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The Effects of Context, Meaning Frequency, and Associative Strength on Semantic Selection: Distinct Contributions from each Cerebral Hemisphere

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Abstract

The visual half-field procedure was used to examine hemispheric asymmetries in meaning selection. Event-related potentials were recorded as participants decided if a lateralized ambiguous or unambiguous prime was related in meaning to a centrally-presented target. Prime-target pairs were preceded by a related or unrelated centrally-presented context word. To separate the effects of meaning frequency and associative strength, unambiguous words were paired with concordant weakly-related context words and strongly-related targets (e.g., *taste-sweet-candy*) that were similar in associative strength to discordant subordinate-related context words and dominant-related targets (e.g., *river-bank-deposit*) in the ambiguous condition. Context words and targets were reversed in a second experiment. In an unrelated (neutral) context, N400 responses were more positive than baseline (facilitated) in all ambiguous conditions except when subordinate targets were presented on left visual field-right hemisphere (LVF-RH) trials. Thus, in the absence of biasing context information, the hemispheres seem to be differentially affected by meaning frequency, with the left maintaining multiple meanings and the right selecting the dominant meaning. In the presence of discordant context information, N400 facilitation was absent in both visual fields, indicating that the contextually-consistent meaning of the ambiguous word had been selected. In contrast, N400 facilitation occurred in all of the unambiguous conditions; however, the left hemisphere (LH) showed less facilitation for the weakly-related target when a strongly-related context was presented. These findings indicate that both hemispheres use context to guide meaning selection, but that the LH is more likely to focus activation on a single, contextually-relevant sense.

Keywords

Lexical Ambiguity; Cerebral Hemispheres; Context Effects; ERP; N400; LPC

Based on evidence from studies using the visual half-field (VF) procedure with neurologically-intact individuals (e.g., Burgess and Simpson, 1988), as well as studies involving participants with unilateral brain damage (e.g., Tompkins, Baumgartner, Lehman, and Fassbinder, 2000), it has been argued that the cerebral hemispheres differ in their processing of lexical semantics.

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More specifically, it has been postulated that there are hemispheric differences in the scope of meaning activation (Beeman et al., 1994; Jung-Beeman, 2005), as well as the processes involved in selection of a specific meaning (Burgess and Simpson, 1988; Tompkins et al., 2000). However, evidence in support of these hypotheses has been mixed, with conflicting findings both within and between participant populations.

For instance, patterns seen in word pair priming studies have been taken to support the hypothesis that the right hemisphere (RH) activates a broader range of meanings than does the left hemisphere (LH; Chiarello, 1998). However, some have suggested instead that such patterns reflect asymmetries in the timecourse, rather than the scope, of meaning activation (Koivisto, 1997). Other work has shown that when ambiguous homonyms are presented in a neutral context, the LH selects the dominant (most frequent) meaning, whereas the RH activates and maintains both the dominant and the subordinate (less frequent) meanings (Burgess and Simpson, 1988). Yet, the opposite pattern (RH selection of the dominant meaning, along with a lack of selection in the LH) has also been reported, despite the use of similar methods (Hasbrooke and Chiarello, 1998[1]).

Similar discrepancies are seen in studies that examine meaning activation and selection processes in richer contexts. For example, when words are embedded in sentences that are biased toward one meaning of a homonym, there is evidence to suggest that the LH is more likely to select the contextually-consistent meaning (Faust and Gernsbacher, 1996), regardless of meaning frequency (Faust and Chiarello, 1998), whereas the RH fails to select (but see also Coney and Evans, 2000). These VF studies with neurologically-intact participants thus seem to indicate that the LH controls meaning selection processes, and, in support of this conclusion, LH damage has been linked to meaning selection deficits (Copland, Chenery, and Murdoch, 2002; Swaab, Brown, and Hagoort, 1998). However, participants with unilateral RH damage have also been found to exhibit deficits in context-based meaning selection (McDonald et al., 2005; Tompkins et al., 2000), suggesting that the RH contributes essential functions as well.

Thus, the literature does not yet provide a coherent picture of the role each hemisphere normally plays in the processing of word meaning. There is evidence to suggest that the contributions of both hemispheres are likely important – and also that they are probably not identical. However, the exact nature of each hemisphere’s ability to activate and select meaning information remains elusive because of striking discrepancies in the inferences afforded by different studies. As discussed next, there are several factors that may be contributing to the lack of agreement across the extant literature.

Homonymy vs. Polysemy

The idea that the RH might activate more broadly and/or be less likely to select a meaning has been tested using both ambiguous homonyms and relatively unambiguous words, but there has been little discussion of the potential differences between these classes of items. Semantic distance in studies using unambiguous items is typically defined in terms of associative strength. This is consistent with the formulation of breadth in the coarse coding hypothesis (Beeman et al., 1994), which argues that the cerebral hemispheres differ in their activation of weakly-related word meanings, regardless of ambiguity. In contrast, studies using ambiguous items typically manipulate the meaning frequency of multiple, disparate senses of the homonym and interpret their results in these terms (e.g., Burgess and Simpson, 1988). However, in many experiments on ambiguity resolution, meaning dominance and associative strength are confounded, as such studies typically present dominant- and subordinate-related

[1]At a 750 ms SOA, Hasbrooke and Chiarello (1998) found accuracy priming for the dominant meaning in the RH and accuracy priming for multiple meanings in the LH. Reaction time priming for the dominant meaning was found in both hemispheres.

targets that also differ in their degree of association with the ambiguous word, with dominant-related targets more strongly associated (e.g., *money*, compared to *river*, is a stronger associate of *bank*). Thus, it is unclear if the observed effects are due to meaning frequency, associative strength, or some combination of the two.

To disentangle these issues, Atchley, Burgess, and Keeney (1999) conducted a VF study involving polysemous words, which do not have distinct, unrelated meanings as do homonyms, but instead have distinct, **related** meanings. One might therefore expect the processing of these two words classes to be qualitatively different. Consistent with this expectation, in studies using central presentation polysemy has been found to confer a processing advantage for word recognition (Klepousniotou and Baum, 2007), whereas unrelated meanings produce a disadvantage (Rodd, Gaskell, and Marslen-Wilson, 2002). However, Atchley et al. point out that polysemy is actually multifaceted, as a polysemous word can have secondary meanings that are relatively inconsistent with its most frequent meaning (such as the *food* meaning of “lamb,” as opposed to the most frequent *animal* meaning; see also Klein and Murphy, 2002). In addition, polysemous words can have features related to the same meaning that differ in associative strength (such as *wool* and *ears*, both related to the *animal* meaning of “lamb”). To separately examine the influence of associative strength and meaning consistency, therefore, Atchley et al. presented strongly-associated consistent targets (LAMB-WOOL), weakly-associated consistent targets (LAMB-EARS), and weakly-associated inconsistent targets (LAMB-CHOPS). At a 750 ms stimulus onset asynchrony (SOA), priming occurred for all three conditions when targets were presented to the LVF-RH. In contrast, with RVF-LH presentation, priming occurred for both types of consistent targets but not for the inconsistent targets. Based on these findings, Atchley et al. argue that, for words out of context, the LH selects features that are compatible with the most frequent meaning, irrespective of relatedness strength (see also Fassbinder and Tompkins, 2006). Thus, as predicted by the coarse coding hypothesis, there was an overall greater breadth of activation in the RH. However, contrary to this hypothesis, the greater breadth of activation was specific to meanings that were inconsistent with the preferred reading of the word and did not extend more generally to any weak associate. This pattern emphasizes the importance of considering both association strength and meaning compatibility when investigating asymmetries in the scope of semantic activation.

Polysemous words have also been used in neuropsychological studies that have looked at the ability to use context information to select appropriate word meanings. Klepousniotou and Baum (2005) used biasing sentence contexts to examine the processing of homonymy, non-metaphorical polysemy (e.g., the *animal* and *food* meanings of *lamb*), and metaphorical polysemy (e.g., the *temperature* and *emotion* meanings of *cold*) in participants with left-hemisphere damage (LHD), right-hemisphere damage (RHD), and normal controls. By a late SOA, controls had selected the contextually-consistent meaning in all cases. In contrast, LHD participants selected the dominant meaning in a dominant-biased context, but showed activation for both dominant and subordinate meanings in a subordinate-biased context. RHD participants failed to select a meaning for any type of ambiguity, and also failed to activate metaphorical meanings (cf. Brownell et al., 1990). Thus, this work suggests that, with the exception of metaphorical meanings, ambiguous and unambiguous words can be processed similarly within each hemisphere. However, the conclusions about the nature of each hemisphere’s processing that are drawn from this study are quite different from those of Atchley et al. (1999). Consistent with other work suggesting that context-based meaning selection is driven by the LH (Faust and Chiarello, 1998; Faust and Gernsbacher, 1996, Exp. 1), Atchley et al. found that the LH, but not the RH, selected the dominant meaning in an unbiased context. In contrast, Klepousniotou and Baum’s data showed that participants with an intact LH failed to select a meaning even in a biasing context, whereas participants with an intact RH were able to use context to select a dominant (but not a subordinate) meaning. More work is thus clearly needed to determine (1) what information each hemisphere tends to activate in response to words with multiple meanings or senses and (2) how context shapes that activation.

Methodological Issues

To date, the majority of studies investigating hemispheric asymmetries in the processing of word meanings have relied on reaction time and accuracy data from the lexical decision task, in which participants are asked to decide if a letter string is a word or nonword (for studies using a relatedness judgment task, see Atchley and Kwasny, 2003; Faust and Gernsbacher, 1996; Tompkins et al., 2000; Swaab et al., 1998). Some of the discrepancies among the studies cited above may be due to a lack of sensitivity of the lexical decision task for the full range of processes engaged during meaning comprehension. Based on a series of priming experiments involving lexical decision, naming, and relatedness judgment tasks, Balota and Paul (1996) have argued that the lexical decision task fails to tap into inhibitory semantic processing. This type of processing may be especially important for the comprehension of homonyms, as selection of a specific meaning may require inhibition of other, disparate meanings (Gernsbacher, Varner, and Faust, 1990; Gernsbacher, Robertson, and Werner, 2001; Simpson and Kang, 1994; Simpson and Adamopoulos, 2001). As Balota and Paul have argued, a task such as relatedness judgment, in which participants decide if a target word is semantically related to preceding context, may be necessary to engage selection and tap into inhibitory semantic processing.

More generally, some aspects of semantic processing may not be easy to capture with discrete measures such as response time or accuracy. For instance, it can be difficult to examine meaning revision with these measures, since typically only one probe can be presented per trial. Instead, processes like meaning revision may be monitored more effectively using methodologies -- such as eye tracking or event-related potentials (ERPs) -- that allow for continuous sampling of cognitive processing and provide multidimensional indices of processing. For example, Binder and Morris (1995) used eye tracking to examine ambiguity resolution in a discourse context that required revision of the interpretation originally supported by context. Participants read paragraphs that supported two different meanings of a homonym (e.g., “gathered outside the *club* on the street” and “struck on the head with a *club* and robbed” occurred in the same passage). Compared to a control condition, the amount of time spent fixating the target homonym did not increase, but fixation times for the post-target region (e.g., “and robbed”) did increase, indicating that participants had difficulty integrating the non-selected meaning with the discourse context. The differential effects of a meaning switch on fixations of target and post-target regions illustrate the utility of methodologies that allow for continuous sampling.

ERPs have also proven useful for separating different aspects of the computation of meaning that may be engaged even during the processing of a single word in a larger language context (e.g., Federmeier, Wlotko, De Ochoa-Dewald, and Kutas, 2007). The ERP waveform consists of functionally-specific components; two that are of special interest for meaning processing are the N400 (Kutas and Hillyard, 1980) and the late positive complex, or LPC (e.g., Curran, Tucker, Kutas, and Posner, 1993). The N400 is a negative-going potential that peaks approximately 400 ms after a meaningful stimulus such as a word or a picture. The amplitude of the N400 is larger following a stimulus that is inconsistent with the semantic context (see Kutas and Federmeier, 2001, for a review). In previous studies, differences in N400 amplitude relative to an unrelated baseline have been used to examine the extent to which specific meanings of ambiguous words are activated or selected; these studies have primarily utilized auditory or centrally-presented visual stimuli (Gunter, Wagner, and Friederici, 2003; Swaab, Brown, and Hagoort, 2003; Titone and Salisbury, 2004; Wagner and Gunter, 2004; Van Petten and Kutas, 1987; for a study involving VF presentation, see Atchley and Kwasny, 2003). The

LPC, which follows the N400, is thought to reflect more explicit wrap-up or meaning revision processes (e.g., Swaab et al., 1998). In some circumstances, the N400 response to target words that are related to contextually-inconsistent meanings of ambiguous words overlaps with the N400 response to unrelated words, indicating that the contextually-inconsistent meaning is not active; however, a difference may then emerge in the time window of the LPC, with greater positivity for the related word, indicating that the contextually-inconsistent meaning has been (re)activated following the processing of the related target (Swaab et al., 1998, 2003). ERPs thus provide a means of determining not only whether particular meanings are activated, but also when in the course of processing that activation (or inhibition) occurs.

The Current Study

The current study was designed to further investigate hemispheric asymmetries in meaning processing while taking into consideration the factors just described. In particular, two experiments jointly examine the processing of ambiguous and unambiguous words, using ERPs in conjunction with VF presentation and a relatedness judgment task. Although separate VF studies have examined hemispheric asymmetries in the processing of ambiguous and unambiguous words (e.g., Burgess and Simpson, 1988; Atchley et al., 1999), and studies involving participants with unilateral brain damage have examined both types of words within the same study (e.g., Klepousniotou and Baum, 2005), to our knowledge no previous study involving neurologically-intact participants has investigated the processing of both types of words within the same paradigm. In order to separate the effects of ambiguity and degree of relatedness (as indexed by associative strength), unambiguous words were paired with strongly- and weakly-related targets that were similar in associative strength to the dominant- and subordinate-related targets in the ambiguous condition (see Table 1).

Each experimental trial involved a sequence of three words: a centrally-presented “context word” (related or unrelated to the next word), a lateralized prime (ambiguous or unambiguous), and a centrally-presented target (related or unrelated to the immediately preceding prime). On ambiguous trials, the context word and the target were related to different meanings of the ambiguous homonym prime; on unambiguous trials, the context word and target were related to the same meaning of the unambiguous prime. In Experiment 1, subordinate-related context words were presented in order to bias selection toward the less frequent meaning; in Experiment 2, dominant-related context words were presented to bias selection toward the most frequent meaning. On each trial, participants decided if the target was related to the lateralized prime (the behavioral response was delayed until a prompt appeared, in order to prevent contamination of the ERP components of interest by response-related activity). Because previous work (e.g., Faust and Gernsbacher, 1996) has suggested that the resolution of lexical ambiguity (i.e., meaning selection) occurs when controlled processing is engaged at longer (750 ms or greater) SOAs, this study employed a relatively long SOA of 1000 ms.

The primary purpose of this study was to examine meaning selection in the cerebral hemispheres, as selection in each hemisphere may be differentially influenced by meaning frequency and context (Burgess and Simpson, 1988; Faust and Chiarello, 1998). Effects of these variables can be ascertained via the pattern of ERP responses across VF and experiment. For unambiguous trials, it was predicted that N400 priming – i.e., more positive responses than in the unrelated context/unrelated target (UU) baseline condition – would occur in all related conditions, for both hemispheres (Atchley et al., 1999). For ambiguous trials, selection of a consistent meaning should yield N400 priming, whereas selection of a meaning that is inconsistent with the target should result in an N400 amplitude that is equivalent to the UU baseline condition. If the inconsistent meaning selection is revised, then the amplitude of the LPC is expected to become more positive than baseline. In Experiment 1, which involves subordinate-related context words and dominant-related targets, selection based on frequency would thus result in a smaller (compared to baseline) N400 when the dominant-related target is encountered; this would occur for both unrelated and subordinate-related context conditions. Then, in Experiment 2, which involves dominant-related context words and subordinate-related targets, selection based on frequency would result in a large (similar to baseline) N400 when the subordinate-related target is encountered, irrespective of context. In contrast, selection based on context would result in a large N400 to the dominant-related target after processing of the subordinate-related context in Experiment 1 and a large N400 to the subordinate-related target in the presence of a dominant-related context word in Experiment 2. Based on at least some prior work (Faust and Chiarello; Faust and Gernsbacher, 1996), the LH might be predicted to show context-based selection, whereas the RH might tend to maintain both meanings in a relatively context-blind manner.

Experiment 1

Results

Recognition Accuracy—Mean *A′* was .78 (*SE* = .01)[2], indicating that participants attended to the context words and were able to discriminate between these words and distractors.

Relatedness Judgment Accuracy—Because a delayed response task was utilized, response time data were not analyzed. Accuracy data were subjected to a 2 (Visual Field) × 2 (Ambiguity) × 3 (Relatedness) analysis of variance (ANOVA). None of the interaction effects were significant (all *p*'s > .05). The main effects of VF [$F(1, 19) = 23.31$, $p < .001$, $MSE = .004$], ambiguity [$F(1, 19) = 18.2$, $p < .001$, $MSE = .01$], and relatedness [$F(2, 38) = 4.36$, $p < .05$, $MSE = .02$] were significant. Consistent with the RVF-LH advantage for word recognition that is typically observed in VF studies (e.g., Jordan, Patching, and Thomas, 2003), accuracy for LVF-RH trials ($M = .86$, $SE = .02$) was lower than accuracy for RVF-LH trials ($M = .90$, $SE = .01$). Accuracy for ambiguous trials ($M = .85$, $SE = .02$) was lower than accuracy for unambiguous trials ($M = .90$, $SE = .01$), indicating that disparate meanings made the task more difficult. Accuracy for UR trials ($M = .85$, $SE = .02$) was lower than accuracy for both RR and UU conditions [RR: $M = .88$, $SE = .02$; UU: $M = .90$, $SE = .02$; UU vs. RR: $t(19) = 1.05$, $p = .33$; UU vs. UR: $t(19) = 2.59$, $p < .05$; UR vs. RR: $t(19) = -2.69$, $p < .05$]. The lower accuracy for UR trials suggests that performance was negatively affected by a mismatch between the relatedness of the centralized prime and target. Importantly, the overall accuracy rates were good, suggesting that participants were attending to and able to read the lateralized words.

Event-Related Potentials—For the lateralized prime and target epochs, three time windows of interest were defined: the 300–500 ms window was examined for differences in N400 amplitude across conditions, and the 500–700 and 700–900 ms windows were each examined for differences in the amplitude of the Late Positive Complex. In order to select electrodes at which each effect was maximal, a 2 (Relatedness: UR vs. UU) × 2 (Hemisphere: RH and LH electrode sites) × 2 (Laterality: Lateral and Medial electrode sites) × 4 (Anteriority: Prefrontal, Frontal, Central, and Occipital electrode sites) distributional analysis was conducted within each time window.

In the N400 window, the effect of Relatedness interacted with each of the distributional variables [Relatedness × Hemisphere: $F(1, 19) = 8.09$, $p < .05$, $MSE = 0.61$; Relatedness × Laterality: $F(1, 19) = 26.74$, $p < .001$, $MSE = 1.98$; Relatedness × Anteriority: $F(3, 57) = 5.61$, $p < .05$, $MSE = 1.62$]. On average, the effect of relatedness was greater over right hemisphere channels, medial channels, and more posterior channels. However, these interactions were moderated by a significant four-way Relatedness × Hemisphere × Laterality × Anteriority

[2] *A′* is a non-parametric measure of discriminability. Values range from 0 to 1, with 0.5 indicating chance performance.

interaction [$F(3, 57) = 15.04$, $p < .001$, $MSE = 0.04$], which indicated that the RH skew occurred only at lateral, anterior sites. Next, planned *t* tests were used to compare activation within each scalp region (paired left and right channels) with activity at the medial, central electrodes where the distributional analysis had indicated that effects were largest. Channels from a given region were selected for further analysis if their activity was not significantly lower than peak. This procedure resulted in the selection of 10 channels for inclusion: Left and Right Medial Frontal, Left and Right Medial Central, Middle Central, Left and Right Dorsal Parietal, Middle Parietal, and Left and Right Medial Occipital. In the early LPC window, Relatedness interacted with Laterality and Anteriority, with larger effects occurring at medial and posterior sites [Relatedness × Hemisphere: $F(1, 19) = .17$, $p = .69$, $MSE = 1.03$; Relatedness × Laterality: $F(1, 19) = 29.62$, $p < .001$, $MSE = 2.88$; Relatedness × Anteriority: $F(3, 57) = 16.24$, $p < .001$, $MSE = 2.07$]. Again, there was a Relatedness × Hemisphere × Laterality × Anteriority interaction [$F(3, 57) = 15.86$, $p < .001$, $MSE = .06$], with greater right than left activation over lateral, anterior sites. For this window, peak activation was at medial occipital channels. The procedure for channel selection identified the same 10 channels as in the N400 window. In the late LPC window, the effects and pattern of results were similar to the previous window [Relatedness × Hemisphere: $F(1, 19) = 1.75$, $p = .20$, $MSE = 1.16$; Relatedness × Laterality: $F(1, 19) = 32.51$, $p < .001$, $MSE = 2.18$; Relatedness × Anteriority: $F(3, 57) = 8.10$, $p < .01$, $MSE = 2.35$; Relatedness × Hemisphere × Laterality × Anteriority $F(3, 57) = 8.46$, $p < .001$, $MSE = .09$]. Peak activation was again at medial occipital sites, and the same 10 channels were selected.

Further analyses were conducted using the 10 selected channels. For the lateralized primes, mean amplitude data from each window were subjected to a 2 (Visual Field) × 2 (Ambiguity) × 2 (Relatedness: Related vs. Unrelated) ANOVA. For the targets, a 2 (Visual Field) × 2 (Ambiguity) × 3 (Relatedness: Related-Related [RR] vs. Unrelated-Related [UR] vs. Unrelated-Unrelated [UU]) ANOVA was employed.

For the lateralized prime epoch, only the main effect of relatedness was significant in the N400 [$F(1, 16) = 8.91$, $p < .01$, $MSE = 15.35$] and LPC windows [500–700 ms: [$F(1, 16) = 10.12$, $p < .01$, $MSE = 37.22$; 700–900 ms: $F(1, 16) = 4.62$, $p < .05$, $MSE = 33.34$]. Thus, the subordinate- and weakly-related context words primed the lateralized words, resulting in more positive waveforms, compared to the unrelated baseline, during the N400 and LPC time-windows; this effect was independent of ambiguity and VF. To compare effect sizes across the VFs, unrelated minus related difference waves were constructed and compared for RVF and LVF presentation using ANOVAs. No comparison was statistically significant in any time window (all *p*'s > .40), indicating that the magnitude of the context-to-prime-word facilitation did not differ based on the VF of the lateralized prime.

To preview the results of the target epoch, in both VFs N400 and LPC priming were present for unambiguous UR and RR conditions, but N400 priming for the ambiguous condition was limited to UR, whereas LPC priming occurred for both UR and RR. N400 priming for the unambiguous RR condition was larger in the LVF-RH.

The only significant interaction was Ambiguity × Relatedness, in both the N400 [$F(2, 38) = 8.41$, $p < .001$, $MSE = 18.13$] and early LPC windows [$F(2, 38) = 4.58$, $p < .05$, $MSE = 23.81$]. For targets following unambiguous primes, in both VFs, N400 responses were decreased (i.e., became more positive) and LPC responses were increased for the strong associates, irrespective of context (see Figure 1). However, a different pattern emerged for targets following ambiguous primes (see Figure 2). In the unbiased context (UR), the dominant meaning showed N400 priming and increased LPC responses for presentation to both VFs. In contrast, when a subordinate-related context word was presented (RR), N400 priming was absent in both VFs; differences began to emerge only later, in the early LPC window. By the late LPC window, the effects of relatedness did not differ between ambiguous and unambiguous trials. In this time window, the main effect of Relatedness was significant $F(2, 38) = 50.45$, $p < .001$, $MSE = 50.23$; both UR and RR were facilitated, with greater positivity for UR. The main effect of Ambiguity was also significant $F(1, 19) = 12.50$, $p < .01$, $MSE = 31.24$, with greater positivity occurring on unambiguous trials. Thus, it appears that, in both VFs, the subordinate-biased contexts led to selection of the subordinate meaning of the lateralized primes, such that the dominant-related target was not activated in the N400 time window -- though the meaning relationship did have an effect later in the epoch, beginning in the early LPC window.

In order to more fully explore the priming effects observed in this experiment, planned comparisons were used to examine the effects of ambiguity and relatedness in each VF; within each time window, ambiguous and unambiguous RR and UR conditions were compared to their respective UU baselines, and RR and UR were also compared for each trial type (ambiguous and unambiguous). See Table 2 for the results of these comparisons. The same pattern of results was observed in each VF. For unambiguous trials, both related conditions were primed in all windows (see Figure 1). Priming for the ambiguous UR condition occurred in all windows, whereas priming for the ambiguous RR condition only occurred in the LPC windows (see Figure 2).

To compare effect sizes across the VFs, unambiguous and ambiguous RR and UR conditions were subtracted from their respective UU baselines to form difference waves (see Figure 3). The difference waves were then compared across VFs using ANOVAs. The only significant comparison was from the N400 window, when positivity for the unambiguous RR condition was greater in the LVF-RH, $F(1, 19) = 6.15$, $p < .05$, $MSE = 19.03$.

Discussion

The results of this first experiment do not provide evidence for hemispheric asymmetries in the processing of dominant meanings of ambiguous words. Both hemispheres were affected by a subordinate-biased context word (RR condition), failing to show facilitation for the dominant-related target in this condition until the LPC time windows. However, in both VFs facilitation was seen from the centrally-presented subordinate-related context word onto the lateralized prime. This pattern suggests that the subordinate-related context word led to selection, in both hemispheres, for the subordinate meaning of the ambiguous homonym, with concomitant suppression of the dominant meaning (Gernsbacher et al., 2001). Upon presentation of the target, then, the dominant meaning of the homonym may have been recovered through an explicit revision process indexed in increased LPC amplitudes (Swaab et al., 1998). In contrast, when the context word was unrelated to the lateralized prime (UR condition), priming of the dominant-related target occurred on both the N400 and the LPC, in both VFs. From these results, it would appear that meaning selection is driven by biasing contextual information when it is present, whereas in the absence of such information, selection is driven by frequency. However, confirmation of the latter portion of this argument would require evidence that N400 priming does not occur when a subordinate-related target is presented in an unbiased context; this will be examined in the second experiment.

The results further suggest that the hemispheres process strong associates of unambiguous words in a similar manner. In contrast to the results for the ambiguous trials, N400 priming was observed for the RR condition in the unambiguous trials. Thus, a weakly-related context word does not have a negative effect on the processing of a more strongly-associated target, provided that the two words are related to the same concept (Atchley et al., 1999). On the other hand, while one might have predicted larger priming effects when a related context word was used (since both the context word and the target are related to the same meaning of the lateralized prime), no significant difference between UR and RR occurred for either hemisphere, though priming from the weakly-related context word onto the lateralized prime itself was observed for both VFs. It is possible that priming for the strong associate was sufficiently robust as to create a kind of ceiling effect, whereby any additional facilitation from the weakly-related context word was not visible in the waveforms; the results from the next experiment, where the context and target word positions are reversed, can help speak to this possibility.

However, one significant hemispheric difference was found when difference waves from the unambiguous conditions were compared: greater N400 facilitation (positivity) was found for the LVF-RH in the RR condition. Furthermore, the UR vs. RR comparison for this window approached significance in the RVF-LH (p = .07), with greater positivity for UR. One explanation for such a pattern would point to differential effects of the context word on the lateralized prime itself – e.g., if priming of the lateralized unambiguous word by the weakly related context word were greater in the RH, resulting in more spreading activation that facilitated processing of the target. However, analysis of the lateralized prime epoch failed to show any significant hemispheric differences, indicating that the observed hemispheric difference results from the effect of the context word on target processing. Thus, it seems that the LH's processing of an unambiguous target may be negatively influenced by a context word that is weakly associated with the prime (and potentially points to a slightly different meaning sense than does the target). This pattern is consistent with prior findings that have been argued to support the coarse coding hypothesis (Beeman et al., 1994). In particular, the RH has been shown to exhibit stronger meaning activation (compared to the LH) from several weakly-related primes ("summation priming"). The LH, instead, seems to benefit more from a single, strongly-associated prime than from several weakly-associated primes, whereas the RH benefits equally. According to the coarse coding hypothesis, the LH strongly activates central features of words, whereas the RH weakly activates a broad range of features. These differences in activation are relative rather than absolute, and attention also influences LH processing: priming by weak associates does occur in the RVF-LH, and, under conditions that promote automatic processing, this priming is equivalent across the hemispheres (Beeman et al., 1994). Thus, it seems that weakly-related information can be activated in the LH, but that controlled processes focus attention on more strongly-related information. In the current study, the relatedness judgment task would be expected to elicit controlled processing, and the long (1000 ms) SOA allows sufficient time for such processes to be implemented (Gernsbacher et al., 1990).

To further explore the effects of context, ambiguity, and meaning frequency on semantic processing by the two cerebral hemispheres, Experiment 2 involved the presentation of dominant- or strongly-related context words and subordinate- or weakly-related targets. If hemispheric asymmetries in lexical processing are dependent on meaning frequency, then a different pattern may emerge for this experiment. In particular, although the hemispheres respond similarly when a dominant-related target is utilized, previous findings suggest that the hemispheres might be more likely to differ if a subordinate-related target is presented (e.g., Burgess and Simpson, 1988).

Experiment 2

Results

Recognition Accuracy—Mean A' was .80 (SE = .01), indicating that participants attended to context words and were able to discriminate between these words and distractors.

Relatedness Judgment Accuracy—Accuracy data were subjected to a 2 (Visual Field) × 2 (Ambiguity) × 3 (Relatedness) analysis of variance (ANOVA). The main effects of VF [$F(1, 19) = 16.87$, $p < .01$, $MSE = .01$], ambiguity [$F(1, 19) = 28.38$, $p < .001$, $MSE = .01$], and relatedness [$F(2, 38) = 32.97$, $p < .001$, $MSE = .04$] were significant. Similar to Experiment 1, accuracy for LVF-RH trials (*M* = .78, *SE* = .02) was lower than accuracy for RVF-LH trials (*M* = .83, *SE* = .01), and accuracy for ambiguous trials (*M* = .77, *SE* = .02) was lower than accuracy for unambiguous trials (*M* = .84, *SE* = .01). Accuracy for UU trials (*M* = .93, *SE* = .01), which, in this task, were associated with a "no" response, was greater than that for both RR and UR conditions, which were associated with "yes" responses [RR: *M* = .75, *SE* = .02; UR: *M* = .74, *SE* = .02; UU vs. RR: $t(19) = 6.10$, $p < .001$; UU vs. UR: $t(19) = 6.43$, $p < .001$; UR vs. RR: $t(19) = -.79$, $p = .42$]. Compared to Experiment 1, accuracy for related targets was lower [Expt. 1 Related: *M* = .86, *SE* = .02; Expt. 2 Related: *M* = .74, *SE* = .02; $t(38) = 4.59$, $p < .001$], whereas accuracy for unrelated targets was not significantly different [Expt. 1 Unrelated: *M* = .90, *SE* = .02; Expt. 2 Unrelated: *M* = .93, *SE* = .01; $t(38) = -1.08$, $p = .29$]. These findings indicate that performance was lower when there was a weak relationship between the lateralized prime and target. Nevertheless, accuracy remained high, suggesting that participants were attending to and able to read the lateralized words, and that they typically judged the semantic relationship correctly.

The main effects were moderated by a significant three-way interaction [$F(2, 38) = 3.31$, $p < .05$, $MSE = .003$]. To explore this effect, the Ambiguity × Relatedness interaction was examined for each VF. For the RVF-LH, the interaction was not significant [$F(2, 38) = 1.87$, $p = .17$], but there were significant main effects of Ambiguity [$F(1, 19) = 11.90$, $p < .005$] and Relatedness [$F(2, 38) = 22.31$, $p < .001$]. Accuracy for unambiguous triplets (*M* = .86, *SE* = .01) was greater than for ambiguous triplets (*M* = .80, *SE* = .02), and accuracy for unrelated targets (*M* = .94, *SE* = .01) was greater than for both related conditions **[**RR: *M* = .78, *SE* = .02; UR: *M* = .76, *SE* = .02; UU vs. RR: $t(19) = 5.34$, $p < .001$; UU vs. UR: $t(19) = 5.53$, $p < .001$; UR vs. RR: $t(19) = -.79$, $p = .42$**].**

For the LVF-RH, the Ambiguity × Relatedness interaction was significant [$F(2, 38) = 10.47$, $p < .001$]. Among ambiguous triplets, the main effect of Relatedness was significant [$F(2, 38) = 44.98$, $p < .001$]. Accuracy for unrelated targets (*M* = .91, *SE* = .02) was greater than for both related conditions [RR: *M* = .64, *SE* = .03; UR: *M* = .66, *SE* = .03; UU vs. RR: $t(19) = 7.32$, $p < .001$; UU vs. UR: $t(19) = 7.26$, $p < .001$; UR vs. RR: $t(19) = 1.14$, $p = .28$]. Among unambiguous triplets, the main effect of Relatedness was significant [$F(2, 38) = 14.06$, $p < .001$]. Accuracy for unrelated targets (*M* = .93, *SE* = .02) was greater than for both related conditions [RR: *M* = .80, *SE* = .03; UR: *M* = .76, *SE* = .03; UU vs. RR: $t(19) = 3.46$, $p < .005$; UU vs. UR: $t(19) = 4.47$, $p < .001$; UR vs. RR: $t(19) = -1.75$, $p = .10$]. Thus, although the Visual Field × Ambiguity × Relatedness interaction was significant, the same pattern of significant effects was observed for each VF: accuracy for unrelated targets was greater than that for related targets, and this occurred for both ambiguous and unambiguous triplets. The significant three-way interaction was likely due to the different pattern for ambiguous and unambiguous UR and RR in the LVF-RH: for ambiguous conditions, UR was numerically larger than RR, a difference that did not approach significance ($p = .28$); for unambiguous conditions, RR was numerically larger than UR, a difference that did approach significance ($p = .10$).

Event-Related Potentials—Analyses were conducted using the set of 10 channels selected in Experiment 1. For the lateralized primes, mean amplitude data from each window were subjected to a 2 (Visual Field) × 2 (Ambiguity) × 2 (Relatedness: Related vs. Unrelated) ANOVA. For the targets, a 2 (Visual Field) × 2 (Ambiguity) × 3 (Relatedness: Related-Related vs. Unrelated-Related vs. Unrelated-Unrelated) ANOVA was employed.

In the lateralized prime epoch, only the main effect of relatedness was significant, in both the N400 window [$F(1, 14) = 34.53$, $p < .001$, $MSE = 10.79$] and early LPC window [$F(1, 14) = 11.04$, $p < .01$, $MSE = 27.33$]. No effects were significant in the late LPC window, although the effect of relatedness approached significance [$F(1, 14) = 3.78$, $p = .07$, $MSE = 31.78$]. Thus,

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the dominant- and strongly-related context words primed the lateralized words, resulting in decreased N400 responses and increased (early) LPC responses (i.e., more positivity in both time windows) compared to the unrelated baseline; this effect was independent of ambiguity and VF. To compare effect sizes across the VFs, unrelated minus related difference waves were constructed and compared for RVF and LVF presentation using ANOVAs. No comparison was statistically significant in any time window (all p's > .10), indicating that the magnitude of the priming effect did not differ based on the VF of the lateralized word.

To preview the results for the target epoch, N400 and LPC priming was present for unambiguous UR and RR conditions in both visual fields; UR priming was larger in the RVF-LH. In the ambiguous condition, UR was primed in N400 and LPC windows in the RVF-LH, but only in LPC windows in the LVF-RH. In the late LPC window, RR was marginally primed in the RVF-LH and was significantly primed in the LVF-RH.

The Visual Field × Relatedness interaction was significant in the N400 window, $F(2, 38) = 4.85$, $p < .05$, $MSE = 25.85$, was marginally significant in the early LPC window, $F(2, 38) = 2.84$, $p = .07$, $MSE = 35.48$, and just missed significance in the late LPC window, $F(2, 38) = 3.16$, $p = .05$, $MSE = 38.17$. For the RVF-LH, responses were more positive, relative to baseline, for both related conditions in all windows, though there was more facilitation for UR than RR. For the LVF-RH, only UR was more positive than baseline in the N400 window, but both UR and RR showed greater positivity in the LPC time-windows, with no difference in facilitation between UR and RR. Thus, independent of ambiguity effects, both hemispheres showed some evidence of sensitivity to the context word.

The Ambiguity × Relatedness interaction was significant in the N400 window, $F(2, 38) = 5.99$, $p < .01$, $MSE = 22.17$, and early LPC window, $F(2, 38) = 8.62$, $p < .001$, $MSE = 17.37$. The same pattern was observed in both time-windows: for unambiguous trials, priming occurred for both related conditions, with greater priming following the unrelated context word (i.e., UR > RR). For ambiguous trials, priming occurred when the context word was unrelated (UR), but not when the context word was biased toward the dominant meaning of the homonym (RR). In the late LPC window, the main effect of relatedness was significant, $F(2, 38) = 29.09$, $p < .001$, $MSE = 54.89$, and priming occurred for both related conditions, with greater priming for UR. Thus, when the context word biased processing toward the dominant meaning of a homonym, priming for the subordinate-related target was suppressed until the late LPC time window. For the unambiguous trials, processing of a strong lexical associate dampened (but did not eliminate) priming for a weaker associate.

As in Experiment 1, planned comparisons were used to fully examine the effects of ambiguity and relatedness in each VF. See Table 3 for the results of these comparisons, and see Figures 4 and 5 for the ERP waveforms from unambiguous and ambiguous conditions, respectively. In the unambiguous condition, the difference between UR and RR (with greater priming for UR) was significant in all time windows for the RVF-LH but was never significant for the LVF-RH. In the ambiguous condition, UR was primed in all windows for the RVF-LH. In contrast, ambiguous RR was not greater than baseline in the N400 and early LPC windows, and the comparison only approached significance in the late LPC window. For the LVF-RH, ambiguous UR was not primed until the early LPC window, and ambiguous RR was not primed until the late LPC window.

To compare effect sizes across the VFs, unambiguous and ambiguous RR and UR conditions were subtracted from their respective UU baselines to form difference waves (see Figure 6 for the mean difference wave amplitudes). The difference waves were then compared across visual fields using ANOVAs. In the N400 and early LPC windows, the main effect of VF was significant [N400: $F(1, 19) = 8.16$, $p < .05$, $MSE = 76.98$; Early LPC: $F(1, 19) = 4.81$, $p < .05$, *MSE* = 98.51], indicating that difference wave amplitudes were typically larger in the RVF-LH. Planned comparisons revealed that the unambiguous UR difference wave was greater for the RVF-LH in the N400 and late LPC windows, and was marginally greater in the early LPC window [N400: $F(1, 19) = 4.81$, $p < .05$, $MSE = 54.43$; Early LPC: $F(1, 19) = 4.37$, $p = .05$, $MSE = 74.00$; Late LPC: $F(1, 19) = 4.91$, $p < .05$, $MSE = 79.67$]. In the N400 window, the mean amplitude of the ambiguous UR difference wave was greater for the RVF-LH, $F(1, 19) = 4.73$, $p < .05$, $MSE = 49.50$, which is consistent with the pattern observed in the untransformed waveforms.

Discussion

Whereas Experiment 1 suggested that the processing of the dominant meaning of ambiguous homonyms is similar in the two hemispheres, the results of Experiment 2 revealed asymmetries in the processing of subordinate meanings of these words. Perhaps most notably, when the context word was unrelated to the homonym prime (UR condition), N400 priming for the subordinate-associated target was seen with RVF-LH presentation but not with LVF-RH presentation. Priming for the UR condition was observed later for LVF-RH presentation, in the LPC time windows, suggesting that the RH eventually activated the subordinate meaning, perhaps through an explicit revision process (Swaab et al., 1998). Taken together with the results of Experiment 1, this pattern suggests that the RH is more strongly affected by meaning frequency, initially failing to show priming for the subordinate meaning in an unbiased context (cf. Burgess and Simpson, 1988). In contrast, the LH seems to immediately activate both dominant and subordinate meanings in an unbiased context. However, this activation is context-dependent, as priming for the subordinate-related target was suppressed in the presence of a dominant-associated context word (RR condition) until the late LPC time window.[3] The RH showed some evidence of context-sensitivity as well, since priming for the subordinate-associate was observed in the early LPC window when the context word was unrelated, but not when the context word was related to the dominant meaning of the homonym.

Both hemispheres were slow to recover the target meaning in the ambiguous RR condition; more rapid recovery from an inconsistent meaning selection was observed in Experiment 1, when the LPC to the inconsistent target diverged from baseline in the earlier (500–700 ms) time window. Given the long (1000 ms) SOA used in the current study, these findings do not differentiate between selective (i.e., context-dependent; Swinney and Hakes, 1976) and exhaustive (i.e., context-independent; Swinney, 1979) models of lexical access, since exhaustive models typically predict that multiple access is followed by rapid selection (e.g., Seidenberg, Tanenhaus, Leiman, and Bienkowski, 1982). Both models can accommodate these data on the assumption that meaning selection makes it more difficult to access or recover a different meaning (Balota and Paul, 1996; Gernsbacher et al., 1990; Simpson and Kang, 1994) and that this type of effect is stronger when the dominant meaning has been selected. However, similar effects have been observed following dominant and subordinate selection (Simpson and Kang, 1994; Gernsbacher et al., 2001; Morris and Binder, 2001). Instead, the most parsimonious explanation of the differences observed in the time course of recovery across the two experiments would involve a hybrid model of lexical access that incorporates effects of both frequency and context (Duffy, Morris, and Rayner, 1988; Tabossi, 1988). For example, the reordered access model (Duffy et al., 1988) argues that the dominant meaning is automatically and rapidly activated when a homonym is preceded by a subordinate-biased context; this obligatory activation might facilitate reactivation of the dominant meaning following subordinate selection. In contrast, the subordinate meaning might not be activated

[3]Priming only approached significance for the RVF-LH in the untransformed waveforms, whereas significant priming occurred for the LVF-RH; however, a comparison of difference waves for this effect indicated that its magnitude was similar across the hemispheres.

in a strongly constraining dominant-biased context (Tabossi, 1988; Tabossi and Sbisa, 2001), making meaning revision more difficult.

For unambiguous trials, both hemispheres showed priming for weak associates when the context word was unrelated (UR condition), though the difference waves revealed that this priming was greater for RVF-LH than for LVF-RH trials. When this difference is taken together with the RH's lack of N400 priming for the subordinate meaning, it suggests that the RH, compared to the LH, may generally show reduced activation or selection of less frequent and/or weakly-associated aspects of word meanings. This pattern is opposite to that predicted by the coarse coding hypothesis (Beeman et al., 1994). Given that the RH showed significant N400 priming for unambiguous UR triplets, weakly associated but consistent meanings may simply be activated less strongly than in the LH, but less frequent meanings that are inconsistent (e.g., on ambiguous UR trials in the current experiment) may not be activated at all, or may decay or be suppressed in the RH (cf. Atchley et al., 1999). Alternatively, the N400 differences between unambiguous and ambiguous UR triplets may have been due to a small but statistically reliable difference in associative strength between weakly-associated and subordinate-related targets (see Table 1).

Interestingly, facilitation for weak associates of an unambiguous word was also context-dependent, at least for the RVF-LH.[4] Whereas one might have expected more robust priming for unambiguous trials when a related context word was present (since both the context word and the target are related to the same meaning), priming in the RVF-LH was actually smaller compared with that after the unrelated context word, and there was no difference between the related conditions for the LVF-RH. Although both the context word and the target were related to the same meaning of the lateralized word, some primes and targets were related to somewhat different senses (e.g., the triplets *syrup-maple-tree* and *harmony-peace-quiet)*. Rather than enhancing priming for the weakly-related target, the more strongly-related context word could result in decreased target priming if meaning selection involves inhibition of other senses (Gernsbacher et al., 1990;Klein and Murphy, 2001). In Experiment 1, the corresponding RVF-LH effect approached significance ($p = .07$), suggesting that even a weakly-related context word may be able to induce this effect to some extent. Thus, the LH may tend to use context information to focus activation on a single meaning or sense, whereas the RH is less likely to do so (although the N400 results from the ambiguous condition in Experiment 1 indicate that some context-based meaning selection can occur in the RH).

General Discussion

The goal of this pair of studies was to examine the ability and tendency of the two cerebral hemispheres to (1) activate strong and weak associates and dominant and subordinate meanings of unambiguous and ambiguous words, respectively, and (2) use context information to shape meaning activation and selection. To that end, ERPs were recorded as participants judged whether or not a lateralized prime word was related in meaning to a centrally-presented target word. Prime-target pairs were preceded by a centrally-presented context word. In Experiment 1, the processing of dominant/strongly-associated targets was examined in the presence of unrelated or subordinate-biased/weakly-associated context words. In Experiment 2, context and target words were reversed in order to examine the processing of subordinate/weakly-associated targets in the presence of unrelated or dominant-biased/strongly-associated context words. Prior VF studies have tended to examine processing of a lateralized target word in the presence of a centrally-presented (e.g., Burgess and Simpson, 1988) or laterally-presented (e.g.,

[4]It is difficult to say whether the RH is similarly sensitive to context in this case. The planned comparisons failed to show a difference between UR and RR in any time window for the LVF-RH condition, suggesting a lack of context effects. However, the weaker facilitation of the target in the unbiased condition may make it more difficult to see context-related modulations.

Chiarello, Liu, Shears, Quan, and Kacinik, 2003) prime word. In the current study, in contrast, the critical prime words (unambiguous or ambiguous) were lateralized and the targets were centrally-presented; this has the advantage of allowing a comparison of the ERP responses to perceptually identical stimuli, as a function of which hemisphere initially received (and thus preferentially processed) the prime.

Consistent with prior ERP studies of word pair priming in the two hemispheres (Coulson, Federmeier, Van Petten, and Kutas, 2005; Bouaffre and Faita-Ainseba, 2007), we observed N400 decreases and LPC increases in both VFs for the lateralized prime words when these were preceded by related (as compared with wholly unrelated) context words. This priming did not differ as a function of ambiguity and, importantly, was similar in size and timing across the VFs. This indicates that word processing in both hemispheres is affected by the limited context provided by a single related word. Furthermore, the similarity of this effect across conditions allows for uncomplicated interpretation of the target word data, where results across the two experiments did reveal differences in how the hemispheres process both ambiguous and unambiguous words for meaning.

When ambiguous homonyms were lateralized to the RVF-LH under conditions in which the context word was unrelated in meaning (UR condition), N400 facilitation (and greater positivity in the LPC time window) was seen for both the dominant- (Experiment 1) and the subordinate- (Experiment 2) associated target words. Thus, in the absence of a biasing context, the LH seems to activate both meanings of the homonym. Alternatively, it is possible that the LH is able to rapidly recover the subordinate meaning in an unbiased context, resulting in decreased N400 responses. The N400 component seems to reflect both automatic and controlled semantic processes (e.g., Deacon, Hewitt, Yang, and Nagata, 2000; Holcomb, 1988). Thus, in Experiment 2, the LH may have used controlled attention to facilitate rapid recovery following an inappropriate dominant meaning selection; this hypothesis is consistent with numerous studies indicating that the LH is more likely to engage in controlled processing (e.g., Beeman et al., 1994; Chiarello, 1985; Nakagawa, 1991). We are currently using eyetracking methods with these materials in a similar paradigm to try to adjudicate between these possibilities.

The results further indicate that the LH’s processing of ambiguous words is context-dependent. In both experiments, N400 facilitation was suppressed in the presence of an inconsistent biasing context (RR condition); indeed, N400 responses under these circumstances did not differ from those to a wholly unrelated word. Thus, the LH seems to select the context-appropriate meaning of the homonym, in both dominant- and subordinate-biasing contexts. When the context information is misleading, the LH then seems to be able to recover the appropriate meaning of the ambiguous word, as manifested in increased amplitude of the LPC. This recovery process takes longer for the subordinate than for the dominant meaning (appearing in the 700–900 ms and 500–700 ms time windows, respectively). The more rapid recovery of the dominant meaning is consistent with hybrid models of lexical access that incorporate effects of both frequency and context (Duffy, Morris, and Rayner, 1988; Tabossi, 1988).

The RH showed a different pattern of responses when the context word was unrelated (UR condition), as N400 amplitude decreases were found in Experiment 1, for the dominant associate, but not in Experiment 2, for the subordinate associate. Thus, in a non-biasing context the RH seems to be influenced by meaning frequency, initially activating only the dominant meaning of an ambiguous lexical item (cf. Klepousniotou and Baum, 2005). Activation of the subordinate meaning is delayed (first appearing in the early part of the LPC time window, between 500 and 700 ms), and may require additional processing. However, like the LH, the RH seems to be able to make use of biasing contextual information to select an appropriate meaning. In Experiment 1, N400 facilitation for the dominant meaning was suppressed when the context word was biased toward the subordinate meaning (RR condition). Similarly, in Experiment 2, the enhanced LPC response in the early time window was absent in the biasing context. As was true for the LH, the RH seems to be able to then recover from an incorrect meaning selection, and does so earlier for the dominant than for the subordinate meaning. Furthermore, the planned comparisons revealed no evidence for striking hemispheric differences in the timecourse or nature of the observed context effects for the ambiguous trials.

Overall, then, whereas behavioral VF studies have indicated that the LH is more likely to select the contextually-consistent meaning (Faust and Chiarello, 1998; Faust and Gernsbacher, 1996), the current data suggest that the hemispheres respond similarly to a biasing context, but differ in an unbiased context. The biasing context findings are consistent with the pattern across neuropsychological studies, which have suggested that both LH and RH damage interfere with normal meaning selection (e.g., Grindrod and Baum, 2003; Swaab et al., 1998; Tompkins et al., 2000), and are also consistent with recent neuroimaging findings of bilateral activation during ambiguity resolution (Rodd, Davis, and Johnsrude, 2005; Zempleni, Renken, Hoeks, Hoogduin, and Stowe, 2007). For unbiased contexts, our N400 findings conflict with the reaction time effects that Burgess and Simpson (1988) found for a lexical decision task at a long (750 ms) SOA, but are consistent with the accuracy effects that Hasbrooke and Chiarello (1998) observed for a comparable lexical decision task with the same SOA: the LH showed activation for multiple meanings, whereas the RH only showed activation for the dominant meaning. Interestingly, if one compares the behavioral priming effects at the 35 and 750 ms SOAs utilized by Burgess and Simpson to the N400 and LPC priming effects observed in the current study, the pattern of activated meanings is identical (with the exception that we did not observe late LH inhibition of the subordinate meaning): each study found early activation of both meanings in the LH, along with early dominant activation and late activation of both meanings in the RH. Thus, although 35 ms is much shorter than the 1000 ms SOA we employed, SOA may be less important when a multidimensional methodology like ERPs is used – examination of early and late components allows one to differentiate between early meaning activation and later, more explicit processes.

In the current study, asymmetries were also observed in the hemispheres' responses to unambiguous trials as a function of association strength and context. When the context word was unrelated in meaning to the lateralized, unambiguous prime, we found N400 facilitation for both strongly- and weakly-associated targets in both VFs. However, in all time windows, the RH showed less facilitation for the weakly associated information than did the LH. This pattern is opposite to that predicted by coarse coding (Beeman et al., 1994), which argues that the RH should show greater activation for distant semantic information. However, the pattern is consistent with prior ERP work that also found greater LH facilitation for lexically associated information (Bouaffre and Faita-Ainseba, 2007; Coulson et al., 2005; Deacon et al., 2004). A set of behavioral studies (Kandhadai and Federmeier, 2007) using materials similar to those used here (but in a different order, with the homonym or corresponding unambiguous word occurring as a lateralized target in the triplet) also failed to find evidence in support of coarse coding; this was true whether distance was defined in terms of association strength or meaning consistency, as we find in the present study as well.

Nonetheless, for LVF-RH trials, significant N400 priming for weakly-related unambiguous targets did occur, in contrast to an absence of such priming for subordinate meanings of ambiguous words. This pattern indicates either that the RH shows differential priming effects as a result of small differences in the strength of weak associations (see Table 1), or that meaning consistency plays a role in RH meaning processing. An explanation based on consistency conflicts with Atchley et al. (1999), who found that the RH maintained both dominant-consistent and dominant-inconsistent features of polysemous words. However, in contrast to Atchley et al., Klepousniotou and Baum (2005) found that participants with an intact

RH were able to select the contextually-biased dominant meaning of both homonymous and non-metaphorical polysemous words, but not the biased subordinate meaning. It is difficult to determine if a consistency-based argument conflicts with these results, since for polysemous words the subordinate-related target varied in its consistency with the dominant meaning. However, an explanation based on associative strength is inconsistent with their results: although Klepousniotou and Baum did not report the strength of prime-target associative relationships, an analysis of forward association proportions (taken from Nelson et al., 1998) for homonyms indicates that subordinate targets were more weakly associated than dominant targets ($p < .05$), but this was not the case for non-metaphorical polysemous stimuli ($p = .83$). Thus, it appears that the effects observed for participants with an intact RH are due to meaning dominance or frequency, rather than associative strength.

Effects of context were also evident for the unambiguous trials, especially for the LH. In Experiment 2, responses for RVF-LH items were highly affected by context, as facilitation for the weakly-associated target was reduced in the presence of a strongly-associated context word (which sometimes pointed to an alternate sense of the unambiguous prime). LVF-RH responses were less affected by context (though this seems to have been due primarily to the overall reduced facilitation observed for the weakly-associated targets in the unbiased contexts). In Experiment 1, there was more RR priming for LVF-RH than RVF-LH trials, which is consistent with findings of greater summation priming in the RH (Beeman et al., 1994); thus, although the RH did not show more activation for the weakly-associated target, it seemed to make more use of weakly-related contextual information to facilitate target processing. The two hemispheres seem to use context information differently, with the LH more likely to focus activation on a single, contextually-relevant sense.

In some ways, the pattern of effects seen here may be analogous to those seen in the ERP literature looking at asymmetries during sentence processing. Although word processing in both hemispheres seems to be influenced by the message-level meaning information available from a sentence context (e.g., Coulson et al., 2005; Faust, Bar-Lev, and Chiarello, 2003), context seems to affect processing in different ways in each (Federmeier and Kutas, 1999, 2002; Federmeier, Mai, and Kutas, 2005; Wlotko and Federmeier, in press). In particular, the LH seems more likely to use the top-down information available from a sentence context to predict features of likely upcoming words, whereas processing in the RH seems to be more stimulus-driven and integrative in nature (see Federmeier, in press, for a more extensive discussion). Thus, in both single word and sentence-level contexts the LH seems to use controlled processing to focus attention on specific, contextually-appropriate features of likely upcoming words – affording strong, rapid facilitation when those features are actually encountered. The RH seems less likely to do this, and thus may have more difficulty processing weakly-associated information, as in the present study (cf. Wlotko and Federmeier, in press). However, its more stimulus-driven approach to processing may afford it the flexibility to integrate unexpected information with context – e.g., in Experiment 1, to appreciate the meaning relationship between the sometimes different senses of the weak and strong associates in the unambiguous RR condition. Furthermore, although the present study did not find striking hemispheric differences in the use of a single word context to facilitate meaning selection for ambiguous words, such differences might be more likely to occur in sentence contexts. For example, when processing a sentence such as “He dug with the …”, the LH would be expected to use context to predict a conceptual category like *digging implements* (Federmeier and Kutas, 1999), which would facilitate selection of the corresponding meaning of the word *spade* following its presentation (Faust and Gernsbacher, 1996, Exp. 1). In contrast, the RH would not be expected to activate a conceptual category prior to the presentation of the word *spade*, and would attempt to integrate any activated meaning with the preceding context, resulting in slower meaning selection.

The findings of the current study provide further evidence that meaning activation and selection processes are different in the two cerebral hemispheres, and that this has important implications for theories of normal language processing. In particular, while much effort has been devoted to uncovering “the” mechanism of ambiguity resolution, results from the VF literature suggest that multiple mechanisms may actually be implemented in parallel. Part of the inconsistency across the literature, therefore, may arise because different stimuli and task conditions (and possibly different participant samples) tap differentially into RH and LH processes. Although LH processes may tend to dominate in some cases, there is evidence that RH processes may be foremost in other circumstances. For example, when taken together with the results of a centralized study that utilized similar stimuli and the same SOAs (Titone and Salisbury, 2004), our results provide evidence that the RH can play a strong role in the processing of subordinate meanings. With subordinate-related targets, Titone and Salisbury report a pattern of results that matches the LVF-RH results from the current study: N400 facilitation did not occur for inconsistent (RR) or unbiased (UR) conditions. In contrast, we found facilitation for the unbiased condition for RVF-LH presentation. However, consistent with our findings from Experiment 1 (for both VFs), Titone and Salisbury observed N400 facilitation for dominant-related targets in an unbiased context, but not an inconsistent one. Thus, it appears that RH processing may prevail when a less frequent meaning is being processed. However, rather than maintaining less frequent meanings (Burgess and Simpson, 1988), as proposals such as coarse coding would suggest, it seems that the RH may tend to select the dominant meaning (Hasbrooke and Chiarello, 1998). Dominant meaning selection is most consistent with models of lexical access that incorporate effects of meaning frequency, such as the ordered access (Hogaboam and Perfetti, 1975) and reordered access models (Duffy et al., 1988); nevertheless, both selective access (Swinney and Hakes, 1976) and exhaustive access (Swinney, 1979) models would also predict that the dominant meaning would eventually be selected when biasing contextual information is unavailable. Thus, in some situations the RH, rather than the LH, appears to process ambiguous word meanings in the “expected” manner. This finding emphasizes the importance of understanding the hemispheres’ separable abilities and tendencies in order to more fully understand the mechanisms at work during normal language comprehension as people derive meaning from words.

Experimental Procedure

Experiment 1

Participants—The final set of participants included 20 native English speakers (11 female) with no early (< age 5) exposure to a second language. All participants were right-handed as determined by the Edinburgh handedness inventory (Oldfield, 1971); the mean laterality quotient was 0.78 (range = 0.58 to 1.0), with 1.0 being strongly right-handed and −1.0 being strongly left-handed. Nine participants reported having immediate family members who were left-handed. The mean age was 19.7 (range 18–25).

Materials—The stimuli consisted of word triplets selected from existing stimulus sets (Balota and Paul, 1996; Bennett and McEvoy, 1999) or derived using homograph norms (Twilley, Dixon, Taylor, and Clark, 1994), the MRC database (Coltheart, 1981), and/or word association norms (Nelson, McEvoy, and Schreiber, 1998). A total of 104 ambiguous and 104 unambiguous words were selected. For the ambiguous words, the mean dominant and subordinate meaning frequencies were 74% and 13%, respectively (Twilley et al., 1994). Both ambiguous and unambiguous word types were concrete (mean concreteness rating of 505 for ambiguous, 514 for unambiguous), imageable (mean imageability rating of 518 for ambiguous, 551 for unambiguous), and moderately frequent (Kucera and Francis (1967); mean log frequency of 1.59 for ambiguous, 1.85 for unambiguous). Ambiguous words had a mean length of 4.4 letters, while unambiguous words had a mean length of 4.8 letters. For each ambiguous word, one dominant-related and one subordinate-related word was selected; for each unambiguous word, one strongly-related and one weakly-related word was selected. In addition, two unrelated words were selected for each ambiguous and unambiguous word. For all related and unrelated word types, the selected words were concrete (mean concreteness ratings between 463 and 510), imageable (mean imageability ratings between 487 and 530), and of moderate frequency (Kucera-Francis mean log frequency between 1.12 and 1.54). Mean word length was between 5.0 and 5.7 letters. At least 75% of the words in each target condition had a noun meaning, approximately half had a verb meaning, and the overall distribution of word types was similar.

Ambiguous trials involved the presentation of a subordinate-related or unrelated context word and a dominant-related or unrelated target (e.g., *river-bank-deposit* if both prime and target were related; see Table 4). The parallel unambiguous trials involved the presentation of a related "weak" context or an unrelated context and a related "strong" target or an unrelated target (e.g., *taste-sweet-candy* if both prime and target were related). Note that "strong" is being used in a relative sense, as the association with the lateralized prime words is still fairly weak (see Table 1). For all conditions, context words and targets were unassociated. We refer to the conditions in the rest of the paper as UU (unrelated context, unrelated target), UR (unrelated context, related target), and RR (related context, related target). Although trials involving a related context word and an unrelated target (RU) were also included in the experiment to prevent the targets from being predictable, these were omitted from statistical analyses of the target epoch because they were not of theoretical relevance for the current experiment.

Table 4 gives examples of the conditions formed by crossing ambiguity with relatedness. When these conditions were crossed with VF (left or right), there were eight conditions for each ambiguity type, resulting in a total of 16 conditions. Eight stimulus lists were created, and each ambiguous or unambiguous word appeared in the eight possible conditions across these lists. To increase the number of items per condition, each ambiguous or unambiguous word was presented an additional time in the second half of the experiment, but with a different prime and target (e.g., RR trials became UU trials, and RU trials became UR trials); this procedure resulted in a total of 416 trials and 26 items per condition.

Procedure—Participants were seated in a dimly-lit room, one meter from a computer screen. They were told that a series of three words would appear on each trial, instructed to read each word without moving their eyes from a central fixation point, and informed that the primary task was to decide if the second and third words had related meanings. Participants were also told that the first word might be related to the second word and that reading the first word could facilitate perception of the rapidly-presented, lateralized second word. In addition, they were informed that there would be a recognition test over the first words between blocks.

On each trial, context words (first words) were presented above the central fixation cross for 500 ms, with a 1000 ms stimulus onset asynchrony (SOA). The prime (ambiguous or unambiguous) was presented two degrees to the left or right of fixation for 200 ms, with a 1000 ms SOA. The target was then presented above fixation for 500 ms. One second after the target's offset, a prompt ("?") appeared on the screen, indicating that participants should make their relatedness judgment response by pressing a "yes" or "no" button. For a given participant, each response button was paired with the left or right hand; response/hand pairings were counterbalanced across participants.

There were eight blocks of trials, with 52 trials per block. Between blocks, participants took a short break and were also given a recognition memory test over a subset of the centrally-presented context words from the previous block, to ensure that participants attended to these words.

EEG Recording and Analysis—The electroencephalogram (EEG) signal was recorded from 26 geodesically-arranged, silver/silver-chloride (Ag/AgCl) scalp electrodes (for a depiction of the electrode array, see Federmeier and Kutas, 1999). Eye movements were monitored via a bipolar montage of electrodes placed on the outer canthus of each eye. Blinks were detected by an electrode placed below the left eye. All data were sampled at 250 Hz and bandpass filtered online from 0.02 to 100 Hz. Data were referenced online to the left mastoid and rereferenced offline to the algebraic mean of the left and right mastoids.

Trials containing eye movements or recording artifacts (amplifier blocking or signal drift) were rejected offline, using thresholds set for individual subjects based on visual inspection of the data. For target words, epochs containing blinks were rejected, or corrected (Dale, 1994) when blinks occurred on a number of trials that was sufficient to develop a stable filter (correction was employed for 16 participants). For epochs corresponding to the lateralized primes, blink correction was not employed for any subject, due to an insufficient number of blinks. To ensure that presentation of the lateralized primes remained lateralized (i.e., 2 degrees from fixation), trials containing saccades during the 200 ms of stimulus presentation were marked, and both lateralized prime and target epochs were discarded for these trials. For three participants, data from lateralized prime epochs was not usable due to a high overall rejection rate. The overall average trial loss was 16.4% for the lateralized primes (remaining 17 participants) and 11% for the targets (20 participants). Following artifact rejection, ERPs were computed for the epoch from 100 ms prior to stimulus onset to 920 ms after onset. After subtraction of the 100 ms prestimulus baseline, averages were formed for each experimental condition. A digital bandpass filter of 0.2 to 20 Hz was employed before analyses were performed.

Experiment 2

Participants—The final set of participants included 20 native English speakers (11 female) who met the same criteria as the participants from Experiment 1. The mean laterality quotient was 0.75 (range = 0.27 to 1.0), and eight participants had left-handed family members. The mean age was 20.1 (range 18–24).

Materials—The materials were the same as those used in Experiment 1, albeit in a rearranged sequence (see below). Examples are given in Table 5; note that the same stimuli were used in Experiments 1 and 2 but different examples are given in Tables 4 and 5 to illustrate a wider range of the stimuli.

Procedure—For related ambiguous and unambiguous stimuli, the context words and targets used in Experiment 1 were reversed, resulting in dominant-related context words and subordinate-related targets, or strongly-related context words and weakly-related targets. The unrelated primes and targets did not change position. All other aspects of the procedure were unchanged.

EEG Recording and Analysis—The same procedures were used as in Experiment 1. For five participants, data from lateralized prime epochs was not usable due to a high overall rejection rate. The overall average trial loss was 16.7% for the lateralized primes (remaining 15 participants) and 12.3% for the targets (20 participants). Blink correction was not employed for prime epochs; target epochs were blink corrected for 13 participants.

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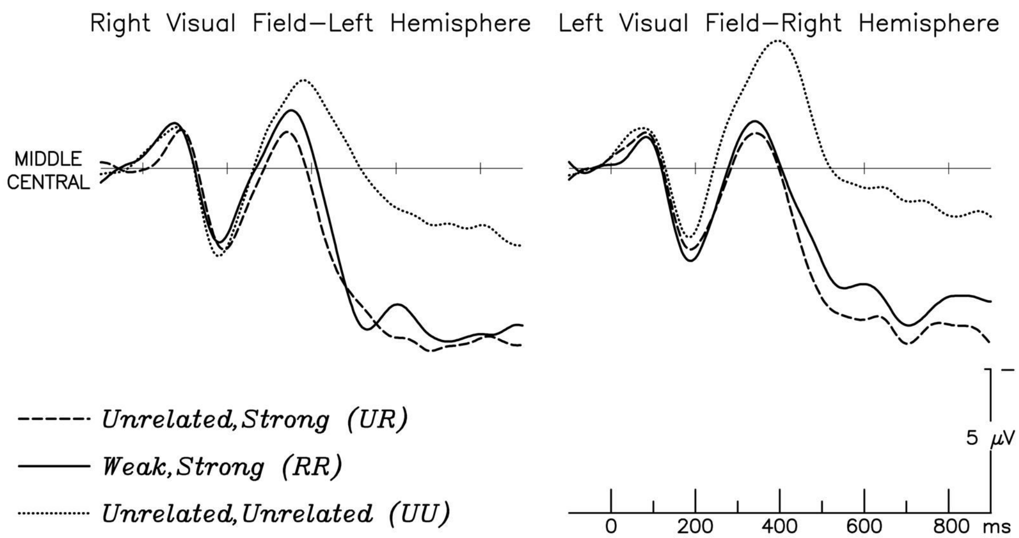

Figure 1.
Effect of relatedness during the target epoch for the unambiguous condition in Experiment 1. Similar effects were observed in each visual field: both related conditions were more positive than baseline in N400 and LPC windows.

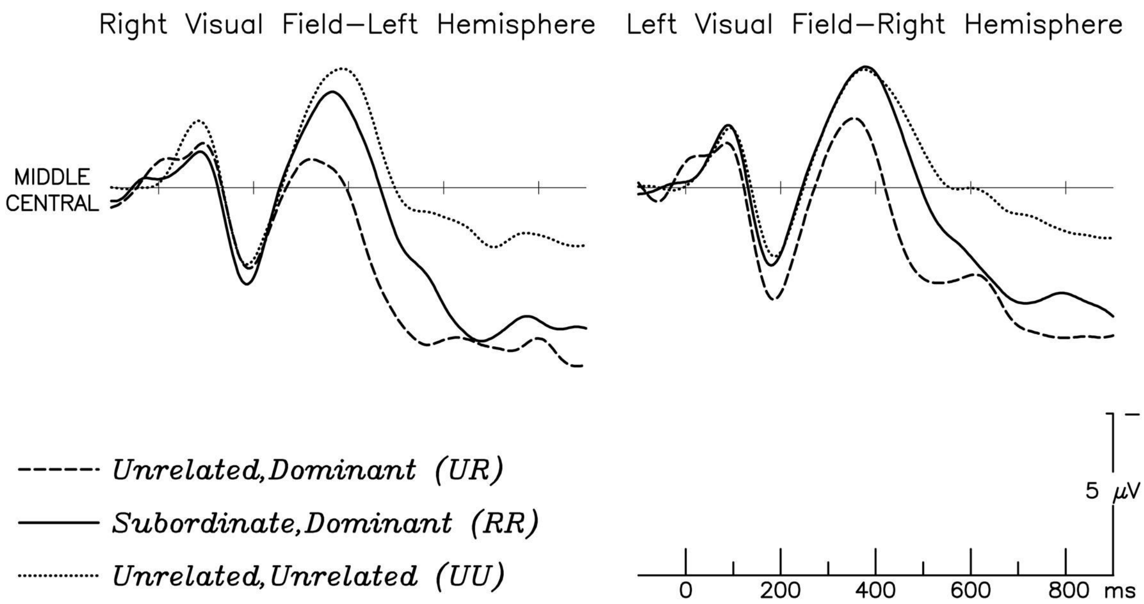

Figure 2.

Effect of relatedness during the target epoch for the ambiguous condition in Experiment 1. Similar effects were observed in each visual field: N400 and LPC amplitudes were significantly more positive than baseline for the unbiased condition (UR); for the biased context condition (RR), LPC amplitude diverged from baseline in the early window (500–700 ms).

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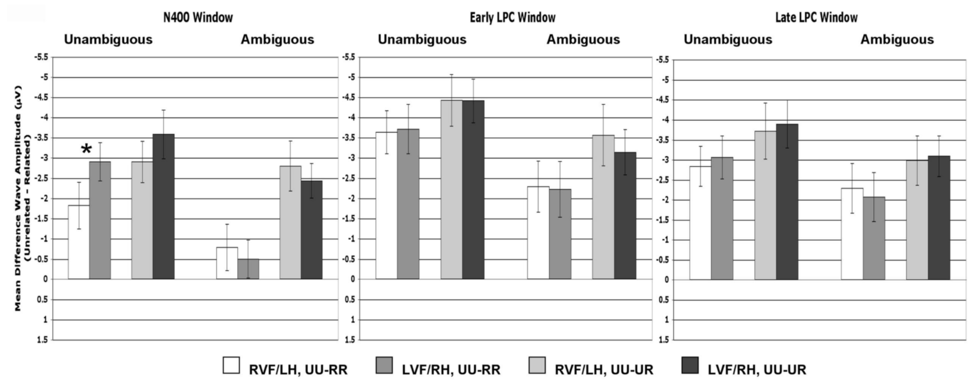

Figure 3.

Comparison of target epoch difference waves across visual fields for Experiment 1. Within each window, the mean amplitude for the 10 selected channels is depicted. The only significant comparison was for the unambiguous RR condition, in which larger N400 facilitation was observed for the RH.

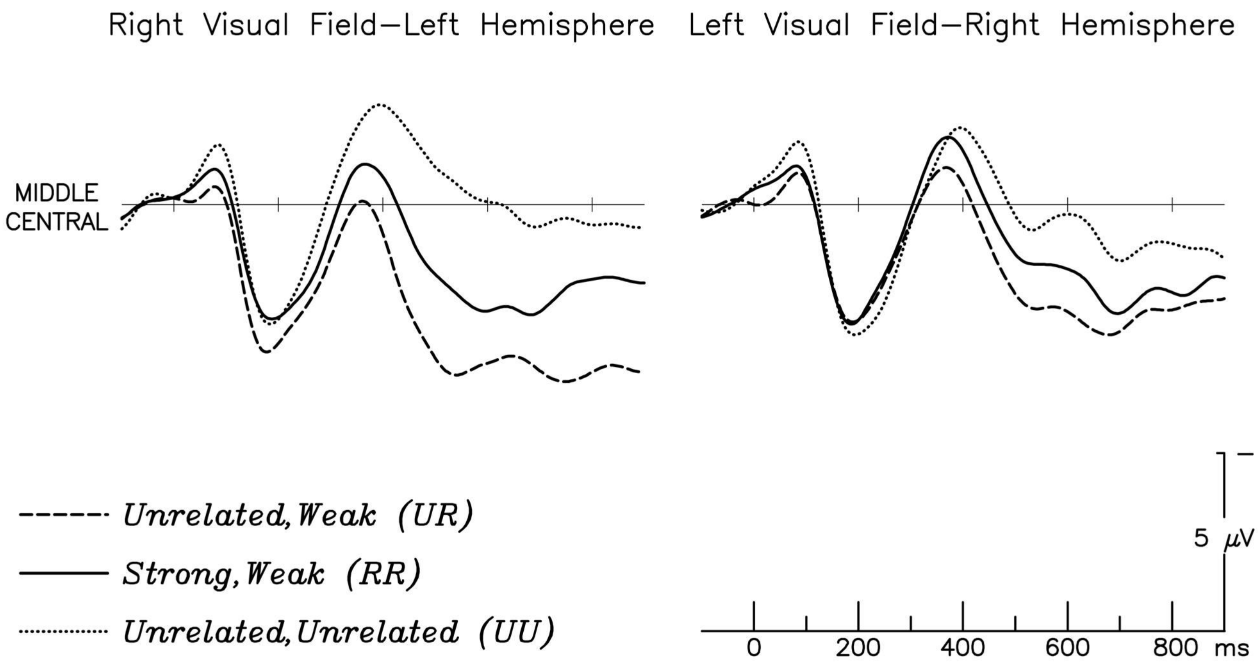

Figure 4.
Effect of Relatedness during the target epoch for the unambiguous condition in Experiment 2. In each visual field, both related conditions were more positive than baseline in N400 and LPC windows, but facilitation for the unbiased condition (UR) was greater than that for the biased context condition (RR) in the RVF-LH.

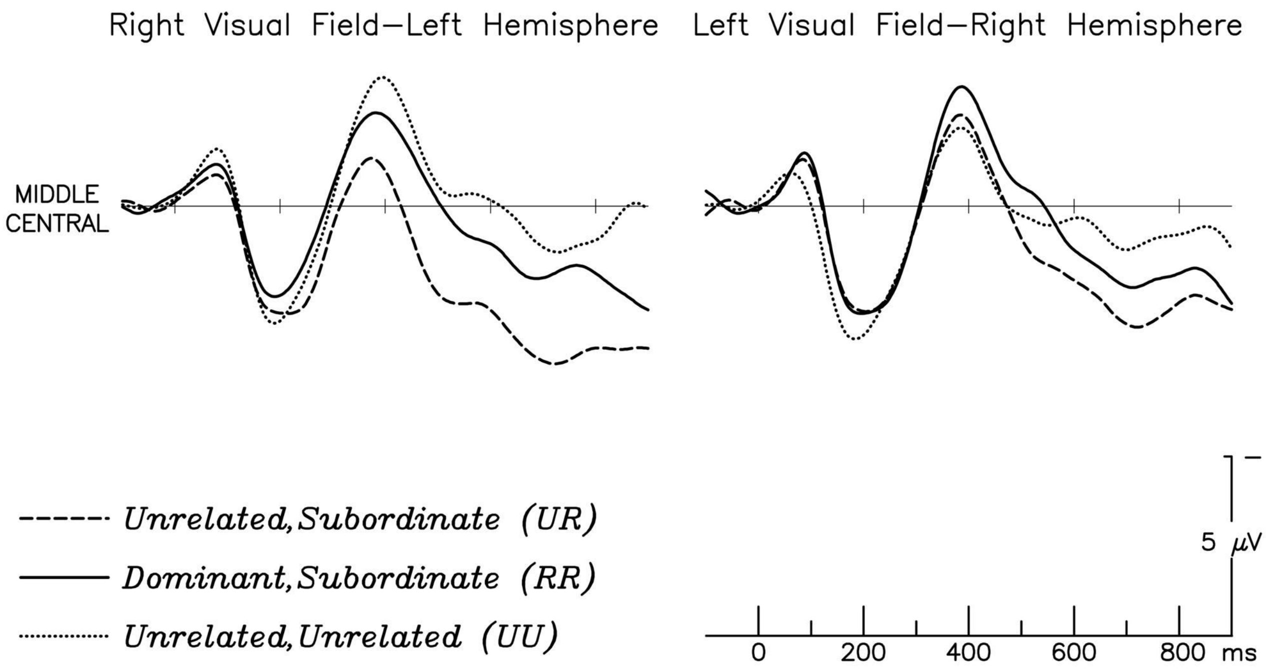

Figure 5.

Effect of relatedness during the target epoch for the ambiguous condition in Experiment 2. A different pattern was observed in each visual field. In the RVF-LH, N400 and LPC amplitudes were significantly more positive than baseline for the unbiased condition (UR); for the biased context condition (RR), LPC amplitude was marginally more positive than baseline in the late window (700–900 ms). In the LVF-RH, facilitation for the unbiased condition began in the early LPC window (500–700 ms), whereas facilitation for the biased condition occurred in the late LPC window.

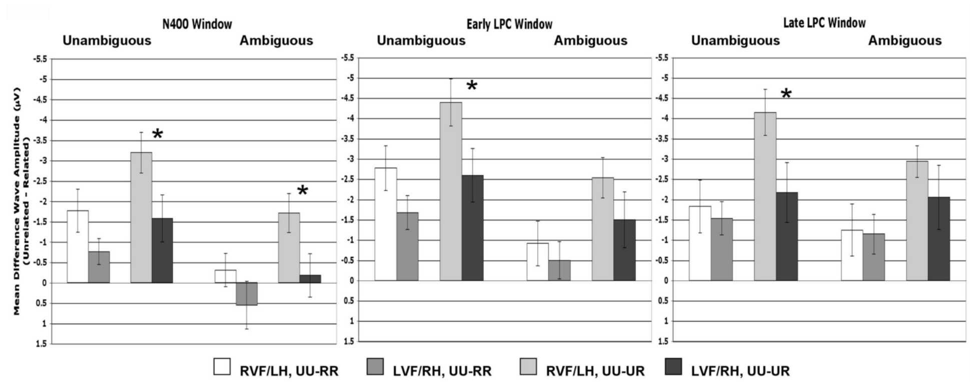

Figure 6.
Comparison of target epoch difference waves across visual fields for Experiment 2. Within each window, the mean amplitude for the 10 selected channels is depicted. Planned comparisons showed that N400 facilitation for the ambiguous UR condition was greater in the RVF-LH. In all windows, facilitation for the unambiguous UR condition was greater in the RVF-LH.

Table 1

Mean Forward Associations

	Ambiguous			Unambiguous	
Frequency	**Context-Prime**	**Prime-Target**	**Strength**	**Context-Prime**	**Prime-Target**
Dominant	.142	.134	Strong	.216	.144
Subordinate	.051	.027	Weak	.096	.052

Association proportions taken from Nelson et al. (1998).

Table 2

Planned Comparisons, Experiment 1

	Ambiguous						Unambiguous					
	RVF-LH			LVF-RH			RVF-LH			LVF-RH		
	$F(1, 19)$	**p**	**MSE**	**$F(1, 19)$**	**p**	**MSE**	**$F(1, 19)$**	**p**	**MSE**	**$F(1, 19)$**	**p**	**MSE**
N400												
UR vs. UU	**20.74**	**<.001**	**37.80**	**32.66**	**<.001**	**18.15**	**32.51**	**<.001**	**25.88**	**35.06**	**<.001**	**36.66**
RR vs. UU	1.85	.19	33.10	1.12	.30	21.95	**9.79**	**<.01**	**33.90**	**37.14**	**<.001**	**22.73**
UR vs. RR	**8.41**	**<.01**	**48.40**	**10.68**	**<.01**	**35.17**	3.68	.07	31.60	1.90	.18	24.36
Early LPC												
UR vs. UU	**21.83**	**<.001**	**58.17**	**31.37**	**<.001**	**31.40**	**48.60**	**<.001**	**40.30**	**66.59**	**<.001**	**29.24**
RR vs. UU	**13.30**	**<.01**	**39.47**	**10.27**	**<.01**	**48.20**	**46.56**	**<.001**	**28.39**	**36.69**	**<.001**	**37.61**
UR vs. RR	4.00	.06	40.50	1.66	.21	50.21	2.20	.15	28.31	2.28	.15	21.32
Late LPC												
UR vs. UU	**22.96**	**<.001**	**38.66**	**37.27**	**<.001**	**25.62**	**28.29**	**<.001**	**48.88**	**42.64**	**<.001**	**35.57**
RR vs. UU	**13.84**	**<.01**	**37.83**	**11.51**	**<.01**	**37.13**	**32.34**	**<.001**	**24.86**	**32.00**	**<.001**	**29.28**
UR vs. RR	1.06	.32	45.01	3.13	.09	33.45	3.43	.08	22.72	1.77	.20	39.23

Table 3

Planned Comparisons, Experiment 2

	Ambiguous						Unambiguous					
	RVF-LH			LVF-RH			RVF-LH			LVF-RH		
	F(1, 19)	p	MSE	*F*(1, 19)	p	MSE	*F*(1, 19)	p	MSE	*F*(1, 19)	p	MSE
N400												
UR vs. UU	**12.65**	**<.01**	**23.31**	.12	.73	28.05	**40.96**	**<.001**	**24.94**	**7.46**	**<.05**	**33.39**
RR vs. UU	.58	.45	16.94	.85	.37	35.34	**11.01**	**<.01**	**28.24**	**5.60**	**<.05**	**10.51**
UR vs. RR	**8.02**	**<.05**	**24.53**	1.92	.18	27.91	**7.36**	**<.05**	**27.71**	1.77	.20	37.09
Early LPC												
UR vs. UU	**25.49**	**<.001**	**25.18**	**4.68**	**<.05**	**47.87**	**58.33**	**<.001**	**33.10**	**15.25**	**<.01**	**44.12**
RR vs. UU	2.80	.11	29.94	1.15	.30	21.29	**25.53**	**<.001**	**30.13**	**15.88**	**<.001**	**17.64**
UR vs. RR	**11.25**	**<.01**	**23.24**	2.76	.11	36.36	**7.00**	**<.05**	**37.51**	1.59	.22	53.24
Late LPC												
UR vs. UU	**58.0**	**<.001**	**14.86**	**6.79**	**<.05**	**61.82**	**52.88**	**<.001**	**32.52**	**8.61**	**<.01**	**54.62**
RR vs. UU	3.76	.07	41.06	**5.40**	**<.05**	**24.24**	**7.97**	**<.05**	**41.87**	**14.08**	**<.01**	**16.73**
UR vs. RR	**6.86**	**<.05**	**41.80**	2.57	.13	31.92	**14.97**	**<.01**	**35.95**	.65	.43	62.05

Table 4

Example Triplets from Experiment 1

Condition	Ambiguous (Subordinate-Dominant)		Unambiguous (Weak-Strong)	
Unrelated-Related	Ever-Pen-Ink	Boom-Bank-Deposit	Check-Sweet-Candy	Script-Chair-Desk
Related-Related	Pig-Pen-Ink	River-Bank-Deposit	Taste-Sweet-Candy	Couch-Chair-Desk
Unrelated-Unrelated	Ever-Pen-Braid	Boom-Bank-New	Check-Sweet-Fiber	Script-Chair-Sinister
Related-Unrelated	Pig-Pen-Braid	River-Bank-New	Taste-Sweet-Fiber	Couch-Chair-Sinister

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Table 5

Example Triplets from Experiment 2

Condition	Ambiguous (Dominant-Subordinate)		Unambiguous (Strong-Weak)	
Unrelated-Related	Shutter-Ruler-King	Student-Yellow-Coward	Fate-Door-Handle	Charm-Horse-Ranch
Related-Related	Measure-Ruler-King	Golden-Yellow-Coward	Window-Door-Handle	Ride-Horse-Ranch
Unrelated-Unrelated	Shutter-Ruler-Bait	Student-Yellow-Girl	Fate-Door-Wasp	Charm-Horse-Planet
Related-Unrelated	Measure-Ruler-Bait	Golden-Yellow-Girl	Window-Door-Wasp	Ride-Horse-Planet