

## Cycling up the Garden Path: Oscillatory Phase Predicts Downstream P600

Lena Henke & Lars Meyer

Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany  
{henke, lmeyer}@cbs.mpg.de

Language processing is constrained in time because the continuous speech stream rapidly fades from working memory (Baddeley, Thomson, & Buchanan, 1975). This challenge could be mitigated by sampling words into perceptual chunks of limited duration allowing them to be recoded into linguistic units, such as phrases and clauses (Christiansen & Chater, 2015). While the relationship between chunking and incremental parsing is a matter of ongoing debate, research on attachment ambiguities has shown that the formation of syntactic structure can be enforced by temporal processing windows: the longer a word sequence, the more likely its chunking (Hwang & Steinhauer, 2011; Swets, Desmet, Hambrick, & Ferreira, 2007). Specifically, the analysis of spontaneous speech suggests an optimal chunk length of 2.6 seconds (Vollrath, Kazenwadel, & Krüger, 1992), converging on a similar time window of 2.7 seconds found by electroencephalography (EEG) work on sentence comprehension (Roll, Lindgren, Alter, & Horne, 2012). Here, we hypothesized that this perceptual chunking window reflects internal electrophysiological processing cycles within the delta frequency band ( $< 4$  Hz), providing temporal receptive windows long enough to accommodate phrases and clauses (Lerner, Honey, Silbert, & Hasson, 2011; Meyer, Henry, Gaston, Schmuck, & Friederici, 2017). We recorded participants' EEG ( $N = 47$ ) while they listened to sentences containing a coordination ambiguity (Hoeks, Hendriks, Vonk, Brown, & Hagoort, 2006); see an English translation of a stimulus in Example 1a. In the example, *the drummer* is syntactically ambiguous because it could either be conjoined with *the flutist* into a single noun phrase (Example 1b) or serve as subject for a new clause (Example 1c). In the first case, the following verb (i.e., *delights*) elicits a garden path and requires reinterpretation. The latter case leads to the correct interpretation of the sentence and no garden path.

(1a) The conductor interrupts the flutist and the *drummer* delights the listener.

(1b) The conductor interrupts [the flutist and the drummer] ...

(1c) [The conductor interrupts the flutist] and [the drummer delights the listener].

We aimed to elicit these interpretations by manipulating the speech rate of the sentences: in the FAST condition, the clause including the conjoint noun phrase (i.e., *the flutist and the drummer*) fell into a single time window of 2.7 seconds, intended to elicit the wrong chunking pattern (1b) and a subsequent garden path. In the SLOW condition, 2.7 seconds already concluded after *the flutist*, avoiding the garden path (1c). Additionally, we examined whether the time constraint would be strong enough to suppress prosodic cues, which overtly indicate a chunk boundary and thus, help disambiguation. To this end, we manipulated the presence of an intonational phrase boundary after *the flutist*.

In line with the suggested time constraint of 2.7 seconds, we observed a main effect of speech rate independent of prosodic cues at the disambiguating verb; neither a main effect of prosody nor an interaction was found. Specifically, a cluster-based permutation analysis of the event-related potential (ERP) at the disambiguating verb showed a P600 in the FAST condition indicating the reinterpretation at the encounter of a garden path (Dröge, Fleischer, Schlesewsky, & Bornkessel-Schlesewsky, 2016; Kuperberg, Brothers, & Wlotko, 2019; Osterhout & Holcomb, 1992). Additionally, delta-band oscillations at the point at which the continuation of a chunk was determined (i.e., towards the end of *flutist*) correlated with the amplitude of the ERP at the verb later in the sentence. Circular-linear correlation analysis revealed that across conditions, single-trial ERP amplitudes, extracted at the peak of the P600, correlated with the earlier phase of the delta-band oscillation. Overall, these findings imply that a sequence of words was chunked when the underlying neural oscillator had reached a specific phase of its cycle, determining the interpretation of an ambiguity later in the sentence. We thus suggest that cycles of delta-band oscillations are an internal electrophysiological constraint on chunking, possibly underlying the previously described 2.7-seconds chunk length.

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