CORTEX 68 (2015) 20–32

Available online at www.sciencedirect.com

ScienceDirect

Journal homepage: www.elsevier.com/locate/cortex

Special issue: Research report

Time for prediction? The effect of presentation rate on predictive sentence comprehension during word-by-word reading

Edward W. Wlotko [a,*] *and Kara D. Federmeier* [a,b,c]

[a] *Department of Psychology, University of Illinois, Champaign, IL, USA*
[b] *Beckman Institute, University of Illinois, Champaign, IL, USA*
[c] *Program in Neurosciences, University of Illinois, Champaign, IL, USA*

ARTICLE INFO

Article history:
Received 2 October 2014
Reviewed 5 November 2014
Revised 26 January 2015
Accepted 15 March 2015
Published online 1 April 2015

Keywords:
Prediction
Sentence processing
Timing
Event-related potentials
N400

ABSTRACT

Predictive processing is a core component of normal language comprehension, but the brain may not engage in prediction to the same extent in all circumstances. This study investigates the effects of timing on anticipatory comprehension mechanisms. Event-related brain potentials (ERPs) were recorded while participants read two-sentence mini-scenarios previously shown to elicit prediction-related effects for implausible items that are categorically related to expected items ('They wanted to make the hotel look more like a tropical resort. So along the driveway they planted rows of PALMS/PINES/TULIPS.'). The first sentence of every pair was presented in its entirety and was self-paced. The second sentence was presented word-by-word with a fixed stimulus onset asynchrony (SOA) of either 500 msec or 250 msec that was manipulated in a within-subjects blocked design. Amplitudes of the N400 ERP component are taken as a neural index of demands on semantic processing. At 500 msec SOA, implausible words related to predictable words elicited reduced N400 amplitudes compared to unrelated words (PINES *vs* TULIPS), replicating past studies. At 250 msec SOA this prediction-related semantic facilitation was diminished. Thus, timing is a factor in determining the extent to which anticipatory mechanisms are engaged. However, we found evidence that prediction can sometimes be engaged even under speeded presentation rates. Participants who first read sentences in the 250 msec SOA block showed no effect of semantic similarity for this SOA, although these same participants showed the effect in the second block with 500 msec SOA. However, participants who first read sentences in the 500 msec SOA block continued to show the N400 semantic similarity effect in the 250 msec SOA block. These findings add to results showing that the brain flexibly allocates resources to most effectively achieve comprehension goals given the current processing environment.

* *Corresponding author*. Department of Psychology and Sackler School of Graduate Biomedical Sciences, Tufts University, 490 Boston Avenue, Medford, MA 02155, USA.
E-mail addresses: ewwlotko@alumni.pitt.edu (E.W. Wlotko), kfederme@illinois.edu (K.D. Federmeier).
http://dx.doi.org/10.1016/j.cortex.2015.03.014
0010-9452/

1. Introduction

The ability to learn and exploit regularities in the environment is a fundamental feature of the nervous system (Bar, 2011). As such, the anticipatory use of sensory information in a context-sensitive manner underlies neural responses associated with many levels of processing, from early perceptual effects through complex higher level cognition. Indeed, a great deal of evidence has accumulated pointing toward prediction as a core component of normal human language processing. The use of contextual cues in the language stream can allow the pre-activation of features of likely upcoming input at multiple levels and grains of representation (see, e.g., Kutas, DeLong, & Smith, 2011). In this study, we examine the role of timing in the ability of predictive processing to affect on-going semantic processing during sentence comprehension.

Event-related brain potentials (ERPs) have provided key evidence for anticipatory language processing mechanisms. As a direct measure of neural activity with millisecond-level temporal resolution, the technique provides a view of ongoing brain activity as it occurs in real time. Furthermore, ERPs can be measured continuously and without an overt secondary task over and above attending to and comprehending language. Therefore, brain responses can be measured before, during, and downstream from experimental manipulations of predictability.

In a series of ERP studies designed to probe interactions between contextual influences on word processing and the structure of semantic memory, Federmeier and colleagues showed that two-sentence mini-discourse contexts that constrain for a particular sentence completion can lead to pre-activation of semantic features of expected words (Federmeier & Kutas, 1999a, 1999b; Federmeier, McLennan, De Ochoa, & Kutas, 2002). For example, given the context, *'They wanted to make the hotel look like a tropical resort. So, along the driveway, they planted rows of…'* many people[1] would expect the sentence to end with the word *'palms'*. Consistent with all ERP studies of sentence comprehension, brain responses showed an effect of semantic context, evident in a comparison between expected words and words that violate expectations. In Federmeier et al.'s studies, message-level expectations were violated with words of a different semantic category than expected words, such as the completion *'tulips'* in the example sentence. This effect was apparent on the N400 component of the ERP, a neural measure of the demands on semantic processing. An observed reduction in the amplitude of the N400 is interpreted as evidence of facilitated semantic processing (for a complete discussion see Kutas & Federmeier, 2011). Thus, expected words elicit smaller N400 amplitudes than words that violate contextual constraints, taken as an indication that the context has 'eased' processing of the meaning of the expected word.

The critical manipulation in this paradigm is a third type of stimulus that also violates message-level expectations but that overlaps significantly in semantic features with the word expected in each context. This condition was created by choosing words from the same semantic category as the expected word (e.g., *'pines'*). These 'within-category' violations elicited N400 amplitudes intermediate in size compared to the expected words and the 'between-category' violations. Thus, brain responses showed simultaneous effects of contextual expectations and the out-of-context structure of semantic memory. Importantly, this pattern provides evidence that the brain can use context to pre-activate semantic features of upcoming words. The logic of this inference rests on the observation that both within- and between-category violations disconfirm message-level expectations, so that neither type of word is an appropriate completion to the context. The reduction in N400 amplitude for the within-category violations, therefore, is due to the contextual pre-activation of semantic features of the expected (but never presented) words, which overlap to a greater degree with the features of the within-category violations compared to between-category violations. Further support for this interpretation of the results was provided by an examination of constraint: this semantic similarity effect was larger in strongly constraining (more predictable) contexts compared to less constraining contexts.

In addition to providing evidence for contextual pre-activation of semantic features, ERP studies have also demonstrated that the brain can generate predictions of orthographic, grammatical/syntactic, and phonological features of words (DeLong, Urbach, & Kutas, 2005; Laszlo & Federmeier, 2009; Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wicha, Moreno, & Kutas, 2004). Similar findings have been reported in studies using other paradigms and methodologies, such as behavioral decision times and eye-tracking (Kamide, Altmann, & Haywood, 2003; Schwanenflugel & LaCount, 1988).

In light of this large body of evidence, the predictive nature of typical language comprehension is well established. However, prediction is not necessarily engaged to the same extent across all processing circumstances. For example, recent work on second language acquisition suggests that native-like prediction may depend on factors such as proficiency and similarity of the first and second languages (Foucart, Martin, Moreno, & Costa, 2014; cf. Kaan, 2014; Martin et al., 2013). Additionally, age-related changes may lead to decreased reliance on contextual pre-activation for older adults (see Wlotko, Lee, & Federmeier, 2010). Recently, we have demonstrated that monolingual young adults, too, fail to pre-activate predictable words when placed in an environment that reduces the validity of contextual cues for predicting a specific word in a given context. For example, when strong predictions are violated with synonyms of the predictable words, electrophysiological signs of prediction are diminished (Wlotko & Federmeier, 2011). This flexibility in the implementation of anticipatory comprehension mechanisms suggests that predictive processing is at least partially resource-dependent.

We have argued that predictive comprehension arises through production-like mechanisms (Federmeier, 2007; cf. MacDonald, 2013; Pickering & Garrod, 2013). That is, neural systems that subserve language production are engaged during ongoing language comprehension. This view was motivated in part by exploring hemispheric asymmetries in

[1] In studies of prediction in sentence comprehension, expectancy is typically operationalized by cloze probability (Taylor, 1953), the empirically estimated proportion of individuals who would complete a particular context with the same word.