



## Original Articles

# Cognitive control ability mediates prediction costs in monolinguals and bilinguals

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## ABSTRACT

In this study, we examined the role that cognitive control and language regulation ability play in mediating readers' susceptibility to prediction error costs when reading in the native language (L1) or a second language (L2). Twenty-four English monolinguals (Experiment 1) and 28 Chinese-English bilinguals (Experiment 2) read sentences in English while their EEG was recorded. The sentences varied in the predictability of an upcoming expected word and in whether that prediction was confirmed. Monolinguals showed sensitivity to sentence contexts in which expectations were not met (i.e., when unexpected words were encountered) in the form of a late, frontally-distributed positivity, but for bilinguals this effect was more complex. For both groups, performance on the prediction task was modulated by individual differences on the AX-CPT, a measure of inhibitory control. However, the bilinguals' reading performance in the L2 was affected not only by inhibitory control, but also by their performance on an L1 verbal fluency task that indexed language regulation and production capability, related to their language dominance and immersion context. Bilinguals with better regulation of the L1 generated a larger frontal positivity in response to unexpected words in the L2, an effect that was attenuated by inhibitory control ability. In contrast, bilinguals with lower regulatory ability generated a larger, late negativity, which was also mediated by control. These findings suggest that the ability to regulate the native language when immersed in a second language environment can influence mechanisms underlying the prediction process when reading in the L2. In addition, cognitive control ability, specifically inhibitory control, appears to mediate the difficulty readers incur when predictions are disconfirmed, not only in the native language, but also for proficient bilinguals reading in the L2. We argue that the mechanisms engaged during prediction in the L1 and L2 are fundamentally the same, and that what differs for bilinguals are the additional demands imposed by their language experience and language use.

## 1. Introduction

Prediction errors, and their neurological and behavioral repercussions, have been the focus of recent research across multiple cognitive domains, including attention, perception, action, learning, social motivation, and decision-making (for reviews, see Bubic, von Cramon, & Schubotz, 2010; den Ouden, Kok, & de Lange, 2012). Prediction itself has been proposed to be a hallmark of the human cognitive experience, especially the ability to efficiently adapt when conflicts or errors arise to contradict an individual's expectations. Prediction errors can take many forms, and their magnitude often depends upon how frequently errors have occurred, how rewarding it is to adapt to these errors, and whether an individual is personally motivated to do so. An additional concern is whether it is likely that predictions have been generated and how strong those predictions may be, as any error experienced as a

result of a disconfirmed prediction should be proportionate to the strength of the prediction that had previously been formed. In this paper, we present evidence from two experiments in the language domain that attempt to elucidate aspects of prediction that are common across multiple cognitive domains: (1) when predictions are likely to be generated, and (2) what mechanism(s) may attenuate prediction errors and potentially contribute to later adaptation. We do this by utilizing two groups of readers: monolinguals reading in their native language (L1) and bilinguals reading in their highly proficient, but second language (L2).

### 1.1. Prediction in language processing

In the language domain, readers and listeners use contextual information to generate expectations about the meaning of upcoming

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words, an effect that has been demonstrated quite extensively in both sentence and discourse processing (see Federmeier, 2007; Van Berkum, 2008, for reviews). For example, sentences like (1) that are more highly semantically constraining tend to result in processing benefits for high cloze or expected target words (e.g., *disease*) when compared to sentences like (2) that are less semantically constraining.

- (1) The woman was born with a rare *disease*.  
 (2) The woman had discovered a rare *disease*.

This benefit is often indexed by a reduction in the amplitude of the N400 event-related potential (ERP), which is widely regarded as an electrophysiological index of lexico-semantic activation (Federmeier & Kutas, 1999; Kutas & Hillyard, 1984; Van Berkum, Hagoort, & Brown, 1999; Van Petten, 1993; for a review, see Swaab, Ledoux, Camblin, & Boudewyn, 2011). Previous research has suggested that these effects are the result of readers being able to take advantage of the highly constraining context in such a way that semantic features of the expected target word were active before it was actually encountered in the sentence. However, it can be difficult to disentangle whether modulation of the N400 ERP effect is due to prior prediction, later lexical access and/or semantic integration, or some combination of these processes (except in cases where these EEG effects are tied to situations in which prediction is likely to have occurred, e.g., Brothers, Swaab, & Traxler, 2015, or when these effects manifest in prior discourse, e.g., Van Berkum, 2012).

In addition to these processing benefits, several studies have also reported that readers incur costs when the predictions that they have generated are not verified later in the sentence (e.g., DeLong, Groppe, Urbach, & Kutas, 2012; Federmeier, Kutas, & Schul, 2010; Federmeier, McLennan, De Ochoa, & Kutas, 2002; Federmeier, Wlotko, De Ochoa-Dewald, & Kutas, 2007). In contrast to sentences like (1), comprehenders who encounter sentences like (3) tend to generate a larger, frontally-distributed positivity between 500 and 900 ms after the onset of an unexpected, though plausible, target word (i.e., *gift*).

- (3) The woman was born with a rare *gift*.

Importantly, this late, frontally-distributed positivity is an effect that typically manifests in cases where plausible violations of a prediction have occurred, making it a useful index of the repercussions of prediction processes. In the language domain, it has largely been found in work involving the processing of unexpected words in highly predictable or constraining contexts (e.g., with jokes; Coulson & Wu, 2005), and is often interpreted as a repercussion of comprehenders having to revise or suppress a previously generated prediction (e.g., Federmeier et al., 2007; or discourse representation, e.g., Brothers et al., 2015). The ability to predict upcoming words and to quickly recover when predictions are disconfirmed (i.e., to adapt quickly to a situation where a meaningful conflict occurs) could, therefore, result in a reduction in processing load and free up cognitive resources for other tasks. A question that remains, then, is to what extent constraints on cognitive resources may affect prediction generation and recovery. One way to further examine this is to investigate possible changes in the prediction process when readers are engaged in a highly resource-demanding task, such as reading in the L2. Contexts that increase cognitive demand in language processing are also likely to affect the prediction process. As such, we might expect that reading and predicting in an L2 will mimic the same processes when individuals read under conditions with increased cognitive load.

### 1.2. Prediction in a second language

Bilinguals may provide a unique opportunity for understanding the way cognitive resources are engaged during online processing. When bilinguals read or speak in one of their languages, the language not in

use is also active (e.g., Van Hell & Tanner, 2012). As a result, information from the non-target language often affects performance (especially in the L2; see Kroll & Dussias, 2013). This can involve cross-language conflict (e.g., with interlingual homographs or homophones, and for competing syntactic parsing preferences) or overlap, when the two languages converge in a manner that supports processing (e.g., with cognate words or parsing preferences shared across both languages). Efficiently regulating this cross-language activation, to allow for appropriate cross-language support and suppress irrelevant cross-language interference, is a necessary part of successful communication and comprehension for bilinguals. Due to these constraints, highly proficient L2 comprehension may provide a unique opportunity for understanding how cognitive resources are engaged during online prediction, in a way that may not as easily be revealed through the very skilled, native reading of monolinguals.

Several studies have now shown that young adults are capable of rapidly forming expectations when reading or listening for comprehension in their native language. If the ability to predict the meaning of upcoming words is a hallmark of skilled comprehension in young adulthood, then predicting in the L2 may be a natural part of attaining high L2 proficiency. To our knowledge, only a few published studies have investigated prediction during L2 comprehension (Foucart, Martin, Moreno, & Costa, 2014; Foucart et al., 2015; Kaan, Kirkham, & Wijnen, 2016; Martin et al., 2013; but see the following for work on the effect of contextual constraint on L2 sentence processes: Lagrou, Hartsuiker, & Duyck, 2013; Schwartz & Kroll, 2006; Titone, Libben, Mercier, Whitford, & Pivneva, 2011; Van Assche, Drieghe, Duyck, Welaert, & Hartsuiker, 2011; Van Hell & De Groot, 2008). Martin et al. (2013) had Spanish-English bilinguals (reading in the L2, English) and English monolinguals read highly semantically constraining sentences with either expected or unexpected sentence-final nouns. For example, in (4), *singer* is expected and *artist* is unexpected. This in turn changes the expectancy of the preceding article, with “a” being more expected because it would precede *singer*, and “an” being less expected because it would precede *artist*, at least for readers who are actively predicting the expected word.

- (4) She has a nice voice and always wanted to be (a *singer*/an *artist*).

The authors aimed to identify effects of prediction or prediction costs prior to the expected or unexpected target word. For monolinguals, as expected, N400 responses to the article preceding an unexpected noun were larger than for the article preceding the expected noun, suggesting that native readers were predicting not only the meaning of the final word, but also its orthographic form (i.e., whether it began with a vowel or a consonant). Monolinguals also produced a larger frontal positivity to the articles preceding the unexpected nouns, reflecting early difficulty with encountering a prediction error. This effect was not found for bilinguals, however, who only showed a larger N400 effect for unexpected words. Based on these results, the authors suggested that L2 processing may occur too slowly in the L2 (Frenck-Mestre & Pynte, 1997) for predictions to either be generated or for preactivation to occur rapidly enough for prediction costs to be incurred. However, the L2 readers in this study were still capable of taking advantage of semantic information in prior context (leading to changes in N400 amplitude for expected and unexpected nouns), suggesting a reasonably high level of L2 proficiency.

Bilinguals may be less likely or less able to engage in language processing in the L2 on par with native speakers of that language (Clahsen & Felser, 2006), possibly due to the constraints and/or cognitive demands that L2 processing imposes (Hasegawa, Carpenter, & Just, 2002; McDonald, 2006). Based on the results from the study by Martin et al. (2013), this may also be the case for semantic prediction in the L2. However, a recent ERP study demonstrated that, when bilinguals’ two languages are more closely related (e.g., for Spanish and French), both early and late acquirers of an L2 are capable of

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