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Hemispheric asymmetry in interpreting novel literal language: An event-related potential study

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ABSTRACT

Conceptual mapping, or making connections between conceptual structure in different domains, is a key mechanism of creative language use whose neural underpinnings are not well understood. The present study involved the combination of event-related potentials (ERPs) with the divided visual field presentation technique to explore the relative contributions of the left and right hemispheres (LH and RH) to the construction of novel meanings in fully literal language. Electroencephalogram (EEG) was recorded as healthy adults read sentences that supported either a conventional literal reading of the sentence final word ("His main method of transportation is a boat,"), or a novel literal meaning derived from conceptual mapping ("The clever boys used a cardboard box as a boat,"). The novel and conventional conditions were matched for cloze probability (a measure of predictability based on the sentence context), lexical association between the sentence frame and the final word (using latent semantic analysis), and other factors known to influence ERPs to language stimuli. To compare effects of novelty to previously reported effects of predictability, a high-cloze conventional condition ("The only way to get around Venice is to navigate the canals in a boat.") was included. ERPs were time-locked to sentence final words ("boat") presented in either the left visual field, to preferentially stimulate the RH (lvf/RH), or in the right visual field, targeting the LH (rvf/LH). The N400 component of the ERP was affected by predictability in both presentation sides, but by novelty only in rvf/LH. Two distinct late frontal positive effects were observed. Word predictability modulated a frontal positivity with a LH focus, but semantic novelty modulated a frontal positivity focused in RH. This is the first demonstration that the frontal positivity may be composed of multiple overlapping components with distinct functional and anatomical characteristics. Extending contemporary accounts of the frontal positivity, we suggest that both frontal positivities reflect learning mechanisms involving prediction based on statistical regularities in language (LH) and world knowledge (RH).

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1. Introduction

Mapping, or making connections between conceptual domains, has been identified as a key mechanism of creativity in language (Fauconnier, 1997; Fauconnier & Turner, 2002; Lakoff & Johnson, 1980; Pinker, 2007). Metaphor, for instance, relies on mappings such as that between love and travel in the sentence, "This relationship isn't going anywhere," in which the word relationship is used as though it refers to a vehicle as well as a real relationship. Since the mid-1990s, the neural basis of creative language has become a topic of increasing interest in cognitive neuroscience (for recent reviews, see Giora, 2007; Coulson & Davenport, 2011). Although early neurological work implicated the right hemisphere (RH) in metaphor processing (Winner & Gardner, 1977), a number of subsequent studies have shown that in terms of both processing difficulty and neural activation sources, a conventional metaphorical expression is processed more easily and with less reliance on RH neural substrates than a novel metaphor (e.g., Ahrens et al., 2007; Faust & Mashal, 2007). This implies that the neural resources recruited for processing depend on whether the expression is novel or conventional, rather than whether it is literal or metaphorical (Giora, 1997).

It is worth noting that the experimental results that led to this theoretical focus on the novel/conventional distinction came entirely from comparisons of novel and conventional metaphors. However, speakers are also able to use novel conceptual mappings in purely literal language (Coulson & Matlock, 2001). In a sentence such as, "The clever boys used a cardboard box as a boat," the word *boat* must be understood as bearing some of the semantic features of a

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cardboard box as well as some semantic features of a boat. Deciding which features of each input domain to activate is computationally difficult, yet such sentences are easily understood. Previous ERP experiments on novel mappings in literal language revealed a late frontal ERP effect distinct from that elicited by novel metaphors (Coulson & Van Petten, 2002), and distinct from that elicited by the manipulation of predictability (Davenport & Coulson, 2011).

However, no study has yet investigated whether novel and conventional literal expressions display hemispheric asymmetry similar to novel and conventional metaphorical language. Accordingly, the present study employs divided visual field presentation to assess differences in hemispheric sensitivity to novel and conventional literal language, using the same materials as Davenport and Coulson (2011). Continuity between literal and metaphorical meanings (Coulson & Van Petten, 2002; Giora, 1997) naturally predicts similar effects of novelty in literal language as in metaphorical language: a left hemisphere (LH) advantage for conventional language and a RH advantage for novel language (Giora, Zaidel, Soroker, Batori, & Kasher, 2000).

1.1. Hemispheric asymmetry in semantic processing

Neuropsychological investigations into the neural basis of creative language typically begin with the dichotomy between the two cerebral hemispheres. It is well established by now that both the left and right hemispheres (LH and RH) perform semantic processing during language comprehension (Chiarello & Beeman, 1998). However, lesion studies and divided visual field experiments have also shown that, at least in right-handed people, LH and RH contribute differently to language comprehension. In particular, LH lesions can impair the "core" language functions as in Broca's aphasia and Wernicke's aphasia, while RH lesions typically lead to impairments in applying social and discourse cues to language use (Brownell, Potter, Bihrle, & Gardner, 1986; Brownell, Carroll, Rehak, & Wingfield, 1992). RH lesion patients have been reported to have difficulties comprehending metaphor (Winner & Gardner, 1977), jokes (Brownell, Michel, Powelson, & Gardner, 1983), verbal irony (Kaplan, Brownell, Jacobs, & Gardner, 1990), indirect requests (Stemmer, Giroux, & Joanette, 1994), anaphor resolution (Brownell et al., 1992), and causal inference (Tompkins, Scharp, Fassbinder, Meigh, & Armstrong, 2008). These results have contributed to a neat, perhaps over-simplified, theoretical picture in which the LH handles the linguistic processes necessary for literal language comprehension, while the pragmatic processing relevant for figurative language resides in the RH.

However, neuroimaging, event-related potential (ERP) and behavioral studies on neurotypical individuals have complicated this neat division (see Coulson & Davenport, 2011 for a review). While an early neuroimaging study supported the prevailing hypothesis that metaphor is the province of the RH (Bottini et al.), later studies that better controlled for the difficulty of the literal and metaphorical stimuli have found more LH activation in the metaphor condition (Rapp, Leube, Erb, Grodd, & Kircher, 2004; 2007; Lee & Dapretto, 2006; Mashal, Faust, Hendler, & Jung-Beeman, 2009). Convergent evidence has come from studies of literal language comprehension that varied task difficulty. As the difficulty of the task increased, so did RH activation (St. George, Kutas, Martinez, & Sereno, 1999; Xu, Kemeny, Park, Frattali, & Braun, 2005), suggesting that difficulty, rather than figurativity per Xu et al., 2005; Mashal et al., 2009).

Researchers using ERP and reaction time methods have exploited the organization of the human visual system to target one hemisphere at a time with visual stimuli. In the divided visual field technique, a visual stimulus such as a printed word is flashed on a computer monitor far enough to the left or right of the fixation point that the word is outside of the participant's fovea. This visual information stimulates only the parts of the retina that are linked to the contra-lateral hemisphere of visual cortex. Consequently, stimuli presented in left visual field are initially processed in the right hemisphere (lvf/RH), and vice-versa for the opposite visual field (rvf/LH). Although information about this stimulus is shared with the contra-lateral hemisphere beginning about 10–20 ms after presentation, the initial targeting of one hemisphere appears to bias processing of the stimulus in that hemisphere's favor (Banich, 2002).

Researchers have also found it fruitful to combine divided visual field presentation with the recording of ERPs (see e.g. Kutas & Federmeier, 2011). A multi-dimensional signal, ERPs allow the investigator to examine how the lateralized presentation affects the brain's real time response to language stimuli. For example, examination of visual potentials in the ERP (e.g. the P1 and N1 components) can provide the investigator with evidence that the VF manipulation effectively stimulated the desired hemisphere. Examination of later components such as the N400, a neural response to meaningful stimuli that is thought to index the difficulty of retrieving semantic information in a particular context (Kutas & Hillyard, 1980, 1984; Kutas & Federmeier, 2011), and late positivities – referred to alternately as the P600 (see e.g., Kuperberg, Sitnikova, Caplan, & Holcomb, 2003), late positive complex (LPC; see e.g., Wlotko, Federmeier, & Kutas, 2012), or post-N400-positivities (PNP; see e.g. Van Petten & Luka, 2012) – can reveal how increasing the contribution of either the left or the right hemisphere affects the brain's real time response to the linguistic manipulation of interest.

Combination of the DVF techniques with ERPs is particularly valuable for examining the RH contribution to language ERP effects observed under normal processing conditions (Federmeier, Wlotko, & Meyer, 2008). For example, Coulson and Williams (2005) found that with rvf/LH presentation, the N400 was larger for the critical word in a joke than a non-joke control ("My mechanic couldn't fix my brakes, so instead he fixed my HORN/TIRES"); with lvf/RH presentation, the N400 was similar sized for jokes and non-jokes, as if joke-relevant information was more active in the RH. Accordingly, joke relevant probes ("INFIDELITY") elicited larger N400 priming effects following jokes than non-joke controls ("A replacement player hit a home run with my GIRL/BALL") with lvf/RH than rvf/LH presentation, suggesting an important RH contribution to the semantic processing of jokes (Coulson & Wu, 2005).

To date, divided visual field experiments have provided mixed evidence for the hypothesis that metaphorical language has a RH basis. An early study using two word phrases such as "stinging bee" and "stinging insult" suggested that metaphoric meanings were initially activated in both hemispheres but decayed more rapidly in LH (Anaki, Faust, & Kravets, 1998). However, attempts to replicate those results failed (Kacinik, 2003). Moreover, studies using sentential primes have shown metaphorical priming in both presentation sides (Kacinik & Chiarello, 2007) and larger metaphor priming effects in rvf/LH (Faust & Weisper, 2000). Coulson and Van Petten (2007) conducted a divided visual field study comparing the processing of sentence final words used either literally or metaphorically. Examining ERPs recorded to the lateralized critical words, they found that critical words in metaphorical sentences elicited larger amplitude N400 than those in cloze-matched literal sentences. However, the size of the N400 effect was similar with rvf/LH and lvf/RH presentation, arguing against a RH advantage for metaphorical language processing.

1.2. Theories of hemispheric asymmetry

To explain hemispheric asymmetries in processing different kinds of creative and figurative language, a number of hypotheses