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Electrophysiological evidence for size invariance in masked picture repetition priming

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Abstract

This experiment examined invariance in object representations through measuring event-related potentials (ERPs) to pictures in a masked repetition priming paradigm. Pairs of pictures were presented where the prime was either the same size or half the size of the target object and the target was either presented in a normal orientation or was a normal sized mirror reflection of the prime object. Previous masked repetition priming studies have found a cascade of priming effect sensitive to perceptual (N190/P190) and semantic (N400) properties of the stimulus. This experiment found that both early (N190/P190 effects) and later effects (N400) were invariant to size, whereas only the N190/P190 effect was invariant to mirror reflection. The combination of a small prime and a mirror reflected target led to no significant priming effects. Taken together, the results of this set of experiments suggests that object recognition, more specifically, activating an object representation, occurs in a hierarchical fashion where overlapping perceptual information between the prime and target is necessary, although not always sufficient, to activate a higher level semantic representation.

Keywords

masked repetition priming; size invariance; object recognition; picture processing; event-related potentials (ERPs)

One of the greatest challenges in modern cognitive neuroscience has been to provide a better understanding of how the human brain is able to perceive the visual world around us. One particularly vexing problem is how our visual systems are able to rapidly and accurately recognize salient objects under varying viewing conditions. For example, we recognize different variations in a particular object in our environment even with discrepancies in size, color, and orientation. Perhaps most impressive, the human brain is able to accomplish this feat of object recognition in a seemingly effortless and automatic manner, and in most cases in less than a second.

Many different experimental techniques have been used in the study of object recognition, but one in particular, priming, has proven particularly useful. The typical behavioral effect observed in priming tasks is facilitation in reaction time or accuracy to target objects or words

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preceded by the same (so-called repetition priming) or a related prime in comparison to targets items preceded by unrelated or unrepeatable primes. The basic assumption is that presentation of the prime activates certain representations in memory and that the subsequent processing of the related or identical target item, which occurs shortly thereafter, benefits from the overlap of representations between the two items. In the case of unrelated primes and targets, there is little or no overlap in representations and therefore processing of target items is not facilitated.

Forster and Davis (1984) modified the standard priming paradigm by pattern masking the prime stimulus (in their case words) and shortening its duration (50 ms), thus limiting the visibility of the prime. They showed similar behavioral repetition priming effects to those observed with unmasked primes. Because participants are not aware of the prime, recognition effects in masked priming studies have been attributed to fast feed-forward processing (Forster, Mohan, & Hector, 2003). In particular, Lamme, Zipser, and Spekreijse, (2002), have argued that masking words blocks so-called recurrent or feedback processing. By manipulating variables such as prime visibility and the similarity of the prime and target stimuli, this paradigm has been used successfully over the past twenty years to probe a variety of issues concerned with visual word recognition (for a review of this literature see Kinoshita & Lupker, 2003).

ERPs are ideal for examining the feed-forward processes involved in masked priming because of their high temporal resolution (on the millisecond scale) and continuous nature (ERPs measure processing from stimulus onset through several seconds later). This contrasts with behavioral measures such as reaction time which typically occur several hundred milliseconds after the presentation of the stimulus. In this regard, Holcomb and Grainger (2006) demonstrated that ERPs to target words in a masked priming paradigm resulted in a cascade of ERP effects starting as early as 100 ms and extending through the N400 component. They argued that these effects reflected the overlap in processing of the prime and target word and were sensitive to the stream of sub-processes involved in word recognition.

ERPs have also proven useful in the study of mechanisms underlying object recognition in repetition priming paradigms (e.g., Eddy, Schmid, & Holcomb, 2006; McPherson & Holcomb, 1999; Barrett & Rugg, 1990). A series of effects have been observed in the repetition of the same object or a related object. Previous ERP experiments examining masked and unmasked repetition priming with pictures have, like studies with words (Holcomb & Grainger, 2006), revealed a series of ERP components occurring between 100–500 ms (Eddy et al., 2006; McPherson & Holcomb, 1999; Holcomb & McPherson, 1994).

The earliest studies using unmasked priming and long prime-target intervals (500 ms or more) found two dissociable effects with repetition (Barrett & Rugg, 1990; McPherson & Holcomb, 1999; Holcomb & McPherson, 1994). Barrett and Rugg (1990) found a frontally distributed effect that was more negative for the non-matched pictures than matched pictures called the N300 effect and a more widespread N400 effect for unmatched pictures in comparison to the matched pictures. Two other studies where line drawings (Holcomb & McPherson, 1994) and color pictures of objects (McPherson & Holcomb, 1999) were presented in semantically related or unrelated prime-target pairs also found N300 and N400 effects.

Of most relevance here is one masked priming ERP study that used a short stimulus-onset-asynchrony (SOA; 110 ms) and a short prime duration (50 ms – Eddy et al., 2006). This study found an early anterior negativity that inverted in polarity at posterior sites. This effect occurred between 100–250 ms (N190/P190; Eddy et al., 2006). The N190/P190 component is thought to reflect early perceptual processing of objects (Eddy et al., 2006). Other studies using masked repetition priming with letters have found a similar effect, termed the N150/P150 (Holcomb & Grainger, 2006; Petit et al., 2006). Specifically, these studies have suggested that the N150/P150 effect reflects low level feature based processing with words, possibly supporting the

idea that the N190/P190 effect with pictures is indexing a low level perceptual based process (Holcomb & Grainger, 2006; Petit et al., 2006).

Another important effect observed in priming paradigms with pictures was a middle level component, the N300, which has been associated with object specific representations in previous unmasked priming studies (McPherson & Holcomb, 1999; Holcomb & McPherson, 1994) or mapping of perceptual features onto object representations (Eddy et al., 2006). Eddy et al. (2006) also observed this component with masked repetition priming of pictures. Again, a component occurring during a similar time window has been observed in masked priming of words. This effect typically peaks around 250 ms after target onset and is referred to as the N250 (e.g., Holcomb & Grainger, 2006). Holcomb and Grainger (2006; 2007) speculate this effect reflects overlap of form representations as it is differentially sensitive to full and partial repetitions of words. While this effect is not completely analogous to the N300 effect observed in pictures, the N300 most likely reflects some form specific picture representation that is sensitive to the overlap of the form of the representation activated by the prime with the representation of the target, but prior to higher level semantic processing.

The third effect observed in picture priming studies is the N400. The N400 is thought to reflect a general semantic mediated process or a process that activates a higher level representation of the object or word (e.g., Brown & Hagoort, 1993; Holcomb, 1993). The N400 has been found to be larger for unrepeated/unrelated pictures compared to repeated/related pictures in masked and unmasked conditions (Eddy et al., 2006; McPherson & Holcomb, 1999; Holcomb & McPherson, 1994). Reflecting the a-modal nature of this effect, the N400 has also been observed in masked repetition priming of words (Holcomb & Grainger, 2006).

The aim of this experiment was to address how the series of ERP components observed in masked repetition picture priming (Eddy et al., 2006) are affected by changes in physical features of the stimuli. Specifically, two changes in physical features of the stimuli were examined: the size of the prime stimulus and also mirror flipping the target stimulus, along with the combination of these two features. Examining ERP effects to these stimulus manipulations is important to our understanding of exactly which attributes of objects are important during specific stages in object processing. Masked priming studies with words have demonstrated size invariance (Chauncey et al., 2008) and also invariance to mirror reflection has been found behaviorally with objects, although not always (see Stankiewicz, Hummel, & Cooper, 1998). These two manipulations were ideal because they manipulate a lower level stimulus feature, size, which is presumably processed early on in the visual stream as compared to left-right orientation, which may be processed at a later point in the visual stream because it involves more complex stimulus characteristics such as spatial arrangement of parts and shape. Probably most importantly, these manipulations change only 2-D information about the objects and not 3-D information about the spatial relationship of parts, visibility of parts and overall shape like a rotation in depth would. By manipulating these variables, this allows us to combine and compare these two attributes, along with allowing for us to draw some parallels between the results observed with 180 degrees of rotation in depth.

While functional fMRI studies have addressed whether or not the brain represents objects in an invariant manner in terms of size, there are no ERP studies of how changes in size affect ERP repetition priming components with objects. There is one study examining this manipulation with words in a similar masked priming paradigm (Chauncey, Holcomb, & Grainger, 2008). By manipulating word size and also font, they were able to examine when in the time course of word recognition, the processing of these stimulus attributes becomes invariant. During a time window indexing early perceptual processing (N/P150), size was found to be processed in an invariant fashion, whereas font was not (e.g., priming effects were intact for size, but not font). The later priming effects (N250, P325, and N400), all showed

invariance to both word size and changes in font, suggesting at these later components, font change and size are invariant (Chauncey et al., 2008). Overall, these results suggest processing of size establishes invariance earlier than a type of shape invariance (font) with words.

The finding that the processing of size is invariant at a very early stage in visual word recognition parallels findings from fMRI where size invariance has been found with pictures (e.g., Malach et al., 1995; Grill-Spector et al., 1999; Grill-Spector & Malach, 2001; Vuilleumier, Henson, Driver, & Dolan, 2002). From the fMRI literature we know that adaptation or reduction in neural activity occurs when items are repeated, thought to indicate an overlap in the representation of the object. Adaptation has been observed for small and normal size pairs of the same object (Grill-Spector et al., 1999; Vuilleumier, et al., 2002) as well as for faces and cars (Grill-Spector & Malach, 2001). Specifically, Grill-Spector and colleagues (1999) found that the lateral occipital complex (LOC) responds in the same manner regardless of whether the repeated items are the same size and again showed this same effect with faces and cars (Grill-Spector & Malach, 2001). Malach et al. (1995) found there could be up to a four-fold change in size without disruption of object processing in the LOC. Vuilleumier et al. (2002) also found similar effects in the fusiform gyrus, finding that only early retinotopically mapped areas were sensitive to differences in size between object pairs.

The current experiment also aimed to examine the effect on ERP components of mirror flipping target stimuli as well as how having a small prime stimulus followed by a mirror flipped normal sized stimulus affects object processing. A behavioral study manipulating attention and mirror reversal of stimuli in a priming paradigm found no priming effects with mirror reflections of objects when they were ignored (Stankiewicz et al., 1998). However, when the mirror reflected objects were attended to, priming effects were observed for mirror flipped objects (Stankiewicz et al., 1998). Eger et al. (2004), using a similar paradigm in fMRI, found when objects were attended to, repetition priming effects in the fusiform and LOC bilaterally generalized across view (either the original or mirror images). However, in contrast to Stankiewicz et al.'s (1998) study, attention did not modulate behavioral reaction times for mirror images in priming. Other behavioral studies have found a similar pattern of effects, where mirror reflecting an object still leads to intact priming effects (Cooper & Shepard, 1973; Shepard & Cooper, 1982; Biederman & Cooper, 1991). These behavioral effects of priming can be difficult to interpret since the participant's response is several hundred milliseconds after the underlying process(es) have occurred that are responsible for this decision. Also, most of these behavioral studies use study-test memory paradigms with long durations between the prime and target, making it difficult to establish the rapidly occurring processes underlying the long-term mechanisms involved in this invariance to mirror reflection.

While these behavioral and fMRI studies can give us some idea as to whether or not mirror-reversal results in invariant processing, it is difficult to know when during visual processing these effects may be invariant. When attention was not explicitly directed to objects, no priming effects for mirror targets were found by Stankiewicz et al. (1998), however, it is difficult to know the precise timing of why an effect was not found. Alternatively, with fMRI, Eger et al. (2004) did find priming effects with mirror-reflected objects in the LOC and fusiform. Taking these results together, it is possible with ERPs we will see a temporal distinction in these priming effects.

On the basis of these previous studies, some predictions were made about when invariance would also be observed in some, if not all of the ERP components. Our first prediction for when prime size is manipulated is that since the early effect (N190/P190) is thought to reflect processing of perceptual/feature-based properties of the stimuli, this effect should not change due to manipulations in size since it has been suggested the N190/P190 effect is possibly generated in the fusiform gyrus (see Doninger et al., 2000; Eddy et al., 2007), an area of the

brain thought to produce invariance with regard to size (Vuilleumier et al., 2002). A second prediction for the manipulation of prime size is that later effects, the N300 and N400, should also not be affected since the same representation of the object should be activated regardless of size, since the shape and local features are still the same. On the level of the N400, the representation of the smaller object should map onto the same semantic representation of the target object. Evidence from masked word priming, manipulating size, demonstrated a similar cascade of effects, suggesting a small size prime provides sufficient overlap to produce higher level semantic effects (Chauncey, Holcomb, & Grainger, 2008).

Predictions with regard to mirror flipping the target object are that some differences in the ERP waveforms are expected. First, the N190/P190 effect should be sensitive to lower level perceptual aspects of the stimuli, and if it reflects processing of local features or shape of the object regardless of left-right arrangement, then the early effect (N190/P190) should remain intact. However, the N300 may not be present since it possibly involves mapping object features, such as shape or parts, to the representation and the mirror flipped target does not share higher level features with the prime such as shape and spatial arrangement of parts in most cases. Similarly, an N400 effect would not be observed since mapping the representation to the name of the object would not be modulated by the target representation that has mirror reflected object features and shape. This prediction suggests the representation of an object would be activated in a hierarchical fashion, where object features or shape must correspond between the prime and target in order to activate the object representation and a more abstract name or semantic representation. If it takes a large, distributed network of neurons to represent lower level perceptual features, there may not be enough overlap or enough pooling of similar features to activate these higher level semantic representations that rely on a smaller number of neurons to represent more complex features (Riesenhuber & Poggio, 2000).

On this basis, the final predictions for the condition where prime size and mirror reflected target is combined are an elimination of the N300/N400 effects that is even more drastic in the mirror reflected condition. As for the N190/P190 effect, two predictions can be made: 1. it may remain intact, if enough overlap exists between perceptual features or 2. it is also possible this effect will be attenuated by both the manipulations of size and left-right reflection of the object. We will test these hypotheses by examining differences in masked repetition priming effects for three manipulations: prime size, mirror reflection of target, and prime size-mirror reflection of target.

Methods

Participants

Twenty-four volunteers (13 female, $M = 19.6$ years old, $SD = 1.2$ years), undergraduate students at Tufts University, were paid \$20 to participate in this experiment. All were right-handed with normal or corrected to normal visual acuity.

Stimuli and Procedure

Color photographs of 620 common objects (from Hemera Photo Objects), taken from conventional views, were displayed on a white background (each 256×256 pixels) on a 19-in. display (visual angle 2°) time-locked to the vertical refresh signal of the video card (100 Hz resolution). Each subject viewed 390 pseudorandomly arranged trials composed of a unique prime–target object pairs. In the 320 critical trials (those used to form the ERPs of interest), four sets of 40 pairs of stimuli were presented (see Figure 1A for repetition conditions). The first condition constituted the *identity condition*, where the prime and the target were the exact same object. The second repetition condition was composed of a small prime (half the size of the target) that was the same object as the target item (*size condition*). The third repeated

condition was composed of a prime and target pair where the target was a mirror flipped image of the prime (*mirror condition*). And finally, the fourth repetition condition consisted of a small prime followed by a target that was a normal size mirror flip of the prime (*size-mirror condition*). Another four sets of 40 pairs of different, unrelated pictures of objects in the prime and target positions constituted the four unrepeated conditions where each of the manipulations mentioned above was present (identity, size, mirror, size-mirror - see Figure 1B). The remaining 70 trials contained a 'probe' object (food item) paired with a nonfood object filler (40 food items in the prime position and 30 food items in the target position) divided among the four manipulations, so sometimes a food item in the prime position was a small version of that item and so forth. Twelve counterbalanced lists resulted in each repeated and unrepeated object being presented an equal number of times across participants, but each object being presented in only one trial for each participant. Stimuli were presented with a forward and backward mask, with a prime presented for 50 ms in between. The forward mask was presented for 300 ms and the backward mask was presented for 60 ms. The target was then presented for 300 ms. The stimulus onset-asynchrony (SOA) for the prime and target was 110 ms, whereas the inter-trial interval was 3 seconds. Figures 1A and 1B depict examples of the four types of critical trials and their timing. Participants were instructed to attend to the screen and rapidly press a button whenever they detected an object depicting a food item. Participants were given clear instructions on what constituted a food item (e.g., live animals are not food items; food related items are not food items). All other items, including the critical items, were viewed passively.

EEG Recording

A 29-channel electrode cap (Electro-cap International) was used to collect the electroencephalogram (EEG; see Figure 2 for electrode locations) along with 3 externally placed electrodes. All electrodes, including one over the right mastoid, were referenced to an electrode over the left mastoid (the right mastoid was used to monitor differential left mastoid activity; none was found). The ground electrode was placed on the top of the head between FPz and Fz. Horizontal and vertical eye movements and blinks were detected from electrodes placed below and to the side of the eyes (scalp impedances of 5 k Ω). The EEG (250 Hz sampling rate, bandpass 0.01 and 40 Hz) was recorded continuously (SA Instruments amplifier, San Diego, CA) and ERPs were averaged time-locked to the onset of targets. Trials with blinks, eye movements, and muscle artifact were rejected prior to averaging (approximately 15% of trials). Approximately 34 items per condition were averaged (mean = 33.48, SD = 3.72) and the number of trials averaged per condition did not differ significantly ($F(1,7) = 0.552$, $p = 0.771$).

Data Analyses

Mean amplitude measurements were made in three time windows (early N190/P190 region 100–250 ms; N300 region 250–350 ms, and N400 region 350–500 ms). For each time window we used repeated measures Analysis of Variance (ANOVA) to examine the differences in processing between each manipulation (identity, size, mirror manipulations). First to examine overall effects of size and mirror reflection we performed a repeated measures ANOVA with Stimulus Size (small or normal), Reflection (mirror or regular), Repetition (repeated or unrepeated), Electrode Site (midline: FPz, Fz, Cz, Pz, Oz; medial: FC(1–2), C(3–4), CP(1–2); lateral: F(3–4), FC(5–6), CP(5–6), P(3–4); peripheral: FP(1–2), F(7–8), T(3–4), T(5–6), O(1–2), and Hemisphere (left (odd #'s) or right (even #'s) – indicated by numbers following electrode labels, except midline) as within-subject factors in four separate columnar analyses (e.g., Holcomb, Reder, Misra, & Grainger, 2005; see Figure 2 for four columns). When the overall ANOVA indicated interactions of size or mirror reflection with repetition, we performed ANOVA's for each of the four conditions in comparison to one another to examine effects of repetition between each of the manipulations to determine whether repetition effects for each

manipulation varied between one another. These ANOVAs included the within-subject factors of Stimulus Type (either size vs. identity; identity vs. mirror; identity vs. size-mirror; mirror vs. size; mirror vs. size-mirror), Repetition, Electrode Site, and Hemisphere (except midline). The Geisser and Greenhouse (1959) correction was applied to all repeated measures with more than one degree of freedom (df) (all p values reported for comparisons with more than 1 df are Greenhouse-Geisser corrected) and partial eta squared (η_p^2) values were reported to assess effect size.

Additional comparisons holding prime size constant (as small or normal) and the target as orientation (reflected or not) were also performed to assess separable and combined effects of these manipulations. These effects were investigated by holding size constant as small and entering the factors of mirror (reflected, not reflected) $\times$ electrode site $\times$ hemisphere into a repeated measure ANOVA. Then mirror reflection was held constant (reflected) and a size (small, normal) $\times$ electrode site $\times$ hemisphere repeated measures ANOVA was performed.

Results

This experiment examined how changes in size and mirror reflection of objects would affect ERP components related to masked repetition priming. A masked repetition priming paradigm where prime size and target left-right orientation were manipulated along with whether or not the prime-target pairs contained repeated or unrepeated objects.

Behavioral Data

The average d' was calculated for probe food items in the prime position for identity food and small food primes (the primes for the other conditions involved the same manipulations). When a food prime was a normal size the d' was 1.81 and when it was a small food prime the d' was 1.71, suggesting that participants were NOT able to identify food objects in the prime position regardless of prime size ($t(23) = 1.119$, $p = 0.275$). The average d' for food items appearing in the target position was 4.45 (significantly different from the prime items ($t(23) = -9.436$, $p = 0.000$) when preceded by a normal size non-food filler prime and 4.75 when preceded by a small non-food filler prime (significantly different from the prime items ($t(23) = -10.275$, $p = 0.000$). These d' values demonstrate that the masking worked effectively and that participants were still processing targets for meaning and that prime size did not affect how accurately subjects responded to food items. The manipulation of food items being mirror flipped would not have provided any additional information since the prime or target is an unrelated item and the mirror reversal would not be apparent to subject.

Visual Inspection of ERPs—A visual inspection of the ERPs shows repetition effects (unrepeated trials showing greater negativity compared to repeated trials in anterior sites and greater positivity in posterior sites) in the N190/P190 time window for all comparisons, although smaller in magnitude for the conditions with a small prime (see Figure 3–Figure 6, Figure 7 A–D for a subset of electrodes). When examining the N300/N400 time window, effects of repetition are only evident for the identity priming and small prime-identity target conditions. Statistical analyses were performed to further clarify the effects of prime size and target mirror reflection on these repetition priming effects.

N190/P190 Epoch (100–250 ms)—In this time window we examined the effect of size and mirror reflection on an ERP repetition effect sensitive presumably to perceptual aspects of the stimulus. In the omnibus ANOVA significant interactions between Repetition and Mirror Reflection of the target object occurred in the midline and medial electrodes (midline: $F(1,23) = 7.675$, $p = 0.011$, $\eta_p^2 = 0.250$; medial: $F(1,23) = 5.999$, $p = 0.022$, $\eta_p^2 = 0.207$) while significant interactions of Prime Size $\times$ Repetition $\times$ Electrode Site occurred in midline ($F(4,92)$

= 10.176, $p = 0.000$, $\eta_p^2 = 0.307$), lateral ($F(3,69) = 6.897$, $p = 0.009$, $\eta_p^2 = 0.231$) and peripheral ($F(4,92) = 15.004$, $p = 0.001$, $\eta_p^2 = 0.395$) electrode columns. These interactions can be seen in Figure 3–Figure 6 or Figure 7A–D, where repetition effects are evident for the normal targets compared to mirror reflected targets regardless of prime size, whereas, in the small prime conditions compared to those with normal size primes, the N190/P190 effect appears larger (Figure 7 A–D), warranting further comparison to see exactly in which conditions this anterior-posterior change in the N190/P190 effect is driving these interaction.

Effect of Prime Size – N190/P190 Epoch

To test our first prediction, that prime size should not affect the N190/P190 effect, we examined not only the repetition effect for this condition alone, but also in comparison to the other conditions of interest. Importantly, if we predict that the small prime should not alter the priming effect on the N190/P190, then we would not expect the small prime condition to differ from the identity priming condition on repetition during the N190/P190 epoch (indicated by main effects of repetition, but no interaction with prime size).

To examine these predictions the effect of size was examined in pairwise comparisons between all conditions that manipulated size. When comparing small prime-identity target pairs to the identity priming condition (normal size prime), we found main effects of Repetition and interactions between Repetition and Electrode Site across all electrode columns regardless of prime size. The only electrode columns where repetition effects were more dependent on the size of the prime were the midline column and the peripheral column as indicated by a Repetition $\times$ Size $\times$ Electrode Site interaction (midline: $F(4,92) = 5.289$, $p = 0.008$, $\eta_p^2 = 0.187$; peripheral: $F(4,92) = 9.151$, $p = 0.003$, $\eta_p^2 = .0285$). This effect can be seen in Figure 5 and 7C where the difference between repeated and unrepeated trials is attenuated in anterior electrode sites when the prime is small compared to the identity condition (i.e., prime and target are the same size) and also the posterior positivity is smaller for the small prime condition whereas it is larger for the identity condition.

A comparison of the small prime condition with the mirror reflected target condition (but not the combination of the two) was carried out to examine if there was a difference in the N190/P190 between these two conditions. A significant Repetition $\times$ Stimulus Type $\times$ Electrode Site interaction was observed at the midline ($F(4,92) = 6.132$, $p = 0.003$, $\eta_p^2 = 0.210$), lateral ($F(3,69) = 4.861$, $p = 0.027$, $\eta_p^2 = 0.174$) and peripheral ($F(4,92) = 8.088$, $p = 0.003$, $\eta_p^2 = 0.260$) electrode columns. As can be seen in Figure 4 and Figure 5, Figure 7 B and C, this interaction is driven by a larger repetition effect (greater difference between repeated and unrepeated trials) for the mirror reflection condition in comparison to the small prime condition during this time epoch, particularly in posterior electrodes sites (e.g., site O2, Figure 7 B and C).

In examining the repetition effect for small prime-identity targets condition alone, a Repetition by Electrode Site interaction was significant at midline ($F(4,92) = 4.629$, $p = 0.014$, $\eta_p^2 = 0.168$) and peripheral ($F(4,92) = 5.045$, $p = 0.018$, $\eta_p^2 = 0.180$) columns. In the medial column an interaction of Repetition by Electrode Site by Hemisphere was observed ($F(2,46) = 6.814$, $p = 0.004$, $\eta_p^2 = 0.229$). And finally in the lateral column an interaction of Repetition by Hemisphere was observed ($F(1,23) = 5.993$, $p = 0.022$, $\eta_p^2 = 0.207$). Both interactions with hemisphere appear to be driven by a greater difference between unrepeated and repeated trials on the left compared to right hemisphere, whereas the Repetition $\times$ Electrode Site interaction can be seen in the polarity change of this effect between anterior and posterior electrodes (Figure 5).

Effect of Mirror Reflection – N190/P190 Epoch

To test our prediction about the manipulation of a mirror reflected target on early perceptual processing (N190/P190) we examined how this condition differed from the other conditions (small prime, identity, small prime-mirror target) as well as if this condition alone produces a significant priming effect. If our prediction that left-right arrangement does not affect this early perceptual effect, then the mirror reflected condition should show a repetition priming effect that does not differ from the identity priming condition. When comparing trials where a mirror target was presented to trials where an identity target was presented, both preceded by normal size primes, effects of repetition interacted with whether or not the target was mirror reflected across the midline ($F(1,23) = 5.168$, $p = 0.033$, $\eta_p^2 = 0.183$) and medial ($F(1,23) = 4.394$, $p = 0.047$, $\eta_p^2 = 0.160$) columns. In Figure 7A and 7B, this effect is apparent where the repetition effect is much larger for identity repetitions than trials with a mirror-reversed target in both the anterior negativity and posterior positivity. Lateral and peripheral electrode columns demonstrated interactions of Repetition and Electrode Site as did the midline and medial columns, reflected by both manipulations showing an inversion of the repetition effect from anterior to posterior electrode sites regardless of whether or not the target was mirror reflected (all F 's > 11 , p 's < 0.002).

Examining effects of mirror reversal repetition (normal prime-mirror reversed target) alone, interactions of Repetition with Electrode Site were significant in the midline ($F(4,92) = 13.392$, $p = 0.000$, $\eta_p^2 = 0.368$), medial ($F(2,46) = 5.331$, $p = 0.023$, $\eta_p^2 = 0.188$), lateral ($F(3,69) = 11.476$, $p = 0.001$, $\eta_p^2 = 0.333$) and peripheral ($F(4,92) = 23.431$, $p = 0.000$, $\eta_p^2 = 0.505$) electrode columns, reflecting the change in polarity of this effect between anterior and posterior electrodes (see Figure 4 and Figure 7B).

Effect of Size and Mirror Reflection – N190/P190 Epoch

Comparing trials where the prime was small and the target was mirror reflected, to the identity condition (identity prime, identity target) showed effects of repetition interacting with the small prime-mirror target pairing in the medial column ($F(1,23) = 4.428$, $p = 0.046$, $\eta_p^2 = 0.161$) while an interaction of repetition, small prime-mirror target pairing, and electrode site were observed in the midline ($F(4,92) = 6.012$, $p = 0.006$, $\eta_p^2 = 0.207$) and peripheral ($F(4,92) = 8.309$, $p = 0.005$, $\eta_p^2 = 0.265$) electrodes, warranting a further examination of this effect (see Figure 7A and 7D).

To further examine whether effects of combining the size and mirror manipulations was primarily driven by prime size or the target being mirror reflected, first the effect of prime size was examined while holding mirror reflection constant with a 2 (Prime Size: small prime-mirror target; regular prime-mirror target) $\times$ 2 (Repetition) $\times$ Electrode Site $\times$ Hemisphere (except midline) ANOVA. All electrode columns showed interactions of Repetition $\times$ Electrode Site; however no interaction of prime size was observed when the target was mirror flipped. By examining Figure 7B and 7D it is evident that the early negativity and posterior positivity is observed for both conditions, although it appears smaller when a small prime is followed by a mirror target.

In a second comparison, an ANOVA holding the size of the prime constant (as small) and manipulating whether or not the target was mirror reflected was examined. Across all electrode columns, Repetition by Electrode interactions were observed ($F > 5$, $p < 0.015$). However, no interactions were observed between whether the target was a mirror reflection or not. This effect can be seen in Figure 7C and 7D where repetition effects look very similar for trials with a small prime-identity target and small prime-mirror target between 100 and 250 ms.

While significant repetition effects are observed for the small prime-identity target condition (see results above), when investigating repetition effects for the small prime – mirror reversal condition alone, no repetition effects are observed ($F < 3$, $p > 0.065$) within this early time window (see Figure 6 and 7D). Examining effects of mirror reversal repetition (normal prime-mirror reversed target), significant repetition priming effects are observed (see results above), however, when combining together both of these stimulus attributes (small prime – mirror target) there are no significant repetition effects.

Identity Priming Effects – N190/P190 Epoch

Widespread repetition effects were observed for the identity priming condition where the prime and target were the exact same object as indicated by main effects of Repetition (midline: $F(1,23) = 8.016$, $p = 0.009$, $\eta_p^2 = 0.258$; medial: $F(1,23) = 12.589$, $p = 0.002$, $\eta_p^2 = 0.354$; lateral: $F(1,23) = 9.111$, $p = 0.006$, $\eta_p^2 = 0.284$) and Repetition by Electrode Site interactions at all columns (midline: $F(4,92) = 19.065$, $p = 0.000$, $\eta_p^2 = 0.453$; medial: $F(2,46) = 5.870$, $p = 0.017$, $\eta_p^2 = 0.203$; lateral: $F(3,69) = 10.745$, $p = 0.002$, $\eta_p^2 = 0.318$; peripheral: $F(4,92) = 26.161$, $p = 0.000$, $\eta_p^2 = 0.532$). As in the other conditions, this interaction of Repetition $\times$ Electrode Site can be seen in the change in polarity of this effect between anterior and posterior electrodes (see Figure 3, Figure 7A).

N300 Epoch (250–350 ms)—An omnibus ANOVA revealed an interaction of Repetition $\times$ Mirror Reflection $\times$ Electrode Site at the medial electrode column ($F(2,46) = 5.507$, $p = 0.013$, $\eta_p^2 = 0.193$), however, as can be seen in Figure 5, for the identity prime-mirror target condition, this interaction appears to be driven by unrepeated trials being more positive than repeated, the opposite direction of the typical N300 effect. Therefore, additional comparisons were not performed during this time window.

N400 Epoch (350–500 ms)—During the N400 epoch, a main effect of Repetition (medial: $F(1,23) = 7.273$, $p = 0.013$, $\eta_p^2 = 0.240$; lateral: $F(1,23) = 9.982$, $p = 0.004$, $\eta_p^2 = 0.303$; peripheral: $F(1,23) = 8.116$, $p = 0.009$, $\eta_p^2 = 0.261$) and interactions of Repetition and Mirror Reflection (regardless of prime size) were found in an omnibus ANOVA for the midline ($F(1,23) = 14.958$, $p = 0.001$, $\eta_p^2 = 0.394$), medial ($F(1,23) = 11.655$, $p = 0.002$, $\eta_p^2 = 0.336$), lateral ($F(1,23) = 12.042$, $p = 0.002$, $\eta_p^2 = 0.344$) and peripheral ($F(1,23) = 8.174$, $p = 0.009$, $\eta_p^2 = 0.262$) electrode columns. In examining the ERP waveforms (see Figure 7B and 7D), this interaction can be observed in the identity prime - mirror reflected target and small prime-mirror reflected target conditions where there is no obvious N400 (no difference between repeated and unrepeated trials) whereas, in the other conditions, identity repetition and small prime conditions (see Figure 7A and 7C), there is evidence for a difference between repeated and unrepeated trials in the form of a greater negativity for unrepeated trials between 350 and 500 ms.

Effect of Prime Size – N400 Epoch

Pairwise comparisons to examine the effect of size showed, when comparing small primes paired with identity targets to the identity priming condition (normal size prime), main effects of Repetition (midline: $F(1,23) = 30.02$, $p = 0.000$, $\eta_p^2 = 0.566$; medial: $F(1,23) = 36.12$, $p = 0.000$, $\eta_p^2 = 0.611$; lateral: $F(1,23) = 36.994$, $p = 0.000$, $\eta_p^2 = 0.617$; peripheral: $F(1,23) = 18.419$, $p = 0.000$, $\eta_p^2 = 0.445$). Interactions between Repetition and Electrode Site were observed at the midline column ($F(4,92) = 3.864$, $p = 0.029$, $\eta_p^2 = 0.144$) and a Repetition by Hemisphere interaction was found in the peripheral column ($F(1,23) = 6.368$, $p = 0.019$, $\eta_p^2 = 0.217$). However, no electrode columns showed any interaction with the size of the prime as influencing repetition effects. This effect can be seen in Figure 7A and 7C where the difference between repeated and unrepeated trials is similar in magnitude for both the small prime and identity conditions.

Comparing the small prime condition with the mirror reflected condition, interactions between condition (small prime or mirror reflected target) and repetition were observed at midline ($F(1,23) = 6.082, p = 0.022, \eta_p^2 = 0.209$) and medial columns ($F(1,23) = 4.775, p = 0.039, \eta_p^2 = 0.172$). This effect is clearly seen where an N400 effect is present for the small prime condition (Figure 7C), but not for the mirror reflection condition (Figure 7B). Examining the repetition effect for trials with small prime-identity targets alone, a main effect of Repetition was significant at all electrode columns (midline: $F(1,23) = 9.495, p = 0.005, \eta_p^2 = 0.292$; medial: $F(1,23) = 14.482, p = 0.001, \eta_p^2 = 0.386$; lateral: $F(1,23) = 13.724, p = 0.001, \eta_p^2 = 0.374$; peripheral: $F(1,23) = 7.055, p = 0.014, \eta_p^2 = 0.235$).

Effect of Mirror Reflection – N400 Epoch

When trials with a mirror reflected target were compared to trials with identity targets, both preceded by normal size primes, effects of repetition interacted with whether or not the target was mirror reflected or not in the midline ($F(1,23) = 7.256, p = 0.013, \eta_p^2 = 0.240$) and medial ($F(1,23) = 5.631, p = 0.026, \eta_p^2 = 0.197$) columns. In Figure 7A and 7B, this effect is evident where the repetition effect is much larger for identity repetitions than trials with a mirror-reversed target. An ANOVA examining repetition effects for the mirror reflected target condition showed no effects of repetition for this condition alone ($F < 2, p > 0.05$).

Effect of Size and Mirror Reflection – N400 Epoch

When trials where the prime was small and the target was mirror reflected were compared to the identity condition (identity prime, identity target), there were effects of repetition interacting with the manipulation of both size and mirror require a further examination of the this effect (midline: $F(1,23) = 5.661, p = 0.026, \eta_p^2 = 0.198$; medial: $F(1,23) = 5.709, p = 0.025, \eta_p^2 = 0.199$; lateral: $F(1,23) = 7.240, p = 0.013, \eta_p^2 = 0.239$; peripheral: $F(1,23) = 4.862, p = 0.038, \eta_p^2 = 0.175$).

To investigate whether the lack of effects observed when combining small primes and mirror targets is primarily driven by prime size or the target being mirror reflected, we examined the effect of size of the prime while holding mirror reflection constant with a 2 (small prime-mirror target; regular size prime-mirror target) $\times 2$ (repetition) $\times$ electrode $\times$ hemisphere (except midline) ANOVA. No electrode columns showed significant effects, suggesting the N400 effect in the small prime – mirror target condition is not influenced by the size of the prime.

Holding the size of the prime constant, we examined the effect of mirror reflection in a 2 (small prime-mirror target; small prime-identity target) $\times 2$ (repetition) $\times$ electrode $\times$ hemisphere (except midline) ANOVA. In the midline ($F(1,23) = 4.284, p = 0.05, \eta_p^2 = 0.157$) and lateral ($F(1,23) = 5.406, p = 0.029, \eta_p^2 = 0.190$) columns a repetition by mirror reflection interaction was observed. By examining the waveforms (see Figure 7C and 7D) this interaction is evident where a clear N400 effect is observed in the small prime – normal target condition, whereas the N400 effect is not observed in the small prime – mirror reflected target condition.

No significant main effects of Repetition (all F 's $< 2, p$'s > 0.1) or interactions with Repetition (all F 's $< 3, p$'s > 0.08) were observed for the small prime-mirror target condition when examined alone. Since a repetition priming effect was found for small primes-identity targets (see results above) and no repetition priming effect was found for the identity prime-mirror reflected target condition (see statistics above), the lack of repetition effect for the small prime-mirror flipped target condition is primarily driven by the mirror reflection of the target.

Identity Priming Effects– N400 Epoch

During this time epoch, robust N400 effects were observed when the prime and target were exact repetitions. This effect was reflected by significant main effects of Repetition at all

electrode columns (midline: $F(1,23) = 11.295$, $p = 0.003$, $\eta_p^2 = 0.329$; medial: $F(1,23) = 12.474$, $p = 0.002$, $\eta_p^2 = 0.352$; lateral: $F(1,23) = 13.688$, $p = 0.001$, $\eta_p^2 = 0.373$) and a significant interaction of Repetition with Electrode Site at the midline column ($F(4,92) = 3.212$, $p = 0.041$, $\eta_p^2 = 0.123$). The interaction of Repetition by Electrode Site at the midline column is driven by the centro-parietal distribution of this effect (see Figure 3, voltage maps Figure 8 B).

Overall Summary—In the early time window (N190/P190), repetition priming effects were observed for all priming conditions with the exception of when a small prime was paired with its mirror reflected target. These effects can be clearly seen in the difference wave plots as well as the voltage maps in Figure 8 A and B. From examining the difference waves (Figure 8A), it is obvious that this early effect is affected by prime size as the small prime condition shows a much smaller priming effect during this epoch compared to the identity and mirror priming conditions. During the N400 epoch, again repetition priming effects are observed for the identity priming condition and small prime conditions. However, the N400 is not observed when the target is mirror reflected, regardless of whether or not it was preceded by a small or normal size prime. Again, these effects can be clearly seen in Figure 8B where the voltage maps show large centro-parietal negativities for the identity and small prime conditions, but not for either of the conditions with a mirror reflected target. There even appears to be almost no difference between these two priming conditions and their unrepeatable counterpart as can be seen in the voltage maps (small-prime mirror target condition, Figure 8B, bottom right).

Discussion

Overall, the results of manipulating size and mirror reflection of common everyday objects demonstrates a degree of invariance in terms of ERP components observed when the size of the prime is changed, however, there appears to be a lack of invariance in later ERP components when the object is mirror reflected, regardless of whether it is preceded by a normal size prime or not. While the early anterior negativity/posterior positivity remains intact for manipulations of size and mirror reflection separately, combining together these manipulations of a small prime and mirror reflected target leads to no significant repetition effects in this early time window or any of the later ERP component epochs. As we predicted, both the small prime and mirror reflected conditions demonstrated repetition priming effects in the N190/P190 epoch, while the small prime-mirror reflected condition did not. However, since these repetition effects did differ from the identity priming condition, there also appears to be a graded effect of prime size and mirror reflection of targets on the N190/P190 effect.

N190/P190 Effect and Size Manipulation

From the results of this study, we can deduce something about the representations underlying these three separate ERP components. The early N190/P190 effect shows a degree of invariance to size. However, there was an interaction of size with repetition and electrode site (anterior/posterior distribution) when examining overall repetition effects in this time window. Visual inspection of the ERPs suggests there was a difference in magnitude of this effect in the small prime condition (the difference between repeated and unrepeatable trials with the small prime condition having a slightly smaller N190/P190 effect than the identity or mirror target priming conditions). This visual observation was confirmed by a comparison of the identity priming condition with the small prime-identity target condition (significant Size $\times$ Repetition $\times$ Electrode Site interaction). Therefore, this early effect is indexing processing of object features and shape in a way that compensates for differences in size, but not without a small processing cost associated with this compensation.

N190/P190 Effect and Mirror Reflection Manipulation—Similarly, the N190/P190 effect was still intact when target objects were mirror reflected from the prime object (preceded

by a normal size prime), although again, the magnitude of this effect was smaller than the effect for the identity priming condition. This change in left-right orientation appears to affect this early perceptual processing less than a change in prime size, confirmed by a significant difference between these two conditions on the N190/P190 effect where the mirror reflected condition showed greater priming effects than the small prime-identity target condition. Although this effect was larger for mirror reflection condition, the difference from the identity priming condition indicates there was still a cost incurred by the difference of spatial arrangement between the prime and target objects.

N190/P190 Effect and Size-Mirror Manipulation

The manipulation of a small prime and mirror reflected normal size target did not produce a priming effect during the N190/P190 epoch, as predicted. While this effect did not reach statistical significance, it was in the correct direction, but the difference between repeated and unrepeated trials was much smaller and less reliable than the other conditions. It seems by combining together more than one transformation, the additional processing costs dampens the repetition priming effect even more. If a compensation process must equate the prime and target as the same when they are different sizes and mirror reflected, an increase in processing effort (as indicated by greater amplitude for the repeated condition and less of an N190/P190) would be expected, like the effect observed in the current experiment. It is more effortful to match the prime and target in terms of features and shape when there is a difference in the left to right orientation and also the size of the object.

Summary of N190/P190 Effects

The results of this experiment suggest processing reflected in the N190/P190 represents an object in terms of local features or shape of the object in a way that is invariant to mirror reflection and size, while this process still incurs a cost for equating the difference between the prime and target for both manipulations, this cost is less for mirror reflection than when there is a change in size. It is possible when the object is mirror reflected it retains most of the same perceptual features such as the same coarse outline shape and parts. When the prime size changes, the spatial configuration of parts remains the same, but the one-to-one correspondence of these parts and also outline shape is not shared between the prime and target.

One factor that was not controlled for was how symmetrical objects were when mirror reflected. This could also be contributing to the significant N190/P190 effect observed for the mirror reflected condition. It is possible this effect was mainly driven by overlap in overall shape of the prime and target, rather than internal features. If less symmetrical items were used as primes and targets, this effect may have been attenuated, although other studies using manipulations of mirror reflection with asymmetrical items, still found behavioral priming effects (Cooper & Shepard, 1973; Shepard & Cooper, 1982; Biederman & Cooper, 1991). The occipital part of this component (P190) for mirror reflected targets is more similar to the identity priming condition than any of the other conditions, although it is difficult to determine exactly which perceptual aspects of the stimuli were driving this similarity, shape overlap could be one potential common attribute. How these early perceptual effects relate to higher level effects is of interest in establishing a hierarchy for processing to map which object features are important for activating higher level object representations.

Higher Level Priming Effects (N300/N400)

In terms of higher level processing, no significant N300 effects were observed for any of the conditions. One possibility for this could be the rapid presentation rate of the objects, leading to a streamlined process where the N300 effect is somehow combined or smeared with the N400. We have observed N300 effects in repetition priming previously (Eddy et al., 2006), however this effect has also been observed to merge with the N400 at a 50 ms prime duration

and become more evident as a separate component with longer prime exposure (Eddy & Holcomb, 2007). It is also possible that the features of the object are sufficient to activate a semantic or higher level representation of the object, especially in the case where the size of the object does not match and therefore may require a higher level representation rather than a representation reliant on mapping of the object's feature and shapes to a corresponding object representation.

N400 Effect and Size Manipulation

Supporting our predictions that only the identity and small prime conditions should show significant priming effects on the N400, a significant N400 effect was observed when a change in size between the prime and target objects occurred; further supporting the idea that size is invariant at this stage of object recognition and still allows for activating a representation of the object on a semantic level. Importantly though, the N400 unlike the N190/P190 appears to be fully invariant to size, since the repetition effect for the small prime condition did not differ from the repetition effect for the identity priming condition. This finding is consistent with the findings of intact series of priming effects with changes in word size by Chauncey et al. (2008) as well as findings in neurophysiological studies (e.g., Ito et al., 1995) where a significant change in size still led to invariant firing the inferior temporal (IT) cortex of monkey. Because changing the size of the object does not lead to a change in the overall object shape or the arrangement of its parts, the fact that invariance is found to this manipulation is not surprising.

N400 Effect and Mirror Manipulation

In our experiment when objects were mirror reflected, no significant N400 effect was observed. The rearrangement of spatial configuration of parts (by mirror reflection) appears to be enough to attenuate the N400 effect, which suggests the hierarchical processing of perceptual features to semantic features was interrupted by this manipulation. As previously suggested, the N190/P190 effects for the mirror reflected condition may have been dependent on the level of global shape overlap and not object features. If object features, in a particular spatial configuration, are necessary in the hierarchy of processing to activate a more complex, featured based representation to allow for activation of the semantic representation of the object, it is possible that the lack of spatial configuration of object features led to the attenuated N400 effect.

This finding of an attenuated N400 effect for the mirror reflected condition is inconsistent with the findings of Fiser and Biederman (2001) who found intact priming effects regardless of left-right orientation. One possible explanation for the divergence of our findings is that the priming effects observed in Fiser and Biederman's (2001) study represent a long-term memory process insensitive to orientation when participants are performing a naming task and it is possible that they relied more on physical cues than semantic ones to perform this task. This explanation works for two reasons: firstly, Fiser and Biederman (2001) did not find priming effects for different exemplars and secondly, we did find priming effects on the N190/P190 which suggests a perceptual process being involved in invariance to mirror reflection.

An additional explanation can come from neurophysiological studies that examine the properties of receptive fields in different areas of the ventral visual stream. If the mirror reflection is placing visual features activated by the prime outside the receptive field of a cell activated for the target, then no benefit in priming would be expected. V4 has the ability to accommodate a diameter of 7° and larger unlike earlier visual areas (Van Essen, 1985). In macaques, even though the receptive field size is much larger in V4 and TEO, visual representations from one hemisphere only overlap a small amount (less than 2°) with the other hemisphere (Boussaoud, Deismone, & Ungerleider, 1991). It is possible that the change in left-right orientation is disrupting invariant processing between the prime and target representation,

where the prime and target features are falling within different receptive fields and later feed-forward processing is disrupted (or does not benefit from previous prime exposure). It is possible in the feed-forward mechanisms that accounts for at least the early, rapid phases of object recognition; mirror reflection produces a different distribution of activation in terms of the receptive fields that parts are activating. In inferior temporal cortex, it is possible the feed-forward information being projected to this area does not overlap when the prime and target differ in left right orientation.

N400 Effect and Size-Mirror Manipulation

By this logic, and again consistent with our predictions, when both manipulations are combined (i.e., small prime and mirror reflected target), it is not surprising the N400 effect was not significant, both because of a lack of an earlier N190/P190 effect for this condition, and because of the mirror reversal and size change together disrupts the spatial configuration of object features. The lack of an N190/P190 effect appears to indicate a lack of overlap in neurons activated to low level features of the prime and target objects. Without this initial “start-up” of processing, further processing of semantic representations does not occur if this feed-forward process acts in a hierarchical fashion.

Overall Summary—As Riesenbuber and Poggio (2000) suggest, feature processing at low levels in the hierarchy requires many neurons to represent a small set of features, and this activity must be sufficient to activate a representation higher along the hierarchy. Higher along the hierarchy, a large number of complex features are represented by a small number of representation specific neurons. It is possible that a large number of neurons are active to encode perceptual features of the prime object that overlap with the target object, but there is not sufficient activation to pool together to activate an intermediate representation that relies on a more complex integration of these features. In the small prime, mirror target condition, this pooling of neurons responding to low level features may not be sufficient to activate scale and translation invariant neurons, whereas in the small prime condition, the overall pooled priming effect is smaller for the N190/P190 than if the prime was normal size, however, there is sufficient overlap to activate higher level representations invariant to size. The attenuated N400 in the identity prime-mirror target condition may be a result of lower level perceptual properties not sufficiently activating a higher level representation that relies on a more complex representation of features, possibly one sensitive to the spatial configuration of features.

Conclusions

The results of this study help elucidate the time course of previous fMRI findings of size invariance in adaptation paradigms and also when during object processing left-right arrangement of objects becomes important for activating an object representation. While manipulations of size and mirror reflection produced significant priming effects during earlier time epochs sensitive to perceptual aspects of the stimuli, invariance in priming effects for higher level ERP effects were only observed for the manipulation of prime size. These findings suggest that while lower level perceptual areas may produce invariant priming effects, more overlap in object representations is necessary to facilitate priming effects for higher level processes (e.g., activating a semantic representation).

Future Directions

Future studies can aid in the investigation of the precise nature of these ERP components through manipulating other stimulus features and systematically controlling for specific stimulus attributes (e.g., amount of overlapping perceptual information). One interesting manipulation would be holding the amount of semantic overlap constant while changing the overlap in perceptual features (different exemplar manipulation). Chouinard et al. (2008), with

fMRI has shown that effects with different exemplars (same name, different physical attributes) can be attributed to solely the overlap in perceptual features. Using a stimulus set similar to the one used in their fMRI experiment would be interesting (very physically dissimilar exemplars) to use in ERPs to examine whether or not semantic effects would be observed in the absence of overlapping perceptual features.

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A. Repeated Trials

B. Unrepeated Trials

Figure 1.

Example of typical trials in each condition. A shows the repeated pairings, whereas B show unrepeated object pairs. Each condition is counterbalanced in such a way that size of the prime manipulation also occurs in the unrepeated condition and the mirror reflected target also appears in the unrepeated condition.

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Figure 3.
Grand Average plots for each of the priming conditions.
Identity Priming Condition Grand Average (N = 24)

Figure 4.
Grand Average plots for each of the priming conditions.
Identity Prime - Mirror Target Condition Grand Average (N = 24)

Figure 5.
Grand Average plots for each of the priming conditions.
Small Prime - Identity Target Condition Grand Average (N = 24)

Figure 6.
Grand Average plots for each of the priming conditions.
Small Prime - Mirror Target Condition Grand Average (N = 24)

Figure 7. Subset of electrodes representative of the grand average for each condition. F4 is frontal electrode site, C4 is central and O2 is occipital.

A. Difference Wave: Unrepeated - Repeated Trials **B. Voltage Maps** **Figure 8.**

Difference waves and voltage maps. A: the difference waves show the priming effect (subtracted unrepeated from repeated trials). B: the voltage maps show the distribution of these priming effects in A. The voltage maps were created by from the difference waves in A.