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Multiple priming of lexically ambiguous and unambiguous targets in the cerebral hemispheres: the coarse coding hypothesis revisited

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Abstract

The coarse coding hypothesis (Jung-Beeman 2005) postulates that the cerebral hemispheres differ in their breadth of semantic activation, with the left hemisphere (LH) activating a narrow, focused semantic field and the right (RH) weakly activating a broader semantic field. In support of coarse coding, studies (e.g., Faust and Lavidor 2003) investigating priming for multiple senses of a lexically ambiguous word have reported a RH benefit. However, studies of mediated priming (Livesay and Burgess 2003; Richards and Chiarello 1995) have failed to find a RH advantage for processing distantly-linked, unambiguous words. To address this debate, the present study made use of a multiple priming paradigm (Balota and Paul, 1996) in which two primes either converged onto the single meaning of an unambiguous, lexically-associated target (LION-STRIPES-TIGER) or diverged onto different meanings of an ambiguous target (KIDNEY-PIANO-ORGAN). In two experiments, participants either made lexical decisions to targets (Experiment 1) or made a semantic relatedness judgment between primes and targets (Experiment 2). In both tasks, for both ambiguous and unambiguous triplets we found equivalent priming strengths and patterns across the two visual fields, counter to the predictions of the coarse coding hypothesis. Priming patterns further suggested that both hemispheres made use of lexical level representations in the lexical decision task and semantic representations in the semantic judgment task.

Keywords

cerebral hemispheres; word processing; semantic priming; summation priming; coarse coding hypothesis; lexical ambiguity

1. Introduction

Given the multifaceted nature of language, it is perhaps not surprising that language processing engages much of the brain, including areas in both cerebral hemispheres (Bookheimer 2002). Yet, ever since Broca's discovery of an association between fluent speech and the left frontal

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operculum, it has been clear that the two halves of the brain do not make identical contributions to language. Indeed, language is strikingly asymmetric, considering the overall anatomical, physiological, and chemical similarity between the left (LH) and right (RH) hemispheres. It is well known that damage to LH areas can cause profound, permanent language deficits, whereas damage to the RH homologues of these areas generally leaves basic word and sentence processing relatively intact. Nevertheless, there is increasing realization that the RH also makes important, albeit different, contributions to language comprehension (Chiarello and Beeman 1998) – contributions that still remain incompletely understood.

One means of assessing the ability of each hemisphere to comprehend language has been to present stimuli separately to the left and right hemispheres of commissurotomized patients. These patients have had their corpus callosum (and often other neocortical commissures) severed in order to control medically intractable epilepsy. As a result, the two hemispheres of the brain can no longer communicate, and each can be selectively stimulated by taking advantage of the contralateral organization of the visual system. In particular, when patients are fixated centrally, stimuli presented in the left half of visual space are projected unilaterally to the RH while stimuli presented in the right half of visual space are projected to the LH (Banich and Nicholas 1998; Hellige 1983). Left visual field presentation is typically abbreviated LVF/RH and right visual field presentation abbreviated RVF/LH to emphasize which hemisphere receives the information. Such studies corroborate the pattern gleaned from aphasia in pointing to a general LH superiority for speech and language (for review, see Gazzaniga 2000). However, they also suggest that the RH has more capacity for language comprehension than was previously suspected and that, indeed, it may make important contributions to several aspects of normal processing, such as inferences, joke comprehension, and insight problem-solving (for review, see Baynes 1998; Zaidel 1998).

The visual half-field (VF) technique has also been successfully used to study asymmetries in language comprehension by brain-intact individuals. Although in this case the two hemispheres of the brain can eventually communicate, only the contralateral hemisphere receives the stimulus initially. The resulting temporal and information-quality advantage elicits processing biases that reveal hemispheric differences (Banich and Nicholas 1998). Similar to research with commissurotomized patients, VF studies in brain-intact individuals show reliable RVF/LH advantages for language processing (for review, see Bradshaw and Nettleton 1981, 1983; Springer and Deutsch 1985). Yet, it has also been found that word processing in both hemispheres is facilitated by the prior presentation of a related word in a semantic priming paradigm (e.g., Chiarello, Burgess, Richards and Pollock 1990). Tracking patterns of facilitation as a function of VF allows for the evaluation of RH semantic processing in the face of the standing RVF/LH advantage for word recognition, and, indeed, studies of this kind have revealed several informative asymmetries.

For example, Chiarello and her colleagues (Chiarello, Burgess et al. 1990) used prime-target pairs consisting of strongly associated (e.g., sofa-chair) and weakly associated (e.g., lamp-chair) words from the same semantic category. Similar priming (relative to an unrelated baseline) was observed for the strongly associated pairs with both RVF/LH and LVF/RH presentation. However, priming for the weakly associated pairs emerged only with presentation to the LVF/RH. Norming data (Chiarello and Richards 1992) showed that the strongly associated category members shared more semantic features in common than did the weakly associated category members. Thus, the observed VF effects could be driven by semantic overlap rather than lexical association as such.

These conclusions have been buttressed by work done by Beeman and his colleagues (Beeman, Friedman, Grafman, Perez, Diamond and Lindsay 1994) using a somewhat different paradigm. Their study employed a series of three primes that were either weakly related (white-ceremony-

tuxedo) or unrelated (soap-tunnel-mouse) to a lateralized target (wedding). In a condition in which the proportion of related trials was low (thereby indexing automatic semantic activation), naming accuracy measures to the weak associates were facilitated only with presentation to the LVF/RH. On the basis of findings like these, Beeman proposed the *coarse coding hypothesis*, which postulates that one important source for language processing asymmetries lies in the granularity of semantic coding (Jung-Beeman, 2005). This hypothesis states that each word is associated with a large, diffuse semantic field in the RH and a smaller, more focal semantic field in the LH. Thus, according to the coarse coding view, words elicit weak activation of a large set of concepts in the RH, including concepts that are only distantly related to the input words and the current context. This process is ineffective for rapid interpretation or selection, but increases the likelihood of semantic overlap (and hence facilitation) among distantly related words. In contrast, the same words are proposed to elicit more focal semantic activation in the LH, which extends only to a few concepts closely related to the input word in the given context.

The coarse coding hypothesis successfully explains a range of findings in the semantic priming literature (Beeman, Friedman et al. 1994; Faust and Kahana 2002; Faust and Lavidor 2003) and has been extended to higher-order aspects of language processing (Beeman, Bowden and Gernsbacher 2000; Coulson and Williams 2005; Titone 1998) and even problem solving (Bowden and Jung-Beeman 2003; Jung-Beeman 2005). However, not all data patterns are consistent with this view. In particular, a notable exception comes from work looking at hemispheric differences in mediated priming. Richards and Chiarello (1995) argued that one way to quantify semantic distance is by the number of intervening associations between two concepts in semantic memory. Accordingly, they compared priming patterns in naming latency for word pairs that were directly associated (e.g., WATER-DRINK) or indirectly associated (e.g., SOAP-DRINK, which are linked by the mediating concept WATER). Because mediated associates are more distantly related than direct associates, the coarse coding hypothesis should predict that priming for these pairs would be seen only or primarily with LVF/RH presentation, whereas priming for the direct associates should be evident with presentation to either VF. As expected, Richards and Chiarello observed more overall priming for direct than for mediated associates. However, this pattern was equivalent in the two VFs and, in particular, there was no indication that the mediated associates were more facilitated after LVF/RH presentation. They replicated this finding across a range of stimulus onset asynchronies (SOAs: 50, 250, and 750 ms). Livesay and Burgess (2003) obtained a similar pattern of results using contextually consistent and inconsistent mediated prime-target pairs. The contextually consistent pairs were likely to be experienced in the same context (e.g., *bat* and *bounce*, mediated by a common context, *ball*) whereas the contextually inconsistent pairs were not (e.g., *summer* and *snow*, mediated by *winter*). Participants saw either related, mediated or unrelated prime target pairs and named lateralized targets. Livesay and Burgess found that both hemispheres showed equivalent amounts of mediated priming and thus suggested that the lexical representations in the two hemispheres might be similar. Therefore, this particular conceptualization of semantic distance has not yielded results consistent with the idea that facilitation spreads further in the RH than in the LH.

Another way to study asymmetries in the breadth of meaning activation has been to use semantically ambiguous words -- that is, words with more than one distinct meaning. Results using this approach have yielded mixed support for the coarse coding hypothesis. Tompkins and colleagues (Tompkins, Baumgaertner, Lehman and Fassbinder 2000; Tompkins, Lehman-Blake, Baumgaertner and Fassbinder 2001) examined the processing of lexical ambiguity in adults with right hemisphere damage and found results that seem to contradict coarse coding. In one study (Tompkins, Baumgaertner et al. 2000), patients and controls listened to sentences (e.g., “He dug with a SPADE”) biased toward one meaning of the sentence-final homograph, and then judged whether a probe word (e.g., CARDS) fit the overall sentence meaning. Probes

were associated with the contextually inappropriate meaning of the homograph. Probe judgment response times indicated that only the group without brain damage suppressed inappropriate interpretations over time. Patients were slower to reject the probes that were contextually inappropriate, suggesting impaired suppression. This argues against the coarse coding hypothesis that attributes focused, contextually-relevant semantic processing to the LH and not to the RH.

Behavioral studies looking at the processing of lexically ambiguous words in normal individuals using the VF method, however, have found results more in line with the predictions of the coarse coding account (e.g., Faust and Kahana 2002; Faust and Lavidor 2003; Simpson 1984; Titone 1998). For example, in a study by Burgess and Simpson (1988), participants were shown homographs in central vision and then asked to make lexical decisions (word/nonword judgments) to letter strings presented in either VF. The word targets were either related to the dominant or the subordinate meaning of the ambiguous word or were unrelated to either sense. For instance, a related (e.g., BANK) or an unrelated ambiguous prime (e.g., RIDDLE) was followed by either a word target or a non-word target. When related, the word targets were either associated with the dominant, more frequent meaning (e.g., MONEY) or with the subordinate, less frequent meaning (e.g., RIVER) of the ambiguous word. For RVF/LH targets, facilitation (relative to the unrelated baseline) was found for the stronger (dominant) associate at both short and long SOAs (35 and 750 ms), whereas facilitation for the weaker (subordinate) associate decayed between the short and long SOA. In contrast, for LVF/RH targets, there was a decay of facilitation for the stronger associate at the longer SOA (750 ms), while activation for the weaker associate actually increased. By the long SOA, then, the pattern of results was consistent with the predictions of the coarse coding hypothesis, in that facilitation for the weaker (subordinate) associate was greater in the RH than in the LH. However, the fact that the RH did not show more subordinate priming at the short SOA (35 ms) argues against this finding as reflecting an asymmetry in the nature of automatic semantic activation. Instead, the authors interpreted the pattern as suggesting that control processes act to narrow the range of facilitation for weakly related meanings of words in the LH but not the RH.

Finally, a recent study by Faust and Lavidor (2003) specifically tested a version of the coarse coding hypothesis that states that the LH focally activates the dominant interpretation of an ambiguous word whereas the RH activates multiple separable, sometimes even incompatible, interpretations. This study employed a multiple priming paradigm in which a series of prime words was followed by a lateralized, lexically ambiguous target word. The multiple primes converged onto the dominant meaning of the ambiguous target (e.g., MAYBE-PERHAPS-MIGHT), converged onto the subordinate meaning of the target (STRENGTH-POWER-MIGHT), or diverged onto multiple meanings of the target (MAYBE-STRENGTH-MIGHT). One experiment employed a lexical decision task and another asked participants to decide whether both the primes were or were not related in meaning to the target. Following the coarse coding hypothesis, Faust and Lavidor predicted that the RH would benefit from the mixed (divergent) prime condition. The LH, instead, should be unable to benefit from semantically divergent primes that require the sustained activation of discrete, separable subsets of semantic features.

Results in the lexical decision task showed that priming for targets presented to the RVF/LH was a function of the number of primes related to the dominant meaning of the ambiguous word. Thus, the greatest facilitation (relative to an unrelated baseline) was observed for the dominant, convergent condition, intermediate facilitation for the mixed, divergent condition, and the least facilitation for the subordinate convergent condition. In contrast, with LVF/RH presentation of the targets, the greatest facilitation was seen for the mixed, divergent condition, with comparable facilitation for the two convergent prime conditions. A similar pattern was seen for LVF/RH presentation for the semantic judgment task, whereas, for this task,

facilitation in the RVF/LH was smaller for the mixed, divergent condition than the two convergent conditions (which were comparable). Thus, in line with the predictions from coarse coding, the RH seemed to process the mixed, divergent condition particularly well (in fact, perhaps surprisingly, even better than the convergent conditions). The LH, instead, showed more facilitation when a single meaning was being primed. Faust and Lavidor suggested that facilitation in the mixed, divergent condition could arise via mediated priming, with the target (e.g., MIGHT) serving as a mediating word/concept for the otherwise dissimilar primes (MAYBE-STRENGTH). Based on their results, they therefore argued that the RH might be especially sensitive to mediated priming.

There is thus an interesting dissociation between the Richards and Chiarello (1995) and Livesay and Burgess (2003) findings, which suggested no RH advantage for distant semantic priming from mediated primes, and the Faust and Lavidor (2003) results, which have been taken to suggest that the RH can benefit more from distant semantic priming, in line with coarse coding. However, direct comparisons between the studies are difficult because of differences in both the nature of the stimuli and how the data were analyzed. First, Faust and Lavidor did not directly compare priming effects for the mixed condition across the two VFs; thus, it is not clear if there was actually more overall facilitation for the mixed condition with LVF/RH presentation. Instead, it is possible that the differences in the pattern of results across VF were driven more by responses to the convergent conditions than to the divergent ones. This may be particularly important because in the Faust and Lavidor study the convergent conditions consisted of primes that were also related in meaning to one another. This raises the possibility that the result pattern could be influenced by asymmetries in how context information accrues over time and/or in what kind of task-related strategies are adopted (especially in the semantic judgment task, where noting a relationship between the two primes provides useful information about the upcoming response). Federmeier and her colleagues, for example, have argued that the LH, but not the RH, can use context information to predict features of likely upcoming words (Federmeier and Kutas 1999; Federmeier, Mai and Kutas 2005). Such prediction would be facilitated by the presence of multiple, interrelated primes. Finally, the differences between the mediated priming studies and the Faust and Lavidor (2003) results could reflect something about how the two hemispheres represent and/or process unambiguous versus ambiguous words.

The current study, therefore, set out to adjudicate between these possibilities by examining the processing of both unambiguous and ambiguous target words in a multiple priming paradigm in which the primes are always unrelated to one another. To do this, we adopted a paradigm originally designed by Balota and Paul (1996), in which two primes are sequentially presented, followed by a third, target word (*prime 1-prime 2-target*). Each prime may be related or unrelated to the target. In the unambiguous condition, the two related primes point to the same sense of the target word and are each lexically associated with it, but **not** with one another (e.g., LION-STRIPES-TIGER). Although priming to the target word is direct from each prime, the relationship between the primes thus constitutes the kind of mediated relationship investigated by Richards and Chiarello (1995) and Livesay and Burgess (2003), with the target serving as the mediating word/concept. In the corresponding ambiguous condition, the related primes are again lexically associated with the target and not with one another, but in this case they point to different semantic senses of a target homograph (e.g., KIDNEY-PIANO-ORGAN). This condition thus parallels Faust and Lavidor's (2003) mixed, divergent stimuli. For each type of triplet, then, there are four conditions created by crossing prime-target relatedness (related versus unrelated) with prime position (first versus second): related-related (RR), unrelated-related (UR), related-unrelated (RU), and unrelated-unrelated (UU). Samples of each type of triplet can be seen in Table 1. Crucially, this design thus provides a comparable multiple priming design for both lexically unambiguous and ambiguous targets.

The use of Balota and Paul's (1996) design also allows us to address additional questions about the locus of any priming effects we might observe. In particular, their original study was designed to tease apart lexical and conceptual influences on semantic priming. This is possible because the unambiguous and ambiguous triplets differ in their underlying representations at the conceptual level but not at the level of word form. Only a single lexical representation is needed for both the ambiguous and the unambiguous targets. However, at the semantic level, the ambiguous target (ORGAN) has two representations, one for each sense of the word that is related to the two primes (KIDNEY and PIANO). In contrast, the unambiguous target (TIGER) requires only one representation for its meaning related to both of the primes (LION and STRIPES). Based on this architecture, Balota and Paul argued that if behavioral priming effects arise as aresult of spreading activation at the lexical level, then effects for ambiguous and unambiguous targets should be equivalent. However, if priming effects arise from activity at the semantic level, then the pattern should be different for ambiguous and unambiguous targets. Using this paradigm, they examined priming effects in several different tasks for both ambiguous and unambiguous triplets and found that priming patterns were task dependent. For naming and lexical decision tasks, priming patterns were equivalent across ambiguous and unambiguous triplets. Thus, the authors concluded that priming in these tasks primarily reflects lexical level activation. However, in a semantic relatedness judgment task, there was a significant difference across ambiguity (in particular, there was reduced priming for the RR ambiguous as compared with the RR unambiguous condition), suggesting an influence from semantic/conceptual level representations.

There are reasons to believe that the locus of priming effects could be different for the two hemispheres. Baynes and her colleagues (for review, see Baynes 1998) have used the VF technique with commissurotomized patients to examine the ability of the two hemispheres - and especially the verbally weaker RH - to extract lexical/phonological information from words. The RHs of all the patients could comprehend single words in the auditory modality (as evidenced by their auditory vocabulary scores on the Peabody Picture Vocabulary Test (Zaidel 1990)) and could match printed words with pictures. However, although all the patients could read single words for meaning with their RH, the ability to make accurate lexical decisions was not commensurate with this reading ability. This suggests that levels of word processing (phonological, lexical) that mediate form and meaning for the LH may be relatively weaker in the RH. In light of these findings, it will be interesting to see whether the patterns of priming effects for ambiguous and unambiguous triplets vary with VF and, if so, whether such effects are task dependent. In particular, we will compare, as did Faust and Lavidor (2003), responses for a lexical decision and a semantic judgment task.

In sum, there were three goals for the current study. First, we test the predictions of the coarse coding hypothesis for multiple priming of unambiguous and ambiguous targets. We use a paradigm that should minimize interprime facilitation for both types of stimuli and thereby also eliminate any expectancy-based differences across conditions. The coarse coding hypothesis predicts a RH advantage for activation of more distantly-related semantic information. Thus, if semantic distance is conceptualized as the number of lexico-semantic links between two concepts, then the RH should show more robust summation priming across weakly related primes linked by a mediated concept. Further, broad activation should allow the RH, as compared with the LH, to better hold onto multiple meanings of a lexically ambiguous word. Second, we investigate whether there are asymmetries in the tendency for priming effects to arise at lexical versus conceptual levels of representation. A significant difference in the priming patterns across the triplet types, with reduced benefit from multiple primes for the ambiguous compared to the unambiguous triplets, would suggest that priming effects in the contralateral hemisphere arise at the semantic/conceptual level of processing. In contrast, similar patterns of priming for both unambiguous and ambiguous triplets in either VF would suggest that the corresponding hemisphere derives its facilitation primarily from

activations at a lexical level. If lexical level representations are stronger in the LH than in the RH, then lexical sources of activation may play a more important role in the LH's processing of words, whereas priming effects may be more likely to arise at a conceptual level with LVF/RH presentation. Finally, we employ both a lexical decision and semantic judgment task, in order to determine whether there are task dependencies in the nature or locus (lexical/semantic) of priming effects in each hemisphere.

2. Results

Experiment 1

The purpose of this study was to investigate priming patterns in a lexical decision task for lateralized unambiguous and ambiguous targets preceded by multiple primes.

Response Times—Priming patterns in the lexical decision task were examined using median response times (RTs) for correct (i.e., "yes") responses to targets. These data for each of the conditions (RR, UR, RU, and UU) in each type of triplet (ambiguous and unambiguous) are provided in Table 2 for RVF/LH targets and in Table 3 for LVF/RH targets. RTs were subjected to three-way repeated measures ANOVA with 2 levels of VF (RVF, LVF), 2 levels of triplet type (ambiguous, unambiguous), and 4 levels of prime condition (RR, UR, RU, UU) as factors. There was a main effect of VF ($F_{1,47} = 13.91$, $p < 0.001$) with faster RTs for RVF/LH (680 ms) compared to LVF/RH (708 ms) targets. This is in line with the accuracy patterns for these conditions (described next), and is a typical finding for lexical decision tasks (e.g., Chiarello, Burgess et al. 1990). There was also a main effect of triplet type ($F_{1,47} = 16.44$, $p < 0.001$) with faster RTs for unambiguous (687 ms) compared to ambiguous (702 ms) targets; again, this matches the pattern seen in the accuracy data. Finally, there was a main effect of prime condition ($F_{3,141} = 14.10$, $p < 0.001$). Participants were fastest for the double prime (RR) condition (671 ms) and slowest for the unrelated (UU) condition (711 ms) with the single prime (UR/RU) conditions (699/696 ms) falling in-between. None of the interaction terms was significant ($F_s < 1$); in particular, consistent with Balota and Paul's (1996) findings for this task, there was no interaction between triplet type and prime condition[1].

Planned comparisons between each pair of prime conditions for each triplet type in the RVF/LH (left side of Table 4) and the LVF/RH (right side of Table 4) revealed facilitation for the double prime (RR) condition relative to all other conditions (UR, RU, and UU) for both triplet types in both VFs. The two single prime conditions (UR and RU) did not reliably differ from one another in either triplet type in either VF. There was significant facilitation for the RU prime condition relative to the UU prime condition only for the ambiguous triplet types in the RVF/LH; all other single prime conditions (UR and RU) did not reliably differ from the UU prime condition. Figure 1 shows a graph of the response times to targets for the double prime (both primes related to the target), single prime (one prime is related to the target), and no prime (no prime is related to the target) conditions for the two VFs.

Comparison of Priming Effects Across Visual Field: To compare the magnitude of the priming effects across the two VFs, the facilitation for each of the related prime conditions was computed as the difference between that condition (RR/UR/RU) and the corresponding UU prime condition (Figure 2 shows these priming effects). Pairwise comparisons across VF (RVF/LH vs. LVF/RH) were then conducted on these difference scores for each related prime condition (RR facilitation/UR facilitation/RU facilitation) within each triplet type (unambiguous, ambiguous). All comparisons yielded non-significant p-values ($F_s < 1$). Thus,

[1]Exactly the same pattern arises if 2 × 2 ANOVAs are conducted within each VF. In particular, there are no ambiguity by prime condition interactions in either.

despite faster overall RTs for RVF/LH relative to LVF/RH targets, there was no indication of any differences in the pattern of facilitation across VFs.

Accuracy—Accuracy data (percent correct) for each of the conditions (RR, UR, RU, and UU) in each type of triplet (ambiguous and unambiguous) are provided in Table 2 for RVF/LH targets and in Table 3 for LVF/RH targets. Overall accuracy was good, averaging 87% correct, suggesting that participants were able to apprehend the target words in the visual periphery and perform the lexical decision task. Accuracy measures were subjected to a three-way repeated measures analysis of variance (ANOVA) with VF (RVF, LVF), triplet type (ambiguous, unambiguous) and prime condition (RR, UR, RU, UU) as factors. There was a main effect of VF ($F_{1,47} = 23.62$, $p < 0.001$) with more accurate responses to RVF/LH (90%) compared to LVF/RH (84%) targets; this is consistent with general biases favoring word apprehension in the RVF/LH (e.g., Jordan, Patching and Thomas 2003). There was also a main effect of triplet type ($F_{1,47} = 44.05$, $p < 0.001$), with more accurate responses to unambiguous (89%) than to ambiguous (85%) targets, and a main effect of prime type ($F_{3,141} = 28.40$, $p < 0.001$), with more accurate responses to conditions containing at least one related prime (RR: 90%; UR: 89%; RU: 87%; UU: 82%). VF also interacted with triplet type ($F_{1,47} = 7.05$, $p < 0.01$), as the tendency to respond more accurately to targets in unambiguous as compared with ambiguous triplets was more pronounced for the LVF/RH. No other interactions were significant ($F_s < 1$).

Summary—Overall, as is typically observed for lexical decision tasks, responses were faster and more accurate in the RVF/LH. However, there was no difference in priming patterns across the two VFs. In both, there was more priming overall in unambiguous than in ambiguous triplets and more priming for the double prime (RR) condition relative to the single prime (UR/RU) or unrelated prime (UU) conditions, but there was no effect of ambiguity on the priming pattern (no ambiguity by prime condition interaction). Direct comparisons across the VFs also revealed no differences in the amount of facilitation for any of the related prime conditions relative to the unrelated baseline.

Experiment 2

The purpose of this study was to investigate priming patterns in a semantic relatedness judgment task for lateralized unambiguous and ambiguous targets preceded by multiple primes.

Response Times—Priming patterns in the semantic judgment task were examined using median response times (RTs) for correct responses to targets (i.e., “yes” for RR, UR, and RU, and “no” for UU). These data for each of the conditions (RR, UR, RU, and UU) in each type of triplet (ambiguous and unambiguous) are provided in Table 5 for RVF/LH targets and in Table 6 for LVF/RH targets. RTs were subjected to a three-way repeated measure ANOVA with 2 levels of VF (RVF, LVF), 2 levels of triplet type (ambiguous, unambiguous), and 4 levels of prime condition (RR, UR, RU, UU) as factors. There was a main effect of VF ($F_{1,39} = 26.38$, $p < 0.001$) with faster RTs for RVF/LH (1062 ms) compared to LVF/RH (1108 ms) targets; again, this is consistent with general biases favoring the RVF/LH for word apprehension (e.g., Jordan, Patching et al. 2003). There was also a main effect of triplet type ($F_{1,47} = 16.44$, $p < 0.001$) with faster RTs for unambiguous (1067 ms) compared to ambiguous (1104 ms) targets; this matches the pattern seen in the accuracy data (described next). Finally, there was a main effect of prime condition ($F_{3,117} = 87.85$, $p < 0.001$). Responses were fastest for the double prime (RR) condition (899 ms), intermediate for the two single prime conditions (UR: 977 ms; RU: 1073 ms), and slowest for the UU condition (which was associated with a “no” response; 1391 ms). Triplet type interacted with prime condition ($F_{3,117} = 9.60$, $p < 0.001$), and this interaction remained even when the analysis was conducted without the UU condition, which might have been expected to be less affected by ambiguity than the conditions containing

related primes ($F_{2,78}$ =10.31, p <0.001). The interaction reflects the fact that the RT advantage for unambiguous as compared with ambiguous triplets is greater for the double prime condition (RR: 116 ms) than for either of the single prime conditions (UR: 26 ms; RU: 7 ms). In other words, there is less of a benefit for having two related primes when these point to different senses of an ambiguous target. This is the same pattern obtained for this task by Balota and Paul (1996) for stimuli presented in central vision. None of the other interaction terms was significant; in particular there were no significant interactions with VF ($F_s < 1$)[2].

Planned comparisons between each pair of prime conditions for each triplet type in the RVF/LH (left side of Table 7) and the LVF/RH (right side of Table 7) revealed that all prime conditions differed from each other in both triplet types (ambiguous and unambiguous), with the exception of the difference between the RR and UR condition for the ambiguous triplet type in the LVF/RH. Figure 3 shows a graph of the response times to targets for the double prime (both primes related to the target), single prime (one prime is related to the target), and no prime (no prime is related to the target) conditions for both VFs.

Comparison of Priming Effects Across Visual Field: To compare the magnitude of the priming effects across the two VFs, the facilitation for each of the related prime conditions was computed as the difference between that condition (RR/UR/RU) and the corresponding UU prime condition (Figure 4 shows these priming effects). Pairwise comparisons across VF (RVF/LH vs. LVF/RH) were then conducted on these difference scores for each related prime condition (RR facilitation/UR facilitation/RU facilitation) within each triplet type (unambiguous, ambiguous). All comparisons yielded non-significant p-values ($F_s < 1$), except the unambiguous targets in the RU prime condition ($F_{1,39} = 6.90$, $p < 0.01$). The priming in the unambiguous RU condition was greater in the RVF/LH compared to the LVF/RH.

Accuracy—Accuracy data (percent correct) for each of the conditions (RR, UR, RU, and UU) in each type of triplet (ambiguous and unambiguous) are provided in Table 5 for RVF/LH targets and in Table 6 for LVF/RH targets. Overall accuracy averaged 80% correct, suggesting that participants were able to apprehend the target words and judge their semantic relatedness to the primes. The overall accuracy was lower in the semantic judgment task compared to the lexical decision task (Experiment 1); a similar pattern was seen in Balota and Paul (1996) study that presented targets in central vision. Accuracy measures were subjected to a three-way repeated measure ANOVA with VF (RVF, LVF), triplet type (ambiguous, unambiguous) and prime condition (RR, UR, RU, UU) as factors. There was a marginal main effect of VF ($F_{1,39} = 3.03$, $p < 0.08$), with slightly more accurate responses to RVF/LH (81%) compared to LVF/RH (80%) targets. There was a main effect of triplet type ($F_{1,39} = 171.34$, $p < 0.001$), with more accurate responses to unambiguous (84%) than to ambiguous (76%) targets. There was also a main effect of prime type ($F_{3,117} = 27.18$, $p < 0.001$); responses were most accurate to the double prime condition (90%), followed by UU (81%), UR (79%), and then RU (70%). Triplet type and prime condition interacted ($F_{3,117} = 4.74$, $p < 0.01$). For both triplet types, responses were most accurate for the RR condition and least accurate for the RU condition; however, accuracy was higher for UR than UU for the unambiguous triplets, but higher for UU than UR for ambiguous triplets (for unambiguous triplets RR: 94%; UR: 85%; UU: 83%; RU: 76%, while for ambiguous triplets RR: 87%; UU: 80%; UR: 73%; RU: 65%). This difference might arise because participants are more likely to fail to notice the semantic relationship between a single prime and one sense of the related target for the ambiguous triplets. No other interactions were significant ($F_s < 1$).

[2]As in Experiment 1, exactly the same pattern arises if 2 × 2 ANOVAs are conducted within each VF. In particular, in this case, there is a significant ambiguity by prime condition interaction in both.

Summary—Responses to targets presented in the RVF/LH were responded to more quickly and marginally more accurately than when presented in the LVF/RH. These overall VF differences, especially for accuracy, were less pronounced in the semantic judgment task than in the lexical decision task, consistent with claims that the RH is more disadvantaged for lexical decision tasks than for other types of tasks that tap into word meaning (Baynes 1998). Again, however, patterns of priming were essentially identical in the two VFs. In both, there was more priming overall in unambiguous than in ambiguous triplets and more priming for the double prime (RR) condition relative to the single prime (UR/RU) conditions, which, in turn, were facilitated relative to the unrelated prime (UU) condition. Direct comparisons across the VFs revealed a difference in priming magnitude only for the RU condition in the unambiguous triplet types (which showed more facilitation with RVF/LH presentation). Both hemispheres also manifested a triplet type by prime condition interaction, which was not seen in the lexical decision task. In the semantic judgment task, the benefit for the double prime (RR) condition over the single prime (UR/RU) conditions was reduced for the ambiguous as compared with the unambiguous triplets. Thus, the fact that the two primes pointed to different senses of the target in the ambiguous triplets mattered for the semantic judgment task but not for the lexical decision task.

Comparison Across Tasks (Experiment 1 and 2)

An additional analysis was conducted in order to directly compare the response time patterns across the lexical decision (Experiment 1) and semantic judgment (Experiment 2) tasks. For this analysis, the UU condition was dropped, since it was associated with different behavioral responses in the two cases ("yes" and "no", respectively). A four-way repeated measures mixed ANOVA was performed with experiment (lexical decision and semantic judgment) as a between-subject factor and VF (RVF, LVF), triplet type (ambiguous, unambiguous) and prime conditions (RR, UR and RU) as within-subject factors. There was a main effect of experiment ($F_{1,86} = 87.88$, $p < 0.001$) with faster responses in the lexical decision task than in the semantic judgment task. There was also a main effect of VF ($F_{1,86} = 45.94$, $p < 0.001$) with overall faster responses in the RVF/LH. Response times to unambiguous targets were significantly faster than those to ambiguous targets ($F_{1,86} = 43.67$, $p < 0.001$). Finally, there was also a main effect of prime condition ($F_{2,172} = 84.17$, $p < 0.001$) with the fastest responses to the double prime (RR) condition, followed, in order, by the UR and RU single prime conditions.

VF did not interact with any factor (F's < 1.6). The interactions of experiment with triplet type and with prime condition were significant, as was the interaction between triplet type and prime condition (p's < 0.05). These two-way interactions were modulated by a three-way interaction among experiment, triplet type and prime condition ($F_{2,172} = 10.11$, $p < 0.001$). This interaction reflects the different patterns uncovered in the individual experiment analyses, showing that ambiguity affected the priming pattern in the semantic judgment task but not in the lexical decision task.

The results of this analysis thus provide additional support for two important findings. First, there was a significant difference between the two tasks (lexical decision and semantic judgment) in the response time patterns across ambiguity. Further, there were no striking VF differences in the pattern of response times to the related prime conditions.

3. Discussion

The primary goal of this study was to test the predictions of the coarse coding hypothesis (Jung-Beeman 2005) in a multiple priming paradigm, for both lexically unambiguous and ambiguous words. The coarse coding hypothesis posits that the hemispheres differ in their breadth of semantic activation, with the LH activating a more focused, narrow semantic field and the RH weakly activating a broader semantic field. One way of conceptualizing semantic

distance is as the number of lexico-semantic links between two concepts, leading to the prediction that the RH should show greater facilitation from summation priming across primes linked by a mediated concept (for the unambiguous targets) and from primes related to disparate senses of a homograph (for the ambiguous targets). However, support for these predictions has been mixed. Richards and Chiarello (1995) and Livesay and Burgess (2003) found no RH advantage for direct measures of mediated priming of lexically unambiguous words. In contrast, Faust and Lavidor (2003) found more priming from mixed primes (in which two primes diverge onto different meanings of a lexically ambiguous target) than from convergent primes (which pointed to the same meaning of the ambiguous target) in the RH but not in the LH. Differences in the stimuli, task parameters, and analysis strategies used in these studies, however, make it difficult to ascertain why the results diverged. Thus, the present study was designed to allow a direct comparison of the priming patterns in each hemisphere for both unambiguous and ambiguous words.

Following Balota and Paul's (1996) design, we employed a multiple priming paradigm, in which participants saw triplet of words (two primes and a lateralized target) and were required to either make a lexical decision on the target (in Experiment 1) or a semantic relatedness judgment of the target and the primes (in Experiment 2). The primes were each either related or unrelated to the target; when both primes were related to the target, they either converged onto the single meaning of an unambiguous target or diverged onto distinct meanings of a lexically ambiguous target. Critically, in both conditions the primes were never directly related to each other, even when they were both related to the target. For the unambiguous triplets, this meant using primes that bore a mediated relationship with one another (e.g., LION and STRIPES, with TIGER as the target). For the ambiguous triplets, this meant using primes that pointed to different senses of the ambiguous target (e.g., KIDNEY and PIANO, with ORGAN as the target).

We observed a main effect of VF for both the lexical decision and the semantic judgment tasks, with faster responses to LH compared with RH targets. Participants were also significantly more accurate to make lexical decisions to LH as compared to RH targets, and there was a similar but non-significant trend for the semantic judgment task. Such main effects are almost uniformly observed in language VF studies (Chiarello, Burgess et al. 1990; Jordan, Patching et al. 2003), and are generally taken to reflect the superiority of the LH for basic aspects of word apprehension and processing. Critically, however, we found no significant differences in either task in the patterns of priming across the two hemispheres. In all cases, responses were faster for unambiguous than ambiguous targets, likely due to the overall greater associative strength between the primes and targets in the unambiguous triplet type. Also in all cases, response time facilitation (relative to UU) was greater for the double prime condition (RR) as compared with the single prime conditions (UR and RU). In the lexical decision task, we did not obtain significant facilitation for the single prime conditions (with the exception of ambiguous triplets in the LH). This contrasts with the findings of Balota and Paul (1996), who did obtain significant single prime facilitation with central presentation. However, the magnitude of the priming effect in the current study is very similar to that obtained by Balota and Paul (our study: double prime = 39 ms, single prime = 13 ms; their study: double prime = 38 ms, single prime = 17 ms). Thus, the difference in statistical outcome likely reflects the greater variability engendered by lateralized presentation. As in Balota and Paul's study, in the semantic judgment task the single prime conditions were reliably faster than responses to the UU condition, and this was true for both hemispheres. Of greatest import, there was no difference in the amount of priming for the double prime condition (RR) across the two hemispheres, for either unambiguous or ambiguous triplets, in either task. Indeed, in the lexical decision task, the numerical amount of priming was nearly identical (~ 40 ms) in the two VFs for both ambiguous and unambiguous targets, and the numerical trend in the semantic judgment task actually favored the RVF/LH as compared to the LVF/RH. In other words, the fact that

there was no priming benefit for the LVF/RH targets in these experiments – and, hence, the failure to support the coarse coding hypothesis – does not seem attributable to a lack of statistical power.

Thus, we observed no greater summation priming for the RH compared to the LH across primes that bore a mediated relationship to one another (onto a directly related, unambiguous target). These results differ from those obtained by Beeman, Friedman et al. (1994), in which there was greater LVF/RH priming than RVF/LH priming (in terms of naming accuracy) from multiple primes that were weakly related to one another (and all related to the target). However, the current failure to obtain an LVF/RH summation priming benefit across mediated primes is analogous to studies that have found no evidence of more mediated priming in the RH (Livesay and Burgess 2003; Richards and Chiarello 1995). Although the current study does not investigate mediated priming as such, the tasks should be tapping into the same activation processes. In mediated priming designs, one would expect to see facilitation to the extent that the prime and target both activate the (never actually presented) mediating concept/word. Similarly, in the present task, the degree of summation across the two primes, which bear a mediated relationship to one another, should reflect the extent to which each has independently activated the target. Thus, although the priming itself in this case is direct, the summation of that priming is analogous to the mediated priming case. Prior failures to find a RH mediated priming advantage arose in naming tasks (Livesay and Burgess 2003; Richards and Chiarello 1995) for both contextually consistent and contextually inconsistent prime-target pairs (Livesay and Burgess 2003) across a range of SOAs (50, 250, and 750 ms) (Richards and Chiarello 1995). We now show a similar pattern of results in a multiple priming paradigm, for both lexical decision and semantic judgment tasks. This body of work thus fails to support the prediction, derived from the coarse coding hypothesis, that the RH should be better able to accrue processing benefits across distantly linked information, due to broader semantic activation.

Notably, however, our results for the ambiguous triplets diverge from those of Faust and Lavidor (2003), in two important ways. First, in their semantic judgment task Faust and Lavidor failed to find facilitation for their mixed prime condition (in which the two primes diverged onto different meanings of the ambiguous target) for LH targets but found facilitation for RH targets. On this basis, they concluded the LH may focus on a single interpretation of an ambiguous target, whereas the RH may be better able to hold onto multiple meanings. However, in the present study we found significant facilitation in the RVF/LH for a very similar priming condition (double prime condition for ambiguous targets) relative to the unrelated prime conditions in **both** the lexical decision and the semantic judgment task. These results, combined with the results for the lexical decision task in the Faust and Lavidor (2003) study (in which there was facilitation in the RVF/LH for the mixed prime condition; Faust and Lavidor do not discuss the differences in the pattern across the two tasks), strongly suggest that the LH is capable of maintaining activation for multiple concepts.

Second, Faust and Lavidor reported an LVF/RH benefit for the processing of the mixed prime condition, in the form of greater facilitation for this condition than for the convergent prime conditions (in which both primes pointed to either the dominant or subordinate meaning of the ambiguous target), for both tasks. In contrast, the mixed condition was never the most facilitated for the RVF/LH: in the lexical decision task, priming was intermediate for the mixed condition and in the semantic decision task, the mixed condition was the only one not to show significant facilitation. Thus, there seemed to be a RH advantage for processing the divergent prime condition (though direct comparisons across the VFs were not reported). In the present study, however, we found facilitation for the ambiguous triplet types in both VFs for both tasks, and no difference across VFs in the amount of priming for this condition in either task. Thus, consistent with the pattern observed for the unambiguous triplets, there was no evidence of a

summation priming advantage in the RH; i.e., the RH showed no more facilitation relative to the LH from primes associated with different meanings of a lexically ambiguous target. This raises the possibility that the VF differences in condition-related priming patterns observed in the Faust and Lavidor study may have been driven instead by asymmetric responses to the *convergent* prime conditions.

The convergent prime conditions in the Faust and Lavidor study differed importantly from their mixed prime condition and the triplets used in the present study in that the primes were not only related to the same meaning of the target word, but also related in meaning to one another. Thus, in both tasks, there was the potential for interprime facilitation and, furthermore, in the semantic judgment task, there was the potential for strategic processing, since the presence of two related primes could predict that the target was related as well (and thus that a "yes" response would be required). Thus, priming asymmetries in this paradigm could be driven by differences in each hemisphere's tendency or ability to make use of the kind of information provided by the convergent primes. In the present study, where primes were never directly related to one another, we found no evidence for priming asymmetries and no difference in the priming patterns for ambiguous as compared with unambiguous words, irrespective of task. These results are also consistent with a study looking at the comprehension of puns (Coulson and Severens 2006), which found equivalent priming in both hemispheres (at longer SOAs of 500ms) from ambiguous targets embedded in puns (e.g., *During branding, cowboys have sore* ***calves***) to probes (*cow, leg*) associated with either meaning of the ambiguous word.

Thus, in the present study the results for both ambiguous and unambiguous triplets failed to provide evidence to support the predictions of the coarse coding hypothesis. A number of alternative explanations have been put forward to explain the kind of semantic priming asymmetries that have been observed. For example, Richards and Chiarello (1995) have suggested that categorically related but lexically unassociated information of the type that shows greater priming with LVF presentation (e.g., Chiarello, Burgess et al. 1990) may be more available to the RH. They postulate that, in contrast, lexically associated information, such as that used in mediated priming studies, might be equally available to both hemispheres, even if semantically distant. In turn, such differences could arise either because the two hemispheres actually represent these kinds of relationships differently (e.g., Deacon, Grose-Fifer, Yang, Stanick, Hewitt and Dynowska 2004) or because of more general asymmetries in how each hemisphere processes verbal information. For example, Federmeier and her colleagues (Federmeier and Kutas 1999; Federmeier, Mai et al. 2005) have argued that the LH tends to use verbal information predictively whereas the RH integrates old information with new information in a more post-hoc fashion. Lexical association is typically defined by the tendency for one word to lead to the prediction/generation of another, whereas nonassociated, categorically related information will generally be much less predictable. Therefore, on Federmeier et al.'s account, the LH may show a processing bias favoring predictable, lexically associated information. In contrast, the mechanism postulated for the RH may find both types of stimuli fairly easy to integrate – thus leading to a selective priming asymmetry favoring the LVF/RH for nonassociated category coordinates. In other words, predictability, rather than distance as such, might be the basis for at least some of the observed priming asymmetries. Note that this kind of account would also predict asymmetries in priming patterns between convergent and divergent sets of primes in the Faust and Lavidor study (2003), again based on the predictability of the targets rather than semantic similarity or distance.

Another way of thinking about the source of priming asymmetries is to assume that the hemispheres differ not in what information they represent and/or process but in the timecourse with which that information becomes or remains available. Timecourse differences might arise in the initial buildup of semantic activation in each hemisphere (e.g., Koivisto 1997), with, for

example, a faster ramping up of activation in the LH and a similar but slower activation timecourse in the RH. Alternatively, it may be that automatic aspects of semantic processing are fairly similar, but that the hemispheres deviate in their patterns of activation when processing involves strategic operations. For instance, Burgess and Simpson (1988) found that while automatic activations (at short SOAs with low relatedness proportions) were equivalent in both hemispheres, a more controlled process (at long SOAs with high relatedness proportions) favored the LH (see also Chiarello 1985, Chiarello, Senehi and Nuding 1987, Nakagawa 1991; for an alternate view, see Koivisto 1999, 2000). It is difficult to know how much of the priming in the current task might reflect controlled, expectancy-driven processes. As implemented here, the multiple priming task is not designed to isolate automatic processing, as the SOAs are long and at least one related word is present on 75% of all trials with word targets[3]. Thus, controlled effects are certainly possible. To the extent that these arose, we saw little evidence that they differed between the hemispheres. However, possible support for the hypothesis that the LH is superior at controlled processing can be found in the present study looking at the only condition to show a clear hemispheric difference. The RU single prime condition in the unambiguous triplets showed significantly more priming for LH targets compared to RH targets in the semantic judgment task. Prior work investigating priming effects when primes and targets are separated by intervening unrelated information (e.g., Ratcliff and McKoon 1988) have suggested that facilitation obtained across an intervening unrelated item may require controlled processes such as explicit meaning retrieval (Davelaar and Coltheart 1975; Meyer, Schvanenveldt and Ruddy 1975). If the LH is indeed superior at strategic, controlled processing, then it may have been better able to appreciate the semantic relationship between the prime and target in the presence of an unrelated item (RU condition) when cued to pay attention to meaning in the semantic judgment task.

Other than this priming difference in the RU condition, which was limited to the semantic judgment task, the current study found that, although both hemispheres were sensitive to task condition, there were no notable asymmetries in that sensitivity. The other goals of the current study were, first, to examine each hemisphere's tendency to make use of word-form (lexical) and conceptual (semantic) sources of information during priming and, second, to see how this varied with task. Balota and Paul (1996) used the paradigm we adapted here to investigate whether priming effects derive from lexical or semantic levels of representation. At the word-form level, both unambiguous and ambiguous targets are assumed to have a single representation. In contrast, at the conceptual level, ambiguous targets are assumed to have (at least) two distinct representations (associated with each of the homograph's meanings) whereas unambiguous targets have a single representation. Thus, priming effects arising at the lexical level should be similar for the two triplet types, whereas an interaction of ambiguity and prime condition would suggest effects that emerge at the semantic level. Balota and Paul found that priming patterns vary with task. Priming in lexical decision and naming tasks showed the lexical pattern, whereas priming in a semantic judgment task differed across ambiguity (in particular was reduced for the ambiguous RR condition as compared with the unambiguous RR condition) and thus suggested facilitation at a conceptual level.

Replicating Balota and Paul's (1996) results with central presentation, in the lexical decision task of Experiment 1 we found no significant effect of ambiguity on the pattern of priming, and this was true for both RVF/LH and LVF/RH presentation. Thus, priming in both hemispheres for this task would appear to derive more from the word-form level. Also replicating the pattern seen by Balota and Paul, in the semantic judgment task of Experiment

[3]It is difficult to compare the relatedness proportion in this triplet-priming task with that in word pair priming tasks, since most of the triplets that contain a related word also contain an unrelated word. Whether or not participants might adopt a strategy of trying to anticipate multiple potential targets associated with both primes is unclear; certainly such expectancy strategies would be more difficult for this task than in the word pair case.

2, we did find a significant difference in priming pattern across ambiguity in both VFs. In particular, although priming was generally stronger in the unambiguous than in the ambiguous triplets, the difference between the ambiguous and unambiguous triplets was greater for the RR condition (~100 ms) than for the single prime (UR/RU) conditions (~30 ms). This pattern did not differ across the two hemispheres, suggesting that for this task priming in both arises from activation at the conceptual level of representation.

Thus, there was a task effect for both hemispheres; the lexical decision task seems to tap more strongly into lexical level activation patterns whereas the semantic judgment task seems to tap more strongly into semantic activation patterns. Based on their result pattern, Faust and Lavidor (2003) suggested that RH priming patterns might reflect greater contribution from lexical level representations (that do not include meaning) whereas LH priming patterns might derive more from semantic level activations (especially in the semantic judgment task). However, the results from the current study do not support this hypothesis, and instead highlight the capacity of both hemispheres to make use of both lexical and semantic sources of information, in a manner that varies with task. As stressed by Baynes (1998), it is therefore important to take such task-related differences into consideration with evaluating patterns of hemispheric asymmetry. The results of lexical decision tasks, for example, may not readily allow inferences about hemispheric differences in semantic activation.

In sum, the results of this set of experiments failed to support accounts of hemispheric asymmetries that postulate differences in the breadth of semantic activation or differences in each hemisphere's ability to tap into lexical versus conceptual levels of representation. To a similar degree, both hemispheres proved sensitive to summation priming across primes with a mediated relationship (summation priming effect for unambiguous targets) and both were able to maintain multiple, different meanings associated with a lexically ambiguous word (divergent priming effect for ambiguous targets). Furthermore, both hemispheres showed similar, task-dependent patterns of priming from lexical and semantic levels of representation (task effect). These findings suggest that cerebral asymmetries observed in other tasks must arise from alternative factors, such as the timecourse of activation (e.g., Koivisto 1997), the representation of different types of semantic relations (e.g., Richards and Chiarello 1995), the predictive use of context information (e.g., Federmeier and Kutas 1999; Federmeier, Mai et al. 2005), or the efficacy of strategic, controlled semantic processing (e.g., Burgess and Simpson 1988). Follow-up studies that track asymmetries over time and across processing stages, for example using event related brain potential (ERP) methods, may help to adjudicate between these possibilities.

4. Experimental Procedure

Experiment 1

Participants—Data were obtained from a final set of 48 University of Illinois students[4] (24 men and 24 women) between the ages of 18 and 22 (mean age 19); participants received either cash or course credit for their time. All were native English speakers who were right-handed; mean handedness quotient was 0.73 (0.4–1.0) as measured by the Edinburgh handedness inventory (Oldfield 1971), where "1" is strongly right handed and "−1" is strongly left-handed. Participants were screened for normal vision.

Materials—Stimuli were based on those originally used by Balota and Paul (1996) and consisted of word triplets: prime1; prime2; target. 208 **unambiguous** triplets contained target words with a single meaning, whereas 208 **ambiguous** triplets contained target homographs

[4]Out of 55 subjects that were run, 7 subjects were dropped due to poor performance (accuracy < 50%) leaving a final set of 48 subjects.

with at least two distinct meanings; samples of each type of triplet can be seen in Table 1. Each prime was either related or unrelated to the target, yielding four conditions: **UU** (both prime1 and prime2 unrelated to the target), **RU** (prime1 related and prime2 unrelated to the target), **UR** (prime1 unrelated and prime2 related to the target), and **RR** (both prime1 and prime2 related to the target). For unambiguous triplets (e.g., TEA-BEANS-COFFEE), the two related primes were both lexically associated with the target but not with one another and were conceptually related to the same meaning of the target word. In contrast, for ambiguous triplets (e.g., HOSPITAL-TOLERANT-PATIENT), the two primes were again lexically associated with the target (though not with one another), but were conceptually related to different meanings of the semantically ambiguous target word. The 104 ambiguous targets and 51 unambiguous targets in the original stimuli from Balota and Paul (1996) were supplemented with 53 targets taken from Bennet and McEvoy (1999) and additional items constructed using the MRC Psycholinguistic Database (Coltheart 1987). Ambiguous and unambiguous targets were matched for word frequency (Kucera and Francis 1967) and length. An analysis of forward association norms (Nelson, McEvoy and Schreiber 1998) between the primes and the targets revealed that the primes and the unambiguous targets were more strongly associated (average 0.26) with each other compared to the primes and the ambiguous targets (average 0.11); note that no inferences will be made based on main effects of ambiguity.

In order to generate comparable non-word trials, an additional set of 104 ambiguous and 104 unambiguous triplets were constructed in the same manner, with targets that matched the word target set in word frequency and length. Non-words were then constructed from these 208 targets by replacing one letter at random to form pronounceable letter strings that were not legal English words.

Eight stimulus lists were created from the full stimulus set. Lists contained an equal number of items from each triplet type and prime condition within each VF, and targets were controlled for length and frequency across triplet type, prime condition, and VF. In each list, participants saw the UU and RR versions of half of the triplet sets of each type and the UR and RU versions of the other half (counterbalanced across two lists), such that no prime-target pair appeared more than once. For ambiguous triplets, each participant saw an equal number of primes related to the dominant and subordinate meaning of the targets, and prime position of the dominant and subordinate primes was counterbalanced across lists. Word targets were repeated once within each list, but always appeared in different VFs on first and second presentation; repetitions were separated by an average of 311 trials (range 27–598). Participants saw each non-word exactly once during the experiment. Two additional lists were created with the VF of each item reversed. From these four lists, an additional four were created with the order of the two primes reversed. Thus, across subjects, the UU, UR, RU, and RR versions of each triplet appeared equally often in each VF and both prime orders appeared equally often. Stimuli within each list were presented in random order, with the constraint that no more than three targets in a row appeared within the same VF.

Procedure—Each participant was tested in a single session conducted in a dim, quiet testing room. Stimuli were presented one word at a time on a 21″ SVGA monitor placed at a distance of 40″ from the participant. All stimuli were in white, upper case letters presented on a black background with standing central fixation (red asterisks) to help participants maintain central eye fixation. Stimuli subtended 2.8 degrees of horizontal visual angle (range: 1.3 to 4.3 degrees) and 0.68 degrees of vertical visual angle. Each trial began with a series of pluses to indicate the beginning of a trial; these were presented centrally for 1000 ms with a random SOA of 1000 to 2000 ms. Following this, prime1 was presented centrally for 200 ms, followed immediately by prime2, which was also displayed centrally for 200 ms. After 800 ms, the target item was then presented for 200 ms, at vertical center and lateralized so that its medial edge was two degrees from horizontal center. Participants were told to respond to the target as

quickly and accurately as possible with a lexical decision judgment: i.e., they were to press "yes" with one response button if the target was a legal English word or "no" with the other button if target was a non-word. Hand used to respond "yes" was counterbalanced across participants and lists. The participant's response initiated the next trial sequence. A practice block preceded the experimental session and the session was divided into four equal blocks. Response times were calculated as the time between target presentation and the corresponding response.

Experiment 2

Participants—Data were obtained from a final set of forty University of Illinois students[5] (20 men and 20 women) between the ages 18 and 22 (mean age 19); participants received either cash or course credit for their time. All were native English speakers who were right-handed; mean handedness quotient was 0.77 (range: 0.4–1.0) (Oldfield 1971), where "1" is strongly right handed and "−1" is strongly left-handed. Participants were screened for normal vision.

Materials—Stimuli consisted of all the word trials used in Experiment 1. As in Experiment 1, targets were repeated once within each list, but always appeared in different VFs on first and second presentation; repetitions were separated by an average of 208 trials (range 10–401).

Procedure—Procedures were identical to those in Experiment 1, except for the participants' task. Here, participants were asked to make a semantic relatedness judgment for each triplet: i.e. they were to press "yes" with one response button if one or both of the primes was related to the target or "no" with the other button if neither of the primes was related to the target. Hand used to respond "yes" was counterbalanced across participants and lists.

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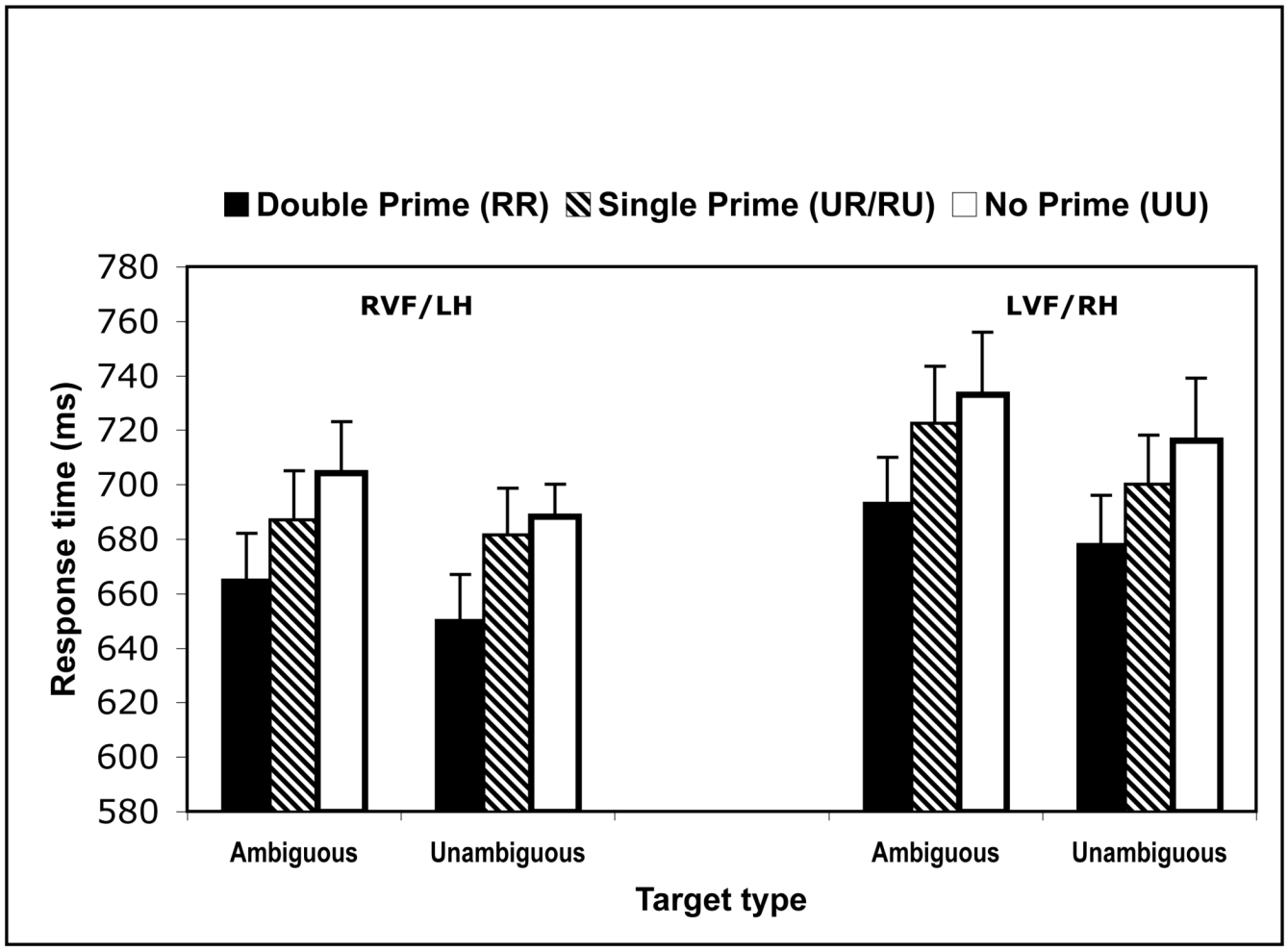

Figure 1. Response times in the lexical decision task

Median response times in each visual field (RVF/LH, LVF/RH) in each triplet type (ambiguous, unambiguous) in the lexical decision task.

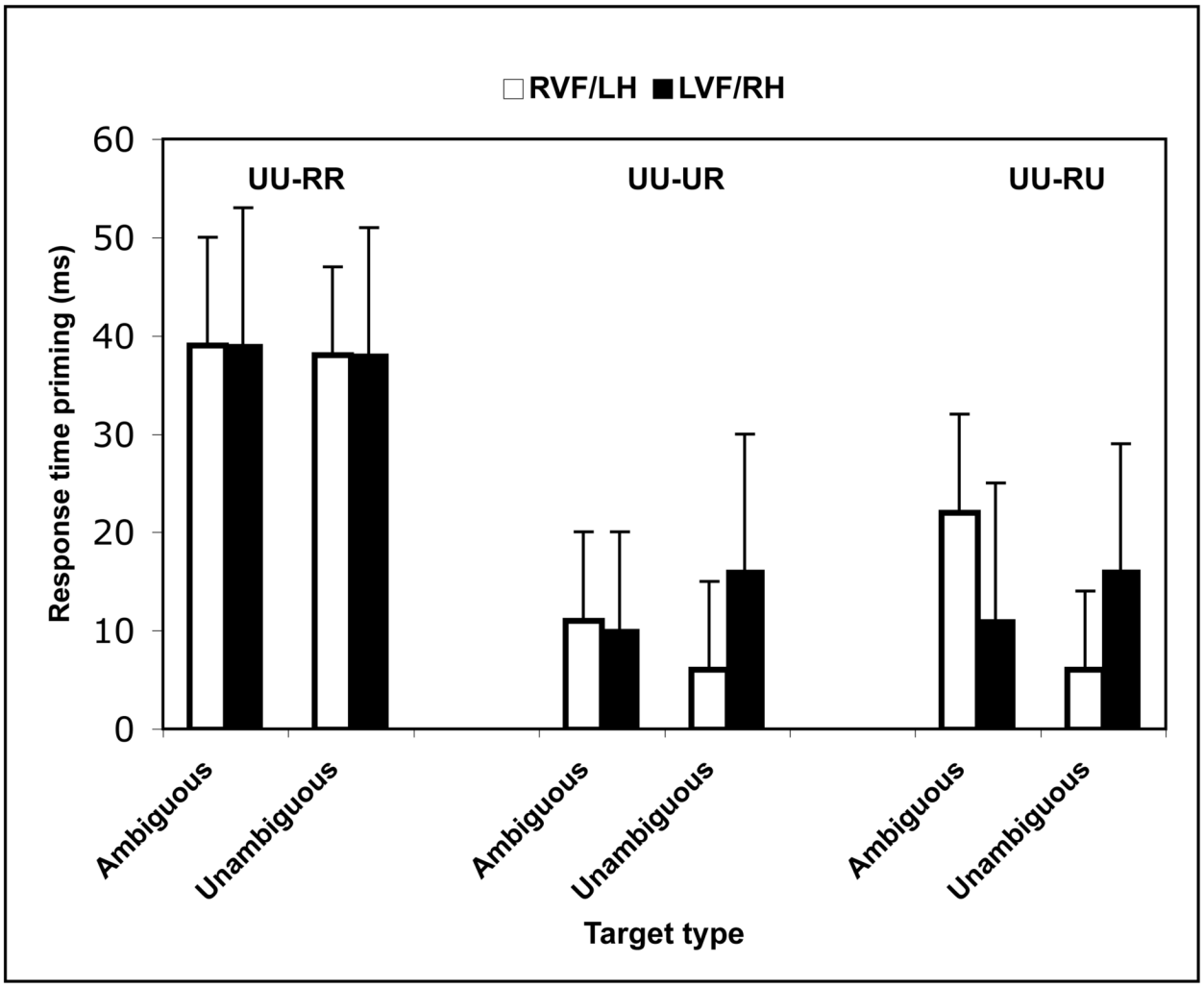

Figure 2. Response time priming in the lexical decision task

Response time priming in each visual field (RVF/LH, LVF/RH) in each triplet type (ambiguous, unambiguous) in the lexical decision task.

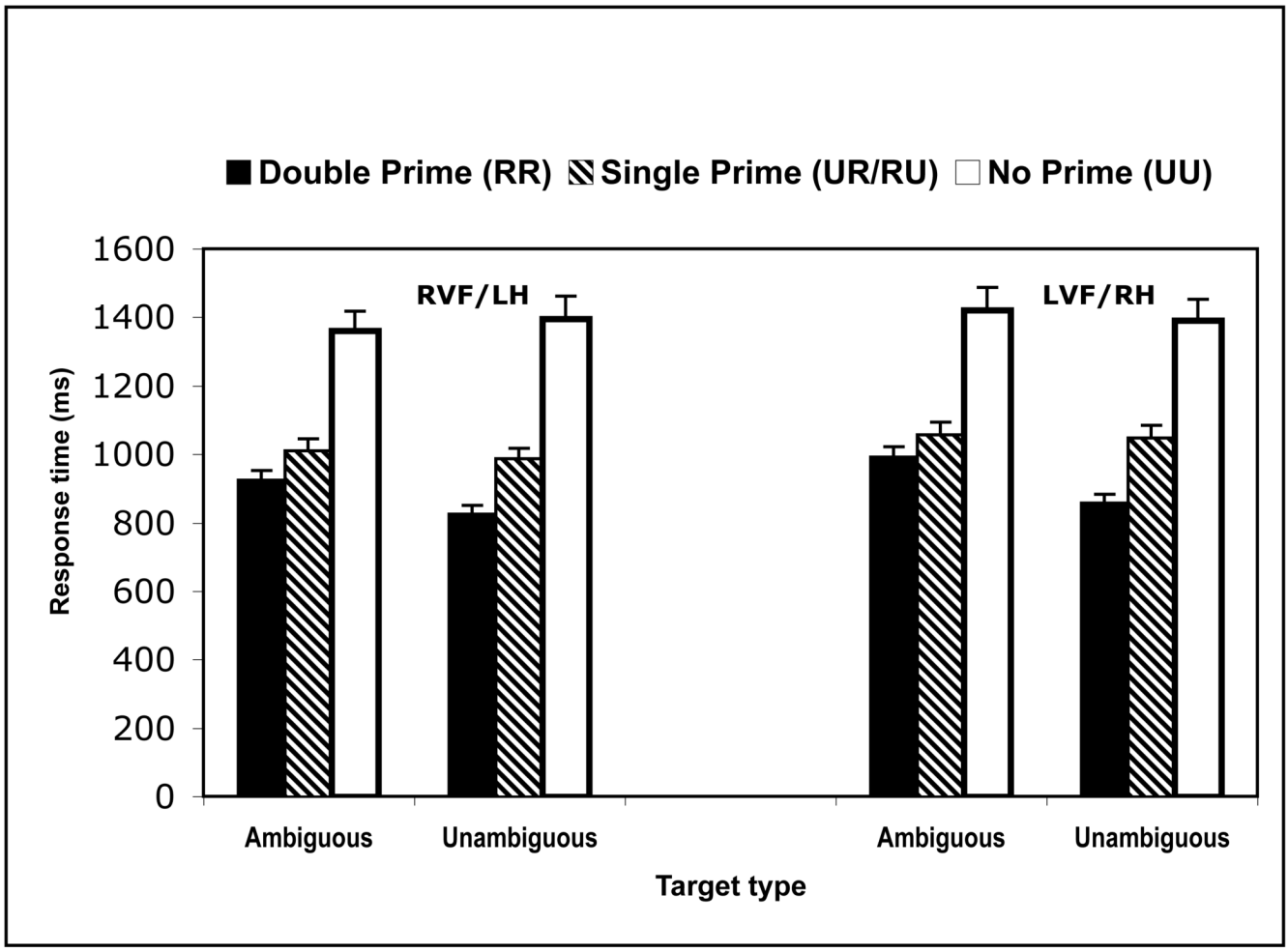

Figure 3. Response times in the semantic judgment task

Median response times in each visual field (RVF/LH, LVF/RH) in each triplet type (ambiguous, unambiguous) in the semantic judgment task.

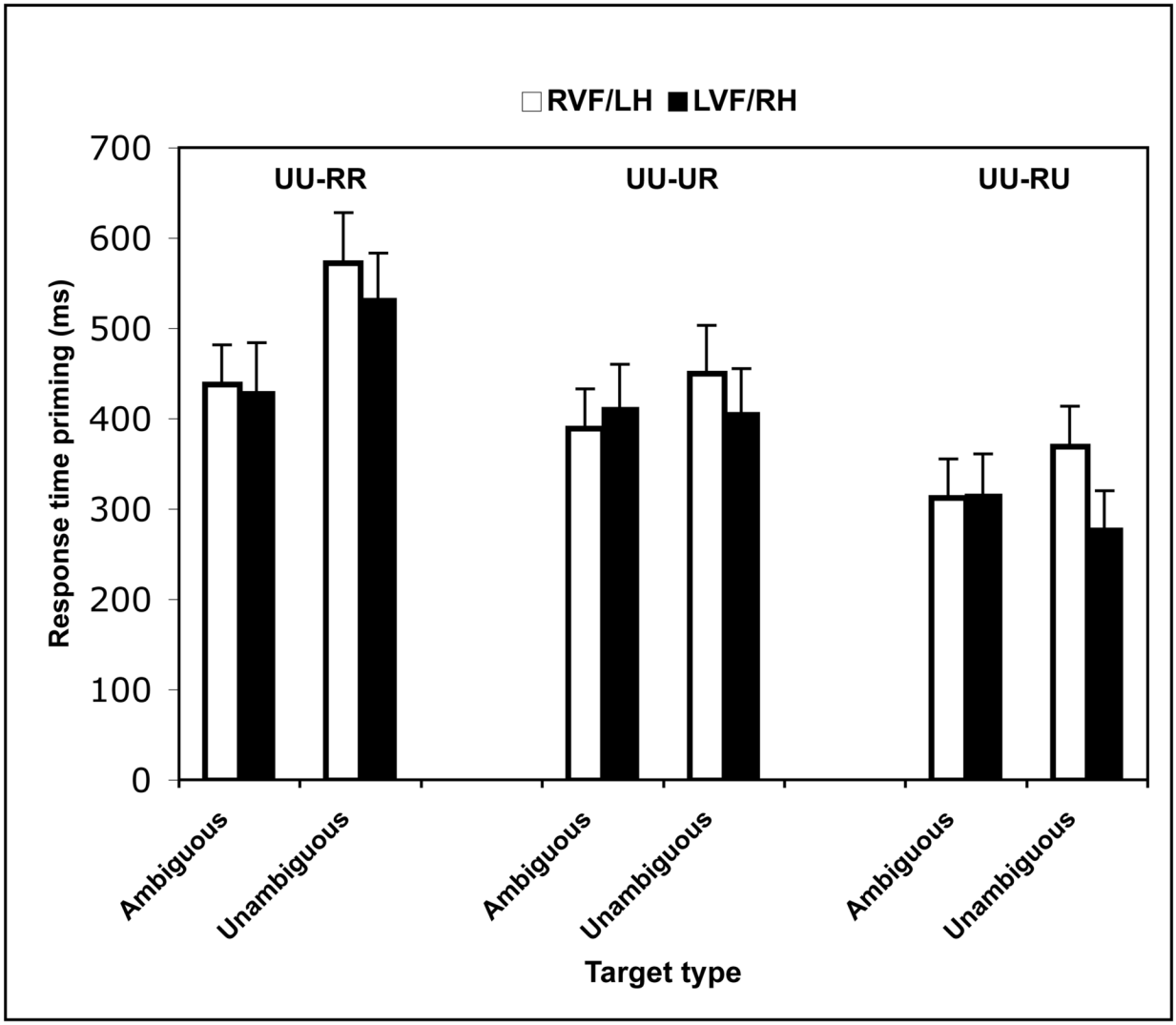

Figure 4. Response time priming in semantic judgment task

Response time priming in each visual field (RVF/LH, LVF/RH) in each triplet type (ambiguous, unambiguous) in the semantic judgment task.

Table 1

Stimulus set

Prime Conditions	Ambiguous	Unambiguous
RR	*Hospital-Tolerant-Patient*	*Tea-Beans-Coffee*
UR	*Champion-Bother-Bug*	*Grime-Empty-Full*
RU	*Roach-Hall-Bug*	*Capacity-Abandon-Full*
UU	*Gangster-Melon-Patient*	*Tax-Duel-Coffee*

A Sample set of stimuli seen by a single participant

Table 2

Response time and accuracy for LH in lexical decision task

	RVF/LH					
	Ambiguous			Unambiguous		
	RT (ms)	SD	% Correct	RT (ms)	SD	% Correct
RR	665	120	91	650	115	93
UR	693	130	89	682	119	93
RU	681	117	89	681	118	91
UU	704	128	86	688	118	88

Median response times for the four prime conditions (*RR/UR/RU/UU*) in each triplet type (ambiguous, unambiguous) in the RVF/LH in the lexical decision task.

Table 3

Response time and accuracy for RH in lexical decision task

	LVF/RH					
	Ambiguous			Unambiguous		
	RT (ms)	SD	% Correct	RT (ms)	SD	% Correct
RR	693	122	85	678	126	91
UR	723	149	83	700	125	89
RU	722	137	83	700	119	87
UU	733	158	76	716	157	79

Median response times for the four prime conditions (*RR/UR/RU/UU*) in each triplet type (ambiguous, unambiguous) in the LVF/RH in the lexical decision task.

Table 4

F-values (degrees of freedom 1 and 47) for pairwise comparisons

	RVF/LH		LVF/RH	
	Ambiguous	**Unambiguous**	**Ambiguous**	**Unambiguous**
RR vs. UU	13.83***	17.04***	8.51*	7.99*
RR vs. UR	9.46**	15.8***	5.87**	4.86
RR vs. RU	4.03*	17.91***	7.97**	6.05**
UR vs. RU	1.29	0.0	0.01	0.0
UR vs. UU	1.5	0.46	1.00	1.40
RU vs. UU	5.26*	0.57	0.59	1.46

Pairwise comparisons between prime conditions (RR/UR/RU/UU) for each triplet type (ambiguous, unambiguous) in each visual field in the lexical decision task.

*** p <= 0.001;

** p <= 0.01;

* p <= 0.05

Table 5

Response time and accuracy for LH in semantic judgment task

	RVF/LH					
	Ambiguous			Unambiguous		
	RT (ms)	SD	% Correct	RT (ms)	SD	% Correct
RR	923	179	88	824	159	94
UR	971	212	72	944	180	86
RU	1048	217	66	1027	207	77
UU	1360	354	78	1395	426	84

Median response times and percent correct for the four prime conditions (*RR/UR/RU/UU*) in each triplet type (ambiguous, unambiguous) in the RVF/LH in the semantic judgment task.

Table 6

Response time and accuracy for RH in semantic judgment task

	LVF/RH					
	Ambiguous			Unambiguous		
	RT (ms)	SD	% Correct	RT (ms)	SD	% Correct
RR	991	185	85	857	167	94
UR	1009	203	74	982	201	84
RU	1105	274	63	1112	273	74
UU	1420	422	81	1389	397	83

Median response times and percent correct for the four prime conditions (*RR/UR/RU/UU*) in each triplet type (ambiguous, unambiguous) in the LVF/RH in the semantic judgment task.

Table 7

F-values (degrees of freedom 1 and 39) for pairwise comparisons

	RVF/LH		LVF/RH	
	Ambiguous	**Unambiguous**	**Ambiguous**	**Unambiguous**
UU Vs RR	97.44***	102.84***	61.09***	108.95***
UR Vs RR	5.94*	49.67***	0.57	34.80***
RU Vs RR	28.53***	65.30***	13.31***	73.12***
UU Vs UR	78.65***	72.59***	69.83***	68.41***
RU Vs UR	7.62**	12.27***	7.93**	16.40***
UU Vs RU	52.85***	66.64***	46.08***	44.29***

Pairwise comparisons between prime conditions (RR/UR/RU/UU) for each triplet type (ambiguous, unambiguous) in each visual field in the semantic judgment task.

*** $p <= 0.001$;

** $p <= 0.01$;

* $p <= 0.05$