



Alignment as a consequence of expectation adaptation: Syntactic priming is affected by the prime's prediction error given both prior and recent experience



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ABSTRACT

Speakers show a remarkable tendency to align their productions with their interlocutors'. Focusing on sentence production, we investigate the cognitive systems underlying such alignment (syntactic priming). Our guiding hypothesis is that syntactic priming is a consequence of a language processing system that is organized to achieve efficient communication in an ever-changing (subjectively non-stationary) environment. We build on recent work suggesting that comprehenders adapt to the statistics of the current environment. If such adaptation is rational or near-rational, the extent to which speakers adapt their expectations for a syntactic structure after processing a prime sentence should be sensitive to the prediction error experienced while processing the prime. This prediction is shared by certain error-based implicit learning accounts, but not by most other accounts of syntactic priming. In three studies, we test this prediction against data from conversational speech, speech during picture description, and written production during sentence completion. All three studies find stronger syntactic priming for primes associated with a larger prediction error (primes with higher syntactic surprisal). We find that the relevant prediction error is sensitive to both prior and recent experience within the experiment. Together with other findings, this supports accounts that attribute syntactic priming to expectation adaptation.

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1. Introduction

When we talk, we align with our conversation partners along various levels of linguistic representation. This includes decisions about speech rate and how we articulate sounds, as well as lexical and structural decisions. Here we focus on alignment of syntactic structure, also known as syntactic priming or structural persistence (Bock, 1986; Pickering & Branigan, 1998). Syntactic priming has received an enormous amount of attention in the psycholinguistic literature (for a recent overview, see Pickering

& Ferreira, 2008). With respect to language production, which we will be concerned with here, syntactic priming refers to the increased probability of re-using recently processed syntactic structures. For example, comprehending a passive sentence (e.g., *The church was struck by lightning*) increases the probability of encoding the next transitive event with a passive rather than an active structure.

A large body of work has investigated under what conditions syntactic priming is observed. Thanks to this work, it is known that syntactic priming is observed in both spoken and written production and that it is observed independent of whether the prime was produced or comprehended (to name just two findings). What has emerged from this work is that priming effects are small but robust. Others have investigated what factors modulate the *strength of syntactic priming* – that is, the

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magnitude of the increase in the probability of re-using the syntactic structure of the prime. For example, a stronger priming effect is observed for target sentences with the same verb as the prime, compared to targets that do not overlap lexically with the prime (the ‘lexical boost’ effect, e.g., Hartsuiker, Bernolet, Schoonbaert, Speybroeck, & Vanderelst, 2008; Pickering & Branigan, 1998; Snider, 2008).

Considerably less is known about what *causes* syntactic alignment. Despite broad agreement on the significance of this question, relatively few studies have addressed it (e.g., Bock & Griffin, 2000; Chang, Dell, & Bock, 2006; Kaschak, 2007; Malhotra, 2009; Pickering, Branigan, Cleland, & Stewart, 2000; Reitter, Keller, & Moore, 2011). We explore the hypothesis that syntactic priming is a consequence of adaptation with the goal to minimize the expected prediction error experienced while processing subsequent sentences, thereby facilitating efficient information transfer (cf. Jaeger, 2010). This view owes intellectual debt to, and builds on, previous accounts of syntactic priming in terms of implicit learning (in particular, Chang et al., 2006; but also Bock & Griffin, 2000; Chang, Dell, Bock, & Griffin, 2000; Kaschak, 2007). We use the term adaptation or expectation adaptation as a mechanism-neutral term to refer to changes in the expectations or beliefs held by producers and comprehenders. By prediction error, we refer to the deviation between what is observed and expectations prior to the observation. In particular, we focus on the syntactic prediction error, the degree to which expectations for syntactic structures are violated during incremental language understanding.¹ The minimization of future prediction errors – or, more cautiously, the maximization of utility, which usually entails the ability to reduce the prediction error – is broadly accepted to be one of the central functions of the brain (for a summary of relevant work, see Clark, *in press*).

In order to situate our approach to syntactic priming within a broader theoretical context, we begin by reviewing the role of prediction errors in language processing. This leads us to recent work on syntactic priming and adaptation in comprehension, and the question as to how comprehenders determine *how much to adapt their expectations* for future sentences whenever a prediction error is experienced. Once we have established this broader context, we discuss the consequences for syntactic priming during language production.

1.1. Prediction errors in language comprehension

The prediction error experienced while processing a word or sentence affects the processing difficulty associated with it. For example, the processing difficulty experienced when temporarily ambiguous sequences of words are disambiguated towards a specific interpretation

(so-called ‘garden path’ effects) depends on how expected that interpretation was given the preceding context (e.g., Garnsey, Pearlmutter, Meyers, & Lotocky, 1997; Hare, McRae, & Elman, 2003; MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell, Tanenhaus, & Kello, 1993). Similarly, word-by-word processing difficulty during reading is a function of how expected the word is given preceding context (among other factors, e.g., DeLong, Urbach, & Kutas, 2005; Demberg & Keller, 2008; Levy, 2008; McDonald & Shillcock, 2003; Rayner & Duffy, 1988; Staub & Clifton, 2006).

Sensitivity to prediction errors is a natural consequence of a processing system that has developed to process language efficiently: expectations based on previous experience help to overcome the noisiness of the perceptual input and to deal efficiently with uncertainty about the incremental parse (see also Levy, 2008; Norris & McQueen, 2008; Smith & Levy, 2008). This assumes that comprehenders’ expectations closely match the *actual* statistics of the linguistic environment, thereby minimizing the expected prediction error. This assumption might be seen as in conflict with another well-known property of language: speakers differ with regard to their production preferences, including syntactic preferences (e.g., Tagliamonte & Smith, 2005; Weiner & Labov, 1983). Even within a speaker, syntactic preference can vary dependent on, for example, register (Finegan & Biber, 2001; Sigley, 1997). As a consequence, the actual linguistic distributions frequently change. From the comprehender’s perspective, linguistic distributions are thus subjectively non-stationary. Provided that differences in environment-specific statistics are sufficiently large, this implies that language understanding will be more efficient if comprehenders continuously adapt their syntactic expectations to match the statistics of the current environment (e.g., speaker-specific production preferences).

Indeed, there is evidence for such behavior, which we have dubbed *expectation adaptation* elsewhere (Fine, Jaeger, Farmer, & Qian, *submitted for publication*). One piece of evidence comes from the burgeoning literature on syntactic priming in comprehension. For example, recent exposure to a syntactic structure results in faster processing if the same structure is encountered again (e.g., Arai, van Gompel, & Scheepers, 2007; Traxler, 2008). That these effects are due to changes in expectations is confirmed by evidence from anticipatory eye-movements during language comprehension. In a visual world eye-tracking paradigm, Thothathiri and Snedeker (2008) find that listeners were biased to expect the most recently experienced structure to be used again. These studies provide evidence that the most recently experienced prime affects expectations for upcoming syntactic structure. Other experiments have found that comprehenders integrate, not only the most recent prime, but rather the cumulative recent experience, into environment-specific syntactic expectations (e.g., Fine, Qian, Jaeger, & Jacobs, 2010; Hanulíková, van Alphen, van Goch, & Weber, 2012; Kamide, 2012; Kaschak & Glenberg, 2004b). For example, consider the case of garden path sentences, which are associated with processing difficulty at the disambiguation point. As mentioned above, this processing difficulty is a function of how unexpected the

¹ We do not imply any specific architecture of the language processing system. For example, it is possible that the syntactic prediction error reduces to prediction errors associated with expectations for sequences of words (e.g., Chang et al., 2006; Frank & Bod, 2011). For a discussion of the relation between syntactic and word-by-word expectations, see also Levy (2008).

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