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Getting it right: Word learning across the hemispheres

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ABSTRACT

The brain is able to acquire information about an unknown word's meaning from a highly constraining sentence context with minimal exposure. In this study, we investigate the potential contributions of the cerebral hemispheres to this ability. Undergraduates first read weakly or strongly constraining sentences completed by known or unknown (novel) words. Subsequently, their knowledge of the previously exposed words was assessed via a lexical decision task in which each word served as visual primes for lateralized target words that varied in their semantic relationship to the primes (unrelated, identical or synonymous). As expected, smaller N400 amplitudes were seen for target words preceded by identical (vs. unrelated) known word primes, regardless of visual field of presentation. When Unknown words served as primes, N400 reductions to synonymous target words were observed only if the prime had appeared under High sentential constraint; targets appearing in the LVF/RH elicited a small N400 effect and modulation of a subsequent late positivity whereas those in the RVF/LH elicited modulation on the late positivity only. Unknown words initially seen in Low constraint contexts showed priming effects only in a late positivity and only in the RVF/LH. Strength of contextual constraint clearly seems to impact the hemispheres' rapid acquisition of novel word meanings. N400 modulation for novel words under strong contextual constraint in the LVH/RH suggests that fast-mapped lexical representations may initially activate meanings that are weakly, distantly, associatively or thematically-related. More extensive and bilateral semantic processing seems to occur at longer processing latencies (post N400).

1. Introduction

There is now abundant evidence that both cerebral hemispheres participate in all manner of linguistic tasks, albeit differently (see Federmeier, Wlotko, & Meyer, 2008 for a review). For example, cerebral asymmetries in word knowledge have been extensively documented over the past several decades (e.g. Bouaffre & Faita-Ainseba, 2007; Burgess & Simpson, 1988; Chiarello, Burgess, Richards, & Pollock, 1990; Grose-Fifer & Deacon, 2004; Koivisto & Laine, 2000). This body of work has repeatedly revealed that both sides of the brain represent and activate non-identical aspects of known word meanings. In contrast, there has been nearly no investigation of how of novel word representations develop across the hemispheres. The major goal of this study is to address this question by exploring the potential contributions of the cerebral hemispheres to the initial representation(s) of fast-mapped word meanings.

How humans understand and represent new word meanings is most commonly investigated in young children even though the majority of our vocabulary is acquired after early childhood and throughout adulthood (Anglin, 1993; Sternberg, 1987). Learners of all ages are able to infer a word's meaning rapidly, sometimes after only a single exposure in certain contexts (a process known as fast-mapping; Carey & Bartlett, 1978; Dollaghan, 1985; Heibeck & Markman, 1987) such as when a word's meaning is strongly constrained. This rapidly acquired knowledge about word meaning is manifold, and can include awareness of its appropriate usage in a sentence and its semantic relationship to other words. However, this initially stored representation is likely to be fragile, and may change significantly with further exposure or consolidation (Dumay & Gaskell, 2007; Gaskell & Dumay, 2003). Both processes are fundamental to word learning: fast-mapping lays the foundation for future learning, while slow-mapping involves reanalysis, integration and consolidation of word meaning. In this study, we focus specifically on the hemispheric contributions to fast-mapped representations.

Older children and adult Learners may frequently encounter novel words through reading (Jenkins, Stein, & Wysocki, 1984; Nagy, Anderson, & Herman, 1987; Nagy, Herman, & Anderson, 1985;

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Sternberg, 1987), thereby requiring them to swiftly (and often implicitly) infer the meaning, appropriate usage, and semantic relationships of a word using contextual cues alone. A primary goal of this study is to examine potential hemispheric contributions to the novel word representation(s) that results from this contextual mode of fast-mapping in young adults.

To date, our understanding of initially acquired neural representations of lexical meanings has been derived from studies that probe joint or coordinated contributions from both cerebral hemispheres. This foundational work has documented that electrical brain activity can rapidly reflect acquisition of word meanings over periods ranging from a single trial to several weeks (Batterink & Neville, 2011; Borovsky, Elman, & Kutas, 2012; Borovsky, Kutas, & Elman, 2010; Friedrich & Friederici, 2008; McLaughlin, Osterhout, & Kim, 2004; Mestres-Misse, Rodriguez-Fornells, & Munte, 2007; Ojima, Nakata, & Kakigi, 2005; Perfetti, Wlotko, & Hart, 2005; Rodriguez-Fornells, Cunillera, Mestres-Misse, & de Diego-Balaguer, 2009; Stein et al., 2006; Torkildsen et al., 2008). In cases where word meanings have been acquired after only a single exposure, the strength of the contextual constraint is a critical determinant in its initial representation. Prior studies have found that strongly but not weakly constraining contexts support knowledge of appropriate usages of a word as the object of a verb, as well as an understanding of semantically-related words (Borovsky et al., 2012, 2010; Frishkoff, Perfetti, & Collins-Thompson, 2010).

A number of neuroimaging studies have examined the neuroanatomical structures involved in word learning (e.g. Breitenstein et al., 2005; Grönholm, Rinne, Vorobyev, & Laine, 2005; Mestres-Missé, Càmara, Rodriguez-Fornells, Rotte, & Münte, 2008; Paulesu et al., 2009; Shtyrov, 2012; Shtyrov, Nikulin, & Pulvermüller, 2010; Ye, MestresMissé, Rodriguez-Fornells, & Münte, 2010). This research has identified a network of regions in the left and right hemisphere (though primarily left-lateralized) associated with learning the sound and meaning of novel words. These include the hippocampus, thalamus, inferior frontal gyrus, posterior middle temporal gyrus, cerebellum, among others. Additional proposals suggest that the left hippocampus may be particularly important in the initial encoding and acquisition of word meanings (Davis & Gaskell, 2009; McClelland, McNaughton, & O'Reilly, 1995), while cortical regions are critical for further consolidation of word meanings. However, to our knowledge, no neuroimaging study has yet measured neural changes associated with fast-mapping a word's meaning after only a single exposure in context.

One prototypical way in which the individual contributions of the hemispheres can be assessed in the representation of word meaning is using a divided visual field paradigm (DVF; see Federmeier et al., 2008 for a review). This method involves randomly flashing stimuli to the right or left visual field (RVF or LVF) as a participant fixates on a central point. Lateralized presentation takes advantage of the wiring of the human visual system, which initially sends the majority of information from each visual field to the contralateral hemisphere. This brief headstart in processing is small (10 ms or so), but has been found to have prolonged consequences in behavioral and electrophysiological measurements. It is thus possible to gauge hemisphere-specific asymmetries in lexical processing via the DVF paradigm. Of course, since language function normally depends on rapid and complex inter-hemispheric communication, the function measured from each hemisphere separately in this way does not mean that central vision effects can necessarily be predicted from a simple sum of the activity of the two hemispheres (Federmeier, Mai, & Kutas, 2005). In fact, behavioral and electrophysiological responses to stimuli presented in the DVF technique can differ from centralized presentation in a number of ways. Depending on the task, responses to stimuli presented in central vision can be largely driven by the LH (e.g. Federmeier & Kutas, 1999a) or RH (e.g. Coulson & Williams, 2005), be identical in both hemispheres (e.g. Coulson, Federmeier, Van Petten, & Kutas, 2005) or be dissimilar to central presentation in both hemispheres (e.g. Wlotko & Federmeier, 2007).

As mentioned above, hemispheric representations of word meaning have been studied via time-locked electrical responses to stimuli of interest, known as event-related brain potentials (ERPs). A specific ERP component, the N400, has been particularly useful for this purpose. The N400 is a negative going potential with a centroparietal maximum peaking approximately 400 ms after the onset of any potentially meaningful stimulus (Kutas & Federmeier, 2001; Kutas & Hillyard, 1980). The N400 response has been extensively studied (Kutas & Federmeier, 2011); its amplitude varies depending on the context in which a word appears, and processing of word meaning. For example, N400 amplitudes are smaller for high frequency words compared to less frequent words (Van Petten & Kutas, 1990), for words that appear in strongly (vs. weakly) expected contexts and thus vary in their expectancy as measured in offline cloze probability (Kutas & Hillyard, 1984), or for words that are preceded by semantically related or identical (vs. unrelated words; Anderson & Holcomb, 1995; Bentin, McCarthy, & Wood, 1985; Brown & Hagoort, 1993; Deacon, Hewitt, Yang, & Nagata, 2000; Nobre & McCarthy, 1994; Ruz, Madrid, Lupianez, & Tudela, 2003). The N400 is also large for pronounceable (pseudo)words whose meaning is unknown or nonexistent (Bentin, 1987; Bentin et al., 1985). Thus N400 amplitudes range from very small when a word is easily understood and integrated into the surrounding context to very large when a (pronounceable) (pseudo)word is unexpected/incongruent or its meaning is unknown.

In addition to the N400, the late-positive component (LPC) is often elicited in conjunction with the N400. The LPC is shown as a late parietal positivity, usually largest between 500 and 900 ms. While the factors that modulate this component are still being determined, it seems to reliably indicate strategic or controlled information retrieval processing during semantic tasks (Olichney et al., 2000; Rugg & Curran, 2007; Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991), or potentially conscious recognition of prime–target relationships (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997). The LPC is thus very large (positive) in cases where meaning relationships may be consciously recognized.

Recently, acquisition of novel word meaning by adults learning words in their first (L1) and second (L2) language has been indexed by electrophysiological components like the N400 (Batterink & Neville, 2011; Borovsky et al., 2010; McLaughlin et al., 2004; Mestres-Misse et al., 2007; Ojima et al., 2005; Perfetti et al., 2005; Stein et al., 2006). These reports detail rapid changes in evoked electrical brain activity to novel words over the course of several weeks of L2 instruction (McLaughlin et al., 2004), over several trials, over the course of a few minutes in L1 (Batterink & Neville, 2011; Mestres-Misse et al., 2007; Perfetti et al., 2005), and even following a single exposure (Borovsky et al., 2012, 2010). Additionally, this work has indicated that the N400 is sensitive to the representation of various dimensions of novel word meanings, including its appropriate usage and semantic relationship to other known words (Batterink & Neville, 2011; Borovsky et al., 2012, 2010; Mestres-Misse et al., 2007; Perfetti et al., 2005).

The semantic organization of lexical knowledge has been examined with both behavioral and electrophysiological measures in the context of the well-studied semantic priming effect (Meyer, 1970). The priming effect is reflected in faster reaction times (RT) (for a review, see Neely, 1991) and/or smaller N400 amplitudes (Anderson & Holcomb, 1995; Bentin et al., 1985; Brown & Hagoort, 1993; Deacon et al., 2000; Nobre & McCarthy,