BRAIN RESEARCH

Research Report

A special role for the right hemisphere in metaphor comprehension? ERP evidence from hemifield presentation

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ABSTRACT

It has been suggested that the right hemisphere (RH) has a privileged role in the processing of figurative language, including metaphors, idioms, and verbal humor. Previous experiments using hemifield visual presentation combined with human electrophysiology support the idea that the RH plays a special role in joke comprehension. The current study examines metaphoric language. Event-related potentials (ERPs) were recorded as healthy adults read English sentences that ended predictably (High-cloze Literals), or with a plausible but unexpected word (Low-cloze Literals and Low-cloze Metaphoricals). Sentence final words were presented in either the left or the right visual hemifield. Relative to High-cloze Literals, Low-cloze Literals elicited a larger N400 component after presentation to both the left and the right hemifield. Low-cloze Literals also elicited a larger frontal positivity following the N400, but only with presentation to the right hemifield (left hemisphere). These data suggest both cerebral hemispheres can benefit from supportive sentence context, but may suggest an important role for anterior regions of the left hemisphere in the selection of semantic information in the face of competing alternatives. Relative to Low-cloze Literals, Low-cloze Metaphoricals elicited more negative ERPs during the timeframe of the N400 and afterwards. However, ERP metaphoricity effects were very similar across hemifields, suggesting that the integration of metaphoric meanings was similarly taxing for the two hemispheres, contrary to the predictions of the right hemisphere theory of metaphor.

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1. Introduction

Metaphoric language involves reference to one domain, known as the *target* or *tenor*, with vocabulary commonly used to refer to another domain, known as the *source* or *vehicle* (Coulson and Oakley, 2005). For example, "winter" in the opening lines of Shakespeare's Richard III ("Now is the winter of our discontent") is used to evoke the concept of finality. Understanding this metaphor involves recruitment of an analogy between the source domain of the seasons of the year and the target domain of a period of discontent in Richard's life. In this analogy, spring maps onto a beginning, and winter maps onto an ending. Thus if Richard is in the winter of his discontent, bad times are soon to be a thing of the

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past. The underlying processes of metaphor comprehension are relevant for an understanding of the neural basis of verbal creativity.

Although metaphor is most obvious in literary venues, linguists have also shown that it is pervasive in everyday language. Average speakers use metaphors to talk about a wide range of subjects, including emotions such as anger and love, abstract concepts such as time and progress, and taboo topics such as sex and death (Lakoff and Johnson, 1980; Turner, 1987). Metaphor is a basic means of extending existing word meanings, and is a major factor affecting the way that languages change over time (Sweetser, 1990). For example, since the late 1990s the word "spider" is used to refer to a computer program (also known as a "webcrawler") that searches the web for new sites and links them to search engines. Over time, metaphoric uses can become so entrenched that speakers no longer recognize them as metaphoric (e.g. "leg" in "table leg"). One study of the frequency of metaphor in spoken language found that, on average, speakers utter 4.08 of these "frozen" metaphors, and 1.80 novel metaphors per minute of discourse (Pollio et al., 1977).

1.1. Right hemisphere metaphor theory

Most neuropsychologists consider metaphor comprehension to be somewhat distinct from other language abilities and, consequently, have hypothesized that it recruits distinct brain regions, stressing an important role for the right hemisphere (RH). For example, metaphor comprehension dissociates from other language skills in patient populations such as schizophrenia, Asperger's syndrome, and Alzheimer's disease, consistent with its characterization as an "extra-linguistic" skill (DeBonis et al., 1997; Dennis et al., 2001; Papagno, 2001; Rapp et al., 2004). In keeping with the idea that the RH plays an important role in this process, these cases of impaired metaphor comprehension have been linked to irregular lateralization patterns often observed with pathologies such as schizophrenia.

More important for the motivation of the right hemisphere metaphor theory are a number of patient studies which suggest that focal lesions in the left and right hemisphere have different effects on a patient's ability to comprehend metaphorical language. Some left hemisphere-damaged (LHD) patients have shown preserved appreciation for metaphoric meanings of adjectives (e.g. cold), while right hemisphere-damaged (RHD) patients preferred the literal meanings for the same terms (Brownell, 1984, 1988). Unlike their LHD aphasic counterparts, basic language production and comprehension skills are intact in most RHD patients, yet their interpretation of idioms is often characterized as being overly literal (Van Lancker and Kempler, 1987; Winner and Gardner, 1977).

The contrast between the detrimental impact of LHD on core language skills such as naming, word-finding, parsing, and sentence comprehension, and the relatively subtle communicative deficits experienced by patients with RHD has led to the suggestion that the left hemisphere mediates basic language skills, while the right hemisphere is implicated in *pragmatics*, or aspects of meaning that depend on an understanding of the physical, social, or cultural context of an utterance. Indeed, RHD patients have been shown to exhibit deficits in a variety of pragmatic abilities, including

joke comprehension (Bihrle et al., 1986; Brownell et al., 1983; Shammi and Stuss, 1999), the production and interpretation of indirect requests (Brownell and Stringfellow, 1999; Foldi, 1987; Stemmer et al., 1994), and the recognition of sarcastic utterances (Kaplan et al., 1990).

The right hemisphere theory of metaphor comprehension is appealing because of the way that it fits into this larger picture of the division of labor in the brain, with the LH specializing in strictly linguistic aspects of meaning, while the RH is assigned to non-literal meaning that presumably includes metaphor. The importance of the RH has been bolstered by an influential positron emission tomography (PET) study that revealed increased RH blood flow in prefrontal cortex, the middle temporal gyrus, the precuneus, and the posterior cingulate in the comprehension of metaphoric sentences relative to literal sentences with the same structure (Bottini et al., 1994). We describe the hemodynamic literature on metaphor comprehension more extensively in Discussion.

1.2. Hemifield priming and hemispheric differences in semantic activation

A technique that has been used to investigate the role of the right hemisphere in neurologically intact individuals is the visual hemifield priming paradigm. By presenting stimuli outside the fovea, it is possible to selectively stimulate visual cortex in the left or right hemisphere. In normal individuals the information is rapidly transmitted to other brain regions, including those in the other hemisphere. Nonetheless, differences in the initial stages of processing can indicate hemisphere-specific computations (Banich, 2002; Chiarello, 1991). Although lexical decision latencies are typically shorter when stimuli are presented to the right visual field (RVF/LH), priming effects, that is, greater accuracy rates and shorter response times for words preceded by related compared to unrelated material, are sometimes greater with presentation to the left visual field (LVF/RH) (Chiarello, 1988).

The hemifield priming literature points to hemispheric differences in the specificity of semantic activations, in that those in the right hemisphere are less specific than those in the left. For example, in a task of generating a semantic associate for a laterally presented word, Rodel and colleagues observed closely related responses for LVF cues, but more distant associates (according to normative association data from central presentation) after RVF cues (Rodel et al., 1989). In word-pair priming studies, most investigators using hemifield presentation report equivalent priming for strongly associated word pairs ("dog–cat") with LVF and RVF presentation, but greater priming effects with presentation to the LVF (RH) for nonassociated category members ("dog–goat") (Chiarello et al., 1990). When ambiguous words serve as the primes, only LVF (RH) presentation yields priming effects for the subordinate and contextually irrelevant senses of ambiguous words, especially when relatively long stimulus onset asynchronies (greater than 200 ms) are obtained between the prime and the target (Burgess and Simpson, 1988; Faust and Chiarello, 1998; Titone, 1998). Finally, people benefit more from so-called summation primes (three words weakly related to a target) when naming target words presented to the LVF (RH) than the RVF (LH) (Beeman et al., 1994).

These observations have led to the suggestion that semantic representations in the LH are coded 'finely', while those in the RH are coded 'coarsely' (Jung-Beeman, 2005), and further that it is these hemispheric differences in semantic activation that lead to the very different functional consequences of focal lesions in the left versus the right hemisphere (Beeman and Chiarello, 1998). Indeed, Beeman and colleagues explicitly link RHD patients' impaired comprehension of metaphor to failure to activate metaphor-relevant information, speculating that while information activated by the LH is usually adequate to connect discourse elements, information activated in the RH can be crucial for connecting distantly related elements in figurative language (Beeman, 1993).

1.3. Hemifield priming and metaphor comprehension

Although the results reviewed thus far appear to build a coherent picture of right greater than left hemisphere involvement in metaphor processing, use of the hemifield priming paradigm has yielded mixed findings on hemispheric asymmetries in metaphor comprehension (see Kacinik and Chiarello, 2007 for review). In the first such study, Anaki and colleagues had healthy adult participants read centrally presented words with literal and metaphoric meanings, and then make lexical decisions to target words presented peripherally (Anaki et al., 1998). If the prime was "stinging", for example, the target might be a word (such as "bee") related to the literal meaning of the prime, or a word (such as "insult") related to the prime's metaphorical meaning. When the stimulus onset asynchrony (SOA) was short (200 ms), both meanings were primed with RVF presentation, but only the metaphoric meaning was primed with LVF presentation. When the SOA was long enough to index-controlled processes (800 ms), only the literal meaning was primed with RVF presentation, and only the metaphorical meaning was primed with LVF presentation. Anaki and colleagues argued that these findings suggest metaphoric meanings are initially activated in both cerebral hemispheres, but decay rapidly in the LH, while being maintained in the RH.

Unfortunately, subsequent attempts to replicate results reported by Anaki and colleagues have failed. Using English materials, Kacinik found literal (stinging BEE) and metaphoric (stinging INSULT) priming with RVF/LH presentation at short SOAs, but only literal priming with an 800 ms SOA. With LVF/RH presentation, literal priming was observed at SOAs of 100, 200, and 800 ms, while metaphor priming was evident only in accuracy scores, suggesting the activation of the metaphoric meaning in the RH was weak, at best (Kacinik, 2003). Further, hemifield priming studies using sentential stimuli have revealed priming for both literal and metaphorical meanings with presentation to both visual fields (Kacinik and Chiarello, 2007), and even shown more pronounced metaphor priming with presentation to the RVF (Faust and Weisper, 2000).

1.4. Event-related brain potentials (ERPs) and metaphor comprehension

One ERP component of particular utility to researchers working on meaning is the N400, a negative-going wave that peaks approximately 400 ms after the presentation of a meaningful stimulus. The N400 was first noted in experiments contrasting sentences that ended sensibly and predictably with others that ended with an incongruous word. Congruous words elicited a late positive wave, while incongruous endings elicited a negative wave beginning about 200 ms after the stimulus was presented and peaking at 400 ms post-stimulus (Kutas and Hillyard, 1980). Subsequent research indicated that N400 is elicited by all words, written, spoken, or signed, and that N400 amplitude is reduced by both prior semantic context and lexical factors (e.g., high frequency of usage) that reduce processing difficulty (see Kutas et al., 2007 for recent review).

Taking advantage of this well-known property of the N400, Pynte and colleagues contrasted ERPs to familiar and unfamiliar metaphors in supportive versus irrelevant contexts. They found that regardless of the familiarity of the metaphors, N400 amplitude was a function of the relevance of the context, just as for literal sentences (Pynte et al., 1996).

Other studies have found that metaphoric statements elicit larger N400s than literal statements, indicating that comprehension of metaphor is more difficult. For instance, Kazmerski and colleagues compared literal statements, metaphors, and scrambled metaphors that were anomalous under any reading (Kazmerski et al., 2003). In participants with both high and average scores on a standardized intelligence test, the N400 elicited by the final words of metaphoric sentences was larger than to literal words, but smaller than the anomalous controls. In low-IQ participants, the metaphor N400 was equivalent to that of the anomalous condition (both larger than literal), suggesting that these individuals had insufficient processing resources for immediate comprehension of metaphor, but that literal statements were easier in some sense.

We have observed larger amplitude N400s for metaphoric than literal words when materials have been carefully controlled for lexical factors such as word length and frequency, and the extent to which the sentence context promotes a particular meaning. We compared ERPs elicited by words in three different contexts on a continuum from literal to figurative (Coulson and Van Petten, 2002). At the literal end of the continuum were sentences that promoted a literal reading of the last term, as in "He knows that whiskey is a strong intoxicant." At the metaphoric end of the continuum were sentences such as "He knows that power is a strong intoxicant." Between these extremes was a literal-mapping condition, as in "He has used cough syrup as an intoxicant." Literal-mapping stimuli involved fully literal uses of words in ways that were hypothesized to include some of the same conceptual operations as in metaphor comprehension. These sentences described cases where one object was substituted for another, one object was mistaken for another, or one object was used to represent another. Like metaphoric language, these contexts require an understanding of a mapping between the two objects in question, as well as the domains in which they typically occur. Although the three sentence types were matched on an offline measure of the predictability of the final word (cloze probability), N400s showed a gradient of amplitude: metaphor largest, literal smallest, and literal-mapping intermediate. The graded N400 difference argues against a literal/figurative dichotomy, and instead suggests that processing difficulty associated with figurative

language is related to the complexity of the underlying mapping and integration operations.

All three studies indicate that metaphoric language is quantitatively more difficult to process than literal language, but also suggest continuity between the two. All observed much the same scalp topography and timing of the ERPs elicited by literal and metaphoric words, with no indication of differential hemispheric asymmetry (Coulson and Van Petten, 2002; Kazmerski et al., 2003; Pynte et al., 1996). ERP studies to date have thus not provided support for the "right hemisphere theory of metaphor comprehension".

However, it is important to note that extant data suggests a largely left-hemisphere source for the scalp-recorded N400 when stimuli are equally accessible to the two hemispheres, as for auditory presentation or foveal visual presentation (see Van Petten and Luka, 2006 for review). It may be more generally the case that left-hemisphere processing dominates right-hemisphere processing under these circumstances, so that the foveal presentation method might not provide the best view of how the right hemisphere operates. Even with literal language and foveal or auditory presentation, the existing results suggest a modest right-hemisphere contribution to the N400, and modest reductions after damage to the right hemisphere (Hagoort et al., 1996; Kotz et al., 1999; Swaab et al., 1997; Van Petten and Luka, 2006). In the present study, we maximize the possibility of observing right-hemisphere processing via hemifield presentation.

1.5. The present study

Given the equivocal nature of the evidence for the right hemisphere metaphor theory, the goal of the present study was to assess this idea via a combination of the hemifield priming paradigm with ERP methodology. ERPs were recorded as participants read sentences that ended with a laterally presented word used in either its literal or its metaphorical sense. The assumption is that hemifield presentation shifts the balance of processing in a way that accentuates the impact of semantic activations in the hemisphere contralateral to the presentation side. That is, early visual processing differences result in greater than normal semantic activation in the contralateral hemisphere, and less than normal semantic activation in the ipsilateral hemisphere.

ERPs provide a continuous measure of word processing that is sensitive to lateralized brain activity over the different stages of processing. Although exact localization of the neural generators of ERP effects is not possible from scalp-recorded data alone, a laterally asymmetric response over the scalp is strongly indicative of an underlying hemispheric asymmetry. The temporal resolution of the ERP signal allows one to draw inferences about the duration of effects of hemifield presentation, such as whether they are confined to early stages of visual processing, or whether they extend into the window of semantic processing. The use of ERPs in conjunction with hemifield presentation also allows one to evaluate whether semantic processing occurs in the LH irrespective of presentation side via callosal transfer from the RH to the LH. In such a case, we would expect hemifield presentation to affect the latency of ERP effects, but not their size or scalp topography.

In this paradigm, as in the behavioral hemifield priming literature, hemispheric differences are signaled by interactions between presentation side and ERP effects of linguistic variables such as metaphoricity. Hemifield presentation is assumed to result in greater than normal lateralization of semantic activation in the brain. If hemispheric differences in semantic activation affect metaphor comprehension, presentation side would be expected either to facilitate the lexical integration of metaphoric language or to make it more difficult. The difficulty of resultant semantic processing is indexed by the amplitude of the N400 component in the ERPs, thus removing the need for the subject to make an explicit meta-linguistic decision on the word of interest. RH linguistic competence is often obscured by such behavioral measures, due to LH superiority in categorical decisions or other components of the behavioral rather than the comprehension task.

A similar method has been used to evaluate hemispheric differences in sensitivity to category membership, lexical association, and sentence constraint (Coulson et al., 2005; Federmeier and Kutas, 1999, 2005). Closer to the current topic, prior work has addressed the role of hemispheric asymmetry in the comprehension of jokes, another pragmatic phenomenon impaired in patients with RHD (Coulson and Williams, 2005). Coulson and Williams (2005) evaluated the brain response to laterally presented "punch words" to one-line jokes, such as "A replacement player hit a home run with my girl/ball" and found that joke endings elicited a larger N400 than nonjoke endings after presentation to the RVF (LH), but not the LVF (RH). This finding suggests that jokes were more difficult to process than nonfunny endings for the LH but not the RH, and is consistent with the suggestion that semantic activations in the RH facilitate joke comprehension.

Further, Coulson and Wu (2005) recorded ERPs as neurologically intact adults read lateralized probe words (e.g. "crazy") preceded either by jokes or nonfunny control sentences (e.g., "Everyone had so much fun jumping into the swimming pool we decided to put in a little water/platform"). Because probes were related to the jokes, but not to the control sentences, they were predicted to elicit less negative N400 after the jokes than the nonfunny controls. Indeed, this joke-related N400 priming effect was observed with presentation to both hemifields, and was larger with presentation to the LVF (RH), suggesting that joke-related information was more 'primed' in the RH than the LH (Coulson and Wu, 2005). Thus when the amplitude of the N400 effect indexed the difficulty of joke comprehension itself, LVF (RH) presentation resulted in a smaller effect than did RVF (LH) presentation, suggesting joke comprehension was easier with LVF (RH) presentation. When the amplitude of the N400 effect indexed the degree of priming for joke-relevant information, LVF (RH) presentation resulted in a larger effect than did RVF (LH) presentation. The latter finding argues against the skeptical response that small N400 effects with LVF presentation result from a general lack of sensitivity to semantic context, suggesting instead that the RH-initiated response is particularly tuned to certain sorts of semantic information.

In the present study, participants read centrally presented sentence contexts that promoted either a literal or a metaphorical meaning of the sentence-final word, which was

presented in either the left or the right visual field. As in our prior study of metaphor comprehension (Coulson and Van Petten, 2002), across stimulus lists each sentence final word occurred twice, once in a literal and once in a metaphorical context (see Table 1 for example stimuli). Literal and metaphorical sentence contexts were matched for number of words, and perhaps more importantly, for the extent to which they led participants to predict sentence final words. To evaluate how lateralized presentation affected participants' processing of fairly complex sentence materials, we asked them to perform three tasks (see Fig. 1). The first was simply to read each sentence one word at a time, and to use their

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Table 1 – Sample stimuli

Lists 1 and 2
High cloze
Sentence   Cars don't last long in the snow belt because the combination of salt and wet makes them rust.
Question   The cold air in the snow belt prevents rust. (T/F)
Sentence   When he stepped into the elevator, he knew Jennifer had just been there by the smell of her perfume.
Question   He saw Jennifer in the elevator. (T/F)

Literal
Sentence   They ended the year with a huge party that everyone remembered as the orgy.
Question   There had been a wild party that year. (T/F)
Sentence   I definitely consider eyeliner to be a cosmetic.
Question   Eyeliner is a kind of makeup. (T/F)

Metaphor
Sentence   That guy thinks the national concern with pollution is hypochondria.
Question   That guy is very concerned about pollution. (T/F)
Sentence   As she spoke, her words were in italics.
Question   She emphasized her words. (T/F)

Lists 3 and 4
High cloze
Sentence   Cars don't last long in the snow belt because the combination of salt and wet makes them rust.
Question   The cold air in the snow belt prevents rust. (T/F)
Sentence   When he stepped into the elevator, he knew Jennifer had just been there by the smell of her perfume.
Question   He saw Jennifer in the elevator. (T/F)

Literal
Sentence   The doctor told him his headaches were due to hypochondria.
Question   The doctor suspected he had a grave illness. (T/F)
Sentence   The editor said that words about to be defined should occur in italics.
Question   The editor had certain rules about when to use italicized type. (T/F)

Metaphorical
Sentence   Unfortunately, what started as mere flirtation with the stock market has become an orgy.
Question   There had recently been a marked increase in stock market activity. (T/F)
Sentence   I've discovered that happiness is an incredible cosmetic.
Question   People look better when they're happy. (T/F)

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peripheral vision to read the last word. About 2.5 s after the presentation of the last word, a prompt appeared and participants were asked to report the laterally presented word or say "didn't see" if they were unable to see or read it. After the delayed naming task, participants were given a true/false comprehension question and asked to respond via a button press.

As in our similarly motivated study of hemispheric asymmetry in joke comprehension (Coulson and Williams, 2005), we reasoned that if hemispheric differences in semantic activation are important for metaphor comprehension in neurologically intact participants, lateral presentation should modulate the size of the N400 amplitude difference between literal and metaphoric uses of the same word in closely matched sentence contexts. If the right hemisphere makes a unique contribution to metaphor comprehension, it could be detected in at least three ways in our paradigm. Accuracy in naming the final words is expected to be lower after LVF than RVF presentation, but the hemifield difference may be smaller for metaphoric than literal words. Second, while literal meanings are also expected to exhibit an RVF advantage in accuracy on the comprehension task, metaphorical meanings might exhibit a left visual field advantage. Finally, if right hemisphere language competence involves broader semantic activation that facilitates metaphor comprehension, we should expect to see a smaller effect of metaphoricity on the N400 component with presentation to the LVF.

2. Results

2.1. Naming lateralized words

Overall, participants correctly named an average of 82% of the sentence final words. The vast majority of naming errors involved participants' saying "didn't see", although participants occasionally produced either a high-cloze completion or a word with the same first syllable as the correct one. Naming scores were analyzed with repeated measures ANOVA with factors sentence type (high-cloze literal, low-cloze literal, and metaphor) and presentation side (left versus right visual field). The last words of high-cloze sentences were named more accurately (96% correct) than either the low-cloze literal (78% correct) or metaphorical (71% correct), resulting in a main effect of Sentence Type [$F(2,38)=96.2$, $p<.0001$, $\varepsilon=.67$]. Words presented to the right visual field were named more accurately (90% correct) than those presented to the left visual field (73%), leading to a main effect of Presentation Side [$F(1,19)=98.0$, $p<.0001$]. However, the right visual field advantage was smaller for high-cloze sentences (5% difference) than for either of the low-cloze sentences (22% difference for literals and 26% difference for metaphors), leading to an interaction of Sentence Type × Presentation Side [$F(2,38)=51.2$, $p<.0001$, $\varepsilon=.94$].

An analysis restricted to the two low-cloze sentence types indicated that literal endings were named more accurately than metaphorical [$F(1,19)=58.2$, $p<.0001$], and that words presented in the right visual field were named more accurately than in the left [Presentation Side, $F(1,19)=108.9$, $p<.0001$]. However, no interaction between sentence type and presentation side was observed [$F(1,19)=2.60$], indicating
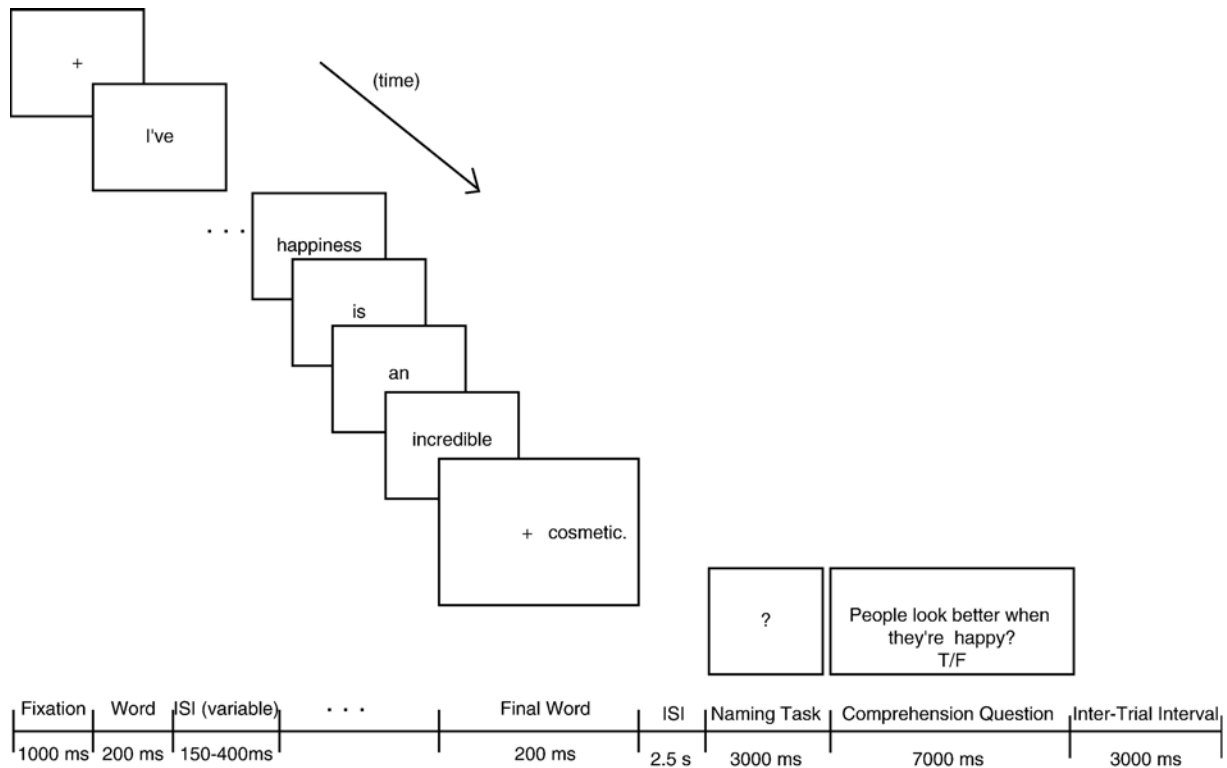
Fig. 1 – Experimental paradigm.

that the magnitude of the right visual field advantage was similar for both sorts of low-cloze endings.

Better performance on high-cloze endings is unsurprising, given that the last words of these sentences were (by definition) predictable. Moreover, assuming that chance performance on the low-cloze sentences is equal to the cloze probability (less than 5%), naming accuracies of greater than 70% clearly indicate that, in spite of the demands of lateralized presentation, participants were capable of reading sentence final words. Finally, the robust right visual field advantage is in keeping with prior observation of left hemisphere superiority in reading, and suggests the hemifield presentation paradigm we employed successfully shifted the balance of processing to the left (RVF) or right (LVF) hemispheres as intended.

Because the words used in the present study were longer (mean of 7.7 characters) than is typical for use with hemifield presentation, we also performed an analysis of accuracy rates as a function of word length with factors Sentence Type (3), Presentation Side (2), and Word Length (short versus long). Participants were more accurate in naming words of 6 characters or less (91% correct) than words of 7 characters or more (75% correct) [Word Length, $F(1,19)=86.74$, $p<.0001$]. However, this word length effect was qualified by a 3-way interaction with condition and presentation side [$F(2,38)=6.37$, $p<.01$, $\varepsilon=.77$] due to near-ceiling performance in the high-cloze literal condition.

Analysis confined to the two low-cloze conditions also revealed a naming advantage for short words [$F(1,19)=102$, $p<0.0001$] which was more pronounced with LVF presentation (80% vs. 50%) than RVF presentation (94% vs. 81%) [Word

Length × Presentation Side, $F(1,19)=40.82$]. However, no 3-way interaction was evident [Condition × Length × Presentation Side, $F(1,19)<1$] suggesting difficulty of reading long words presented to the LVF was similar for literal and metaphorical uses of these nouns.

2.2. Comprehension questions

Because the sentence final word was important for understanding the overall meaning of the experimental materials, comprehension scores were assessed only for sentences in which participants were able to correctly name the final word. Performance was very good overall, with 94% correct answers following the high-cloze sentences, 92% correct after Literal, and 91% after Metaphorical. An ANOVA with factors of Sentence Type and Presentation Side showed that the small advantage for high-cloze sentences was significant [main effect of Sentence Type, $F(2,38)=8.19$, $p<.01$, $\varepsilon=.85$]. However, comprehension did not vary as a function of presentation side ($F<1$), nor did presentation side interact with the sentence type factor [$F(2,38)=1.35$]. Better performance on questions following expected endings is not surprising, given that these sentences tended to be less complex than the sentences with low-cloze endings.

An analysis restricted to literal and metaphorical sentences failed to reveal reliable effects of Sentence Type [$F(1,19)=2.18$], Presentation Side ($F<1$), or an interaction [$F(1,19)=1.57$]. Overall, both of the behavioral measures indicate that low-cloze sentences are more difficult than high-cloze, but suggest no difference between the literal and metaphorical low-cloze sentences, regardless of presentation

side. The behavioral measures were, however, collected with no particular time pressure. We turn now to the ERP measures which can provide indices of processing difficulty in real time.

Event-related potential results are presented in four main sections below. First we examine laterally asymmetric activity that is contingent on the visual field of presentation, collapsed across sentence type (Section 2.3). Like the naming data, these measures allow empirical confirmation that hemifield presentation was successful in shifting the balance of processing between the cerebral hemispheres. Second, we compare ERPs elicited by named versus unnamed lateralized words (Section 2.4). Section 2.5 compares high- and low-cloze literal sentence completions across the two visual fields. Finally, Section 2.6 compares literal and metaphoric completions that were matched for cloze probability.

2.3. ERP asymmetries contingent on presentation side

ERPs to all words presented to the left versus the right visual field can be seen in Fig. 2. At posterior temporal (T5, T6), parietotemporal (TP7, TP8), and occipital (O1, O2) sites over visual cortex, the clearest early response is a negative peak at about 160 ms after stimulus onset – the visual N1. This is a well-studied ERP component implicated in high-level visual processing, and which is reliably larger over the scalp contralateral to visual stimulation for a variety of stimulus material (Bentin et al., 1996; Hillyard and Anllo-Vento, 1998; Neville et al., 1982).

Peak amplitude and latency of the N1 were measured at two electrode sites where this component tends to be largest (T5 and T6) and were subjected to repeated measures ANOVA with factors Presentation Side and Hemisphere. The amplitude of the N1 was larger over the right than left hemisphere (-3.2 vs. -1.3 μV) when words appeared in the left visual field, and showed the reverse asymmetry (-0.4 vs. -3.2 μV) when words appeared in the right visual field [Presentation Side × Hemisphere, $F(1,19)=25.6$, $p<.001$]. Peak latency measures showed a similar cross-over interaction [Presentation Side × Hemisphere, $F(1,19)=7.37$, $p<.05$] as the N1 peaked earlier at T6 than T5 with left visual field presentation (154 vs. 159 ms), but earlier over the left hemisphere electrode site with right visual field presentation (160 at T6 vs. 154 ms at T5). The reversing asymmetries of the visual N1 contingent on hemifield were as expected, and confirm that the procedures for maintaining central gaze fixation and rejection of trials with lateral eye movements were adequate to ensure lateralized processing, at least at the level of visual processing indexed by the N1.

In order to determine whether visual field influenced amplitudes or topographies of ERPs in later intervals relevant to the analyses below, mean amplitudes were also measured for the 300–500 ms and 600–900 ms latency windows, collapsed across sentence type. For the midline sites, there were no significant effects involving Presentation Side in either latency window (all F values < 1.7). However, analyses of ERPs recorded over dorsal and ventral lateral sites indicated that hemifield did influence the topography of the waveforms. As can be seen in Fig. 2, ERPs were less positive (more negative) over the hemisphere contralateral to the presentation side, at posterior temporal, parietotemporal and occipital sites over visual cortex. This sustained activity that reverses asymmetry depending on presentation side has been observed in other ERP studies with lateralized word presentation, and has been referred to as the selection negativity (Coulson et al., 2005; Federmeier et al., 2005), a term we adopt here as well. The term is taken from the literature on spatial attention in which it refers to an ERP component elicited in target detection paradigms that involve central fixation with selective attention directed to peripheral targets (see, e.g., Hillyard and Anllo-Vento, 1998). As in the present study, the selection negativity is larger over the hemisphere contra-lateral to the attended stimulus.

The reversing asymmetry of the Selection Negativity was substantiated in the analysis of data measured between 300 and 500 ms by interactions between Presentation Side and Hemisphere [dorsal: $F(1,19)=46.3$, $p<.0001$; ventral: $F(1,19)=45.3$, $p<.0001$], and between Presentation Side, Hemisphere, and the Anterior/Posterior factor [dorsal: $F(5,95)=12.5$, $p<.0001$, $\varepsilon=.50$; ventral: $F(4,76)=5.17$, $p<0.05$, $\varepsilon=.38$]. Analysis of data recorded 600–900 ms revealed a similar pattern of interactions [dorsal: Presentation Side × Hemisphere, $F(1,19)=33.2$, $p<.0001$; Presentation Side × Hemisphere × Anterior/Posterior, $F(5,95)=20.4$, $p<.0001$, $\varepsilon=.64$; ventral: Presentation Side × Hemisphere, $F(1,19)=24.6$, $p<.001$; Presentation Side × Hemisphere × Anterior/Posterior, $F(4,76)=20.9$, $p<.0001$, $\varepsilon=.51$].

2.4. ERP differences between named and unnamed words

For the core issue of how metaphoric language may be differentially processed in the two hemispheres, the current study uses a conservative procedure of analyzing only items that participants were also able to correctly name. However, we also compare ERPs to named versus unnamed words here, a comparison of interest for two reasons. First, we wanted to test our assumption that these responses would differ, such that failure to exclude unnamed trials would confound comparisons of the right and left hemifield conditions (because there are more unnamed trials for LVF stimuli). Second, this comparison may offer a preliminary look at the cause of naming failures across the hemifields. One can imagine that naming failures reflect fairly early (and fatal) deficiencies in the visual processes required to process letter strings presented outside the fovea. However, naming failures may also arise from deficiencies in later processes, such as associating visual information with lexical/semantic knowledge, converting orthography to phonology, or converting a phonological code to speech output.

One possibility is that all of these troubles are more prevalent when words are presented to the LVF, but that the causes of naming failure are essentially the same after presentation to the RVF – predicting that any named/unnamed difference in brain activity will be very similar across hemifields. Alternately, it is possible that failures arise for different reasons when stimuli are delivered to the left and right hemispheres, for instance, that LVF failures are more likely to reflect perceptual deficiencies whereas RVF failures are more likely to reflect later stumbling blocks. This latter possibility is suggested by the claim that regions of the left

ALL LATERALIZED WORDS
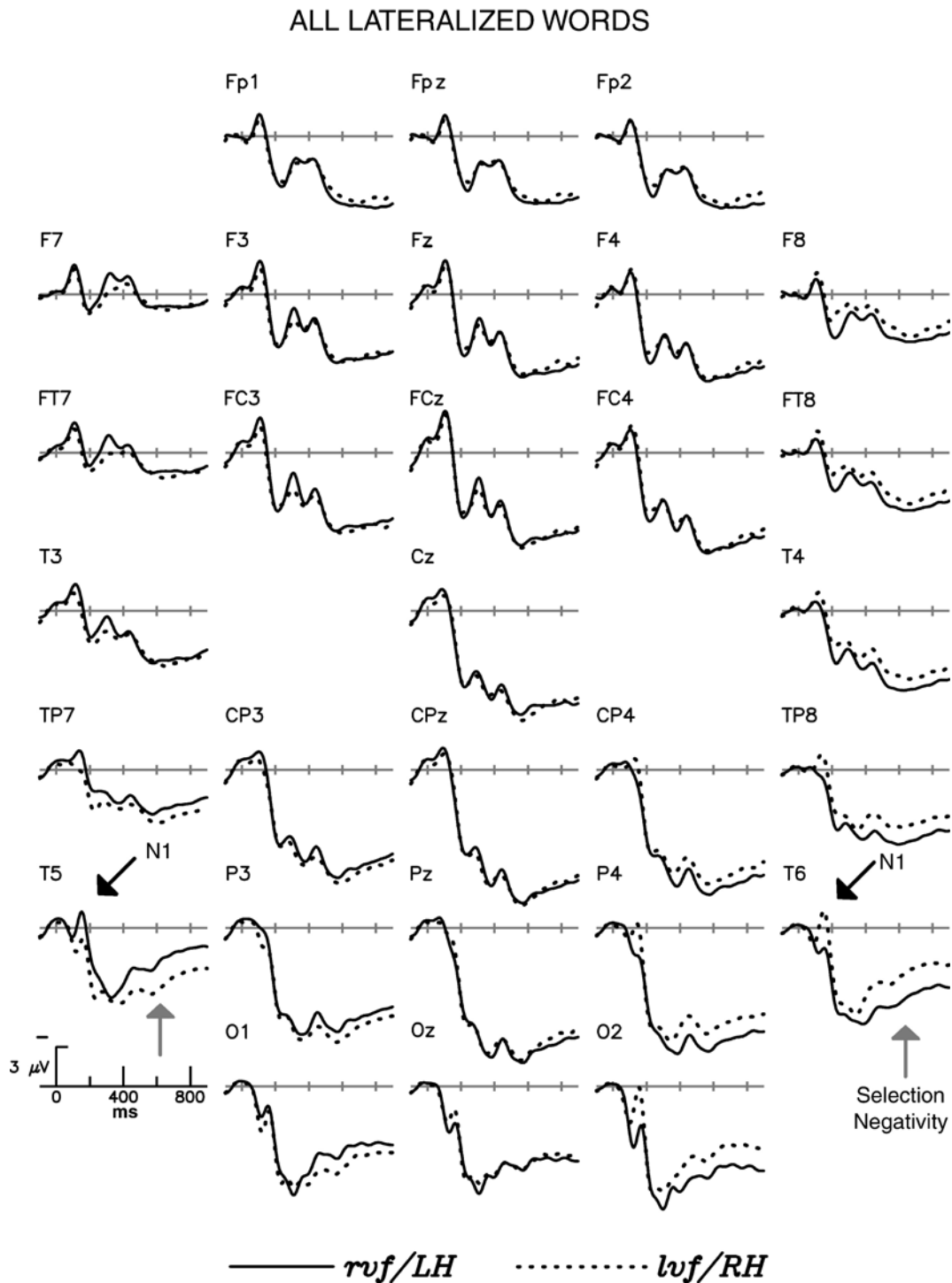

——— rʋf/LH   ·········· lʋf/RH

Fig. 2 – Grand average ERPs to sentence final words presented in the right visual field (solid) and the left visual field (dotted) recorded at each of 29 scalp sites. Negative voltage is plotted upwards in this and all subsequent figures.

occipital and temporal lobe are tuned for visual word forms and the right hemisphere lacks such regions – perhaps because they are instead specialized for faces (Cohen et al., 2002; Gaillard et al., 2006). This latter scenario would predict an earlier differentiation between named and unnamed stimuli in the LVF than RVF.

Naming of predictable sentence completions was extremely accurate (96%), so that only the two low-cloze conditions contributed a sufficient number of naming failures to examine. Because naming performance for low-cloze literal and metaphorical sentence completions was the same, trials from these two conditions were collapsed to obtain the best possible signal-to-noise ratio for the averaged ERPs. Additionally, some participants had very high accuracy for even unpredictable sentence completions presented in the right visual field, which precluded forming an ERP for unnamed RVF

words. The analysis was thus restricted to ten participants who had at least seven trials in each of the four experimental categories (Named LVF, Unnamed LVF, Named RVF, and Unnamed RVF).

Fig. 3 shows that ERPs elicited by words that could not be named were more negative than those elicited by words that
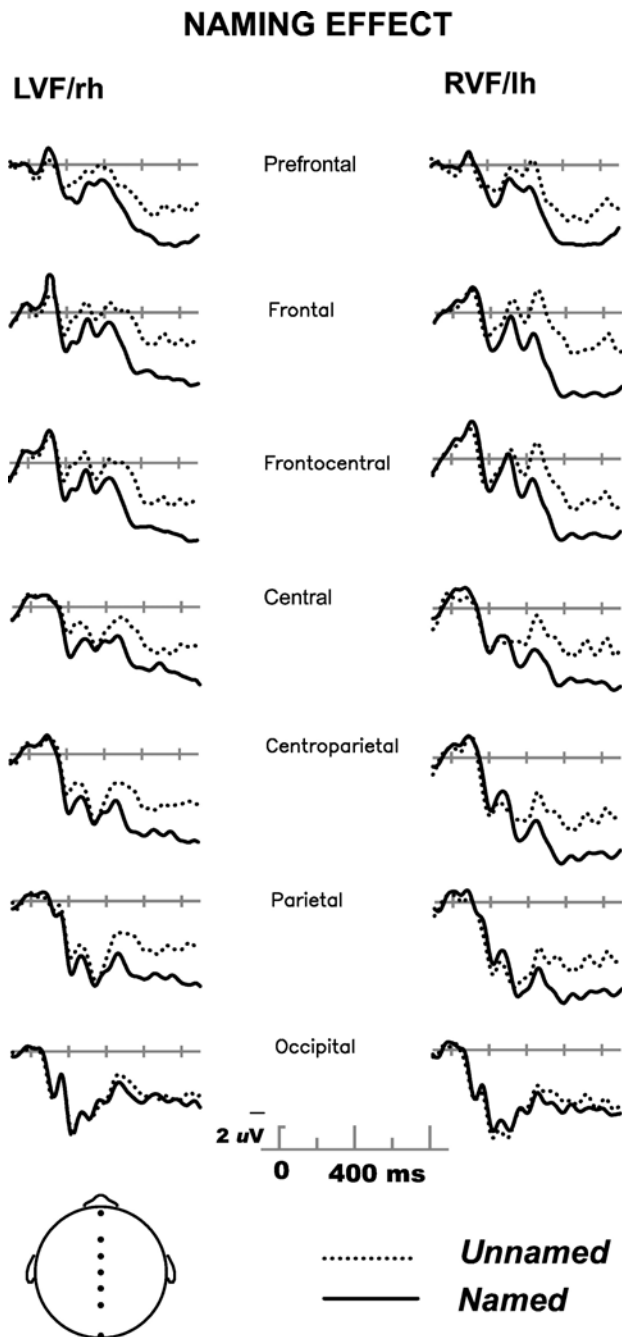
NAMING EFFECT

Fig. 3 – ERP data recorded at medial electrode sites to words in low-cloze sentences that were subsequently named (solid) versus unnamed (dotted) in the delayed naming task. In this and subsequent figures, ERPs to stimuli presented in the left visual field are plotted on the left side of the page, while stimuli presented in the right visual field are plotted on the right.
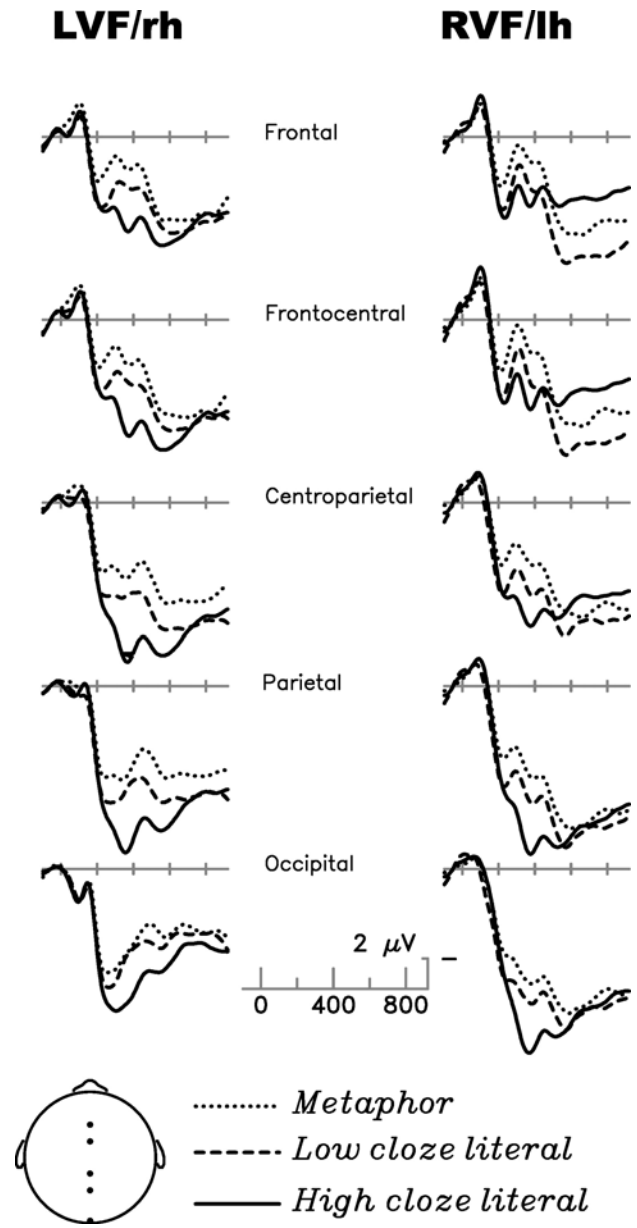

Fig. 4 – Grand average ERPs to sentence final words at medial electrode sites.

could be named. The nameability difference was apparent at all scalp sites, although smaller occipitally than elsewhere. There was no observable difference in N1 amplitude between named and unnamed words.

Named versus unnamed trials were contrasted with ANOVAs taking presentation side and electrode site (anterior-to-posterior, and hemisphere for the lateral sites) as factors. In the 300–500 ms latency window, the difference between named and unnamed was significant in the analysis of midline sites [$F(1,9)=5.2$, $p<.05$], and marginally significant for the two lateral chains [dorsal sites: $F(1,9)=4.51$, $p=.06$; ventral sites: $F(1,9)=4.42$, $p=.06$]. In the 600–900 ms latency window, the nameability difference was significant for all three electrode chains [midline: $F(1,9)=17.0$, $p<.01$; dorsal: $F(1,9)=16.3$, $p<.01$; ventral: $F(1,9)=9.69$, $p<.05$]. Neither latency

window yielded significant interactions between nameability and presentation side (all F values < 1), suggesting a great deal of similarity between the nameability effect in the two hemifields. However, inspection of Fig. 3 suggests that the named/unnamed difference began earlier for words presented in the LVF, so that we additionally analyzed mean amplitudes of the ERPs from 200 to 300 ms after stimulus onset, separately for the two hemifields. For words presented to the LVF, the nameability effect was significant in this relatively early epoch [midline: $F(1,9)=5.46$, $p<.05$; dorsal: $F(1,9)=5.72$, $p<.05$; ventral: $F(1,9)=2.86$, $p=.13$]. For words presented to the RVF, however, the main effect of nameability did not approach significance in the 200–300 ms latency range (all F values < 1).

Overall, a substantial portion of the difference between named and unnamed words is likely to reflect a larger N400 for unnamed words, suggesting that they were not compre-

hended. The substantial ERP difference between named and unnamed items confirms our starting assumption that the unnamed items should be excluded from the core analyses of cloze probability and metaphoricity. The earlier onset of the nameability effect in the LVF is consistent with the idea that words presented in this hemifield undergo less efficient perceptual processing than words presented in the RVF. However, this conclusion must be regarded as very preliminary given the generally low power of analyses based on a relatively small number of trials and participants.

2.5. ERP effects of cloze probability

ERPs to the last words in all 3 conditions are shown in Fig. 4, whereas the specific comparison of high versus low-cloze literal sentences is shown Fig. 5. Presentation to either visual
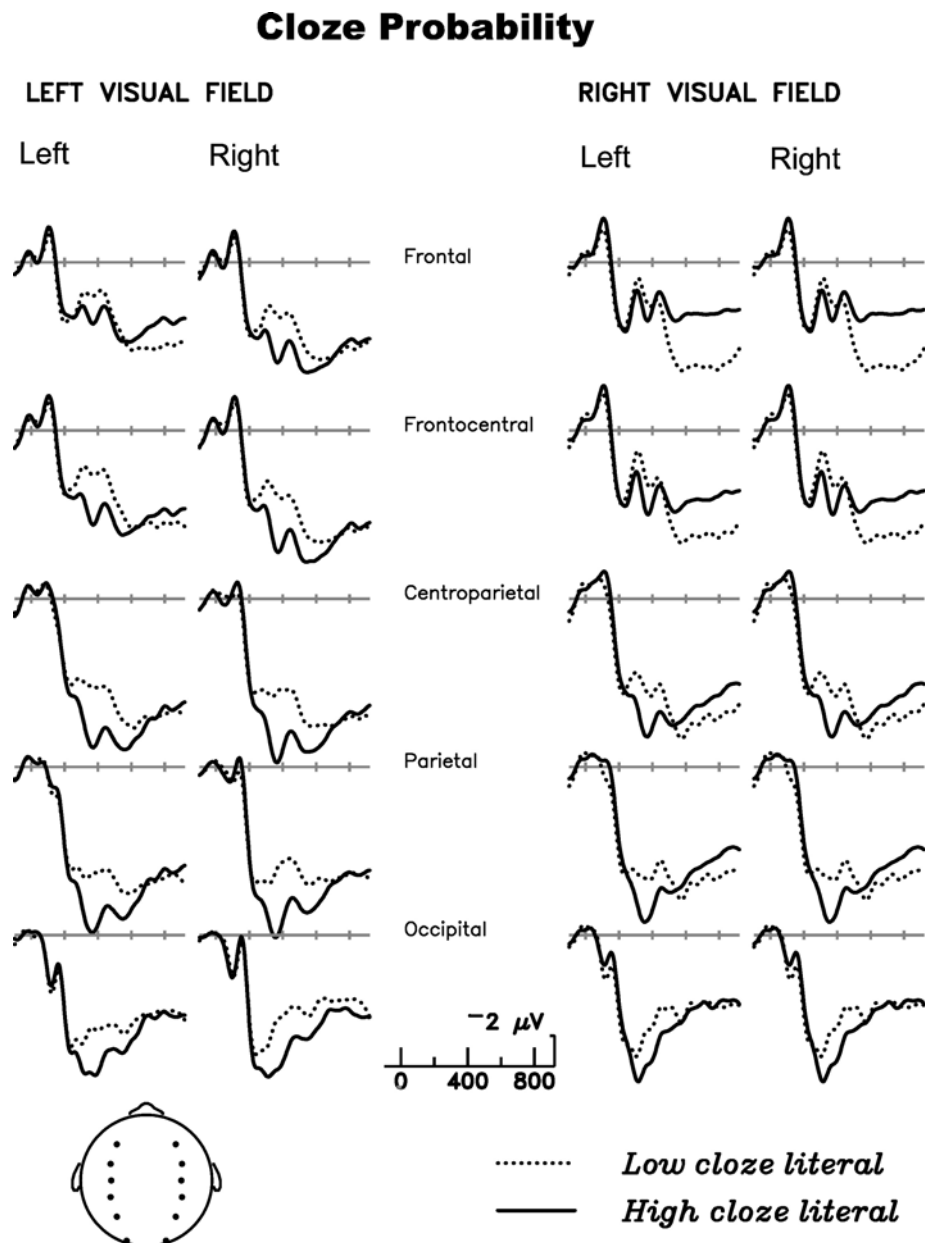

Fig. 5 – Grand average ERPs to high (solid) and low (dotted) cloze literal words at dorsal electrode sites.

field resulted in smaller N400s for more predictable completions, as typically observed after midline presentation. Presentation to the right but not the left visual field resulted in more positive ERPs for low-cloze completions, following the N400, and most prominent at frontal scalp sites. The 300–500 and 600–900 ms latency windows were selected to capture these distinct effects, although it is likely that the two effects overlap in time. Fig. 5 suggests the possibility that the late frontal positivity elicited by low-cloze words may reduce the apparent amplitude of the N400 at frontal sites, after RVF presentation.

2.5.1.　Analyses of 300–500 ms latency window

The larger N400 for low- than high-cloze literal completions led to main effects of cloze for all three electrode chains [midline: $F(1,19)=14.7$, $p<.01$; dorsal: $F(1,19)=14.2$, $p<.01$;

ventral: $F(1,19)=14.2$, $p<.01$]. Amplitudes of this effect were somewhat smaller at prefrontal, frontal, and occipital sites than at central and parietal, leading to interactions between cloze probability and the anterior–posterior spatial factor [midline: $F(6,114)=14.2$, $p<.0001$, $\varepsilon=.33$; dorsal: $F(5,95)=13.2$, $p<.001$; ventral: $F(4,76)=9.12$, $p<.001$, $\varepsilon=.39$]. For the ventral (most lateral) sites, there was also a significant interaction between cloze probability and hemisphere [$F(1,19)=6.19$, $p<.05$], due to a slightly larger cloze effect over RH than LH electrode sites (1.6 vs. 0.7 μV).

In addition to the effects involving cloze probability, the sustained "selection negativity" present for all lateralized words (illustrated in Fig. 2) led to multiple interactions between presentation side and hemisphere [dorsal: Presentation Side×Hemisphere, $F(1,19)=26.0$, $p<.001$; Presentation Side×Hemisphere×Anterior/Posterior, $F(1,19)=11.0$, $p<.0001$,
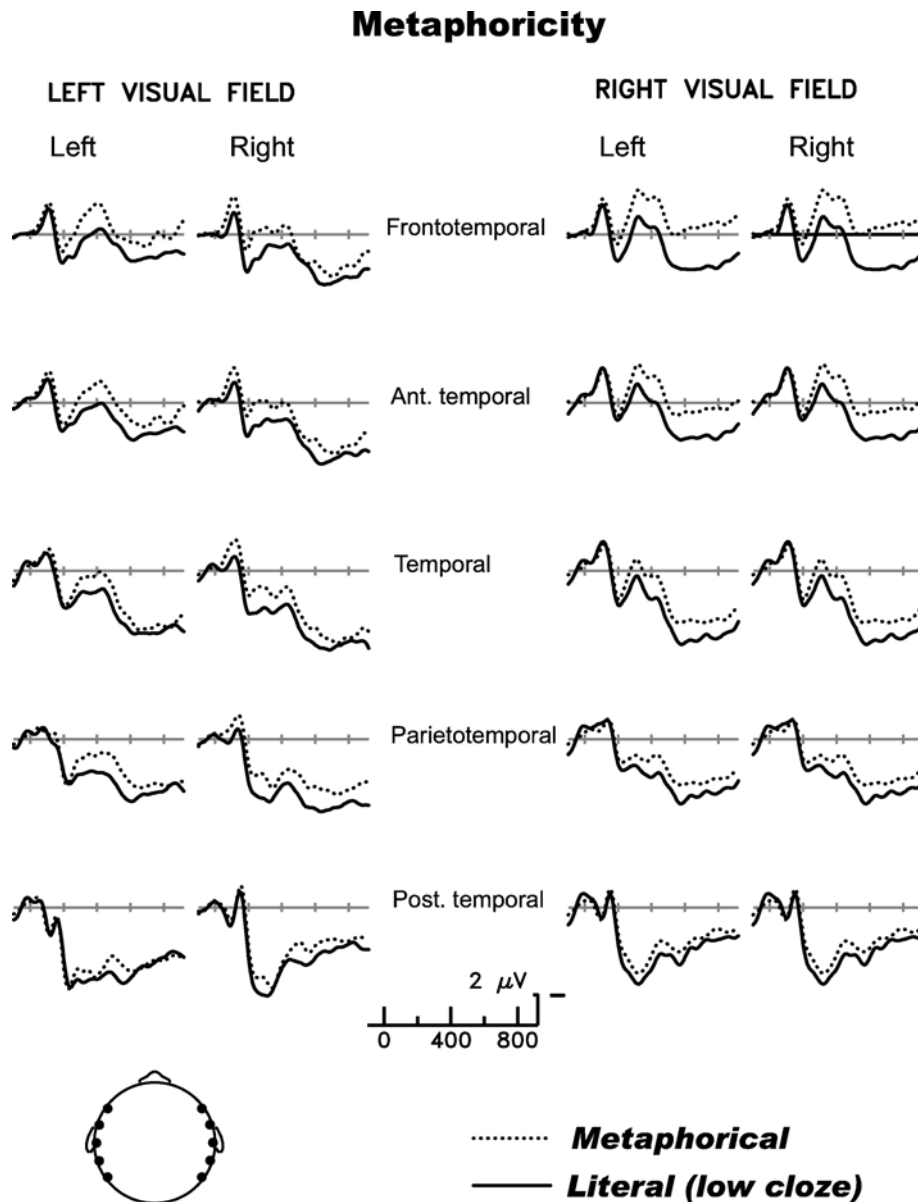

Fig. 6 – Grand average ERPs to low-cloze words used literally (solid) and metaphorically (dotted) at ventral electrode sites.

$\varepsilon = .70$; ventral: Presentation Side×Hemisphere, $F(1,19)=24.0$, $p<.001$]. However, there were no significant interactions between cloze probability and presentation side.

2.5.2. Analyses of 600–900 ms latency window

The late positivity elicited by low-cloze endings after RVF presentation had a pronounced frontal distribution, leading to interactions between cloze probability and the anterior–posterior spatial factor [midline: $F(6,114)=9.55$, $p<.001$, $\varepsilon=.29$; dorsal: $F(5,95)=5.18$, $p<.05$, $\varepsilon=.32$; ventral: $F<1$]. The dependence of the late positivity on RVF presentation led to three-way interactions between cloze probability, presentation side, and the anterior–posterior factor for the midline and dorsal electrode chains [midline: $F(6,114)=2.7$, $p=.05$, $\varepsilon=.47$; dorsal: $F(5,95)=2.88$, $p<.05$, $\varepsilon=.58$] and a two-way interaction between cloze probability and presentation side for the ventral chain [$F(1,19)=4.79$, $p<.05$]. Although dependent on RVF presentation, the late positivity showed no signs of an asymmetric scalp distribution (no interactions between cloze probability and hemisphere were significant).

In addition to the effects involving cloze probability, the sustained "selection negativity" illustrated in Fig. 2 persisted into the 600–900 ms latency range, generating multiple interactions between presentation side and hemisphere [dorsal: Presentation Side×Hemisphere, $F(1,19)=22.3$, $p<.001$; Presentation Side×Hemisphere×Anterior/Posterior, $F(5,95)=14.3$, $p<.0001$, $\varepsilon=.72$; ventral: Presentation Side×Hemisphere, $F(1,19)=13.0$, $p<.01$; Presentation Side×Hemisphere×Anterior/Posterior, $F(4,76)=13.6$, $p<.0001$, $\varepsilon=.52$]. Because they pertain to all the lateralized words, these same interactions were significant in the analyses of metaphoricity below, but will not be reported again.

2.6. ERP effects of metaphoricity

Fig. 6 shows that, after presentation to either hemifield, metaphors elicited larger N400s than the same words used literally. The enhanced negativity elicited by metaphoric words persisted into the 600–900 ms latency range.

2.6.1. Analyses of 300–500 ms latency window

The main effect of metaphoricity was reliable for all three electrode chains [midline: $F(1,19)=14.3$, $p<.01$; dorsal: $F(1,19)=21.1$, $p<.001$; ventral: $F(1,19)=27.6$, $p<.0001$]. Critically, there were no significant interactions between metaphoricity and presentation side (all F values<1).

Presentation side modulated the overall topography of the ERPs due to the presence of the sustained "selection negativity" contralateral to the side of presentation [dorsal: Presentation Side×Hemisphere, $F(1,19)=17.1$, $p<.001$; Presentation Side×Hemisphere×Anterior/Posterior, $F(5,95)=8.47$, $p<.001$, $\varepsilon=.46$; ventral: Presentation Side×Hemisphere, $F(1,19)=19.0$, $p<.001$].

2.6.2. Analyses of 600–900 ms latency window

The more negative ERPs for metaphoric than low-cloze literal completions led to main effects of metaphoricity for all three electrode chains [midline: $F(1,19)=4.58$, $p<.05$; dorsal: $F(1,19)=6.59$, $p<.05$; ventral: $F(1,19)=6.59$, $p<.05$]. Analyses of the midline and dorsal chains showed no significant interactions between metaphoricity and presentation side, nor did the dorsal chain include any significant interactions between metaphoricity and hemisphere (all F values<1.6).

For the ventral (farthest from the midline) sites, one significant and one marginal effect included hints that side of presentation or left/right location on the scalp might interact with metaphoricity [ventral: Metaphoricity×Hemisphere×Anterior/Posterior, $F(4,76)=4.54$, $p<.01$, $\varepsilon=.71$; Metaphoricity×Presentation Side×Hemisphere, $F(1,19)=3.75$, $p=.07$]. Separate analyses of the RVF and LVF stimuli were conducted to pursue these interactions. Both the left and right hemifields showed significant main effects of metaphoricity [$F(1,19)=5.51$, $p<.05$, and $F(1,19)=20.5$, $p<.001$, respectively]. For the RVF only, the main effect was accompanied by an interaction with Hemisphere [$F(1,19)=11.3$, $p<0.01$], and a three-way interaction with Hemisphere and the Anterior/Posterior factor [$F(4,76)=4.96$, $p<.01$, $\varepsilon=.86$]. Inspection of Fig. 6 clarifies the source of these effects: for LVF stimuli, the late metaphoricity effect was of much the same amplitude across different scalp sites, whereas the late metaphoricity effect for RVF stimuli was distinctly larger over left anterior than other scalp sites (compare F7 and FT7 to other sites).

3. Discussion

Electrical brain activity was recorded as healthy adults read sentences whose last word was highly predictable from the preceding sentence frame (High-cloze Literal), less predictable but literal (Low-cloze Literal), or metaphoric. In addition to having the same rates of predictability, the literal and metaphoric low-cloze completions were the same words. For all three sentence types, the final word was presented in either the left or the right hemifield to assess hemispheric asymmetries in comprehension.

Accuracies in reading the final words aloud, and in answering comprehension questions about the sentences, were reduced after LVF presentation as compared to RVF presentation. Naming also showed a three-way accuracy gradient: highest for predictable literal completions, substantially lower for low-cloze literal completions, and lowest for metaphoric completions. The N400 component of the ERP similarly showed a gradient of amplitude: smallest for high-cloze completions, intermediate for low-cloze literals, and largest for metaphoric completions (Fig. 4). Presentation side did not modulate the impact of cloze probability or metaphoricity on the behavioral measures, or on N400 amplitude. However, presentation side did have a dramatic impact on a different ERP component that was also sensitive to cloze probability, and maximal from 600 to 900 ms after stimulus presentation. We first discuss the cloze probability effects and their hemispheric asymmetry in Section 3.1, and then return to the issue of hemispheric asymmetry in metaphor comprehension in Section 3.2.

3.1. Cloze probability effects

Comparison of more versus less predictable literal sentence completions revealed two distinct electrophysiological effects. N400 amplitudes were larger for low- than for high-cloze

completions, but this effect was insensitive to side of presentation. This result is like that of several prior studies that have evaluated the impact of hemifield presentation on N400 sentence context effects, and supports the claim that semantic processes in both hemispheres benefit from supportive sentence context (Coulson et al., 2005; Federmeier and Kutas, 1999; Federmeier et al., 2005). After the N400 (600–900 ms), the cloze probability effect reversed in polarity, such that low-cloze completions elicited more positive potentials in this late temporal epoch. The late effect was largest over frontal cortex, and showed a strong sensitivity to hemifield – much larger after RVF (left hemisphere) than LVF (right hemisphere) presentation (Fig. 5) – suggesting that the left hemisphere is crucial for its generation.

The larger late positivity for low- than high-cloze sentences observed here is an instance of what we have called the *post-N400 positivity* sometimes observed in comparisons between semantically anomalous and congruent sentence completions. In contrast to the robust N400 effect, the post-N400 positivity has been a very inconsistent effect across a large number of published studies manipulating either congruity or cloze probability (see Van Petten and Luka, 2006 for review). When observed, other results have been consistent with the current suggestion that this effect originates in left frontal cortex. Swick and colleagues observed both larger N400s and larger post-N400-positivities for anomalous as compared to congruent sentence completions in healthy participants. In stroke patients with damage to dorsolateral and inferior prefrontal cortex, the N400 effect was unchanged, but the post-N400-positivity was eliminated (Swick et al., 1998). The majority of these patients (8 of 11) had left hemisphere damage. One of our previous experiments included hemifield presentation of probe words that were semantically related or unrelated to a preceding joke. Similar to the current results, presentation to the RVF led to an enhanced anterior positivity for unrelated words, but this potential was much smaller after LVF presentation (Coulson and Wu, 2005).

Despite the clear evidence for a left frontal source, the inconsistency of the post-N400-positivity across experiments is puzzling. One possible reason for this inconsistency is that experimental sentence completions are typically assessed only for their cloze probability (as here) – the extent to which the word presented is predictable based on the preceding context. A different measure of contextual support is the *contextual constraint* of the sentence frame. In cloze-probability tests, highly constraining sentence frames are defined as those that elicit at least one high probability completion, while low constraint frames are those that elicit a large number of responses, each of which is low probability. Because a low-cloze completion might be either the dispreferred completion of a strongly constraining sentence, or one of a number of unexpected completions for a weakly constraining one, contextual constraint is particularly informative for sentences that end with a low-cloze item.

It has been known for some time that N400 amplitude is driven only by cloze probability, and is insensitive to the predictability of other sentence completions not actually presented (Kutas and Hillyard, 1984). However, Federmeier and colleagues have recently demonstrated that low-cloze completions elicit a larger post-N400 positivity when they occur in high-constraint sentences – those that suggest an alternative completion – than when they occur in low-constraint sentences, and have argued that this potential indexes processing costs associated with an unfulfilled expectation (Federmeier et al., 2006). Together with its probable left frontal origin, the association of the post-N400 positivity with prediction costs is consistent with the proposal that the left inferior frontal gyrus plays an important role in the selection of relevant information in the face of competing alternatives (Moss et al., 2005; Thompson-Schill et al., 2002).

3.2.   Metaphoricity effects

The current results replicate our previous study with central presentation in showing larger N400s for words that evoke metaphorical as compared to literal meanings, suggesting the metaphoric interpretation was more difficult (Coulson and Van Petten, 2002). However, the current results provide no support for the right hemisphere theory of metaphor. Despite other indications that hemifield presentation shifted the balance of activity between the two hemispheres during both early (N1) and later (post-N400 positivity) stages of processing, the ERP differences between metaphoric and matched literal sentence completions were essentially identical after RVF and LVF presentation.

Interestingly, observed differences in the scalp distribution of the post-N400 positivity (broadly distributed with LVF presentation but with a left anterior focus with RVF presentation) appear to be driven more by the effect of presentation side on ERPs to low-cloze literal than to metaphorical items (see Fig. 6). Although matched for cloze probability, literal sentence contexts may have been somewhat higher in constraint such that they engendered more unfulfilled expectations about potential completions than did the metaphorical sentence frames. The relatively large response over left anterior electrodes with RVF (LH) presentation may index the demands of selecting among competing information sources, demands slightly greater for our low-cloze literal stimuli.

It is important to note that we removed trials in which the eliciting words could not be named, and that there were more such naming failures after LVF presentation. This procedure acted to eliminate hemispheric asymmetries originating in perceptual or lexical processes, so as to isolate differences in higher-level comprehension. The equivalent metaphoricity effects after presentation to the right and left visual fields thus suggest that metaphor comprehension presents challenges for both hemispheres, but largely equal ones.

The early theory that the comprehension abilities of the right hemisphere were especially suited for metaphor was based on sparse data, and may have also suffered from the assumption that all forms of "nonstandard" language use – metaphor, humor, sarcasm, and so forth – had the same neural bases. Below, we review other recent work that adds to a growing body of evidence that argue against right hemisphere superiority in the comprehension of metaphors and idioms. We review work on both metaphor and idioms because studies of novel metaphors are sparse, and conventional metaphors have been argued to involve many of the same properties as idioms (see Gibbs, 1994 for a review).

3.2.1. Neuropsychological studies

The original studies reporting impaired metaphor comprehension in RHD patients have been criticized for several methodological shortcomings (see e.g. Joanette et al., 1990). For example, in many such studies, perceptual deficits were not assessed, and even the language abilities of the patients were not studied in detail (see Oliveri et al., 2004 for critique). The number of subjects was typically quite small, as was the number of stimuli. Further, because many of the studies that support the view of RHD metaphor comprehension deficits used forced choice paradigms, some researchers have suggested the RHD deficit lies not in comprehension, per se, but in rejecting the alternative meanings of the experimental stimuli.

Recent research on various patient populations suggests that a number of the tasks employed in early studies may have underestimated the metaphor comprehension abilities of patients with right hemisphere damage (RHD). Rinaldi and colleagues found that while RHD patients were significantly impaired on both a picture-matching and a verbal metaphor test, the impairment on the picture-matching task was more severe (Rinaldi et al., 2002). Because even neurologically intact participants perform worse on pictorial than verbal tests of figurative language comprehension (Papagno et al., 2004), the performance of RHD patients may indicate a broader deficit in difficult tasks, and/or visuoperceptual deficits that are emphasized when pictorial materials are used.

The right hemisphere theory of metaphor comprehension is further undermined by the finding that LHD and RHD individuals are both impaired on tests of figurative language comprehension (Chobor and Schweiger, 1998; Gagnon et al., 2003). Unlike their RHD counterparts, LHD patients have been shown to be impaired both on picture matching tasks and on a task that requires them to give a verbal explanation of idiom meaning (Papagno et al., 2004). In contrast to the early hypothesis that RHD patients are more impaired than LHD in multiple varieties of "nonstandard" language comprehension, Giora and colleagues report that a group of RHD patients actually performed better than LHD patients in comprehension of highly conventional metaphors – but not on a test of sarcasm comprehension (Giora et al., 2000; Zaidel et al., 2002). Moreover, these investigators found that metaphor comprehension was negatively correlated with lesion extent in the left hemisphere regions more traditionally associated with language comprehension: the left middle temporal gyrus, and neighboring supramarginal and superior temporal gyri.

Research with repetitive transcranial magnetic stimulation (rTMS) in healthy adults also points to a more critical role for frontal and temporal lobe areas in the left than the right hemisphere in the comprehension of idioms (Oliveri et al., 2004). Left frontal rTMS induced a small but significant impairment, but right frontal rTMS did not. Further, left temporal rTMS disrupted performance on both literal sentences and idioms, while right temporal rTMS actually facilitated performance on both idioms and literal sentences (Oliveri et al., 2004). The basis for improved performance after TMS stimulation is not fully understood, but must rely on interactions between brain areas such that TMS in one region can "disinhibit" another, or reduce competing input to a third region.

Finally, other work suggests that normal interhemispheric communication is useful for idiom comprehension. The condition of agenesis of the corpus callosum (ACC) is one in which the corpus callosum fails to develop, but brain maturation is otherwise relatively normal. In a large sample of these patients with normal IQ scores, Paul and colleagues found normal performance on tests of literal language comprehension, but impaired comprehension of formulaic idioms. The ACC patients tended to err by picking a literal depiction of the idiomatic phrase, much like the errors of RHD patients in picture-matching tasks (Paul et al., 2003). The similarity between performance of RHD patients and ACC patients with intact RHs indicates a crucial role for interhemispheric interaction in idiom comprehension.

Overall, recent neuropsychological studies suggest two conclusions. First, patients with both left and right hemisphere damage are impaired in the comprehension of metaphors and idioms. Second, the deficits of RHD patients are less specific than previously thought, and may sometimes reflect a generalized reduction in processing capacity. The classic finding of "overly literal" responses on picture matching tasks may reflect the fact that, in the face of partial comprehension and reduced processing resources, patients resort to strategies that result in the selection of the literal depiction over the metaphoric one.

3.2.2. Neuroimaging

A second impetus for the right-hemisphere theory of metaphor came from an early hemodynamic imaging study. In a PET study of neurologically intact adults, Bottini and colleagues observed greater blood flow increase in the right hemisphere when participants read blocks of sentences containing metaphors than when they read literal control sentences (Bottini et al., 1994). However, a more recent functional magnetic resonance imaging (fMRI) study in which task difficulty was well-matched for literal and metaphorical sentences revealed additional LH activation for metaphors (Rapp et al., 2004). Other studies in which investigators have made significant efforts to control for task difficulty have revealed LH activations in comparisons of literal versus metaphorical meanings (Lee and Dapretto, 2006; Rapp et al., 2007). Right hemisphere recruitment may depend on overall task difficulty, rather than the figurativity of the meanings (Coulson and Van Petten, 2002).

A systematic review of frontal hemodynamic activity reveals that, as a wide variety of tasks become more difficult, bilateral increases in restricted areas of frontal cortex are observed, as well as additional RH activation in mid-ventrolateral areas (Duncan and Owen, 2000). Other fMRI studies in healthy adults indicate that when literal sentence comprehension places increased demands upon lexical and syntactic processes, increased activation in both classic LH language areas and in their RH homologues are observed (Keller et al., 2001). In general, RH activation is associated with complex sentences and discourse level processing (Bookheimer, 2002; Kircher et al., 2001; St. George et al., 1999), suggesting that it is semantic complexity that triggers the recruitment of RH areas.

The current observation of a larger N400 for metaphoric than literal sentence completions confirms the additional difficulty of metaphor comprehension (see also Coulson and Van Petten, 2002). However, the current stimulus materials were constructed to minimize extraneous differences between

metaphoric and literal sentences, by using the same words for the two types of completions, and by equating the predictability of the completions in an untimed prediction task (cloze probability). The hemifield presentation method also allowed us to evaluate and control hemispheric asymmetries in lower-level processes leading to word identification (naming). When these lower-level processes were successful (such that the individual words could be identified), the residual difficulty in metaphor comprehension showed no hemispheric asymmetry.

3.3. Conclusion

The hemifield presentation paradigm employed in the present study had measurable effects both on participants' behavior and their event-related brain response. However, hemifield presentation did not modulate the size of the N400 metaphoricity effect, suggesting that both hemispheres are sensitive to the processing difficulty engendered by metaphorically used nouns in sentence contexts. These data are consistent with other recent studies that argue against a privileged role for the RH in metaphor comprehension, and are in keeping with the claim that the brain does not treat literal and metaphoric language as qualitatively distinct categories.

However, the current results contrast with those from very similar paradigms indicating that the RH does play an important role in joke comprehension (Coulson and Lovett, 2004; Coulson and Williams, 2005; Coulson and Wu, 2005). This may reflect the fact that appreciation of a joke requires listeners to suppress previously computed inferences and to exploit non-salient aspects of contextual knowledge that may be more prominent in the right hemisphere. Because there are many different ways that linguistic utterances can diverge from literality, we should expect to observe a similar diversity in networks of brain areas recruited to comprehend them. We suggest that just as the brain areas activated in the comprehension of literal language differ as a function of the degree to which visual imagery or emotions are evoked (Ferstl et al., 2005; Just et al., 2003), the comprehension of non-literal language is likely to recruit different brain areas depending on the cognitive processes it engenders. Neural resources recruited for metaphor comprehension have been found to vary as a function of factors such as the novelty and complexity of the mapping that also impact the comprehension of literal language (Coulson and Van Petten, 2002; Mashal et al., 2007). Given that metaphoric mapping is a basic mechanism of meaning extension, perhaps it is not surprising that both hemispheres are similarly sensitive to metaphoric meaning.

4. Experimental procedures

4.1. Materials

Materials consisted of 80 sentences with predictable literal endings (*High-cloze* condition), and 160 pairs of sentences with unpredictable but congruent endings. Cloze probability was assessed via a sentence completion task in which the sentence frames, sans final words, were presented to at least 80 college students who did not participate in the present

study. Cloze probability for a specific completion is defined as the percentage of participants who complete the sentence fragment with that word. Pairs of low-cloze sentences were designed so that two distinct sentence frames ended with the same word, used literally in one case (*Literal low-cloze* condition), and metaphorically in the other (*Metaphorical low-cloze* condition). Mean cloze probabilities for the High-cloze, Literal, and Metaphorical sentence completions were 80.7% (SD = 13.1), 2.3% (SD = 5.7), and 2.6% (SD = 9.3), respectively. Sentence lengths were similar across conditions, with means of 11.6 (SD = 3.6), 12.7 (SD = 2.6), and 12.7 (SD = 2.7) for High-cloze, Literal, and Metaphorical. Because the Literal and Metaphorical sentences used the same completions, the lengths and frequencies of usage of those words were identical, and closely matched to those of the High-cloze completions [mean length, 7.7 letters; mean frequency 18.5 per million (Francis and Kucera, 1982) count, summing across all regularly inflected forms]. Table 1 shows examples of each sentence type. Each participant saw 80 High-cloze, 80 Literal, and 80 Metaphorical sentences of which half of the final words in each stimulus category were presented to the left visual field (LVF) and half to the right (RVF). Four stimulus lists were created so that no individual participant saw the same sentence-final word twice, and each completion appeared equally often in the left and right fields.

4.2. Procedure

Words were presented in black against a white background. Sentence frames were presented one word at a time in the center of the monitor, with a fixed duration of 200 ms, and variable ISI that depended on the length of the word (100 ms plus 37 ms for each character). Sentence-final words were presented laterally together with a fixation cross in the center of the screen for 200 ms. The lateral position was calculated such that the inside edge of final words was 2° visual angle to the left or right of the fixation cross. Two and a half seconds after the onset of the sentence-final word, a blue question mark appeared in the center of the monitor, prompting the participant to report the laterally presented word, or to say "didn't see". Shortly thereafter, a true/false comprehension question appeared in its entirety on the monitor (see Table 1 for examples); participants signaled their responses with keypresses with the right and left index fingers (mapping of true and false to left/right keys was counterbalanced across participants). The overall sequence of events for a trial is illustrated in Fig. 1.

4.3. Electrophysiological methods

The electroencephalogram (EEG) was recorded with 29 tin electrodes mounted in a commercially available elastic cap organized according to the International 10/20 system. Seven electrodes spanned the midline of the scalp from prefrontal to occipital (FPz, Fz, FCz, Cz, CPz, Pz, Oz). Six dorsal pairs were used (FP3/4, F3/4, FC3/4, C3/4, P3/4, and O1/2), and five more lateral pairs spanned inferior frontal and temporal sites (F7/8, FT7/8, T3/4, TP7/8, and T5/6). Each scalp site was referred to the left mastoid on-line, and later re-referenced to an average of the left and right mastoids. Electrodes were also placed

under the right eye and at the outer canthi to monitor blinks and eye movements. The EEG was amplified with half-amplitude cutoffs of 0.01 and 100 Hz, digitized on-line with a sampling rate of 250 Hz and stored on disk for subsequent averaging. Trials with eye movement, muscle, or amplifier saturation (blocking) artifacts were rejected off-line prior to averaging. ERPs were time-locked to the onset of sentence-final words in each of the 6 conditions (3 sentence types × 2 presentation sides).

Unless otherwise noted, all analyses reflect ERPs elicited by stimuli that participants were able to both read and comprehend, as evidenced by behavior on delayed naming and comprehension tasks. ERPs were quantified by measuring the mean amplitude relative to a 100-ms pre-stimulus baseline in two key intervals after stimulus onset: 300–500 ms to assess the N400 and 600–900 ms post-stimulus onset to assess the positivity that sometimes follows the N400. Mean amplitude measurements were subjected to repeated measures ANOVA with factors of sentence type and presentation side. To characterize the scalp distribution of the ERPs, separate analyses were performed on the midline sites, the lateral sites closer to the midline (which we refer to as *dorsal* because they lie primarily over superior/dorsal cortex), and the lateral sites farther from the midline over *ventral* frontal and temporal cortex. These three analyses included a spatial factor of anterior-to-posterior, and a second spatial factor of hemisphere (left vs. right) for the lateral sites. For all *F*-ratios with more than one degree of freedom in the numerator, the Greenhouse–Geisser correction was applied. Reported are the original degrees of freedom, the epsilon correction factor, and the corrected probability level.

4.4. Participants

Participants were twenty healthy adults (seven men), aged 18 to 39 (mean = 22. 6 years, SD = 5.4). All were right-handers with no left-handers in their immediate family. Mean Laterality Quotient, as assessed by the Edinburgh inventory (Oldfield, 1971), was 74.6 (SD = 24.0). Their mean years of education was 15.2 (SD = 2.0), and all participants had at least one year of college education.

Six additional people completed the study, but were not included in the analyses because there were not enough usable EEG trials (more than 7) to form an ERP for one or more of the experimental categories. Trial loss was particularly high in this paradigm both because participants tended to make horizontal eye movements (which, due to short word presentation durations, did not help participants to fixate the words, but did corrupt the ERP data), and because many participants experienced difficulty reading words presented in the left visual field. For the twenty participants whose data were used, the average number of trials in the ERPs for the six experimental categories was 23.3, and ranged from 13.7 to 30.8.

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