Using tonal cues to predict inflections

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Abstract

The present article discusses the Central Swedish word accents – Accent 1 and Accent 2 – and their productive association to suffixes from the point of view of prediction theories of speech processing. Based on recent neurophysiological findings, we propose that both word accents are used predictively, but that Accent 1 is more 'predictively useful' than Accent 2, due to the fact that Accent 1 stems signal a smaller well-defined set of upcoming affixes as compared to Accent 2. This 'usefulness' allows suffixes to be pre-activated before they have even been heard.

Introduction

The brain constantly makes predictions about upcoming events, across many levels of sensory processing (Bar, 2007; Friston, 2010). These predictions allow us to streamline cognitive processing and increase its efficiency (van Boxtel & Böcker, 2004; Skipper, 2015). The present article reviews research into predictive mechanisms in language processing, focusing on the Central Swedish word accents: Accent 1 (a low tone on the stressed word stem vowel) and Accent 2 (a high tone on the stem vowel). The word accents are associated with suffixes in the mental lexicon (Rischel, 1963; Bruce, 1977; Riad, 2012), so that e.g. a noun like *bil* 'car' is associated with Accent 1 if the singular suffix -*en* is attached to the word stem, or Accent 2 if the plural suffix -*ar* is attached (bil_1-*en*/bil_2-*ar*). Furthermore, Accent 2 is associated with compound words in Central Swedish (such as $bildäck_2$ 'car tyre'), leading to the assumption that Accent 2 stems can activate more word forms as compared to Accent 1 stems.

The highly productive association between word accents and endings makes Swedish an excellent candidate for studying rapid, online predictions about upcoming language structures. While both word accents seem to be used predictively, there are differences in the way they are used in speech processing and these differences are currently the target of further investigation. Specifically, Accent 1 has been claimed to be more "useful" for prediction than Accent 2 (Roll, Söderström, Mannfolk, Shtyrov, Johansson, van Westen & Horne, submitted), due to its being associated with fewer word forms. The present article will present findings from a recent study which supports that claim and which sheds further light on the processing differences between Accent 1 and 2.

Theoretical assumptions and previous findings

Using behavioural and neurophysiological methods, several studies have investigated the online processing of word accents (Roll, Horne & Lindgren, 2010; Söderström, Roll & Horne, 2012; Roll, Söderström & Horne, 2013; Roll et al., submitted; Söderström, Horne & Roll, submitted). All of these studies have reached the conclusion that the productive association between word accents and morphology is related to speakers' ability to predict an upcoming suffix based on the word accent. In event-related potential (ERP) investigations, mismatching combinations of word accents and suffixes elicit longer response times and reprocessing effects at suffix onset. One such effect is the 'P600', a positive-going ERP deflection found for various types of violations in cognitive processing. In addition to being associated with e.g. syntactic violations in language processing, it has also been proposed that the P600 reflects more general processes related to violated/disconfirmed predictions (e.g. van de Meerendonk, Kolk, Vissers & Chwilla, 2008). Thus, finding a P600 effect for mismatching tone-suffix combinations could be suggestive of a rapid prediction (from the stem to the onset of the suffix) that has been made and disconfirmed.

However, on its own, the P600 is a relatively late effect which could also be claimed to not have any direct bearing on earlier potentially predictive mechanisms. It is possible that the reanalysis process simply reflects problems with *integration* rather than *prediction*, i.e. that it is simply more difficult to integrate a suffix which has not been primed by its tone. Consequently, one could argue that no prediction is generated upon hearing the stem tone, but rather that the listener waits until all information is available before analysing the utterance as mismatching and that this is reflected in longer response times and late ERP effects.

Definitive evidence that prediction has taken place can only be found by isolating responses (behavioural or neurophysiological) that are made *before* the predicted constituent has been heard or seen. In the case of word accents, this means finding effects of prediction at the stem and signs that the suffix has been pre-activated by the tone.

Investigating neural correlates of predictive tonal cues

One of the first neurophysiological markers to suggest that word accents are used predictively was an ERP component found for Accent 2 (e.g. Roll et al., 2010, 2013) but not for Accent 1 stems (the positive-going 'P2'). The same component has been found for high left-edge boundary tones signalling main clause structures in Swedish (Roll, Horne & Lindgren, 2011).

Interestingly, the Roll et al. (2011) study on initial boundary tones also found that while the high tone functioned as a facilitating cue to upcoming main clause word order for the listener, it did not inhibit the processing of unexpected subordinate clause word order. Similarly, Accent 2 stems have been found to not inhibit the processing of mismatching Accent 1-associated suffixes as much as mismatching Accent 1 stems inhibit the processing of Accent 2-associated suffixes (Roll et al., 2010, 2013; Söderström et al., 2012). These findings have led to the suggestion that both Accent 1 and low left-edge boundary tones actually constitute more strongly constraining "micro-contexts" as compared to Accent 2 and high left-edge boundary tones. As has already been mentioned, Accent 2 stems can be argued to activate more word forms than Accent 1 stems – including both suffixed forms and compounds. From this, it follows that Accent 2 stems can be viewed as less constraining contexts. In a similar way, low left-edge boundary tones can be seen as more strongly constraining contexts since they signal only subordinate clause structure (Roll et al., 2011). This account is supported by findings that unexpected items encountered in strongly constraining contexts are associated with greater processing costs, possibly reflecting prediction revisions (Federmeier, Wlotko, De Ochoa-Dewald & Kutas, 2007). Furthermore, processing costs are also increased in contexts where fewer completions are available, as compared to those with more possibilities (Wlotko & Federmeier, 2012). In short, having excessively many options – as is the case for Accent 2 stems – makes prediction difficult.

Based on these assumptions, the ERP difference between Accent 1 and 2 stems has subsequently been reanalysed as a *negatively* charged effect for low left-edge boundary tones and Accent 1 stems rather than as positivity for high left-edge boundary tones and Accent 2. There are many well-known ERP negativities that have been associated with various types of anticipatory processing that occur before a reaction or the presentation of a feedback stimulus, such as the contingent negative variation (CNV, Walter, Cooper, Aldridge, McCallum & Winter, 1964), the readiness potential (RP, Kornhuber & Deecke, 1965) and the stimulus-preceding negativity (SPN, Damen & Brunia, 1987). However, examples in the literature of investigations into actual "pre-stimulus" pre-activation mechanisms in natural language processing are rare. One magnetoencephalography (MEG) study (Dikker & Pylkkänen, 2013) found evidence that picture primes can lead to the pre-activation of written nouns and another influential study (deLong, Urbach & Kutas, 2005) took advantage of the N400 component to show that listeners form graded predictions about upcoming items and specific predictions about specific phonological word forms (such as the English indefinite article *a*/*an*). In light of this, the Accent 1 negativity could be an important tool to further our understanding of the way in which linguistic material can be pre-activated in sufficiently constraining within-word micro-contexts.

Stem negativities as indices of suffix pre-activation?

Roll et al. (submitted) is the first study to specifically shed light on the Accent 1 stem ERP negativity. It was suggested that the strongly predictive status of Accent 1 is reflected in this stem negativity, which in turn is thought to index the pre-activation of suffix memory traces.

A recent ERP study (Söderström et al., submitted) set out to investigate the predictive functions of Accent 1 and 2 stems more closely. The experiment in this study involved two methodological novelties. Firstly, it made use of pseudo-nouns – or rather pseudo-stems connected to either Accent 1- or 2-associated singular or plural suffixes – such as *tväk* (tfɛːk) embedded in carrier sentences to test the hypothesis that the tone-suffix association still exists in the absence of lexical information on the stem. Secondly, it was the first to include a condition in which some suffixes were replaced with coughing sounds. This cough condition is important, as it makes it possible to directly test any effects of suffix pre-activation in the absence of the relevant prediction feedback stimulus (the suffix). As in previous studies, the participants' task was to determine as quickly as possible whether the word was in the singular or plural.

The study revealed a P600 effect for mismatching suffixes, suggesting that both mismatch combinations elicited reanalysis and reprocessing. It therefore seems likely that both word accents generate predictions which can be disconfirmed by mismatching suffixes. The P600 effect was preceded by a left-anterior negativity (LAN), which is thought to reflect morphological processing and the activation of memory traces of e.g. affixes which have not been properly primed (Pulvermüller & Shtyrov, 2003).

As regards the cough condition, it was noted that there was no difference in response times between Accent 1 and 2 (792 and 798 ms respectively, measured from cough onset), but response accuracy was significantly higher for Accent 1 words (87.8%) compared to Accent 2 words (72.0%). On its own, this suggests that Accent 1 stems cue their suffixes more strongly, but does not necessarily mean that the suffix was pre-activated. However, evidence of suffix pre-activation was found in a correlation between the amplitude of the Accent 1 stem ERP negativity and response accuracy: participants who displayed a larger negativity for Accent 1 stems also showed higher response accuracy in the cough condition. Furthermore, the scalp distribution of the Accent 1 stem negativity displayed similarities to a negativity found for suffixes compared to coughs (LAN), which suggests that suffix pre-activation and processing is indeed present before the suffix has even been perceived. One potential candidate for the brain area underpinning this suffix pre-activation mechanism is Brodmann area 47, which is thought to be involved in e.g. morphological processing (Roll et al., submitted). This is suggestive of an account according to which suffix processing is indeed initiated earlier for Accent 1 stems than for Accent 2 stems.

Conclusion

Results indicate that both word accents can be used predictively, but in different ways. Firstly, P600 effects have been found both for mismatching Accent 1 and Accent 2 words. Secondly, participants were relatively successful in restoring missing suffixes following both Accent 1 and Accent 2 stems (Söderström et al., submitted). Thirdly, the stem negativity points to a strong predictive role for Accent 1. The difference in the predictive status of the word accents thus seems to be based on Accent 1 generating stronger predictions for suffixes while Accent 2 stems generate weaker suffix predictions. The strong predictions allow listeners to commit to the ending of a word more strongly upon hearing an Accent 1 stem, as compared to Accent 2 stems.

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