Journal of Neurolinguistics 37 (2016) 22–33

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

ERP correlates of prosody and syntax interaction in case of embedded sentences

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ARTICLE INFO

Article history:
Received 8 May 2014
Received in revised form 30 July 2015
Accepted 7 August 2015
Available online 25 August 2015

Keywords:
Event related potentials
Closure positive shift
Intonation
Syntax
Embedded sentences

ABSTRACT

Understanding spoken language depends on processing the delicate combination of grammatical structure, meaning and prosody of utterances. Previous studies have established that prosody influences the processing of sentences when the grammatical structure is ambiguous, however it is unclear how closely prosody and syntax are related when there is no ambiguity. In an event-related brain potential (ERP) study, we investigated the processing of embedded normal and pseudosentences in which all function and content words were replaced by meaningless words. Sentences could have either natural prosodic structure or incongruent prosodic structure, where the prosody deviated from the one expected based on the syntactic structure, but otherwise the sentences were unambiguous. The resulting ERP components (CPS) showed that the construction of prosodic structure was similar in normal and pseudosentences, thus suggesting that prosody has an abstract, recursive representation, independent of other linguistic information. Moreover, we found evidence that the incongruent prosody was not only detected (shown by the RAN), but it induced neural reintegration processes (shown by the P600) in spite of the syntactic structure of sentences being intact. These results suggest that the prosodic structure is a mandatory constituent of sentence structure building whenever it is present.

Human language understanding depends on the processing of meaning, grammatical structure and prosody. In the present study we investigated how prosodic features influence the processing of sentence structure and how the brain integrates various sources of linguistic information into generating a consistent interpretation. Contrary to previous studies, we studied the effect of incongruent prosodic structure in processing unambiguous sentences.

Prosody can be defined as “those phenomena that involve the acoustic parameters of pitch, duration and intensity” (Ladd & Cutler, 1983, p.1.), and refers to intonation and rhythmic grouping patterns in speech (Hwang & Steinhauer, 2011). While there is a general consensus that the syntax and prosody of an utterance are closely related, it is a matter of debate just how close this relation is: If the use of prosody is strongly determined by the syntactic structure, or the speaker is free to choose an arbitrary prosodic structure. Frazier, Carlson, and Clifton (2006) propose that whether prosody is constrained by grammar (as

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http://dx.doi.org/10.1016/j.jneuroling.2015.08.001
0911-6044/

suggested by e.g., Nespor & Vogel, 1986 and Selkirk, 1984) or its use is more strategic (as suggested by e.g., Snedeker & Trueswell, 2003) depends in fact on the given linguistic utterance.

One example of the obligatory use of prosody is the case of ambiguous sentences, where prosody disambiguates multiple meanings and the related multiple syntactic structure of the same surface structure (Price, Ostendorf, Shattuck-Hufnagel, & Fong, 1991). For example sentence (1) taken from Price et al. (1991) may have two alternative interpretations depending on the grouping or bracketing of the constituents: Mary and you have a similar background and have both learned many languages, or as an indication not to worry about Mary going abroad, because she knows many languages.

(1) *Mary knows many languages you know*

This is an example of global ambiguity, and the sentence can be disambiguated by placing an intonational phrase boundary (IPB) between "languages" and "you". Without the prosodic information the ambiguity is not resolved. IPBs in spoken language are marked by phonetically defined features, the most frequent being the extension of the last syllable before the boundary, pause, and/or the change of intonation contour (de Pijper & Sanderman, 1994; Shattuck-Hufnagel & Turk, 1996; Wang, Yang, & Lu, 2004; Wightman, Shattuck-Hufnagel, Ostendorf, & Price, 1992).

Sentence (2) illustrates another kind of ambiguity: Here the ambiguity is only temporary, and it is resolved by the occurrence of further linguistic information. This is an example of local ambiguity, and the sentence is called a garden-path sentence. This ambiguity can also be resolved by the insertion of IPBs at the correct positions, namely after "horse" and "barn".

(2) *The horse raced past the barn fell.*

Previous studies have found evidence that prosodic information can indeed alter the parsing preference and interpretation of such locally ambiguous sentences (Carlson, Clifton, & Frazier, 2001; Kjelgaard, 1999). Moreover, event-related brain potential (ERP) studies have demonstrated that a particular ERP component, the closure positive shift (CPS) is elicited synchronized to the IPBs. CPS was first described by Steinhauer, Alter, and Friederici (1999) in a study on brain activity correlates of intonational phrase boundaries. Unlike most ERP components accompanying linguistic processes, CPS was found to be insensitive to linguistic violations, and was exclusively related to the processing of IPBs. Further studies revealed that the CPS is modality independent, and IPBs presented in written form as commas also elicited CPS (Steinhauer & Friederici, 2001; Steinhauer, 2003), however the findings of Kerkhofs, Vonk, Schriefers, and Chwilla (2008) in Dutch suggest that this might depend on the comma rules in a given language. Li and Yang (2009) demonstrated that while the CPS can be elicited by prosodic boundaries of hierarchically lower level prosodic structures and not just IPBs, it is never present to prosodic words, therefore it reflects the processing of boundaries of larger units. The Li and Yang study also confirmed that the CPS, elicited by different acoustic characteristics marking the IPB, is least sensitive to the length of the pause. Other studies confirmed that IPBs are perceived independently of the presence of pause (Männel & Friederici, 2009; Steinhauer et al., 1999), but this may be the result of linguistic development, as Männel, Schipke, and Friederici (2013) found that 3 years olds do not show any CPS to IPBs without boundary pause, but 6 years olds do. Pannekamp, Toepel, Alter, Hahne, and Friederici (2005) demonstrated that the CPS relies purely on prosodic information, and appears in the case of meaningless and even non-speech (hummed) sentences. Finally, developmental studies by Männel and Friederici (2011) found that the processing of IPBs elicited a CPS similar to those in adults in 3 and 6 years olds but not in 21 month old children. Taken together, these results indicate that the CPS is a modality-independent correlate of IPB processing per se, relying on the acoustic characteristics of boundary-marking signals, and appearing in the absence of linguistic (semantic or syntactic) information as well. However, the CPS is not simply a response to acoustic-phonetic cues of IPBs, but rather reflects the structuring or phrasing of the input (Bögels, Schriefers, Vonk, & Chwilla, 2011).

When the IPBs are not in the correct position to disambiguate garden-path sentences, a specific ERP response consisting of a biphasic N400 – P600 pattern can be found as demonstrated in several studies (Hwang & Steinhauer, 2011; Isel, Alter, & Friederici, 2005; Steinhauer et al., 1999; Steinhauer, 2003; Mietz, Toepel, Ischebeck, & Alter, 2008; Pauker, Itzhak, Baum, & Steinhauer, 2011; see Bögels et al., 2011 for a review), with the P600 component missing in some cases (Bögels, Schriefers, Vonk, Chwilla, & Kerkhofs, 2010). This pattern was found for words that disambiguated the sentence towards an interpretation that was not compatible with the syntactic analysis of the sentence, therefore leading to processing problems (Bögels et al., 2011). The N400 component is considered as a correlate of accessing the mental lexicon (Kutas & Hillyard, 1980), or more generally as a correlate of semantic memory access, or semantic conceptual unification (see Kutas & Federmeier, 2011 for a review). The N400 effect in the context of garden-path sentences is thought to reflect lexical re-access to confirm the violation of argument structure (Steinhauer et al., 1999). The P600 has been found to correlate with syntactic structure building, and reintegration or reinterpretation of violated syntactic structures (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992). It is often modulated by non-syntactic factors (for example meaning, processing strategies, task characteristics) therefore it can be considered as a general electrophysiological indicator of structure processing (Steinhauer, 2008). In the case of ambiguous sentences, the P600 is suggested to indicate structural revision after the disambiguating word is heard, and to reflect the effort of syntactic and prosodic revision.

Eckstein and Friederici (2005, 2006) investigated the processing of the mismatch between the syntactically predicted and actually perceived prosodic intonation in an experiment, where they manipulated the prosodic features of penultimate or