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Hemispheric differences and similarities in comprehending more and less predictable sentences

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ABSTRACT

With a growing literature demonstrating the predictive nature of language processing, the current study examines contributions of the brain's two hemispheres in processing more and less probable sentence continuations. Specifically, we use the ERP method in conjunction with the visual half-field paradigm to test for hemispheric utilization of sentential constraint to (pre-)activate lexical information and resolve meaning. Taking advantage of the N400's semantic sensitivities, we find support for both hemispheres exhibiting remarkably similar involvement, across a range of message level constraint, in meaning construction. In contrast, hemispheric ERP patterns at a later processing stage differed, as reflected in an anterior post-N400 positivity (PNP) to constraint violations for words presented to the right but not left visual field (indicating a left hemisphere processing bias). We show here that hemispheric involvement in predictive sentence comprehension varies at different stages of word processing, and we examine these patterns' (in)consistencies with findings from the hemi-field and central visual presentation literature.

1. Introduction

Views of a left hemisphere (LH) specialization for language date back centuries and are well established. However, studies in more recent decades, many relying on neuroimaging techniques, have revealed that the right hemisphere (RH), too, is capable of linguistic processing, albeit with its own set of strengths (for a few examples, see Winner and Gardner, 1977; Kaplan et al., 1990; Shapiro and Danly, 1985; Gardner et al., 1983; Lindell, 2006; Federmeier et al., 2008). One outstanding question, and the focus of the current study, is how—in particular the degree and the timing with which—the brain's two hemispheres may be biased toward using sentence- and discourse-level linguistic information to facilitate processing of subsequent more or less probable language input. This investigation is conducted within a framework that assumes readers and listeners comprehend in a generally predictive manner.

The idea of language comprehenders constructing message level representations during the course of reading or listening to sentences or discourses, and then in turn using those representations to pre-activate additional linguistic information (e.g., words), is an idea that has become more widely accepted in the past decade (see DeLong et al., 2014b; Kutas et al., 2011; Kuperberg and Jaeger, 2016; Federmeier, 2007 for reviews). Online methods, such as event-related brain potentials (ERPs) and eye tracking, have been critical for establishing that there is a predictive time course to comprehension. Some of this work has relied on the N400 ERP component, a negative-going waveform peaking around 400 ms post-stimulus onset, which is part of the brain's normal response to semantic processing of a meaningful stimulus in context. N400 studies have uncovered evidence for semantic prediction at various levels, e.g., for lexical, categorically-related, event-related, and conceptually similar information (e.g., DeLong et al., 2005; Thornhill and Van Petten, 2012; Federmeier and Kutas, 1999a; Metusalem et al., 2012; Boudewyn et al., 2015). In conjunction with these findings, there is also growing support for the idea that there may be processing consequences, when predictions are not validated by the input. An important aspect of our own research (DeLong, Urbach, Groppe and Kutas, 2011; DeLong, Quante and Kutas, 2014; DeLong, Groppe, Urbach and Kutas, 2012) has been detecting effects of constraint violation: that is, if pre-activation during language comprehension runs as a sort of

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default mode, then the neural system may be caught off guard by a surprising but nevertheless sensible continuation.

In previous studies, we have reported two main findings that argue strongly for predictive sentence processing. The first is pre-critical word evidence for pre-activation of likely upcoming words. For instance, in sentence contexts such as '*The day was breezy so the boy went outside to fly…*', N400 amplitudes to English indefinite articles (*a*, *an*) preceding more and less expected critical nouns (*kite*, *airplane*, respectively) were correlated with offline cloze probability estimates of expectancy (DeLong et al., 2005). Accompanying this effect, DeLong et al. (2011), as well as DeLong et al., (2012, 2014a), reported a late (post-N400) sustained frontal, somewhat left ERP positivity to low cloze probability but plausible continuations of highly constraining sentence contexts (e.g., *airplane* in the previous example). This positivity also has been reported by others, under similar experimental circumstances, to unexpected but acceptable continuations in sentences or discourses (Federmeier et al., 2007; Thornhill and Van Petten, 2012; Moreno et al., 2002; Coulson and Van Petten, 2007; Kutas, 1993; Brothers et al., 2015; Boudewyn et al., 2015).

In fact, this late anterior ERP positivity has been proposed to be part of a larger family of late positivities that has begun to be associated with the receipt of information that disconfirms linguistic predictions. Generically, these have been referred to as post-N400 positivities or PNPs (Van Petten and Luka, 2006). Van Petten and colleagues (Van Petten and Luka, 2012; Thornhill and Van Petten, 2012) have outlined distinct PNPs, with varying scalp distributions and sensitivities: a more posteriorally distributed PNP occurring in conjunction with semantically incongruent continuations, and a more anteriorally distributed (often larger over left scalp sites) PNP arising from unexpected but sensical continuations to highly predictable contexts (also see DeLong et al., 2014a). A slightly different contrast is drawn by Kuperberg (2013), who suggests that it is event or structural prediction errors that trigger posterior PNPs (P600s) and lexical prediction errors that trigger more anterior PNPs. A common thread, however, is that anterior PNPs reflect some type of prediction violation cost.

Anterior PNPs occurring in sentence expectancy studies have only recently begun to be systematically examined. This may be due in part to the fact that unlike the widely reported N400s in such studies, the anterior PNP occurs rather inconsistently (Van Petten and Luka, 2006 provide as comprehensive a catalog as any, of such PNP findings). What is known, is that important eliciting conditions for the anterior PNP seem to be that they occur (1) to plausible continuations, or as Boudewyn et al. (2015) suggest, under circumstances in which at least some contextual support is available to trigger updating, and (2) in moderately to highly constraining sentence contexts. Thornhill and Van Petten (2012) also found that the anterior PNP can be elicited by unexpected words both related and unrelated to the expected continuation.

Various functional explanations for the anterior PNP have been proposed, but a clear picture has not yet emerged. At a more general level, it is thought to index some cost to revising discourse representations when unexpected words are received (e.g., Federmeier et al., 2007; Brothers et al., 2015). Thornhill and Van Petten (2012) and Kuperberg (2013) suggest that it indexes a sensitivity to specific lexical word forms, rather than to conceptual expectations. Other proposals range from inhibition of expected but not encountered words (Kutas, 1993), to arguments that it relates to a learning/adaptation mechanism (Kuperberg and Jaeger, 2016; Davenport and Coulson, 2013), where mental models are updated to reflect probabilities in the current environment. Kuperberg and Jaeger (2016) also suggest that PNPs may index a sort of "model switching", reflecting a reallocation of resources to a model corresponding to more immediate statistical patterns.

As mentioned earlier, observations of the anterior PNP have sometimes indicated a more left scalp distribution. While scalp distributions of ERPs are not roadmaps to underlying current sources, the somewhat lateralized scalp pattern is nonetheless suggestive of a hemispheric bias in the processing reflected by the ERPs (an idea also not incompatible with the LH's more general specialization for language). Questions about the hemispheres' roles in dealing with failed linguistic predictions are also grounded in larger debates about the roles the hemispheres play in constructing message level meaning during sentence and discourse comprehension. For instance, some have suggested that the RH, but not the LH, is "message-blind". Several studies (e.g., Chiarello, 2000; Faust, 1998; Faust and Kravetz, 1998) posit that while the LH is capable of integrating information at various linguistic levels to form message-level representations, the RH constructs meaning more on the basis of word-level association, in a bottom-up fashion. This proposition stems in part from behavioral studies manipulating sentence constraint, in which word continuations processed preferentially by the LH showed graded facilitation as indexed by lexical decision times: words processed by the RH, on the other hand, benefitted only from the highest levels of constraint. In another study (Faust et al., 1995), scrambled sentential word order led to priming effects similar to those for congruent sentences for RH-biased processing, whereas LH-biased processing benefitted only from properly ordered sentences.

In contrast to this RH "message-blind" model, others have argued that the RH *can* be involved in constructing message-level meaning. For instance, Coulson et al. (2005) combined the visual hemi-field (VHF) paradigm with ERPs to pit effects of word-level versus sentential-level priming. In the VHF technique, stimuli are presented a few degrees to the left or right of fixation in order to expose only the contralateral hemisphere to that stimulus for the first approximately 10 ms or so (Banich, 2003). The consequence of this slight head start in apprehending the stimulus results in hemispheric processing differences that carry over even into relatively late stages of processing, which, by inference, reflect how the two hemispheres handle different linguistic variables. Coulson et al. (2005) found that isolated associated word pairs and the same words pairs embedded in sentences showed similar ERP priming and context effects, respectively, regardless of visual field of presentation (VF)/hemisphere, as indexed by reduced N400 amplitudes to congruous endings. Decreases in N400 amplitude are thought to be associated with increased semantic activation levels for those items. N400 congruity effects as well as sensitivity to degree of cloze probability at various levels of message level constraint have been demonstrated for processing biased to both hemispheres by others, as well (e.g., Federmeier and Kutas, 1999b; Federmeier et al., 2005). Indeed, Federmeier and colleagues have argued that sentence level constraints facilitate semantic language processing in both hemispheres, but in somewhat different ways. For instance, Federmeier and Kutas (1999b) compared lateralized expected sentence completions to within category (related) and between category (unrelated) violations in high and low constraint sentences. Although both violation types (judged similarly implausible) showed larger N400s relative to expected items, the N400 to the related violations was reduced relative to unrelated violations only for right visual field/left hemisphere (RVF/LH) presentation and only for those contexts in which the critical nouns were highly constrained. These results were explained by the greater overlap in perceptual and semantic features of the related violation with the expected exemplar, and were interpreted as contextual information acting via semantic memory to pre-activate some of the features of the expected exemplar. In contrast, the LVF(RH) exhibited a pattern more consistent with bottom-up processing, where input is integrated only once it is received.

Also at the intersection of hemispheric sentence processing and