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Brain Research

Research report

Neural correlates of prosodic boundary perception in German preschoolers: If pause is present, pitch can go

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ARTICLE INFO

Article history:
Accepted 3 December 2015
Available online 10 December 2015

Keywords:
Prosody
Prosodic boundary
Pause
Pitch change
Event-related brain potentials (ERP)
Closure Positive Shift (CPS)

ABSTRACT

Children's perception of prosodic phrasing provides a head start into the discovery of speech structure. Based on the close prosody–syntax correspondence, children can infer the underlying syntactic structure from the acoustic modulations of prosodic boundaries, typically consisting of co-occurring pitch changes, preboundary lengthening, and pausing. Previous electrophysiological studies revealed that listeners are to some degree flexible in the detection of major prosodic boundaries that are not marked with all three of the suprasegmental cues. Adults and 6-year-olds still showed the brain response for prosodic boundary perception, the Closure Positive Shift (CPS), when pauses marking boundaries were deleted. In contrast, younger children at 3 years did not show this ability yet, but required pausing to complement the other boundary cues. Following the hypothesis that German weights duration cues more heavily than pitch cues, we here examined 3-year-olds' brain responses to prosodic phrasing, testing the role of boundary-related pitch changes. Results revealed that children at this age even showed the CPS in response to pitch-neutralized boundaries with only pausing and preboundary lengthening being present. These results indicate differential roles of acoustic cues in boundary perception, with a preferential reliance on duration cues over pitch changes in 3-year-olds. This preference likely results from the characteristics of the German intonation system and furthers the discussion of cross-linguistic differences in the weighting of prosodic boundary cues.

1. Introduction

Processing of sentence-level prosody is crucial for successful language comprehension, because prosodic phrasing highly correlates with the syntactic structure of utterances (Cooper and Paccia-Cooper, 1980; Schremm et al., 2015; Venditti et al., 1996). While this correlation holds for units at different syntactic levels, clauses as the largest sentence units are particularly dominantly marked by major prosodic boundaries (PBs; Nespor and Vogel, 1986; Selkirk, 1984). Across

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http://dx.doi.org/10.1016/j.brainres.2015.12.009
0006-8993/© 2015 Published by Elsevier B.V.

languages, PBs are primarily characterized by three acoustic cues, namely preboundary lengthening, pitch change and pausing (Hirst and Di Cristo, 1998). Thus, listeners can infer the underlying syntactic structure from the acoustic modulations of prosodic information. This strategy is particularly helpful when hearing sentences with temporary syntactic ambiguities that allow for different sentence interpretations (see Carlson (2009)). Ambiguity resolution was found to be the more successful, the stronger the modulation of the prosodic phrasing (Millotte et al., 2008), proving a beneficial role of the prosody–syntax correspondence in language processing.

Following behavioral studies of the prosody–syntax correspondence, a considerable number of event-related brain potentials (ERP) studies have addressed the neurophysiological underpinnings of speech structure processing. The ERP component Closure Positive Shift (CPS; Steinhauer et al., 1999) was reported as electrophysiological correlate of boundary processing across different languages (for a review, see Bögels et al. (2011)). The CPS has been mostly reported for the perception of PBs framing larger intonational phrases (see Bögels et al. (2011)), but also smaller phonological phrases (Li and Yang, 2009; Holzgrefe et al., 2013). Across these studies, the CPS was interpreted as reflecting the structuring of auditory input, based on a combination of acoustic cues that simultaneously define prosodic and syntactic units. Developmentally, the processes underlying the CPS have been found to mature between the ages of 2 and 3 years (Männel and Friederici, 2011). When presented with PBs in sentences, 2-year-old children showed sensory ERP components that indicate the automatic registration of auditory input (i.e., comparable to the adult N1-P2 complex). In responding to the restart of auditory input after the PB, children must have recognized an interruption of the speech input, most likely driven by the pronounced boundary pause (Männel and Friederici, 2009). In contrast, 3-year-old children responded to PBs by both sensory ERP components and a CPS that reflects higher-level processing of speech structure signaled by prosodic and syntactic information. This developmental progression suggests that once children become more advanced in their language development at the age of around 3 years (e.g., Oberecker et al. (2005), Oberecker and Friederici (2006) and Thothathiri and Snedeker (2008)), they process speech structure at sensory and cognitive levels.

Although major PBs are typically realized by a combination of acoustic cues, ERP studies on German sentence processing suggest listeners' flexibility in boundary perception without full prosodic marking (Steinhauer et al., 1999). Listeners also showed the CPS for PBs that were marked by preboundary lengthening and pitch rise, but lacked the boundary pause. Similarly, Chinese- and English-speaking adults were found to perceive PBs, even if not all acoustic cues were present (Aasland and Baum, 2003; Scott, 1982; Streeter, 1978; Yang et al., 2014). Thus, listeners are to some extent flexible in prosodic speech structure perception, promoting successful language processing in the light of interspeaker variability in prosodic modulations (Cole et al., 2010; Schafer et al., 2000).

The flexibility in boundary perception with less pronounced prosodic marking only seems to evolve during language acquisition. Developmental ERP studies revealed that German 6-year-olds, similarly to adults, showed the CPS to PBs that were only marked by preboundary lengthening and pitch rise, but not pausing (Männel et al., 2013). In contrast, German 3-year-olds did not show the CPS when the boundary pause was missing (Männel et al., 2013), despite the fact that children at this age respond with a CPS to fully marked PBs (Männel and Friederici, 2011). Thus, at three years, when children start to show the CPS in response to major PBs, they require full prosodic marking to signal speech structure. For older children, who are more experienced with the prosody–syntax correspondence of their native language, less prosodic marking is sufficient (Männel et al., 2013). Behavioral studies in English confirm general developmental differences, because infants require more boundary cues for prosodic phrase processing than adults (Aasland and Baum, 2003; Gerken et al., 1994; Seidl, 2007; Streeter, 1978). Moreover, there is an early developmental progression, such that 4-month-old infants detect PBs only if these are marked by all available acoustic cues, while for 6-month-olds fewer cues are sufficient (Seidl and Cristià, 2008). Importantly, these studies employ behavioral techniques, inferring infants' processing of prosodic phrasing from their viewing preferences. The underlying processes might be comparable to what infant ERP studies have captured by sensory ERP components, reflecting the detection of speech input interruptions driven by pronounced acoustic cues (Männel and Friederici, 2009). Because we are here interested in the cognitive processes underlying PB perception, as reflected in the CPS, we focus on an older age group, namely German 3-year-olds.

Across languages, there seems to be a differential weighting of individual boundary cues in PB perception; potentially resulting from the characteristics of the respective intonation systems (see Hirst and Di Cristo (1998)). For example, Peters (2005) systematically analyzed German adults' cue weighting in PB perception. Results indicate that, of all three available acoustic cues, pauses have the most significant impact on the perceived phrasing, followed by pitch changes. Interestingly, these cue weightings are reflected in preschool listeners' brain correlates to different acoustic realizations of PBs: While adults gain sufficient boundary information from a combination of pitch change and lengthening, young children require pausing to be present as well (Männel et al., 2013). Complementing this evidence, studies in Dutch, a language with similar intonational characteristics to German (Gibbon, 1998; T'Hart, 1998), revealed that infants only perceived clauses if boundaries were additionally signaled by pausing (Johnson and Seidl, 2008). In contrast, studies in English, a language with much more modulated pitch movements than German or Dutch (Gibbon, 1998), showed that infants predominantly relied on the presence of boundary-related pitch changes (Seidl, 2007). Interestingly, this preference is mirrored in children's language production, such that between 16 and 25 months, English-speaking toddlers start to use pitch modulations earlier than duration parameters in marking phrase boundaries (Snow, 1994). Thus, the weighting of PB cues in the perception of phrasal prosody seems to be shaped by children's exposure to their native language and underlie cross-linguistic variation.

One of the few developmental ERP studies on differential cue weighting suggested German 3-year-olds' reliance on