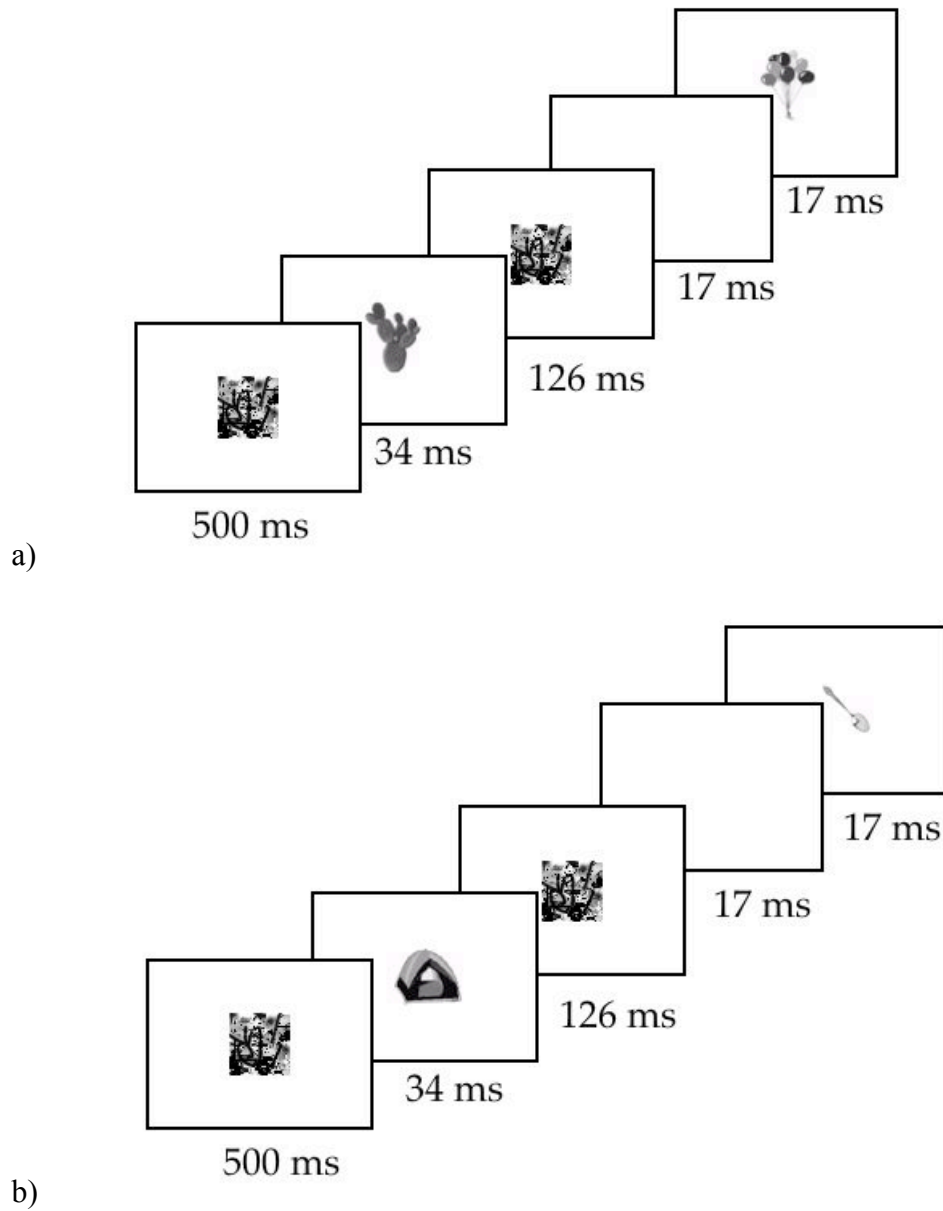


Figure 13 – Example individual trials for the two antipriming conditions: (a) high visual similarity between prime (cactus) and target (balloons) and (b) low visual similarity between prime (tent) and target (spoon).

when directly tested ($F(1,249) = 81.02$, $MS_e = 60.78$, $p < .0001$). These tests validate the high versus low visual similarity variable.

Procedure

The stimuli and procedure were identical to those used in Experiment 2. The only difference was that in the antipriming condition the pairings were set up to either maximize or minimize visual similarity based on the results of the Gabor filtered correlations and human ratings (see Figure 13 for examples of these different conditions).

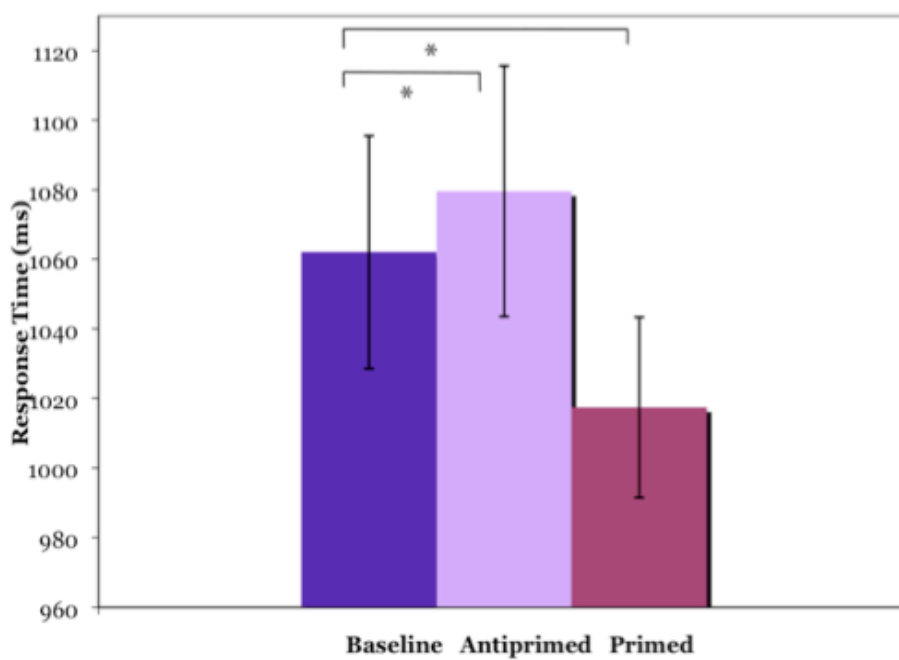
Results

Two repeated-measures analyses of variance (ANOVAs) were conducted using type of prime (primed, antiprimed, or baseline) as the within-subject independent variable, using dependent measures of error rates and mean response times for correct identifications. Counterbalancing assignment of objects to conditions was also included as a between-subjects variable to pull out variance (Pollatsek & Well, 1995).

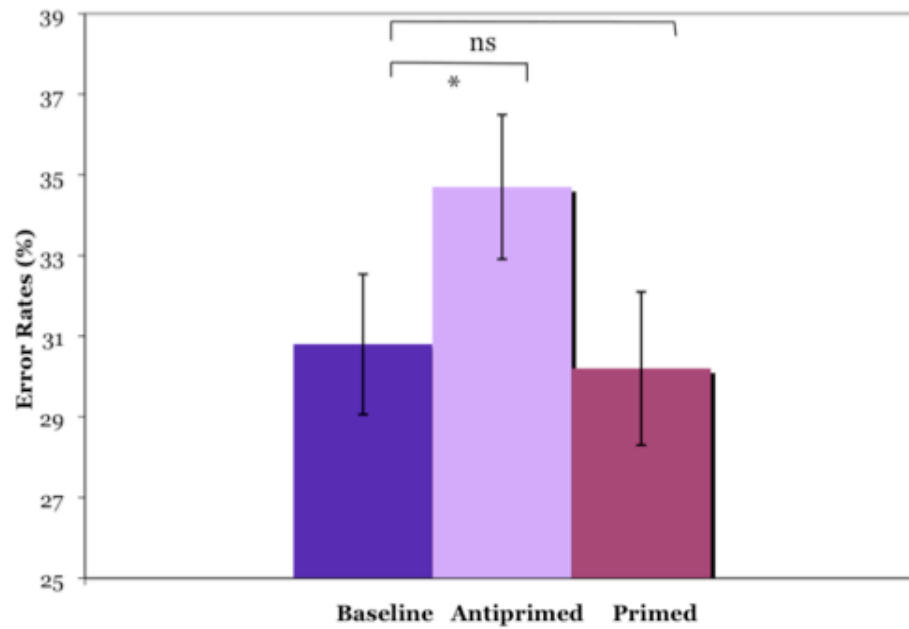
The response time distribution was positively skewed and therefore the response data for each subject was logarithmically transformed before statistical analyses (untransformed response time data are presented in the text and figures for ease of interpretation). The main effect of type of prime was significant for logarithmically transformed response times of correctly identified objects ($F(2,60) = 10.36$, $MS_e =$

.0382, $p < .001$; see Figure 14a). Primed objects were identified faster (1017.4 ms) than objects in the baseline condition (1062 ms; $F(1,60) = 6.39$, $MS_e = .0236$, $p < .05$) and objects in the antiprimed condition (1079.6 ms; $F(1,60) = 20.64$, $MS_e = .0761$, $p < .001$). Most importantly, there was also a significant difference between the antiprimed (1079.6 ms) and baseline (1062 ms) conditions with the baseline condition identified faster than the antiprimed condition ($F(1,60) = 4.06$, $MS_e = .015$, $p < .05$). There was also a significant interaction with type of prime and counterbalancing list ($F(1,60) = 2.10$, $MS_e = .0077$, $p < .05$). Again, counterbalancing lists 4 and 5 appeared to be driving the main effect of type of prime (List 4: $F(2,14) = 10.26$, $MS_e = .032$, $p < .01$; List 5: $F(2,14) = 11.83$, $MS_e = .039$, $p < .01$). For list 4, objects in the primed condition (992 ms) were identified faster than objects in the baseline condition (1142 ms; $F(1,14) = 10.8$, $MS_e = .034$, $p < .01$). For list 5, objects in the antiprimed condition (1127 ms) were identified slower than the objects in the baseline condition (1053 ms; $F(1,14) = 8.68$, $MS_e = .018$, $p < .05$). The objects in the baseline condition were marginally slower than those in the primed condition (1039 ms; $F(1,14) = 3.53$, $MS_e = .012$, $p < .09$).

The main effect of type of prime was also significant for mean error rates ($F(2,60) = 6.05$, $MS_e = .0239$, $p < .01$; see Figure 14b). Most importantly, antiprimed objects were identified with more errors (34.7%) than objects in the baseline condition (30.8%; $F(1,60) = 7.70$, $MS_e = .0304$, $p < .01$) and the objects in the primed condition (30.2%; $F(1,60) = 10.25$, $MS_e = .0405$, $p < .01$). With error rates, there was no



a)



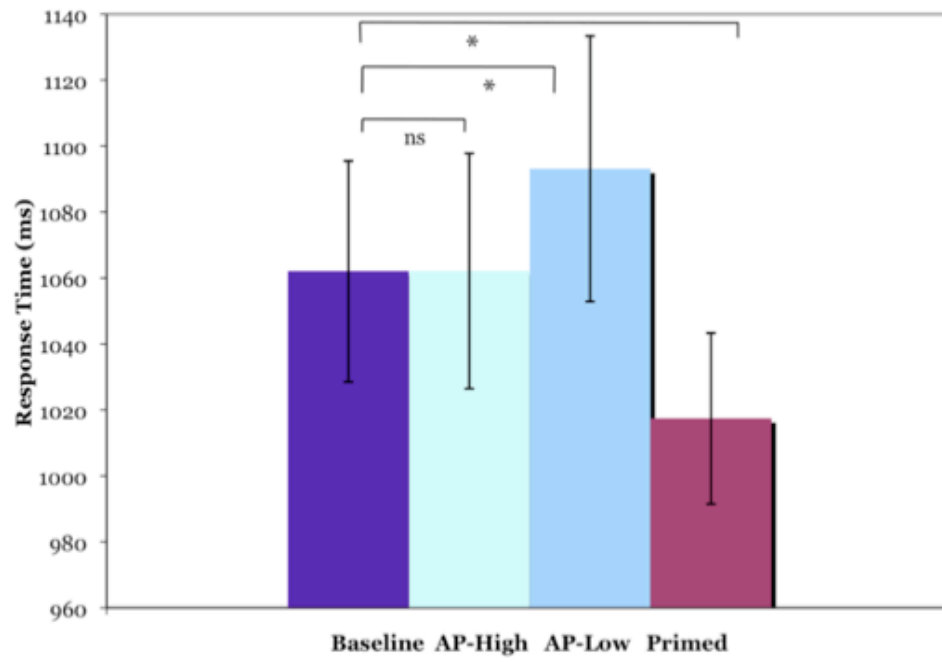
b)

Figure 14 – Results from Experiment 3. a) Mean response times (untransformed) by condition and b) mean error rates by condition. Error bars reflect standard error of untransformed means. (* $p < .05$)

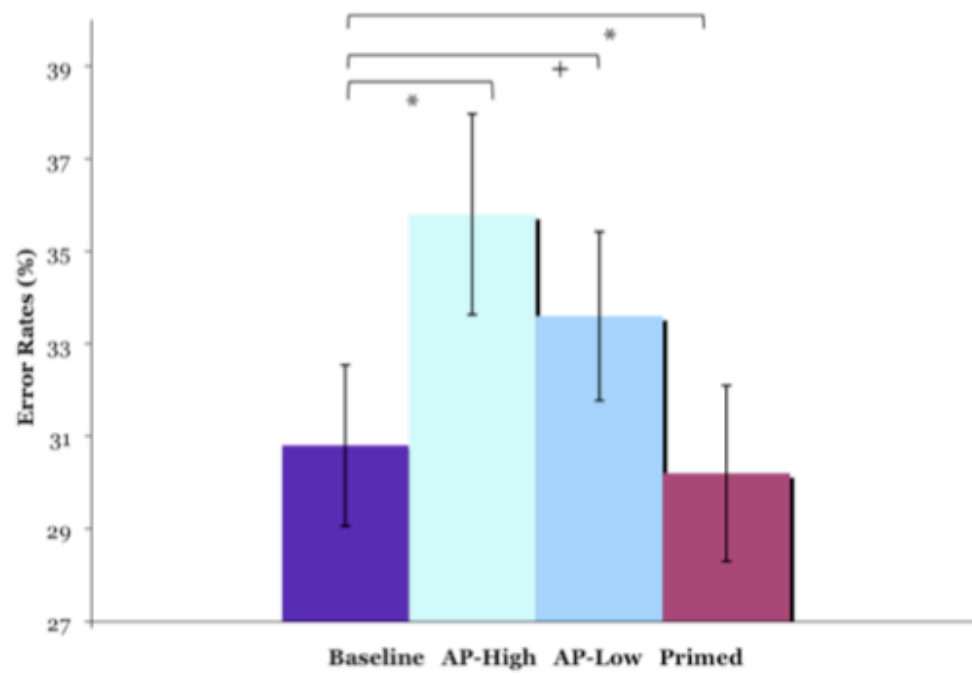
significant difference between the primed (30.2%) and baseline (30.8%) conditions although the numerical trend is in the expected direction ($F < 1$).

To examine the impact of visual similarity on the antipriming effect, further analyses were conducted to examine the differences between the low and high visual similarity pairings. Two repeated-measures analyses of variance (ANOVAs) were conducted using type of prime (primed, antiprimed with high similarity items [AP-high], antiprimed with low similarity items [AP-low], or baseline) as the within-subject independent variable, using dependent measures of error rates and mean response times for correct identifications. Counterbalancing assignment was also included as a between-subjects variable to pull out variance (Pollatsek & Well, 1995).

The main effect of type of prime was significant for mean response times ($F(3,90) = 7.35$, $MS_e = .035$, $p < .001$; See Figure 15a). The linear contrast was also significant (AP-high < AP-low < baseline < primed (1017 ms); $F(1,90) = 15.71$, $MS_e = .0757$, $p < .001$). AP-low objects were identified more slowly (1093 ms) than objects in the baseline condition (1062 ms; $F(1,90) = 5.05$, $MS_e = .0243$, $p < .05$) while there was no significant difference between AP-high and baseline identification rates ($F < 1$). There was no significant difference between the two antiprimed conditions in response times ($F < 1$).



a)



b)

Figure 15 – Results including visual similarity from Experiment 3. The top significance bar reflects the comparison between Baseline and Primed while the second bar reflects the comparison between Baseline and AP-High/AP-Low. a) Mean response times (untransformed) by condition and b) Mean error rates by condition. (* $p < .05$; + $p < .10$)

The main effect of type of prime was significant for mean error rates ($F(3,90) = 5.04$, $MS_e = .02698$, $p < .001$; See Figure 15b). The linear contrast was also significant (AP-high < AP-low < baseline < primed; $F(1,90) = 14.37$, $MS_e = .0768$, $p < .001$). Most importantly, AP-high objects were identified with more errors (35.8%) than objects in the baseline condition (30.8%; $F(1,90) = 9.35$, $MS_e = .05$, $p < .01$) while there was no significant difference between AP-low (33.6%) and baseline error rates. With error rates, there was no significant difference between the two antiprimed conditions.

Discussion

This experiment replicated the results from Experiments 1 and 2. Primed objects were identified faster than objects in the baseline and antiprimed conditions. Most importantly, antiprimed objects were identified slower and with more errors than objects in both the baseline and primed conditions.

Experiment 3 was the first experiment to directly manipulate levels of visual similarity while examining the new phenomenon of antipriming. Theories of antipriming have proposed that antipriming is a consequence of superimposed, overlapping representation of objects (Marsolek et al., 2006; Marsolek, 2008; Marsolek

et al., submitted). Thus, the more features objects have in common (i.e., the more visually similar) the more antipriming should be observed between them.

In the long-term antipriming studies, we proposed that weight changes (potentially involving synaptic modifications) occur after identification in the visual encoding phase, which affects processing of objects in future phases (Marsolek, 2008; Marsolek et al., submitted). Once objects in the test phase have been identified, certain weight changes take place and these changes are influenced by those prior weight changes in the visual encoding phase. The magnitude of weight changes is larger for objects in the antiprimed condition than for those in the primed condition. This was supported by the patterns of activity in the fMRI experiment and how those patterns correspond with the findings from the neurocomputational models (Marsolek et al., submitted). Also, the matched ERP experiment demonstrated patterns of activity reflecting these weight changes occurring around 1100 ms post-stimulus offering another piece of evidence in support of this theory.

In the masked priming paradigm, this same type of synaptic modifications could be responsible for priming and antipriming effects. However, there might be such a brief time between the two object presentations that it may be unlikely that similar synaptic modifications are occurring between the presentation of the prime and the identification of the target. The prime might not be “identified” to a point where these types of weight changes would be implemented before the target onset/target identification. Potentially, a similar effect could be found for short-term memory

through a different underlying mechanism, such as competition that could ensue between settling on a representation for the prime at the same time that the target appears and must be identified through settling on its representation. In either case, the predictions for high and low visual similarity should remain the same for the short-term masked priming task.

In error rates, the highly visually similar pairs drove the significant increase in errors between the antiprimed condition and the baseline condition. This supported the prediction that the more visually similar the objects, the larger the antipriming effect. This was not necessarily the picture presented by the response time measure. In response times, it was the low visually similar antiprimed pairings that drove the significant increase in response times compared to the objects in the baseline condition.

As in Experiment 1, it may be interesting that different patterns emerged in the different measures of error rates and response times. Most of the prior antipriming studies have relied on identification results rather than response times to show a significant antipriming effect (Marsolek et al., 2006). This might be expected - if an object was severely impacted (or "antiprimed"), it would make it very difficult to correctly identify that object. Since response time analyses include only correctly identified trials, these analyses do not include the trials most severely affected by antipriming and therefore may be less likely to demonstrate a significant effect.

Experiment 4: ERP Masked Antipriming Effects

The first step in this dissertation was to establish a masked priming paradigm that included not only a repetition priming condition, but also a measure of antipriming. Experiments 1-3 demonstrated a valid paradigm for examining both priming and antipriming in a masked priming task. Our prior work examining the neural activity related to long-term priming and antipriming suggests that measuring the separate contributions of repetition priming and antipriming can provide interesting insights into the underlying processes. How much of masked priming ERP repetition effects are due to effects of antipriming rather than priming? Would similar post-identification late antipriming effects be found in a masked antipriming experiment as in the prior long-term study? These questions motivated an ERP experiment using the new masked antipriming task.

Object Priming ERP Effects

Few studies have examined effects of repetitions on ERPs using objects as stimuli. Zhang, Begleiter, Porjesz, and Litke (1997) compared repetition effects using word and object stimuli. For both classes of stimuli, they observed a positive deflection for repeated items compared with new items in a simple identification task. Repeated objects showed this positive deflection beginning about 110 ms post-stimulus in the posterior regions. The words did not show a repetition effect until about 240 ms

indicating timing differences between word and object effects. A few other studies have found a similar positive deflection for repeated objects corresponding to effects found with word and face stimuli (Fiebach, Gruber, & Supp, 2005; Schendan & Kutas, 2003)

In addition to this positive deflection, a handful of studies also have found a negative deflection for repeated stimuli (Doniger et al., 2000; Paller, Hutson, Miller, & Boehm, 2003 (with faces); Penney et al. 2001; Rugg et al., 1995). In one of the first visual object priming studies, an increased negativity was observed for repeated objects in posterior regions around 200-400 ms when compared to novel objects (Rugg et al., 1995). This early negative deflection from 200-400 ms for repeated objects was followed by another more widely distributed negative deflection from 400-800 ms. This experiment used immediate repetition and the repeated stimuli did not require responses (the participants were asked to respond to impossible objects and to make no response to the possible geometric objects). The task was also more difficult than the lexical tasks often used in ERP priming studies. These factors may be important for obtaining this different repetition effect. Rugg, Soardi, and Doyle (1995) were the first to report a negative repetition-related deflection in ERP waveforms for object stimuli similar to the typical effect found with words except in polarity.

Penney, Mecklinger, and Nessler (2001) also examined repetition effects using visual object stimuli and found a similar negative deflection to Rugg, Soardi, and Doyle (1995). In one experiment, participants were presented with familiar objects intermixed

with geometric shapes and impossible objects (created by combining two familiar objects) and were instructed to respond only to the geometric shapes. Repeated objects elicited more positivity at frontal areas from about 250-400 ms and an increased negativity at posterior regions from 300-600 ms. These same effects were observed when using impossible and possible unfamiliar objects (using familiar objects as the targets).

Doniger et al. (2000) demonstrated an increased early negativity around 170 ms for repeated objects in areas consistent with the lateral occipital complex. Following this negativity, the more typical repetition-related positivity was found. In their task, they presented objects at differing levels of degradation. This is an example of a repetition-related negativity in ERPs that is not related to immediate repetition. Schendan and Kutas (2003) also demonstrated a repetition-related positivity for visual objects beginning as early as 148 ms and likely generated by the lateral occipital cortex.

ERP repetition effects seem to be a mixture of positive and negative deflections. Especially in visual object priming, there are studies that show a negative effect and other studies that show a positive effect (Penney et al., 2001; Schendan & Kutas, 2003; Rugg et al., 1995). Although in general the polarity of ERP waveforms does not necessarily reflect any interesting information (Otten & Rugg, 2005), these discrepancies may be important because of the variation and inconsistency characterizing these repetition effects.

Unlike most behavioral and fMRI studies of object priming, many of these ERP studies used immediate repetition rather than the more typical separation of encoding and test phases. Using immediate repetition may tap very short-term memory processes that are not necessarily the same as the processes underlying long-term behavioral priming effects but could be similar to what one might expect in a masked priming paradigm.

Masked Priming ERP Effects

Masked priming ERP effects have been examined primarily using lexical stimuli (Holcomb, Reder, Misra, & Grainger, 2005; Holcomb & Grainger, 2006; Kiyonaga, Midgely, Holcomb, & Grainger, 2006; Misra & Holcomb, 2003; Petit, Midgley, Holcomb, & Grainger, 2006; Schnyer, Allen, & Forster, 1997). The earlier studies reported an attenuation of the N400 effect (a less negative deflection between 300-500 ms) for repeated words, but did not elicit any earlier repetition effects (Holcomb et al., 2005; Misra & Holcomb, 2003; Schnyer et al., 1997). More recent studies have found earlier effects between 100-300 ms, including a very early component between 100-200 ms (a positive deflection, “P150”) potentially reflecting early perceptual form processing (Holcomb & Grainger, 2006; Kiyonaga et al., 2006; Petit et al., 2006). Recently several studies have been extending these masked priming effects to face stimuli with similar findings (Henson, Mouchlianitis, Matthews, & Kouider, 2007). The recent widespread finding of earlier masked priming effects was possibly due to the

use of a rapid masked priming paradigm. This refers to employment of a prime presentation of equal to or less than 50 ms and, most importantly, that the time interval between the onset of the prime and the onset of the target (SOA) is less than 100 ms (Eddy et al., 2006). The shorter SOA may increase the effect of the prime on the target both behaviorally and in terms of ERP activity (Ferrand, 1996).

In a recent study, Eddy, Schmid, and Holcomb (2006) were the first to examine masked priming ERP effects using objects. They used a paradigm similar to prior masked word priming studies with a 300 ms forward mask, a 50 ms object prime, a 50 ms backward mask, and a 300 ms target (which was either the same as the prime or a semantically unrelated different object). Participants were instructed to push a button whenever they saw a food item. Food items appeared infrequently as both target and prime objects – and these trials were not analyzed. Repeated items showed an early posterior positive deflection beginning around 100 ms (labeled P190) accompanied by a corresponding anterior negativity. This effect is earlier than typically found in unmasked priming studies, but is similar to those that have recently been found in similar word masked priming studies (Holcomb & Grainger, 2006; Petit et al., 2006). They also found two later components. Between 250-350 ms, there was an increased anterior negativity for repeated items compared to unrelated objects. Also, there was an effect similar to the typical N400 for lexical stimuli, which was a widespread negative deflection for unrelated objects. Eddy et al. (2006) suggested that these three components helped describe the process of object recognition from early visual feature

processing (100-250 ms) to object-specific processing (250-350 ms) to processing of meaning (350-600 ms).

The masked priming ERP literature appears more consistent than the unmasked priming findings, especially in terms of direction of deflection. However, there has not been as much variation in the paradigm or the stimuli used to establish these effects and the possible underlying processes.

Masked Antipriming ERP Effects

In this ERP study, I sought to examine several questions. The first was to determine how much of the typical repetition priming effects in masked priming experiments might instead be due to antipriming effects. All prior masked priming studies conflated the antipriming and priming effects by not including a baseline condition. The new masked antipriming paradigm will allow for the separation of these two effects in the short-term memory task.

As described in the Introduction, our prior antipriming ERP study demonstrated a very interesting late effect beginning around 1100 ms post stimulus in left posterior electrodes (Marsolek et al., submitted). This effect was an increase in amplitude for the antiprimed condition when compared to both the primed and baseline conditions (see Figure 6). Another motivation for this experiment was to examine any late effects which might be similar to those previously found in the long-term antipriming ERP study.

Method

Participants

Participants were 40 University of Minnesota undergraduate students (half male, half female) participating either for research credit or payment. All participants had normal or corrected-to-normal vision and were free of neurological problems. Participants gave written, informed consent in accordance with procedures and protocols approved by the human subjects review committee of the University of Minnesota

Stimuli and Behavioral Procedure

The materials and behavioral procedure were identical to those in Experiment 3.

Electrophysiological Procedure

Participants were tested individually in a sound-attenuated EEG laboratory chamber. Electrophysiological data were collected using two IBM-compatible computers and a 64-channel Neuroscan Synamps Amplifier. One computer used E-Prime to deliver stimuli, accept responses, and send event triggers to a second computer that used Neuroscan Acquire version 4.3 software for data acquisition with the attached Neuroscan amplifier. A 64-channel cap collected EEG activity from 54-scalp sites using sintered Ag-AgCl electrodes placed in accordance with the 10-20 International

System (Jasper, 1958). EEG activity was recorded using CPZ as the reference, and then re-referenced offline to averaged mastoids. All EEG signals collected were digitized at 1000 Hz during data collection. In addition to the scalp sites, electrodes were placed on each participant's face to measure electro-oculogram (EOG) data, which were used later in reduction of eye blink artifacts. Horizontal EOG was measured with electrodes placed on either canthus and vertical EOG was measured with electrodes placed sub- and supra-orbital ridge of the left eye.

Event-Related Potential (ERP) Analyses

ERP epochs, 1000 ms pre-stimulus and 2000 ms post-stimulus, were locked to the onset of the object identification target stimulus. Eye movement artifacts were reduced using an algorithm developed by Semlitsch, Anderer, Schuster, and Presslich (1986), as implemented in the Neuroscan Acquire version 4.3 software. All impedances were kept below 8 k Ω . The data were low-pass filtered at 15 Hz. Epochs were baseline corrected for the 150 ms preceding the beginning of the trial (-850 to -700 before stimulus onset).

Within each trial, individual electrodes in which activity exceeded $\pm 100 \mu\text{V}$ were omitted from analysis. Additionally, only correct identification trials were considered for ERP data analysis. After filtering and removing artifacts, data were averaged across trials, and within test presentation conditions: primed, antiprimed, and baseline.

The data were analyzed in two distinct time windows. In both early and late time windows, the time was first divided into 100 ms bins for a sliding window analysis of mean ERP amplitude. A repeated-measures analysis of variance was conducted including type of prime (primed, antiprimed, or baseline), region (left or right hemisphere) and time window (0-100, 100-200, ... 700-800 ms post stimulus) as the within-subject independent variables, and using the dependent measure of mean ERP amplitude. In addition, components of the ERP waveforms were determined by a principal components analysis (PCA) in a data-driven manner using all electrodes. Statistically independent components over the time courses of the waveform were isolated and the resulting PC weights were used as a dependent measure in an analysis of variance with type of prime (primed, antiprimed, or baseline), region (left or right hemisphere) and component as the independent variables. To examine interactions between type of prime and time window or component, two-tailed, paired *t*-tests were used to test condition differences at each time window or component.

When examining the role of visual similarity, the data was also averaged within the test presentation conditions: primed, AP-high, AP-low, and baseline. For analyses where differences between conditions were tested, the primed and baseline conditions were halved (by using counterbalanced sub-lists) so that trial counts would be comparable across all four conditions.

Results

Behavioral Results

Two repeated-measures analyses of variance (ANOVAs) were conducted using type of prime (primed, antiprimed, or baseline) as the within-subject independent variable, using dependent measures of error rates and mean response times for correct identifications. Counterbalancing assignment of objects to conditions was also included as a between-subjects variable to pull out variance (Pollatsek & Well, 1995). There were no significant behavioral effects of priming or antipriming in either error rates (primed: $M = 32.7\%$, $SD = .12$; antiprimed: $M = 32.3\%$, $SD = .11$; baseline: $M = 32.0\%$, $SD = .12$) or response times (primed: $M = 958$ ms, $SD = 145$ ms; antiprimed: $M = 1023$ ms, $SD = 257$ ms; baseline: $M = 997$ ms, $SD = 187$ ms).

ERP Results

Typical ERP Effects (0-800 ms)

Sliding Window Analysis. A sliding window analysis was performed to assess differences between conditions in mean ERP amplitude for the first 0-800 ms of the epoch in centroparietal electrodes (Left: T7, C3, C1, TP7, CP3, CP1; Right: T8, C2, C4, TP8, CP2, CP4; see Figure 16). These electrodes were chosen to encompass a range of temporal, central, and parietal sites in either hemisphere (related to the subset of central electrodes used by Eddy et al., 2006). In the analysis of mean ERP amplitudes, the interaction between type of prime and time window was marginally

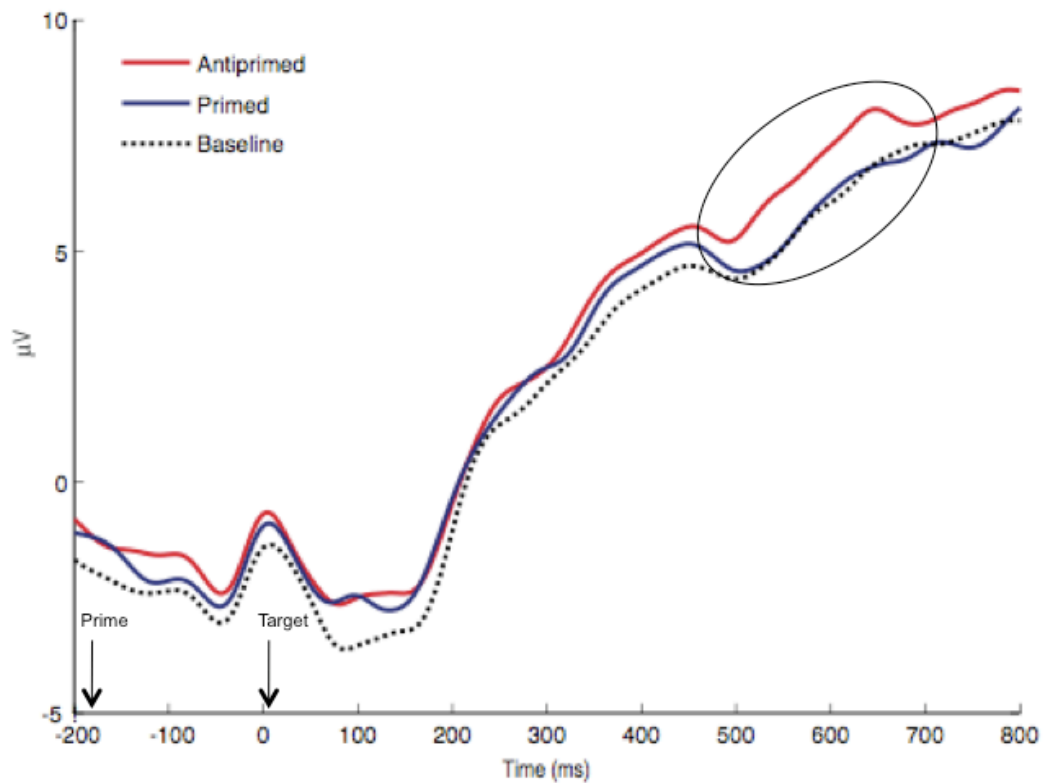


Figure 16 – ERP waveform of a composite of all the electrodes used in the sliding-time window analysis.

significant ($F(14, 546) = 1.695$, $MS_e = 4.382$, $p < .06$; Greenhouse-Geisser: $F(5.51, 218.7) = 1.695$, $MS_e = 6.454$, $p < .13$). There was no significant main effect or interaction with region. Interestingly, within the 500-600 ms time window, the mean ERP amplitude for the antiprimed condition (6.14 μV) is significantly more positive than for the repetition primed condition (4.98 μV ; $t(39) = 2.63$, $p < .02$) and marginally more positive than the baseline condition (4.94 μV ; $t(39) = 1.97$, $p < .06$). There was no difference between the repetition primed and baseline conditions ($t < 1$).

Visual Similarity. When the role of visual similarity was examined by comparing the high similarity antipriming condition to the low similarity condition in mean ERP amplitudes, there was no significant difference for any time window ($t < 1$).

PCA. The principal components analysis of the ERP waveforms produced a four-component solution (see Figure 17). In the analysis of the PC weights using the same subset of electrodes as in the sliding window analysis, the interaction between type of prime and components was significant ($F(6, 234) = 2.206, MS_e = .006, p < .05$; Greenhouse-Geisser: $F(4, 154) = 2.206, MS_e = .009, p < .08$). For the second-to-last component (approximately around 400-600 ms), PC weights were significantly greater for the antiprimed condition than for the primed condition ($t(39) = 2.38, p < .05$) and marginally greater than for the baseline condition ($t(39) = 1.91, p < .07$). There was no difference between the repetition primed and baseline conditions ($t < 1$).

Late ERP Effects (1000-1600 ms)

In a prior antipriming study, interesting effects were present later in the time window than usually explored. To examine whether the masked antipriming paradigm elicits similar late effects, the data were also analyzed in these later time windows (1000-1600 ms). The electrode choice in this analysis was determined by proximity to the location of the fusiform and lateral occipital-temporal fMRI regions of interest.

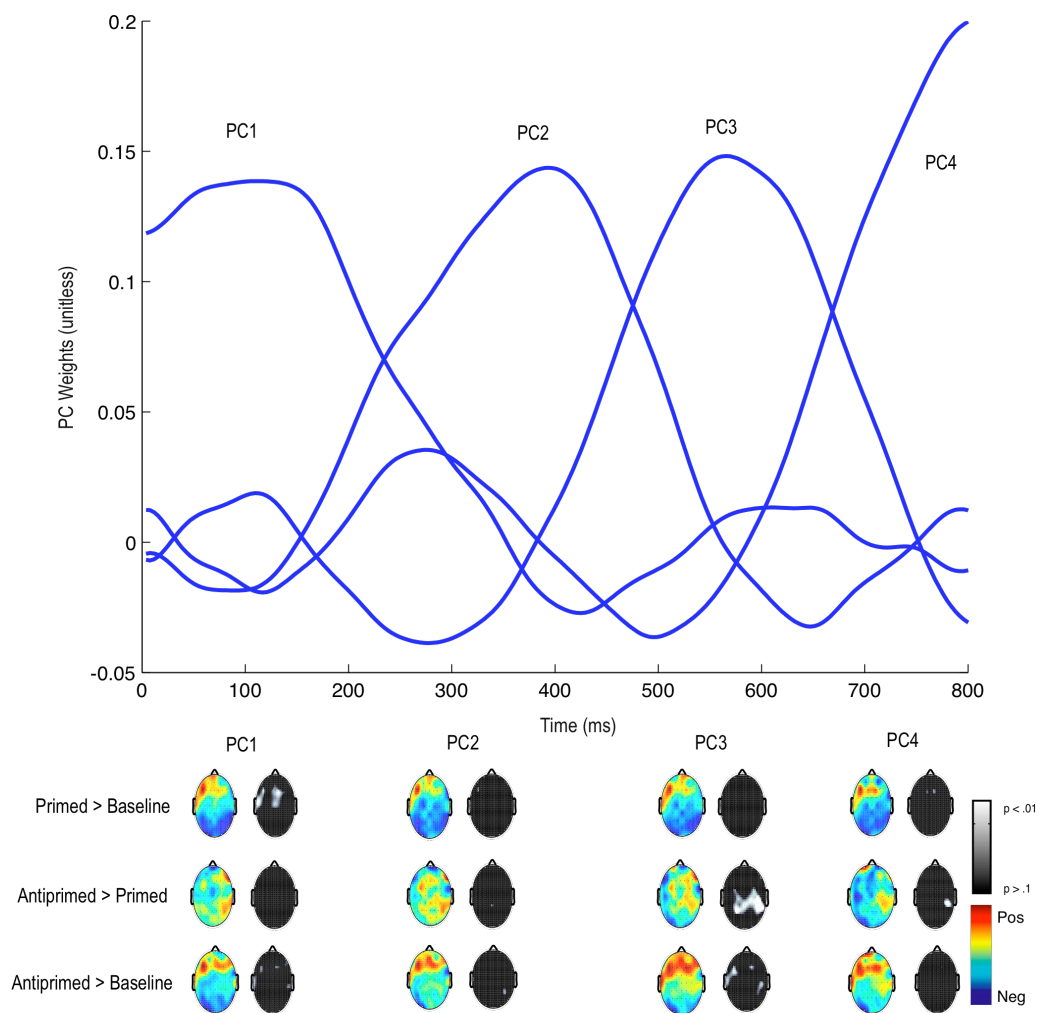


Figure 17 – This is a plot of the four factors in the PCA solution. Below are topographic difference heads and p-value heads for each of the condition comparisons for each component.

Sliding Window Analysis. A sliding window analysis was performed to assess differences between conditions in mean ERP amplitude between 1000-1600 ms of the epoch in temporal-posterior electrodes (Left: T7, C5, TP7, CP3; Right: T8, C6, TP8,

CP4; see Figure 18). In the analysis of mean ERP amplitudes, the main effect of type of prime was marginally significant ($F(2, 78) = 2.56, MS_e = 107.6, p < .09$; Greenhouse-Geisser: $F(1.84, 71.9) = 2.56, MS_e = 116.7, p < .09$). For all the time windows, the mean ERP amplitude for the antiprimed condition was significantly or marginally significantly more positive than for the baseline condition (1000-1100 ms: $t(39) = 1.96, p < .06$; 1100-1200 ms: $t(39) = 2.67, p < .02$; 1200-1300 ms: $t(39) = 2.25, p < .05$; 1300-1400 ms: $t(39) = 2.29, p < .05$; 1400-1500 ms: $t(39) = 2.36, p < .05$; 1500-1600 ms: $t(39) = 2.02, p < .06$). The ERP amplitude was marginally more positive for the antiprimed condition than the repetition primed condition from 1400-1600 ms (1400-1500 ms: $t(39) = 1.78, p < .09$; 1500-1600 ms: $t(39) = 1.89, p < .07$). There was no difference between the repetition primed and baseline conditions ($t < 1$).

PCA. The principal components analysis of the ERP waveforms produced a six-component solution (see Figure 19). In the analysis of the PC weights using the same subset of electrodes used in the sliding window analysis, the main effect of type of prime approached significance ($F(2, 78) = 2.443, MS_e = .067, p < .10$; Greenhouse-Geisser: $F(1.8, 71.7) = 2.443, MS_e = .073, p < .10$). Most interesting, for the second-to-last component (approximately around 1200-1400 ms), PC weights were significantly greater for the antiprimed condition than for the baseline condition ($t(39) = 2.36, p < .05$) and marginally greater than for the repetition primed condition ($t(39) = 1.77, p < .1$). Also, for the last component (approximately around 1400-1600 ms), PC weights were marginally greater for the antiprimed condition than for the primed condition

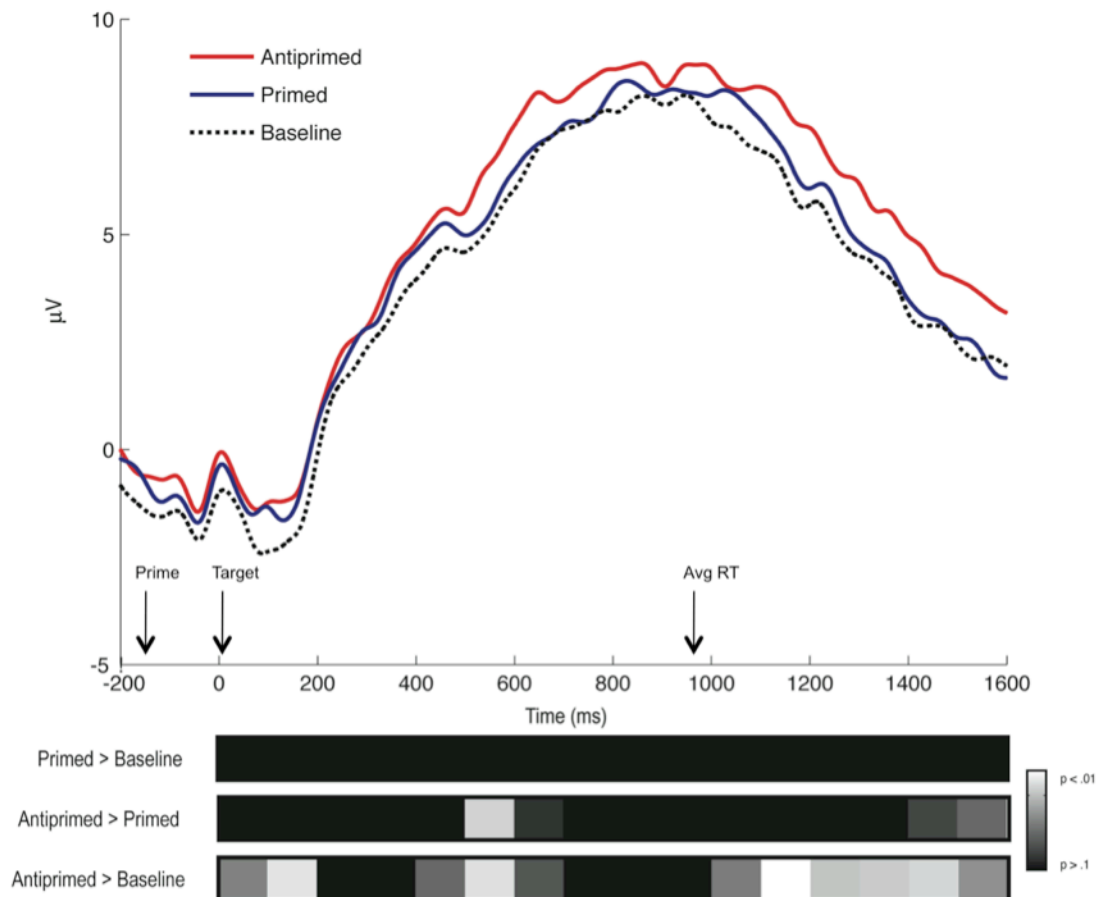


Figure 18 – This is a waveform plot of the composite of the electrodes used in the late sliding-window analysis. Below are bars showing the significance of t-tests between the conditions for each 100 ms time bin.

($t(39) = 1.88, p < .07$) and the baseline condition ($t(39) = 1.87, p < .07$). There was no difference between the repetition primed and baseline conditions in either of these components ($t < 1$).

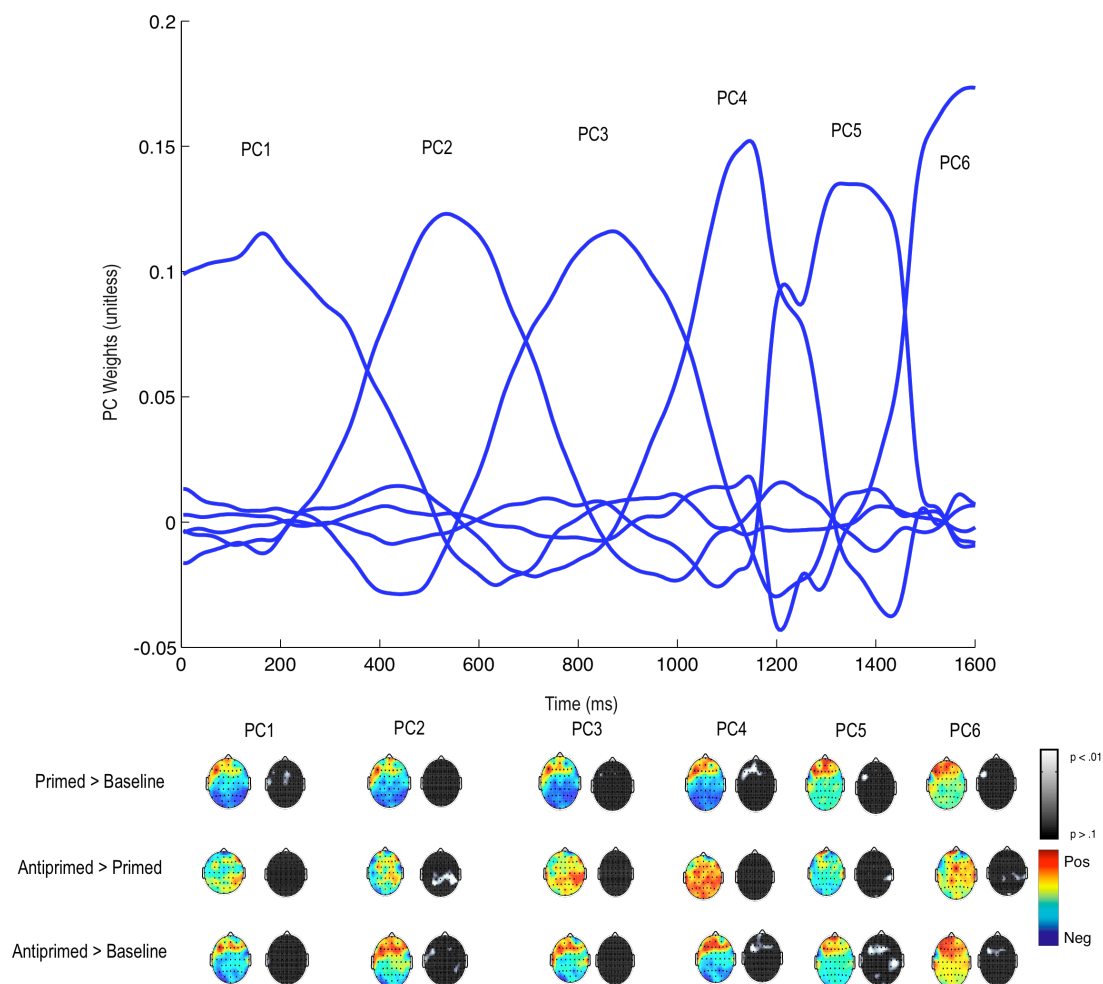


Figure 19 – This is a plot of the six factors in the PCA solution. Below are topographic difference heads and significance heads for each condition comparison for each component.

Along with the more posterior region of interest, there was also a frontal area of activation present in these later time components. To investigate these effects, the PC weights were analyzed for four frontal electrodes (Left: F1, F3; Right: F2, F4) and the main effect of type of prime was significant ($F(2, 78) = 2.4, MS_e = .084, p < .05$;

Greenhouse-Geisser: $F(1.7, 66.7) = 2.4$, $MS_e = .099$, $p < .05$). Beginning a component earlier than the late posterior effects, the fourth component (approximately 1000-1200 ms) showed PC weights greater for the antiprimed condition than for the baseline condition ($t(39) = 2.39$, $p < .05$), and the baseline condition, in turn, was significantly less than for the repetition primed condition ($t(39) = 2.64$, $p < .05$). The second-to-last component (approximately 1200-1400 ms), PC weights were significantly greater for the antiprimed condition than for the baseline condition ($t(39) = 2.31$, $p < .05$). Also, for the last component (approximately 1400-1600 ms), PC weights were marginally greater for the antiprimed condition than for the baseline condition ($t(39) = 2.0$, $p < .06$).

Visual Similarity. When the role of visual similarity was examined by comparing the high similarity antipriming condition to the low similarity condition in mean ERP amplitudes, there was no significant difference for any time window ($t < 1$). However, when comparing the means for the last two components in the PCA analysis using either the high similarity antipriming (AP-High) or the low similarity antipriming (AP-Low), it is clear that it is the high similarity condition driving the effects (PC4 = AP-High vs. Baseline: $t(39) = 1.97$, $p < .06$; AP-High vs. Primed: $t(39) = 2.54$, $p < .05$; AP-Low vs. Baseline: $p > .1$; AP-Low vs. Primed: $p > .1$; PC5 = AP-High vs. Baseline: $t(39) = 2.32$, $p < .05$; AP-High vs. Primed: $t(39) = 1.93$, $p < .07$; AP-Low vs. Baseline: $p > .1$; AP-Low vs. Primed: $p > .1$).

Discussion

The results from this masked antipriming ERP experiment highlight the importance of the antipriming condition. In almost all the findings, it is the antiprimed condition that is different from the baseline and repetition primed conditions. There was virtually no difference between the primed and baseline conditions throughout all of the time windows in posterior regions.

Since the paradigm was as close as possible to Experiments 1-3, it was a little surprising that no behavioral effects, neither in error rates nor response times, were found in the ERP version. Potentially this could mean that this study did not capture all possible priming and antipriming effects. Eddy et al.'s (2006) study, the only other masked priming ERP experiment with objects, did not require a behavioral response, so it is unclear which ERP repetition effects should be more closely tied to behavioral measures of object priming. Future studies will have to make this connection clear as it has not been clearly demonstrated in either masked or unmasked ERP studies of object priming.

Typical ERP Repetition Effects (0-800 ms)

With the brief presentation of the target objects, it is a little surprising that there were not any extremely early effects such as those found beginning around 100 ms by Petit et al. (2006) with words, Eddy et al. (2006) with objects, and Henson et al. (2008) with faces. Typically these effects are thought to reflect facilitated access for primed

items, but perhaps the lack of a strong behavioral effect in this experiment eliminated the ability to detect these earlier effects. One other explanation might be that the briefness of the presentations worked against finding early effects in this experiment as the brief presentation might mean less information was processed about the objects. The only ERP effect in the typical range occurred around 500-600 ms as a posterior positive deflection in waveforms for antiprimed objects as compared to repetition primed and baseline items. This effect was in the opposite direction and with a later onset than the N400 effect demonstrated in prior masked priming studies. Also, it does not resemble the pattern usually found in the parietal old/new effect (which also typically occurs in this region and time frame) in recognition memory tasks (even in masked priming studies; Woollams et al., 2008).

This effect appears to be a later positive component showing stronger activation for the antiprimed objects than for those objects in the baseline and repetition primed conditions. There is no difference between the repetition primed and baseline conditions during this time window, suggesting that this effect is driven by more activity for the antiprimed condition rather than less activity for the repetition primed condition.

Although this effect does not replicate the findings of prior masked priming studies, it is similar to some of the effects found in unmasked priming. Rugg et al. (1995) and Penney et al. (2001) found a similar effect starting a little bit earlier in their priming studies using immediate repetition of objects. Like the typical fMRI repetition

effects, this difference was described as less activity for the primed condition than for the “unprimed” condition. Similar to the fMRI evidence in the long-term memory antipriming experiment, these findings suggest that this repetition effect in ERPs may actually be an increase in activity for the antiprimed condition, or an antipriming effect, rather than a repetition effect.

During the 500-600 ms time window, perceptual identification might still be occurring, although at an advanced stage. In the antiprimed trials, there is competition between the prime and the target object representations before the identification is made, which might require more intensive processing. This increased processing could be responsible for the positive deflection found for the antiprimed condition as compared to the primed and baseline conditions.

Late ERP Repetition Effects (1000-1600 ms)

An antipriming effect was found similar to the late effect in Marsolek et al. (submitted). As shown by both the sliding-window analysis and the PCA, the antipriming condition shows a significant positive deflection from the baseline condition beginning around 1100 ms in central/posterior regions. The antipriming condition also has marginally greater amplitude than the repetition primed condition from 1400-1600 ms.

These effects occur later in the epoch than typical repetition priming studies analyze or even plot which has made it difficult to verify whether such effects have

been found in prior studies. The masked priming task is more difficult than the long-term antipriming task with longer response times, but this effect is still clearly a post-identification response (average response time = 985 ms). It is possible that the same underlying process proposed for the long-term late antipriming effect (magnitude of strengthening of representations) could be used to explain the masked priming effects as described in the Discussion of Experiment 3. These late effects are strikingly similar in onset and distribution to those observed in the prior antipriming ERP study except for the added frontal component in the current experiment.

However, in the case of masked priming and antipriming, the prime objects likely are not fully identified and hence their representations likely are not strengthened after identification (due to the lack of time before the onsets of test objects). Thus, the representational changes that may underlie the late ERP antipriming effect could be guided by the magnitudes of competition between representations during identification processing (Norman, Newman, & Detre, 2007), rather than by interference produced when strengthening of the representation of a prime object hurts subsequent strengthening of the representation of an antiprimed test object. This theory would predict that the antiprimed trials would have the greatest competition between prime and target during identification processing, and as a result antiprimed trials should have the greatest magnitude of weight changes for relearning after identification. Although not conclusive, the early and late antipriming ERP effects were significantly correlated ($r = .549, p < .001$) which is in line with this possibility.

An alternate possibility is that these activations reflect a post-identification verification check possibly initiated by top-down frontal effects. There might be more of a check necessary for the antipriming trials than for either the repetition primed or baseline trials. The identification of the antiprimed objects should have more uncertainty/less confidence especially in the high visual similarity antipriming trials that appeared to drive the effect.

General Discussion

Antipriming is a new implicit effect of prior processing of stimuli measured as *impaired* identification of objects following recent encoding of *other* objects (e.g., identifying a piano is impaired by having recently viewed objects that are not pianos; Marsolek et al., 2006). To establish the antipriming effect, a new baseline condition was added to a repetition-priming task. This baseline was critical to separating out repetition priming effects (better performance compared to baseline) from an antipriming effect (worse performance than baseline). These two effects had been conflated in prior priming work and therefore left current theories of priming potentially incomplete. Antipriming and repetition priming effects have been successfully separated in several behavioral experiments (with young adults, amnesic patients, and age-matched controls), neurocomputational models, and studies measuring neural activity.

Masked Antipriming

In this series of studies, I extended the prior antipriming findings by establishing a new masked antipriming paradigm. This new paradigm allowed examination of the antipriming effect in a task where the prime and target are only separated by milliseconds (a short-term memory task) as opposed to the minutes of separation

typically present between prime and target in the original task (measuring long-term memory).

Experiment 1 demonstrated both repetition priming (faster response times for repetition primed objects compared to objects in the baseline condition) and antipriming (increased error rates as compared to baseline identification). In Experiment 2, speed was emphasized in an effort to detect priming and antipriming in both dependent measures. Repetition priming and antipriming effects were replicated in both Experiments 2 and 3.

A recent behavioral study used a masked priming task to explore object processing (Harris et al., 2008). They used a procedure similar to the one in the current studies except that the target object remained on the screen until a response was made. The prime duration was varied between subjects from 16 ms to 350 ms and the prime object's orientation was also manipulated to examine whether the same object in a different orientation would have similar priming effects as the identical object. Since the target object was displayed for a long period of time, the accuracy in the identification study was very high. In response times, a significant priming effect was found only for prime durations of 70 ms and above (so not for 16 ms or 47 ms durations).

The current study had a prime duration of 34 ms, which was shorter than typical. It was necessary in this experiment to eliminate the conscious perception of the prime object especially since the target object was also presented briefly (the longer target

presentations can help to backward mask the prime). Most masked priming studies have used a prime duration of 50 ms although some studies have had as short a presentation as 17 ms. This includes one of the only other masked priming studies with objects (Dell'Acqua & Grainger, 1999), which also had a SOA of 340 ms (there was a 100 ms backward mask and a 200 ms blank before the target presentation). This study demonstrated a repetition priming effect in response times but not in error rates (which were relatively low due to the long target object presentation) even with the short prime duration.

Experiments 1-3 replicated the findings of Dell'Acqua and Grainger (1999) in that the repetition primed condition was significantly different from the antiprimed (“unprimed”) condition (primed objects compared to antiprimed objects). The addition of the baseline condition allowed for the decomposition of this repetition effect into a repetition priming effect (primed objects compared to baseline objects) and an antipriming effect (antiprimed objects compared to baseline objects).

The new masked antipriming procedure did differ in many important ways from prior masked priming procedures. First, and most important, was the inclusion of a baseline condition as well as the primed and antiprimed (or “unprimed”) conditions. With words as stimuli, the task most often used in masked priming studies is lexical decision (although identification tasks have been used before with both words and objects, see Dell'Acqua & Grainger, 1999; Evett & Humphreys, 1981; Harris et al., 2008). In the only other masked priming studies with objects, the target object was

presented for 200 ms or until a response was made (Dell'Acqua & Grainger, 1999; Eddy et al., 2006; Harris et al., 2008) and so may yield differences from when the target itself is also briefly presented as in this study. One of these differences is that the task is more difficult with the briefly presented object and therefore both response times and error rates show significant effects.

Role of Visual Similarity in Antipriming

In Experiment 3, the role of visual similarity in the antipriming condition was directly manipulated for the first time. The masked antipriming paradigm allowed for direct pairing of particular prime and target objects. Using both a computational measure and human ratings, low and high visual similarity antipriming pairings were created. The antipriming effect in error rates appeared to be driven by the high visual similarity pairings, but response time data did not show this same effect. Once again, these results suggested that response time data and error rates might convey slightly different effects.

Masked Priming ERP effects

fMRI and ERP investigations separating out the distinct contributions of repetition priming and antipriming have proved very informative and novel. Typically fMRI priming studies find a repetition-related decrease in occipito-temporal regions usually described as less activation/more efficient processing for primed than

“unprimed” items. When the baseline condition is included, fMRI results indicate that the typical repetition-related decreases may actually be increased activation for unprimed (or antiprimed) items (compared against baseline) rather than less activation for repetition primed items (compared against baseline; Marsolek et al., 2007; Marsolek et al., submitted). The matched ERP experiment also demonstrated a similar pattern in a positive deflection in the waveform for antiprimed items compared to baseline and primed items in left posterior electrodes occurring post-identification (around 1200 ms – 1600 ms).

The ERP masked antipriming experiment demonstrated two main effects. There were no very early effects and the first effect occurred around 500-600 ms with a positive deflection for antiprimed objects compared to baseline and repetition primed items. The second effect began around 1100 ms also as a positive deflection for antiprimed objects compared to baseline (and sometimes repetition primed items). This effect extends out through 1600 ms and has both a posterior and a frontal location.

The only other masked priming ERP study with objects showed two earlier effects (100-250 ms and 250-350 ms) as well as a third N400-like effect that showed an opposite pattern to the current study (Eddy et al., 2006). Eddy and colleagues did not present an analysis of the data past 600 ms and so it is not clear whether any later effects would have been present in that study.

The first effect in the current study seems most similar to effects found in several unmasked studies of priming (Penney et al., 2001; Rugg et al., 1995). This

pattern, like the fMRI findings, could either be characterized as less activity for the primed condition than for the “unprimed” condition or, as the current study might suggest, an increase in activity for the antiprimed condition, or an antipriming effect, rather than a repetition effect. It is particularly interesting that the prior ERP antipriming study shows a pattern similar to the more typical effect in this time range (a positive deflection for repetition primed objects as compared to antiprimed and baseline objects). This effect could be related to the amount of competition between the prime and the target before identification. The antiprimed condition would have the most competition and therefore should show the largest amount of activity.

The later effect is quite similar to the late effects found in the long-term memory antipriming study with a positive deflection around 1100 ms for the antiprimed condition compared to the baseline condition. This effect could be due to similar mechanisms as the long-term memory effects, strengthening of the representation of the prime object weakens the representation of the target object thus requiring more changes to strengthen the target after its identification. Another possibility is that the increased competition between the representations of the prime and the target is reflected in the representational changes required post-identification. This possibility is supported by the correlation between the early and late ERP antipriming effects.

Future Directions

One of the most interesting questions raised by the ERP findings is the lack of early repetition-related differences. The brief target presentation makes this task quite challenging – it would be made easier by lengthening the presentation of the target object. This increased presentation for the target object could also allow for shorter and yet still effective presentations of the backward mask (creating a shorter SOA). Most procedures present the prime for close to 50 ms, but in this experiment it was shown for only 34 ms. Perhaps this is not long enough to trigger enough processing to lead to robust masked priming ERP effects. Most likely it will be important to demonstrate corresponding behavioral priming effects in a masked antipriming ERP paradigm to conclusively describe all priming and antipriming effects that go into this task. Future experiments should test these differences and how they might relate to different priming and antipriming effects both behaviorally and in ERP/fMRI studies.

Although this series of experiments extends the antipriming effect to a short-term memory paradigm, the effect was still demonstrated through a perceptual identification task. Currently, the antipriming effect has only been found using perceptual identification, but there is no reason to believe antipriming would not generalize to other tasks or to other processing systems beyond visual object identification systems. Antipriming effects should be found using other tasks, but the task itself might determine whether prior encoding of an object will result in priming or antipriming (Marsolek, 2008). For example, prior processing of an object might benefit

a similar object if the subsequent task is to determine whether it is a possible object while it might antiprime subsequent perceptual identification of the object. These differences result from different processing goals. Future studies will extend the antipriming effect to tasks other than perceptual identification.

Several studies have examined differences between masked and unmasked priming by using the same masking procedures but without the mask (Schnyer et al., 1997). It would be interesting to see if an unmasked (but still short-term) version of this procedure would result in the same types of antipriming-driven effects or if the conscious processing of the prime would alter the effects.

The late antipriming ERP effect in this study is very similar to the effect elicited in the long-term version although possibly similar mechanisms are not at work. One critical piece of evidence in determining the differences in underlying mechanisms might be an fMRI version of the masked antipriming ERP experiment. The results from this experiment might show interesting differences (e.g., more frontal activations, different posterior brain regions) that could help distinguish between these effects.

Conclusion

In conclusion, the current experiments provide interesting insights and further development of the new implicit memory effect of antipriming. They demonstrated that antipriming could be measured in a short-term masked priming task and was not restricted to the prior paradigm. Experiment 3 also demonstrated that visual similarity

plays a role in the antipriming effect, with high visual similarity resulting in more antipriming in identification rates. The ERP experiment resulted in two interesting effects both driven by the antiprimed condition. These effects could be explained by the same theory applied to the long-term memory effects or, perhaps, they are due to more immediate effects of competition between object representations. Future experimentation will be conducted to test these alternatives.

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Appendix

Complete list of experimental instructions administered to participants in Experiments 1-4 including the rating of visual similarity.

Experiment 1 (Equal emphasis on speed and accuracy)

This is a study of how people identify familiar objects. We are investigating how well people can identify pictures of common objects that appear very briefly on the computer screen.

Your instructions for each trial are as follows: A scrambled picture will appear in the center of the screen as a warning that an object is about to be presented. Please look at the scrambled picture when it appears, because as soon as it disappears, a line drawing of an object will appear. Your task is to speak aloud into the microphone the name of the object that is shown on the computer screen as quickly and accurately as you can. If you are not sure what object was shown, please guess. The clock measuring your response time starts when the object appears on the screen, therefore you should try to respond just as soon as you realize the identity of the object. You need to speak somewhat loudly to stop the clock, so please hold the microphone close to your mouth and don't be afraid to speak up. The experiment will proceed to the next trial. Each object will appear very briefly--these exposures may seem too brief to see anything, but we've found that with practice people can recognize objects that go by that quickly.

The researcher will first show you several practice trials to get you accustomed to the short viewing times. This will also give you an idea of how loudly you must speak to trigger the microphone during the experiment.

Before we begin the practice trials, let's recap the procedure. Before a trial, please look at the computer screen. A scrambled picture will appear as a warning for the upcoming object presentation. When the object is flashed, ***please name it as quickly and accurately as you can (using a somewhat loud voice).***

If you have any questions at all, please ask the researcher.

Experiment 2-4 (Emphasis on speed)

This is a study of how people identify familiar objects. We are investigating how quickly people can identify pictures of common objects that appear very briefly on the computer screen.

Your instructions for each trial are as follows: A scrambled picture will appear in the center of the screen as a warning that an object is about to be presented. Please look at the scrambled picture when it appears, because as soon as it disappears, a line drawing of an object will appear. Your task is to speak aloud into the microphone the name of the object that is shown on the computer screen **as quickly as you can**. If you are not sure what object was shown, please guess. The clock measuring your response time starts when the object appears on the screen, therefore you should try to respond just as soon as you realize the identity of the object. You need to speak somewhat loudly to stop the clock, so please hold the microphone close to your mouth and don't be afraid to speak up. The experiment will proceed to the next trial. Each object will appear very briefly--these exposures may seem too brief to see anything, but we've found that with practice people can recognize objects that go by that quickly.

The researcher will first show you several practice trials to get you accustomed to the short viewing times. This will also give you an idea of how loudly you must speak to trigger the microphone during the experiment.

Before we begin the practice trials, let's recap the procedure. Before a trial, please look at the computer screen. A scrambled picture will appear as a warning for the upcoming object presentation. When the object is flashed, ***please name it as quickly as you can (using a somewhat loud voice)***.

If you have any questions at all, please ask the researcher.

Experiment 3 (Visual Similarity Ratings Study)

You will be shown several line drawings of objects, one pair of objects at a time. We would like you to judge the visual similarity of the two objects in each pair, on a 1-7 scale.

When a pair is presented, please look at both images and judge the degree to which the two shapes look visually similar or visually dissimilar. Please base your judgment on the **visual** similarity of the shapes of the two images, not on any other aspects of them (e.g., do *not* base your judgment on any classes that the two objects may belong to or on any common ways in which you could use the two objects, etc.). A pair should be judged “very dissimilar” if the two visual shapes look very different, and a pair should be judged “very similar” if the two visual shapes look very close to the same (none of the pairs will be exactly the same shape). It is important that you make the best judgment that you can.

After you have judged the degree of visual dissimilarity/similarity for a pair, please press the number key (from 1 to 7) on the keyboard that reflects your judgment. The scale is as follows. If you feel that the visual shapes are *very dissimilar*, press 1. If you feel that the visual shapes are *very similar*, press 7. If you feel that the shapes are somewhere between those two extremes, please choose a number between 1 and 7 that reflects your judgment. In addition, please distribute your judgments across the whole 1-7 scale over the course of the many judgments that you will make. In other words, please try to use the whole 1-7 scale.

If you have any questions, please ask the researcher. Thank you very much for your help.