Brain Signatures of Prosodic Processing

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The virtually unlimited temporal resolution of event-related brain potentials (**ERPs**) can help advance our understanding of prosodic processing in real time and its critical role in online sentence comprehension.

Prosody often guides the syntactic analysis of sentences. This has been shown in structurally ambiguous 'garden path' sentences such as Early/Late Closure ambiguities (examples from **[1]**):

1a) Late Closure: *When a bear is approaching the people the dogs come running.*
1b) Early Closure: *When a bear is approaching the people come running.*

In reading studies, (1b) has been found to be more difficult to process, as the syntactic parser tends to initially attach the NP *'the people'* to the preceding verb (as required in 1a). However, in speech a prosodic boundary before this NP can prevent these difficulties while rendering sentence (1a) more difficult to process. Behavioral studies of these structures had to rely on quite unnatural tasks until the mid 1990s, producing inconsistent results. ERPs were found to better reflect both the processing of prosodic boundaries as well as their immediate impact on sentence interpretation in real-time – *independent* of task requirements **[2]**. Most importantly, this work identified a novel positive-going ERP waveform labeled *closure positive shift* (**CPS**) that was found to reliably mark the online processing of prosodic boundaries in listeners (**Figure 1**). Since its discovery, the CPS has been replicated in more than ten languages (e.g., Chinese, Dutch, English, French, German, Japanese, Korean and Swedish) and has been used to examine a number of issues related to prosodic sentence processing. For example, developmental research has shown that a CPS is reliably elicited only around age 3 years, potentially suggesting sufficient syntactic knowledge has to be acquired first **[3-4]**. On the other hand, older people (> 75 years) display a CPS similar to that in young adults, but they integrate prosodic, lexical and syntactic information in different ways **[5]**.

De-lexicalized speech and musical phrasing. Some studies observed the CPS in de-lexicalized (e.g., low-pass filtered or 'hummed') speech, indicating that this ERP component is in fact triggered by prosodic phrasing and not by lexical or syntactic processes **[6-7]**. This finding also raises issues about the domain-specificity of the cognitive processes underlying the CPS. In 2005, a study reported a 'music-CPS' at phrase boundaries in melodies **[8]**, but both its timing and the apparent finding that only trained musicians elicited it cast doubt on its equivalence with the prosodic CPS in speech. More recently, Glushko and colleagues demonstrated another CPS in music that strongly resembles the one at speech boundaries **[9]**, whereas the 2005 effect may reflect a different cognitive process. This new finding strongly suggests that phrase boundary processing in speech and music may – at least to some extent – rely on similar neurocognitive mechanisms.

Implicit/covert prosody in silent reading and punctuation. Prosodic representations also seem to be activated during silent reading **[10]**, thus suggesting another application for the CPS in an otherwise extremely difficult-to-study domain. To date, a number of ERP studies in a range of languages have shown that prosodic phrasing in silent reading elicits a CPS component similar to that in speech processing. The CPS for subvocal prosodic phrasing was observed irrespective of whether the boundary was induced by commas **[6, 11-12]**, by mapping a previously heard prosodic contour on the written text **[13]**, or by manipulating the length of noun phrases – as shown in a reading study in Korean **[14]**. However, the reliability of punctuation cues in inducing prosodic phrasing partly depends on the reliability with which readers use punctuation rules **[6, 15]**.

Categorical boundary perception? Annotation systems such as ToBI often assume categorical boundary perception (e.g., an intermediate versus an intonational phrase boundary), while some researchers have argued for a continuum and for relative boundary strength perception. A CPS study from our lab manipulated the strengths of competing boundaries in sentences with early versus late closure ambiguities and found behavioral and ERP evidence for a continuum **[16]** (see **Figure 2**).

Prosodic processing in second language learners. Prosody is usually not part of the curriculum in second language (L2) instruction, and relatively little is known about L2 learners' use of prosodic information in sentence processing. Recent ERP work suggests that both L1 background and language

proficiency shape the integration of prosodic and syntactic cues, and that, importantly, even English native speakers' ERPs are influenced by their English proficiency level **[17]**.

After a general introduction to CPS research, my talk will focus on (a) implicit prosody in Korean garden-path sentences, (b) categorical versus continuous boundary perception, and (c) prosody in L2 learners.

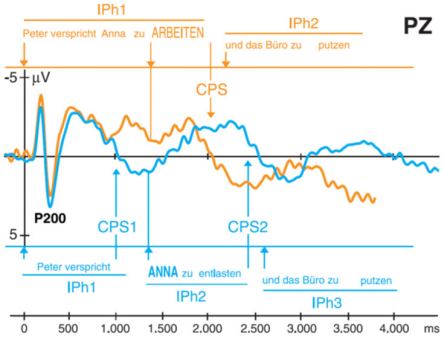

Fig.1 CPS components in ERPs, time-locked to sentence onset (Steinhauer et al., 1999)

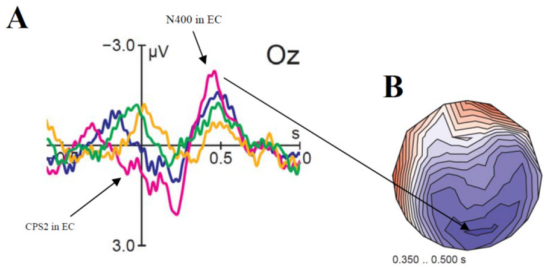

Fig.2 Effects of an incompatible late boundary of increasing strength (yellow=1, pink=4) in Early Closure sentences. The stronger the boundary, the larger the CPS, and the larger the N400 reflecting processing difficulties.

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