No prediction error cost in reading: Evidence from eye movements

Steven Frisson [a,*], David R. Harvey [b], Adrian Staub [c]

[a] *University of Birmingham, UK*
[b] *University of Warwick, UK*
[c] *University of Massachusetts, Amherst, United States*

A R T I C L E   I N F O

A B S T R A C T

Two eye movement while reading experiments address the issue of how reading of an unpredictable word is influenced by the presence of a more predictable alternative. The experiments replicate the robust effects of predictability on the probability of skipping and on early and late reading time measures. However, in both experiments, an unpredictable but plausible word was read no more slowly when another word was highly predictable (i.e., in a constraining context) than when no word was highly predictable (i.e., in a neutral context). In fact, an unpredictable word that was semantically related to the predictable alternative demonstrated facilitation in the constraining context, in relatively late eye movement measures. These results, which are consistent with Luke and Christianson's (2016) corpus study, provide the first evidence from a controlled experimental design for the absence of a prediction error cost, and for facilitation of an unpredictable but semantically related word, during normal reading. The findings support a model of lexical predictability effects in which there is broad pre-activation of potential continuations, rather than discrete predictions of specific lexical items. Importantly, pre-activation of likely continuations does not result in processing difficulty when some other word is actually encountered.

© 2017 Elsevier Inc. All rights reserved.

Introduction

When reading or listening, it is sometimes possible to anticipate which word will appear next in a sentence, and it is very clear that the predictability of a word has consequences for processing during incremental comprehension. Eye movement studies have shown that a predictable word, as measured by the word's cloze probability (i.e., the proportion of participants in an off-line production task who complete a sentence fragment using the word; Taylor, 1953), receives shorter eye fixations during reading than does an unpredictable word (e.g., Balota, Pollatsek, & Rayner, 1985; Rayner & Well, 1996; Zola, 1984) and is less likely to be fixated at all, i.e., the word skipping rate is higher (e.g., Altarriba, Kroll, Sholl, & Rayner, 1996; Rayner & Well, 1996). Staub (2015) reviews this literature. Evidence that predictability can facilitate processing also comes from electrophysiological data. The N400 is a negative peak in Event Related Potential (ERP) recordings that occurs approximately 400 ms after the onset of a word during either visual or auditory presentation of sentences. The amplitude of this response is increased when a word provides a poor semantic fit in its context (Kutas & Hillyard, 1980, 1983), but also when a

word is relatively unexpected, as measured by cloze probability (Federmeier & Kutas, 1999; Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007; Kutas & Hillyard, 1984).

The main focus of the present study is on the processing of a word that is relatively *un*expected in its context. We use eyetracking during reading to address two questions regarding processing of an unexpected word. The first is whether there is an additional processing cost associated with encountering a low cloze probability word in a context in which another word is highly predictable. A word may have low cloze probability following a context for which there is no word that has high cloze probability, i.e., a *neutral* context. On the other hand, a word may have low cloze probability when there is some other word that does have high probability as a cloze continuation, i.e., in a *constraining* context. Assuming that a given low cloze probability word is a sensible continuation in both cases, is there nonetheless a processing disadvantage when this word occurs in the constraining context? We refer to such a potential cost as a *prediction error cost*, as it would presumably reflect inhibition related to the fact that a specific lexical prediction has not been satisfied. A prediction error cost would suggest that, in a constraining context, a comprehender does specifically expect the high cloze probability continuation. The lack of a prediction error cost, on the other hand, would suggest that readers do not typically maintain specific lexical expectations that

---

* Corresponding author at: School of Psychology, University of Birmingham, Edgbaston B15 2TT, UK.

E-mail address: s.frisson@bham.ac.uk (S. Frisson).

are undermined when an unexpected, but sensible, word is encountered instead. In the General Discussion, we return to the question of how such a negative answer is best interpreted.

The second question we address is whether the processing of a low cloze probability word in a constraining context is modulated by the degree to which this word is related in meaning to the more predictable alternative. If an unpredictable word is closely related in meaning to a more expected word, does this relationship facilitate processing? Again, the answer to this question has the potential to inform our understanding of the nature of contextually based expectations in language processing. A positive answer might suggest that context may generate expectations at the level of semantic features or semantic categories, not merely at the level of specific words. However, depending on the empirical details, a positive answer might also implicate the role of late, integrative processes. Specifically, a word that is related to a predictable word may be easier to integrate into the discourse context, even if the word itself is not actually expected.

Several ERP experiments (e.g., Federmeier et al., 2007), thoroughly reviewed by Van Petten and Luka (2012; see also Kutas, DeLong, & Smith, 2011), have investigated the question of whether the N400 is increased for a low-predictability word in a constraining context compared to a neutral context. Van Petten and Luka's (2012) review concludes that while the amplitude of the N400 is very sensitive to the gradations of cloze probability, it is *not* modulated by violation of expectations; they remark that, "current data….provide little hint that amplitudes are increased when an hypothesis/expectation/prediction is disconfirmed" (p. 180). However, they also discuss several studies that have reported a distinct effect in these circumstances, a late positivity that tends to have a frontal scalp distribution. More recently, Delong, Quante, and Kutas (2014) confirmed such a late positivity. In sum, while there is some ERP evidence that contextual constraint may modulate the electrophysiological response to a low cloze probability word, the effect appears to be distinct from the N400 effect of a word's predictability itself, and is delayed relative to this effect.

However, another ERP study using a different logic (Van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; see also DeLong, Urbach, & Kutas, 2005; Wicha, Moreno, & Kutas, 2004; though cf. Nieuwland et al., 2017) arguably points to the conclusion that encountering unpredicted input in a constraining context is disruptive. Van Berkum et al. made use of the fact that Dutch prenominal adjectives agree with the following noun in syntactic gender. Two ERP experiments revealed a distinct effect when readers encountered a prenominal adjective that did not agree in gender with a high cloze probability noun, though the noun had yet to be encountered. Van Berkum et al., who also obtained a hint of a similar effect in a self-paced reading experiment, interpreted these findings as evidence that language comprehenders do predict specific words, with disruption appearing as soon as these predictions are shown to be incorrect.

ERPs have also been used to address the second of the questions outlined above, the question of whether processing of a low cloze probability word is influenced by semantic relatedness between this word and a more expected continuation. In a well-known study, Federmeier and Kutas (1999; see also Federmeier, McLennan, De Ochoa, & Kutas, 2002) manipulated whether the final noun in a constraining sentence was an expected target, an unexpected target from the same semantic category as the expected target, or an unexpected target from a different category (e.g., "The gardener really impressed his wife on Valentine's Day. To surprise her, he had secretly grown some *roses/tulips/palms*"). They found a reduced N400 for unexpected, within-category targets, compared to unexpected, between-category targets.

One potential drawback of most ERP experiments, however, is the unnatural presentation of stimuli (see Clifton & Staub, 2011;

Rayner, Ashby, Pollatsek, & Reichle, 2004; Schotter, Tran, & Rayner, 2014). Words or phrases are typically presented for a fixed amount of time in Rapid Serial Visual Presentation (RSVP) format. On the one hand, the time available to process each word is usually substantially longer than the time taken to read a word in normal reading. On the other hand, re-reading is not possible. In addition, word skipping, which is a normal part of reading and can be indicative of successful pre-processing of upcoming words (more predictable words are more often skipped, e.g., Drieghe, Rayner, & Pollatsek, 2005), is precluded. As a result, it is possible that participants in ERP studies generate predictions more actively, or in a different way, than would be the case in normal reading. Evidence does indeed suggest that prediction can be context- or task-dependent (e.g., Brothers, Swaab, & Traxler, 2017; Huettig & Mani, 2016). For example, in a visual world study, Huettig and Guerra (2015) found that with a normal speech rate, anticipation effects were observable if participants had a long preview (4 s) of the visual scene, but not when the preview was shorter (1 s). Of direct relevance to the interpretation of predictability effects in ERP experiments is the finding by Dambacher et al. (2012) that the rate of RSVP presentation influences the size of predictability-related N400 effects, with smaller effects emerging at rates that approximate natural reading. Also relevant is the recent finding by Brothers et al. (2017) that the predictability-related N400 effect with RSVP presentation was magnified when subjects were explicitly instructed to make lexical predictions, compared to when they simply read for comprehension. Together, these considerations suggest that it is critical to address the issue of prediction error cost in more natural reading paradigms.

Related results from a self-paced reading paradigm have been reported by Roland, Yun, Koenig, and Mauner (2012), who found that reading time was predicted not only by a word's cloze probability, but also by the word's degree of semantic relatedness to other cloze completions. Roland et al. compared reading times for target words after contexts such as "jabbed/attacked the angry lion with…". In a cloze task, the former verb elicited completions that were all pointed weapons (e.g., spear, knife) while the latter elicited some pointed weapons, but also other types of implements (e.g., rock, gun). They found that reading times for the completions were predicted by cloze probability, as expected, but that the semantic similarity of the target word to other possible completions independently affected reading times: Participants read words faster when other words that could have appeared in the same context were highly semantically related to the presented word, as measured by Latent Semantic Analysis (LSA; Landauer & Dumais, 1997). Roland and colleagues suggested that this effect can arise either due to words that are semantically related to an expected word becoming strongly activated by means of spreading activation within the lexicon (e.g., Neely, 1977), or by independent activation of multiple words with semantic features that would satisfy the constraints set by the context.

An older study by Schwanenflugel and LaCount (1988), in which subjects made lexical decisions to words presented after sentence contexts, also reached the conclusion that semantic relatedness between a word and the expected completion influences processing, but found that this influence depended on the context's degree of constraint. In this study, highly constraining sentences (mean cloze probability of modal response = 88.2%) reduced lexical decision latency only for the most expected completion. However, lower-constraint (but still relatively constraining) sentences (mean cloze probability of modal response = 51.6%) facilitated lexical decisions for both expected and semantically related completions, but not for completions unrelated to the expected word. Schwanenflugel and LaCount suggested that a constraining context establishes restrictions on the features a possible completion must possess. When a word's semantics matches these restrictions, pro-