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Examining lateralized lexical ambiguity processing using dichotic and cross-modal tasks

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ABSTRACT

The individual roles played by the cerebral hemispheres during the process of language comprehension have been extensively studied in tasks that require individuals to read text (for review see Jung-Beeman, 2005). However, it is not clear whether or not some aspects of the theorized laterality models of semantic comprehension are a result of the modality of presentation. Extending earlier work examining lateralized semantic processing using lexically ambiguous words, the current experiments utilized two modified lexical-decision tasks (one fully auditory and one cross-modal) with dichotically presented target stimuli. When targets were presented to the right ear/left hemisphere there was a distinct advantage for detecting words that are associated with the dominant meaning of the ambiguous word over the subordinate meaning. In contrast, for left ear/right hemisphere trials, there was either no difference between the pattern of semantic access for dominant and subordinate meaning (dichotic only) or a processing advantage for the subordinate meaning of the ambiguous word (with cross-modal presentation). These data suggest that the complimentary hemispheric strategies that allow for semantic access are not modality specific and instead characterize how the hemispheres each contribute to comprehension for both speech and text. Thus, dichotic presentation does seem to allow for the study of subtle hemispheric difference in meaning comprehension.

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The study of hemispheric differences in the processing of lexical ambiguity has provided ample evidence that the right hemisphere is involved in important aspects of language comprehension (Atchley, Burgess, & Keeney, 1999; Atchley & Kwasny, 2003; Beeman, Friedman, Diamond, & Lindsay, 1994; Burgess & Simpson, 1988; Chiarello, 2003; Coney & Evans, 2000; Faust, Ben-Artzi, & Harel, 2008; Faust & Chiarello, 1998; Faust & Lavidor, 2003; Hasbrooke & Chiarello, 1998; Michael, 2009; Titone, 1998; Titone & Salisbury, 2004). Specifically, the right hemisphere (RH) has been shown to utilize a strategy of maintaining multiple meanings of the ambiguous stimuli. In contrast, the left hemisphere (LH), in the absence of limiting contextual information, selects the dominant meaning of the ambiguous word while either deselecting or even inhibiting alternative semantic representations that are associated with the lexical item. As discussed by Atchley et al. (1999) and Beeman (1993; Jung-Beeman, 2005), one purpose of these alternative strategies for meaning access may be to aid in meeting the goal of rapid comprehension of a linguistic stimulus that might require equally rapid reanalysis in the not-unlikely case that a comprehension error is detected.

It is common that a combination of semantic priming paradigms utilizing a lexical decision task with a divided visual field (DVF) presentation is the approach used to study these hemispheric differences in semantic strategy. Thus, a centrally presented ambiguous prime is presented, followed by a target stimulus that is presented to either the left or right visual field. The participant is to decide if the target is a word or non-word. In their seminal paper, Burgess and Simpson (1988) used this technique to present their participants with a single ambiguous prime word and a lateralized target related to either the dominant or subordinate meaning of the prime word at either 35 ms or 750 ms stimulus onset asynchrony (SOA). They found that in both hemispheres the dominant meanings were activated quickly and this priming for the dominant meaning was found at both the short and long SOA. In contrast, priming for the subordinate meaning was only seen at the short SOA in the right visual field/left hemisphere (RVF/LH) and only at the long SOA in the left visual field/right hemisphere (LVF/RH). Burgess and Simpson proposed that the LH uses a selection process in which the inappropriate, and in most cases the subordinate, word meaning is inhibited. This is thought to be a controlled, attention-driven process of meaning activation and active

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selection. In contrast, the RH showed priming for only the dominant meaning at the short SOA and priming for both meanings at the long SOA. The RH is thus thought to be slightly slower during the initial stage of meaning access, but it maintains all possible meanings in order to reactivate a suppressed meaning or to revise an initial interpretation.

A similar hypothesis was proposed by Beeman et al. (1993, 1994; Beeman & Chiarello, 1998; Jung-Beeman, 2005), known as the coarse semantic coding theory. In this theory, the LH conducts what is described as fine semantic coding, activating the dominant interpretation of a word and possibly a few strongly related associates. Thus in the LH strongly related meanings are activated more than weakly related meanings, but in the RH both strong and weak meanings are highly activated. The RH engages in coarse semantic coding in which it maintains more varied information, including features that are less compatible with the dominant representation (Atchley et al., 1999; Beeman et al., 1994; Jung-Beeman, 2005). The RH activates a broad range of meanings including multiple meanings of ambiguous words (Atchley & Kwasny, 2003; Beeman, 1993; Beeman et al., 1994; Burgess & Simpson, 1988; Faust & Chiarello, 1998; Faust & Kahana, 2002; Faust & Lavidor, 2003), peripheral and unusual associates, and metaphorical interpretations (Abdullaev & Posner, 1998; Atchley et al., 1999; Beeman, 1993, 1998; Seger, Desmond, Glover, & Gabrieli, 2000).

The RH's activation of multiple meanings of ambiguous words and a broad semantic network of distant associates can be very useful when a reader must simultaneously consider multiple meanings during comprehension or when the reader must revise interpretations based on subsequent context (Jung-Beeman, 2005). For example, in many cases, reinterpretation is needed when processing figurative or humorous language. In fact, the RH is shown to play a key role in the interpretation of sarcasm (Voyer, Bowes, & Techentin, 2008), metaphors (Anaki, Faust, & Kraveta, 1998; Coulson & Van Petten, 2002, 2007), puns, and jokes (Coulson & Severens, 2007; Winner & Gardner, 1977). Further evidence of the RH's role in language processing is seen in patients with right hemisphere damage (Fassbinder & Tompkins, 2001; Grindrod & Baum, 2003, 2005; Klepousniotou & Baum, 2005). Consistent with the research mentioned above, these RHD patients have been shown to have problems processing certain types of language that require peripheral (distant) semantic relationships such as jokes (Brownell, Michel, Powelson, & Gardner, 1983), sarcasm (Fournier, Calverley, Wagner, Poock, & Crossley, 2008; Giora, Zaidel, Soroker, Batori, & Kasher, 2000) and metaphors (Brownell, Simpson, Bihrle, Potter, & Gardner, 1990).

Almost all of the work done in the field of hemispheric differences in the processing of lexical ambiguity employs a variant of the DVF paradigm. There are examples of cross-modal semantic studies (for example see Titone, 1998), but even in these studies the target information is still uniformly presented as text and not speech. Although it seems likely that reading and speech share many lateralized processes, speech is evolutionarily older than reading and may well rely on some different processing mechanisms (e.g., Wurm, Vakock, & Seaman, 2004). In contrast to text, speech unfolds over time, and accesses semantics directly from phonology. Semantic effects in speech perception arise even before the uniqueness point at which the word can be perfectly predicted (Marslen-Wilson, 1987; Tyler, Voice, & Moss, 2000; Wurm et al., 2004). Thus, most models of spoken word recognition propose a high level of interaction between phonological and semantic representations (e.g., McClelland & Elman, 1986; Mirman & Magnuson, 2008) or even that semantic and phonological representations are one and the same (e.g., Gaskell & Marslen-Wilson, 1997). Comparing visual and auditory language modalities allows us to determine whether the hemispheric differences that are reliably observed in the DVF literature are unique to the visual–lexical–semantic pathway, or are also observed in a modality which relies more heavily on phonology in order to access semantics.

Dichotic listening studies have proven to be an effective method for examining hemispheric differences in language processing. In the basic dichotic listening paradigm, competing stimuli are presented to the two ears simultaneously. Under these conditions, contralateral auditory projections suppress ipsilateral projections, and so the left ear stimulus is presented primarily to the right hemisphere and the right ear stimulus is projected to the left hemisphere (Brancucci et al., 2004; Bryden, 1982; Kimura, 1967). It is often assumed (e.g., Jancke, 2002; Zaidel, Clarke, & Suyenobu, 1990) that dichotic listening gives rise to hemispheric asymmetry effects through a mechanism of callosal relay. Within the domain of linguistic processing, this means that a left ear stimulus is projected to the right auditory cortex, and then relayed to homologous left hemisphere areas for linguistic processing. If so, stimuli from the left ear should be processed in a qualitatively similar way to stimuli from the right ear, but with an RT cost (and perhaps some drop in accuracy) associated with the relay. Thus, according to this view, dichotic listening may be useful for determining which hemisphere is superior for a particular linguistic process, but not for tapping any specific linguistic capabilities of the right hemisphere. However, studies that have used words instead of nonsense syllables as stimuli have found clear evidence of direct access (that is, right hemisphere processing of words presented to the left ear; Ely, Graves, & Potter, 1989; Grimshaw, Kwasny, Covell, & Johnson, 2003). Such findings are consistent with patient studies, which find that individuals with widespread lesions of left hemisphere language areas are still capable of auditory recognition of single words (Dronkers, Wilkins, VanValin, Redfern, & Jaeger, 2004; Tyler & Marslen-Wilson, 2008). We therefore expect that dichotic listening will allow us to tap the processing of ambiguous words in each hemisphere. This research, therefore, represents a novel application of the dichotic listening method as a tool for studying dissociable lateralized semantic processing.

One factor that complicates the goal of directly comparing DVF and dichotic methods is that dichotic listening requires the simultaneous presentation of competing stimuli to achieve contralateral projections. We developed a modified lexical decision task in which participants hear (in Experiment 1) or see (in Experiment 2) an ambiguous prime word, followed by a dichotic pair that consists of either two nonwords or a target word (related to the dominant meaning, related to the subordinate meaning, or unrelated to the prime) paired with a nonword. The participant must then indicate whether one of the stimuli they heard was a word. The dichotic competition forces both divided attention and the simultaneous processing of competing speech messages, and thus the dichotic task is more difficult than most (or all) DVF tasks. Note however that this situation closely approximates the challenges faced by speech perception mechanisms in most settings. Neuroimaging studies of dichotic (compared to binaural) processing indicate that it is associated with the recruitment of a large network of frontotemporal regions (Jancke & Shah, 2002; Thomsen, Rimol, Ersland, & Hugdahl, 2004) that likely reflect the increase in cognitive and attentional resources required for the task.

Given the distinct lack of psycholinguistics research that has directly compared divided visual field and dichotic listening methods, it is not clear whether or not semantic processing strategies employed by the cerebral hemispheres will prove to be comparable across presentation modality and task. This uncertainty is a central motivating factor driving the current research. However if previous findings in the DVF literature are predictive, then in the current experiments, which will employ a relatively long SOA between the presentation of the ambiguous word and the semantically associated target stimuli, we would expect that participants will respond faster and more accurately for the dominantly related target words (BANK-MONEY) than the subordinately related target words (BANK-RIVER) when the stimuli are presented in the right ear/left hemisphere (RE/LH). Alternatively, when the target stimuli are presented to the left ear/right hemisphere (LE/RH) then the participants will not show this preference for the dominant word meaning and instead will be fast and accurate when identifying both the subordinately related target and the dominantly related words. This pattern of behavior would be consistent with the current theory (Atchley et al., 1999; Beeman et al., 1994; Jung-Beeman, 2005) that the RH maintains all meanings of an ambiguous word, allowing faster access to all the alternative meanings of a lexically ambiguous word during discourse comprehension.

1. Experiment 1

Experiment 1 utilized a fully auditory paradigm for stimulus presentation. A binaurally presented lexically ambiguous word was presented first, followed by a dichotically presented pair of target stimuli. The pair of target stimuli were either both spoken phoneme strings that are not English words (nonwords such as \□ri-tər\ or \□ri-zər\) or a pair of stimuli where one of the spoken tokens is an English word (\□ri-vər\) paired with a nonword (\□ri-tər\). The task performed by the research participant was to make a modified lexical decision in response to the stimulus pair. They were instructed to press one button if the dichotically presented targets were both nonwords and to make an alternative button response if either of the spoken tokens were real English words.

1.1. Methods

1.1.1. Participants

Forty-one undergraduate psychology students, who were all native English speakers, strongly right-handed, and with normal hearing (as per self report) took part in the current experiment for research credit. The Edinburgh Handedness Inventory (Oldfield, 1971) assessed handedness.

1.1.2. Materials

As prime words 120 lexically ambiguous words were used, half were paired with one word and one nonword target (referred to as the word target list), while half were always paired with two nonwords. The two prime lists (each containing 60 words) were balanced on word length (average = 4.9 letters) and word frequency (average Kucera and Francis frequency = 45). Associated with each of the 60 ambiguous primes was a dominant and subordinate target word that were matched on word length (average = 5.5 letters) and word frequency (average Kucera and Francis frequency = 46). Each individual participant only heard one target word type for each ambiguous prime (for a total of 60 word trials per participant: 20 dominant, 20 subordinate, and 20 unrelated word trials), and across lists all 60 primes that were in the word target list were followed by all three word types (dominant, subordinate, and unrelated) presented in a random order. The unrelated condition resulted from pairing each prime with a semantically unrelated target word from a different prime. Thus, each individual target word was in both the related and the unrelated conditions which allows for control of any possible effects caused by subtle item-level differences. For each of the target words, a corresponding nonword was created to allow for effective dichotic presentation. The nonword and word were matched on initial phoneme, number of syllables, and word length, ensuring that the target and nonword initially sounded the same and had the same duration. For half of the 60 word trials the word stimulus was presented to the RE and for half the word was presented to the LE, with ear of word presentation being random.

For the remaining 60 lexically ambiguous prime words, we created two matched nonwords (again matched on initial phoneme, syllable and word length). All stimuli were digitally recorded using the open source software package Audacity (audacity.sourceforge.net) at 44.1 kHZ and all stimuli were recorded using a female speaker who was instructed to keep her voice in a normal speaking tone and asked to minimize all emotional prosody while saying the stimuli. The audio files were trimmed to include only the word stimuli and an initial period of 30 ms before the stimulus beginning, accounting for pronunciation differences in initial phonemes.

1.1.3. Procedure

Participants were alone when doing this study which was run on a Dell PC running E-Prime 1.1 software (www.pstnet.com), and they wore Sony MDR-210 headphones in order to insure appropriate binaural and dichotic presentation. Prior to the experimental trials a total of 10 practice trials were completed so that participants became comfortable with the stimulus presentation style and with the response task. After the practice block, the participants completed a total of 120 experimental trials. The participants were instructed that they would first hear a prime word. The lexically ambiguous prime words varied in length lasting on average around 500 ms and a short segment of silence lasting on average 250 ms was added to the end of each of the word tokens so that total presentation duration for the prime was always 750 ms. Next, the dichotically presented target stimuli were presented. Again, these pairs were either a word and a nonword or two nonwords. The participants indicated whether they heard a word or not in the target pair in either ear. They pressed the 1 key on the computer keypad if there was a word present and the 2 key if there was not a word. Responses were always provided with the dominant, right hand. Following the response, they received the next prime-target set, and this sequence of prime-target pairings was repeated until they heard each prime word. The experiment took approximately 15 min to complete.

1.2. Results

Experiment 1 was a 3 (strength of semantic relationship: dominant meaning, subordinate meaning, or unrelated) × 2 (ear of target presentation: left or right) within-participants design. An analysis of variance (ANOVA) was conducted for the primary dependent variables, mean response accuracy and mean reaction time (RT). For all least significant difference (LSD) planned analyses to be discussed, a $p < 0.05$ was used as the critical value of significance. Because accuracy around 50% percent indicates guessing (with 50% of trials being word and 50% being nonword), we excluded the data from those participants with accuracy at or lower than fifty percent. This resulted in the exclusion of the data for five participants. No additional measures were taken for reducing variance for either the accuracy or RT dependent variables. As discussed earlier, this high error rate likely resulted because of the difficult modified lexical decision task that required discrimination and detection for simultaneously presented target stimuli. Consistent with the analysis strategy used in the DVF literature, only word trials were analyzed.

1.2.1. Accuracy data

We ran an initial analysis investigating hemispheric differences in accuracies, and found that the ear of the stimulus presentation had an overall effect, $F(1, 35) = 18.79$, $p < 0.01$. Participants were more accurate when the target words were presented in the RE/LH (82%, SD = 5%) than they were when presented in the LE/RH (68%, SD = 8%). Thus, consistent with most dichotic studies that require a linguistic judgment, the participants in the current study showed a general right ear advantage (REA) for the modified lexical decision task. There was also a main effect for the semantic relationship variable, $F(2, 35) = 3.66$, $p < 0.05$. The targets related to the dominant meaning of the prime word were the most accurately identified (74%, SD = 3%), while the subordinately related and unrelated trials resulted in lower accuracy (subordinate = 67% SD = 4%, unrelated = 70% SD = 4%). More importantly, there was also a statistically significant interaction of the semantic relationship variable and ear of presentation, $F(2, 35) = 7.01$, $p < 0.01$.

To investigate further this significant interaction, we analyzed accuracy across the three target semantic relationship levels for each hemisphere. Within the RE/LH, we found a significant effect of semantic relationship ($F(2, 35) = 8.47$, $p < 0.01$) such that participants had significantly higher accuracy for dominant meaning targets (80% SD = 2%) and unrelated targets (82% SD = 4%) when compared to the subordinate meaning targets (68% SD = 6%; as seen in Fig. 1). Unexpectedly, there was no significant difference between the dominant and unrelated targets. For the LE/RH, there was a marginal overall effect of semantic relationship type, $F(2, 35) = 2.91$, $p = 0.06$. As seen in Fig. 1, the unrelated trials were significantly less accurate (59% SD = 4%) than both the dominant meaning trials (68% SD = 5%) and the subordinate meaning trials (66% SD = 2%). Consistent with a priori predictions, there was no significant difference in accuracy between the dominant and subordinate meaning target words for LE/RH trials. In looking at these same data utilizing the traditional approach used in the dichotic domain, we first see a significant effect of ear of presentation for both the dominant trials, $F(1, 35) = 3.51$, $p < 0.01$ and the unrelated trials, $F(1, 35) = 6.28$, $p < 0.001$. These statistical analyses indicate that there is a clear right ear advantage (REA) for the dominant trials (RE: 80% vs. LE: 68%) and for the unrelated trials (RE: 82% vs. LE: 59%). While a nonsignificant effect for this same ear analysis is seen for subordinate trials, $F(1, 35) = 0.98$, $p = \text{ns}$. Thus, we lose this expected REA for the subordinate meaning trials (RE: 68% vs. LE: 66%).

1.2.2. Reaction time data

Unlike accuracy, the ear of presentation did not have an overall effect on the RT of the participants ($F(1, 35) = 0.71$, $p = \text{ns}$; RE/LH = 574 ms SD = 39, LE/RH = 642 ms SD = 45), so there was no general REA for the RT variable. There was also no main effect of semantic relationship type for RT ($F(2, 35) = 0.29$, $p = \text{ns}$), nor an interaction of ear of presentation and semantic relationship, $F(2, 35) = 0.13$, $p = \text{ns}$. Given our a priori predictions we went on to confirm that there was no difference in the response times across the target semantic levels for each hemisphere, and consistent with the outcome from the omnibus ANOVA we did not find a significant overall effect for the RE/LH ($F(2, 35) = 0.31$, $p = \text{ns}$) or the LE/RH ($F(2, 35) = 0.06$, $p = \text{ns}$). These findings indicate that the participants did not significantly differ in the response times to the dominant, subordinate, or unrelated meaning targets in either hemisphere.

1.3. Experiment 1 discussion

We sought to extend previous findings of hemispheric differences in ascertaining the meaning of semantically ambiguous words in the visual modality using

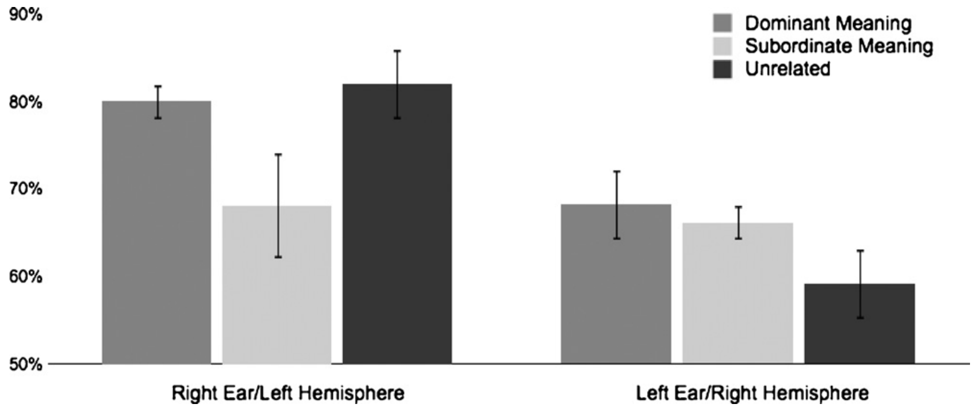

Fig. 1. Experiment 1 mean accuracies as a function of ear of target presentation and type of semantic relationship.

auditory stimuli. For the most part our findings correspond to past research in the visual domain. We found that the trials presented to the RE/LH resulted in a significant difference in accuracy when comparing the dominant and subordinate word meanings. The subordinate meaning was responded to less accurately than either the dominant meaning or unrelated words, suggesting that the LH had selected the dominant meaning and no longer maintained activation for the subordinate meaning of the ambiguous word. In contrast, the LE/RH trials showed a pattern of accuracy data that suggests that the RH is showing sustained access for both dominant and subordinate word meanings (with fewer errors in these two related conditions as compared to the unrelated trials). These findings are consistent with previous findings using visual stimuli of qualitative hemispheric differences in the processing of semantic ambiguity. These qualitative differences are consistent with a direct access interpretation of dichotic performance, and lend support for our argument that left and right ear performance reflect processing in right and left hemispheres, respectively. In considering these same findings, but utilizing the analysis techniques commonly used in dichotic listening studies, we find a very typical REA for both dominantly related and unrelated trials, while this REA is eliminated on subordinate target trials. One might expect to see an LEA on these trials, but this pattern is actually very difficult to obtain in a linguistic task. Instead it is more common to see evidence of effective right hemisphere activation as a reduction in the size or an elimination of the typical REA (see Grimshaw et al., 2003; Grimshaw, Seguin, & Godfrey, 2009 for a discussion of factors that influence the relative size of the REA).

It should be noted that two aspects of our data from Experiment 1 were unexpected. First, the accuracy for unrelated trials presented in the RE/LH was unexpectedly high. This enhanced performance was specific to the left hemisphere, and makes it difficult to claim that the right hemisphere *primes* the dominant meaning. Additionally, accuracy seemed to be the dependent variable that was most sensitive to both hemispheric differences in processing strategy and the influence of semantic relationship. However, it should be noted that there was a high level of variance in the RT data even with the elimination of participants that would contribute a relatively small number of trials to the means analyses (and thus be more influenced by relative outliers in RT). Experiment 2, which utilized a cross-modal paradigm (with visually presented primes and dichotically presented targets) allowed us to replicate our findings in Experiment 1 to determine if these two unexpected characteristics of the data are reliable and thus warrant further consideration.

2. Experiment 2

Experiment 1 provides evidence that the findings generally seen with visual DVF presentation can also be seen using a dichotic listening task. Thus, we have some evidence that hemispheric differences in semantic ambiguity resolution can be studied using spoken words. We next attempted to replicate these findings using a cross-modal presentation strategy (with visual prime presentation and the same dichotic target presentation as used in Experiment 1). By using cross-modal stimuli in the lexical decision task, we will extend our findings on hemispheric differences in semantic ambiguity using only auditory stimuli and we provide a replication using the more difficult modified lexical decision method developed for Experiment 1. This second experiment also allows us to determine if the unexpected findings of Experiment 1 prove reliable.

2.1. Methods

2.1.1. Participants

Forty-five undergraduate general psychology native English-speaking students who were strongly right-handed, and who had normal hearing and normal or corrected-to-normal vision took part for research credit.

2.1.2. Materials

The materials were the same as Experiment 1; the only difference being that the prime stimuli were presented visually. These visual primes were presented centrally on the computer screen in black letters on a white background.

2.1.3. Procedure

The modified lexical decision procedure was similar to the first experiment. Also as in Experiment 1 there were 10 practice trials presented, followed by a total of 120 experimental trials. The participants placed their chin on a chin rest, centered and placed 50 cm from the screen, preventing movement and keeping their eyes focused on the center of the screen. The participants first saw a fixation cross in the center of the screen and were instructed to focus on it. We then visually presented the prime word in place of the fixation cross, lasting for 500 ms, after which the fixation cross returned for 250 ms. This presentation strategy was used to mimic the timing of the auditory prime presentation and resulted in an SOA of 750 ms. After the prime word presentation, the participants heard the target pair dichotically, with one stimulus in each ear. They then responded whether they heard a word or not in either ear for the target pair using the same instructions as in Experiment 1. After responding, the next prime-target pair began, repeating the procedure until viewing each prime word. As with Experiment 1 the experiment took about 15 min to complete.

2.2. Results

Experiment 2 also had a 3 (strength of semantic relationship: dominant meaning, subordinate meaning, or unrelated) × 2 (ear of target presentation: left or right) within-participants factorial design. An analysis of variance (ANOVA) was conducted for the primary dependent variables, mean accuracy and mean RT. For all LSD planned analyses to be discussed, a $p < 0.05$ was used as the critical value of significance. Because the total accuracy scores were all above 50%, no data was excluded from the analysis, and again we included only those trials with a word in the target pair. As with Experiment 1, no additional measures were taken for reducing variance for either the accuracy or RT dependent variables.

2.2.1. Accuracy data

We analyzed accuracy scores across hemispheres, finding that the ear of target presentation significantly affected accuracy (F (1, 44) = 13.10, $p < 0.01$), indicating that the participants again showed a REA, and were more accurate when the stimulus presentation was in the RE/LH (85% SD = 3%) than in the LE/RH (76% SD = 5%). There was no main effect for the semantic relationship variable, F (2, 44) = 0.02, p = ns. The accuracy for targets across the three semantic relationship conditions was nearly numerically identical (dominant = 80% SD = 3%, subordinate = 81% SD = 3%, unrelated = 80% SD = 5%). There was, however, a statistically significant interaction of the semantic relationship variable and ear of presentation (F (2, 44) = 6.35, $p < 0.01$).

To investigate this significant interaction for accuracy, we again analyzed the accuracy data for each target semantic relationship level for each hemisphere. We found a significant difference in accuracy between the semantic conditions when presented to the RE/LH (F (2, 44) = 3.16, $p < 0.05$) and to the LE/RH (F (2, 44) = 3.00, $p < 0.05$). Comparing accuracies across the semantic relationship levels in the RE/LH trials we found that the participants were less accurate for the subordinate meaning targets (81% SD = 2%) than for the unrelated targets (88% SD = 4%) as seen in Fig. 2. Accuracy for the dominant meaning targets (84% SD = 1%) was between those for the subordinate and unrelated meaning targets and in planned comparisons was seen as marginally less accurate than the unrelated condition ($p = 0.05$), but significantly more accurate than the subordinate condition ($p < 0.01$). Thus, as in Experiment 1, we again see the unrelated condition being more accurate in the RE/LH trials than predicted. In the LE/RH trials the highest accuracy was in the subordinate meaning condition (80% SD = 3%), which was significantly more accurate than the unrelated condition (72% SD = 5%, $p < 0.05$) and marginally more accurate than the dominant meaning condition (76% SD = 3%, $p = 0.06$). The dominant meaning targets were not

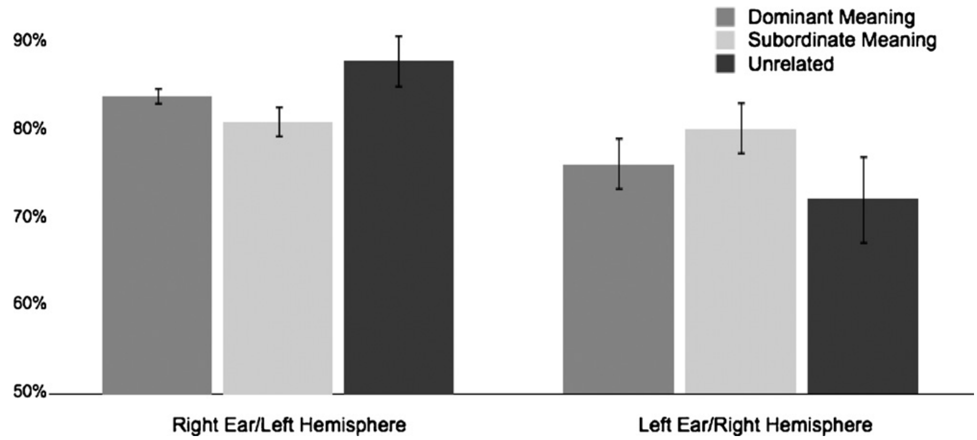

Fig. 2. Experiment 2 mean accuracies as a function of ear of target presentation and type of semantic relationship.

different from the unrelated targets, thus there was no relatedness advantage for targets related to the dominant meaning of the ambiguous word when these targets were presented to the LE/RH. In considering the REA patterns for Experiment 2, we found a pattern that was identical to Experiment 1. For the dominant ($F(1, 44) = 3.11$, $p < 0.05$) and unrelated trials ($F(1, 44) = 5.18$, $p < 0.001$) there was a significant effect of ear of presentation. Specifically there was a clear REA advantage for the dominant trials (RE: 84% vs. LE: 76%) and for the unrelated trials (RE: 88% vs. LE: 72%). In contrast there was no effect of ear of presentation when we looked at the subordinate trials, $F(1, 44) = 0.14$, p = ns. Again, there was no REA for the subordinate meaning trials (RE: 81% vs. LE: 80%).

2.2.2. Reaction time data

As in Experiment 1, we did not find a significant main effect ($F(1, 44) = 0.05$, p = ns) for ear of presentation for RT. There was however, a significant main effect in the Experiment 2 RTs for the three semantic relationship levels of the targets ($F(2, 44) = 3.01$, $p < 0.05$). The unrelated trials (626 ms SD = 21) generally resulted in a longer RT than either the dominant meaning targets (580 ms SD = 18) or the subordinate meaning targets (573 ms SD = 20). This effect was qualified by a significant interaction of ear of presentation and semantic relationship ($F(2, 44) = 4.45$, $p < 0.05$). This interaction seems to be driven by differences in RT between ear for the dominant ($F(1, 44) = 35.20$, $p < 0.001$) and subordinate meaning targets ($F(1, 44) = 12.50$, $p < 0.001$). As illustrated in Fig. 3, for the RE/LH trials the dominant targets (552 ms SD = 20) were faster than the unrelated targets (623 ms SD = 23). The subordinate meaning targets (594 ms SD = 25) were not significantly faster than the unrelated targets, nor were they significantly slower than dominant targets. For the LE/RH targets it was the subordinate meanings (551 ms SD = 15) that were reliably faster than the unrelated targets (630 ms SD = 18), while the dominant meanings (609 ms SD = 16) were only marginally faster than the unrelated targets ($p = 0.09$). For clarification of this inconclusive pattern the dominant and subordinate target conditions were compared for the LE/RH trials and these conditions were not reliably different (p = ns).

The pattern of ear advantage for the RT variable in Experiment 2 also provides some additional clarification that aids in our interpretation of this cross-modal study. As with most of the comparisons in both Experiments 1 and 2, there was a clear REA advantage for the dominant trials (RE: 552 ms vs. LE: 609 ms, $F(1, 44) = 4.33$, $p < 0.01$). However, there was no difference between the LE and RE trials for the unrelated condition (RE: 622 ms vs. LE: 630 ms, $F(1, 44) = 1.05$, p = ns). Finally, for the subordinate meaning trials there was the highly uncommon outcome of a left ear advantage (LEA) observed (RE: 594 ms vs. LE: 552 ms, $F(1, 44) = 3.04$, $p < 0.05$).

2.3. Experiment 2 discussion

As with Experiment 1, we wanted to extend previous findings of hemispheric differences in semantic ambiguity resolution using auditory target presentation. Experiment 2 employed visually presented primes and dichotic targets, making it a cross-modal hybrid of the DVF and dichotic methods. Our results were again proven to be generally similar to previous findings using visual primes and DVF target presentation. First, it should be noted that when using cross-modal presentation there was a significant interaction between ear of presentation and semantic relationship level for both RT and accuracy dependent variables. This indicates that RT can act as an informative dependent variable in conjunction with dichotic presentation, thus providing evidence that this possible concern raised in Experiment 1 was likely due to high levels of variance in the RT data for our first experiment that were not seen with this cross-modal task. Overall accuracy was higher in this cross-modal study, which both allows for the retention of more participant data for final analysis and allows more trials to be included in the RT analyses. These outcomes likely explain this difference in the effectiveness of the RT variable between Experiments 1 and 2. In fact, the magnitude of the ear advantages is similar in Experiments 1 and 2, but Experiment 1 simply has higher variance. It is possible that providing more practice in the purely auditory paradigm might improve overall accuracy and, thus, allow RT to be a more effective or responsive dependent measure.

In looking at the qualitatively different patterns of semantic access seen in the LE and RE data it is clear that, as in Experiment 1, the two hemispheres seem to employ quite different strategies. For the RE/LH trials, the two dependent measures provide a slightly different, but converging pattern. Specifically, in comparing the data from the dominant and subordinate trials with RE/LH presentation there is evidence for both faster access to the dominant meaning of the ambiguous word and lower accuracy when participants were asked to identify the subordinate meaning as an English word. Furthermore, the RTs for unrelated trials were slower, as would be expected from priming patterns typically seen in DVF studies. However, as seen in Experiment 1, the unrelated trials presented to the RE/LH are again strikingly accurate. In fact the unrelated condition is numerically the most accurate condition in both studies. One might suggest that this outcome is in some ways a reflection of the modified lexical decision paradigm employed here, or reflects a speed-accuracy trade-off. Yet, this explanation seems less satisfying given that results for the unrelated LE/RH trials are showing a pattern that is exactly as predicted, with these unrelated trials being the slowest in Experiment 2 and least accurate in both experiments. Although we cannot account for the good performance on unrelated items presented to the LH, we note that negative priming effects specific to the LH have been previously reported in dichotic listening studies. Specifically, Saetrevik and Hugdahl (2007) describe an identity-priming experiment with a binaurally presented CV prime, followed by a dichotic CV pair which participants verbally reported. They found decreased accuracy for reporting the right ear target when it matched the prime, but increased accuracy for reporting the left ear target under the same conditions. Similar (but attenuated) effects were observed with a visual prime. They interpret this finding in terms of a speech-specific inhibitory mechanism that operates within the left hemisphere to facilitate parsing of the speech signal. It is unlikely that priming did not occur for the dominant targets in the RE/LH, which suggests that the SOA may have been too long to capture facilitated semantic access of the dominant meanings in the RE/LH. The accuracy data in both experiments also suggest that inhibition of subordinately related words persists longer than does the facilitation effect for dominant meanings.

There is some convergence and some divergence between the two experiments in the patterns of semantic access that occurs for the LE/RH trials. In Experiment 1 we see the expected pattern of no difference in semantic access for the two meanings of the ambiguous word, such that the dominant and subordinate word meanings are responded to with equal accuracy. For the RT data in Experiment 2 this was also the outcome such that dominant and subordinate trials had comparable RTs when stimuli were presented to the LE. The LE/RH accuracy data was less expected in that there was a marginal accuracy advantage for subordinate trials as compared to dominant trials. Also, for Experiment 2, there is reliable evidence of a relatedness advantage (comparing the related and unrelated conditions) only for the subordinate meaning targets. There is a trend towards a relatedness advantage in RT for the dominant meaning targets, but not in accuracies. In fact, the facilitation obtained for the subordinately related targets is so pronounced in the LE/RH trials that we actually see an overall LEA for the response times. As illustrated in Figs. 2 and 3, there is definitely no evidence that the RH is inhibiting the dominant meaning of the ambiguous word; the dominant condition is always numerically faster and more accurate than the unrelated condition. But the greatest relatedness advantage is clearly for the subordinate meaning of the word, which would be consistent with the idea that the RH works to maintain access to this alternative meaning so that it could potentially be incorporated into the ongoing discourse if needed (Atchley et al., 1999; Beeman et al., 1994; Jung-Beeman, 2005).

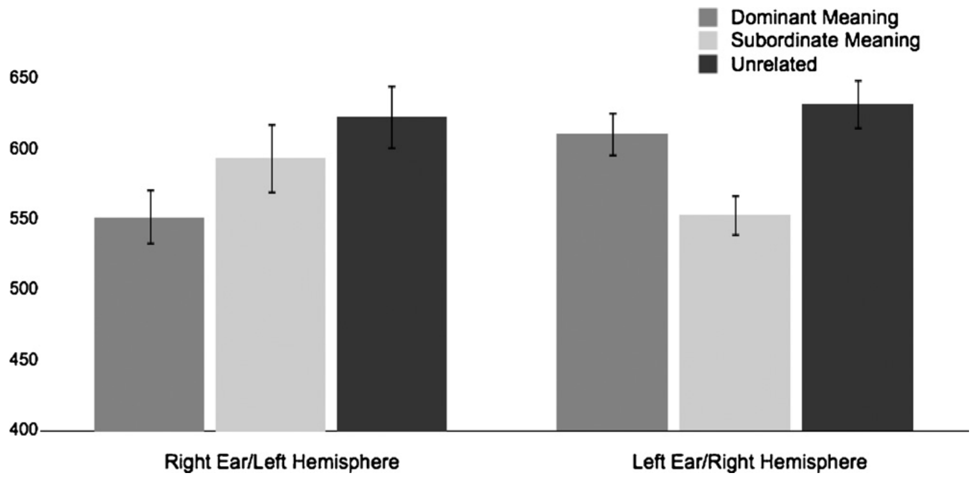

Fig. 3. Experiment 2 mean reaction times as a function of ear of target presentation and type of semantic relationship.

3. General conclusions

The results of the two experiments presented here correspond to previous findings in the DVF literature that the cerebral hemispheres differ in patterns of semantic access for ambiguous words. The use of dichotic presentation and the modified lexical decision task provides evidence that semantic processing strategies employed by the two hemispheres are similar across modalities. This finding is of theoretical import because it suggests that despite the range of differences between speech and text, such as their evolutionary origins, sensory codes, and functional–neuroanatomical underpinnings, there is behavioral convergence with regards to how lateralized semantic processes contribute to later stages of meaning comprehension with little impact of the code used to convey the linguistic message.

The prediction that participants would show an advantage in processing the dominantly related target words over the subordinately related target words in the LH was supported by the observed data. The accuracy data for both experiments also provide possible evidence of inhibition of subordinately related words when presented to the RE/LH (as compared to unrelated trials), which supports previously proposed theories of semantic selection strategies in the LH (Atchley et al., 1999; Beeman et al., 1994; Burgess & Simpson, 1988; Chiarello, 1998, 2003). The RT data in Experiment 2 does show evidence of faster semantic processing of dominant words in the LH, which is also consistent with these earlier findings. While the accuracy results in both studies did not show evidence of facilitated semantic processing of the dominant meanings in the LH, responses to the dominant meanings were significantly more accurate than to the subordinate meanings in both experiments. It is quite possible that the use of a shorter SOA would capture the priming effects of the dominant meanings in the LH in either one or both dependent variables. These speculations warrant further investigation through a study of auditory ambiguity resolution across a range of SOAs.

The findings for stimuli presented to the LE/RH are also generally consistent with previous research proposing that the RH maintains access to both strongly and weakly related associates during semantic processing of ambiguous words. Accuracy data in Experiment 1 correspond precisely with predictions and prior research (Atchley et al., 1999; Beeman et al., 1994; Burgess & Simpson, 1988; Chiarello, 1998, 2003), in that dominant and subordinate meanings were responded to more accurately than unrelated words. In Experiment 2, the subordinate meanings showed an unexpected advantage over dominant meanings in both accuracy and RT in the LE/RH. This subordinate advantage was so pronounced that we even saw a rare example of a LEA for the subordinate targets; LE/RH presentation was better then RE/LH presentation in a purely linguistic task. This is a somewhat surprising finding considering previous DVF research that shows equal levels of access for both dominant and subordinate associates. However, we are aware of two studies in the laterality literature where this general priming pattern has been found (Meyer & Peterson, 2000; Titone, 1998, Exp 3). Both studies were sentence priming studies and the Titone study is a particularly good parallel because it also utilized a cross-modal paradigm, though in her study the primes were auditorally presented and the targets were text. Thus, this pattern of a subordinate advantage in the RH has been seen before and is consistent with the theory that the RH's role is to maintain varied information, including features that are less compatible with the dominant representation (Beeman, 1993; Jung-Beeman, 2005). Maintaining a wide-range of information allows the listener to rapidly reevaluate a linguistic stimulus in the presence of a comprehension error caused by ambiguity (Atchley et al., 1999; Atchley & Kwasny, 2003; Beeman, 1993). Again, it would be interesting to conduct a similar study with varied SOAs in order to get a better idea of the time course of semantic access in the RH when using auditory stimuli.

The outcome of these two experiments indicates that dichotic presentation can be used to study differences in semantic access between the cerebral hemispheres, and that these data are comparable to results obtained using a DVF presentation. This is an important finding because one might be concerned that the strong REA seen in linguistic studies might wash out any influence that the RH may have on behavioral responses provided in semantic judgment tasks. This is clearly not the case and in fact we even see evidence of an LEA in the current study. Also there was reason to be concerned that we would not find strong evidence of RH contributions to meaning processing because of the need for phonological decoding that underlies speech comprehension. Considerable research from commissurotomy patients, DVF, neuroimaging and dichotic techniques provides evidence that the RH is less able to carry out phonological processing such as phonetic decoding and phoneme-to-grapheme translation (Beaton, Suller, & Workman, 2007; Chiarello, 1985; Kraemer & Zenhausern, 1993; Lavidor & Ellis, 2003; Lindell & Lum, 2008; Schweiger, Zaidel, Field, & Dobkin, 1989; Zaidel & Peters, 1981). It must be noted, however, that other researchers have argued that the RH can show evidence of activation of phonological codes and that evidence seen to date of a LH superiority may reflect its privileged role in articulatory rehearsal (Chiarello, Hasbrooke, & Maxfield, 1999) or may be dependent on the kind of phonological category studied

(Smolka & Eviatar, 2006). Although in our current task we do not specifically test for RH phonological competence, we do see evidence that responses to RE/LH and LE/RH speech stimuli can lead to nearly identical response times in a lexical task. In fact, we see no evidence of a reliable main effect for reaction time for ear of presentation in either of our experiments. Therefore, if there is a LH superiority for phonological processing we do not see the influence of this hemispheric processing asymmetry in the current studies which are believed to look at the lateral stages of lexical/semantic processing.

In returning to the theoretically important argument that dichotic listening gives rise to hemispheric asymmetry effects through a mechanism of callosal relay (Zaidel et al., 1990), we find a cross-over interaction between ear and the word meaning variable. We find that for dominant targets there is a strong REA and for subordinate targets there is a strong LEA. This is the kind of qualitatively different pattern of responses across ear that parallels other studies that have used words instead of nonsense syllables as stimuli and have found clear evidence of a direct access model of dichotic listening (Ely et al., 1989; Grimshaw et al., 2003). In particular, the finding of a LEA for subordinate word meanings with the RT variable argues that we are seeing strong evidence of the RH playing a direct role in semantic comprehension.

Regarding the methodological advances offered by the current research, conducting laterality research using the DVF paradigm can be quite challenging. The participant is instructed to focus on a fixation point in the middle of the screen while the target stimuli appear to the right and/or left of the fixation point. One of the primary obstacles when using this method is trying to minimize eye-movements by the participant. If the participant moves their eyes in an attempt to focus centrally on the target stimuli, the attempt to lateralize the stimulus is negated. While there are certain techniques to minimize eye-movement, from rapid presentation to offset masking (Young, Atchley, & Atchley, 2009), it remains a complication in DVF studies. Fortunately, a dichotic listening paradigm is a means to overcoming this problem and thus may become a more popular technique for such laterality studies in the future.

Another advantage of a dichotic methodology for the assessment of hemispheric differences in ambiguity resolution is that the speech signal is by its nature much richer than text. Speech carries intonation and stress that have both connotative and denotative meaning, and that may well play an important role in semantic disambiguation. For example, emotional prosody may play a role in lexical and semantic processing of emotional (and emotionally ambiguous) words (Nygaard and Lunders, 2002; Nygaard and Queen, 2008). Given that processing of emotional prosody is specialized to the right hemisphere (Bryden and MacRae, 1989; Grimshaw et al., 2003, 2009), it is possible that there are hemispheric differences in the mechanisms of linguistic-prosodic integration. The dichotic methodology developed here could easily be adapted to include manipulations of emotional prosody. The paradigm could then be a powerful tool for examining interactions among lexical, semantic, and prosodic processes in speech perception.

The pattern of results seen across the two experiments presented here is consistent with the current theory (Atchley et al., 1999; Beeman et al., 1994; Burgess & Simpson, 1988; Chiarello, 1998, 2003) that the RH maintains all meanings of an ambiguous word, allowing faster access to all the alternative meanings of lexically ambiguous words during discourse comprehension. Thus, overall, we have shown similar findings using auditory stimuli in the lexical decision task that are comparable to the results obtained using visual stimuli. This indicates that lateralized semantic processing strategies are evident regardless of how the linguistic stimuli are communicated.

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