COMBINING BEHAVIORAL MEASURES AND BRAIN POTENTIALS TO STUDY CATEGORICAL PROSODIC BOUNDARY PERCEPTION AND RELATIVE BOUNDARY STRENGTH

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ABSTRACT

Two controversial issues in speech prosody research concern **(i)** the traditional notion of *categorical* boundary perception (i.e., intermediate phrase [ip] boundaries versus intonation phrase boundaries [IPh]), and **(ii)** the suggestion that the *relative strength* of competing boundaries (rather than the mere presence of boundaries) may account for prosody effects on sentences interpretation. An alternative to qualitatively distinct boundary categories is the idea of a *"gradient quantitative boundary size"* (e.g., Wagner & Crivellaro [14]), which may also imply a graded spectrum of relative strength effects. Based on promising behavioral data supporting this view, we propose to study these predictions in more detail using event-related potentials (ERPs). In phonetics and phonology, these electrophysiological measures have been shown to provide an excellent tool to investigate online processes across the entire time course of a spoken utterance, with a temporal resolution in the range of milliseconds. Thus, ERPs are expected to reflect both the real-time processing and integration at the boundary positions as well as its subsequent effects on sentence interpretation.

Keywords: prosody, event-related brain potentials (ERPs), closure positive shift (CPS), garden-path

1. INTRODUCTION

1.1. Prosody and syntactic parsing

Prosody has been shown to have an immediate impact on syntactic parsing in various sentence structures and cross-linguistically (Selkirk; Kjelgaard; Steinhauer; Kerkhofs [5, 6, 10, 13]). For instance, in *reading* studies early closure (EC) vs late closure (LC) ambiguities (see **examples (1a,b)** below) display a systematic parsing preference for LC (Frazier [3]) and result in processing difficulties (garden path effects) on the disambiguating word in EC sentences. But when presented *auditorily*, prosodic boundaries reliably disambiguate the structures *before* the lexically disambiguating information becomes available and thus prevent garden path effects [6, 13].

1.2. Relative boundary strength

Several theories account for the role of prosodic boundaries in resolving attachment ambiguities: (i) The Prosodic Visibility Hypothesis **(PVH)** (Schafer [9]) and (ii) the Informative Boundary Hypothesis **(IBH)** (Clifton, et al. [2]) assume that the *global prosodic structure* of the sentence – manifested by the distribution and relative magnitude among all boundaries within a given utterance – is pivotal to the prosody-syntax mapping. In contrast, (iii) the Anti Attachment Hypothesis **(AAH)** (Watson & Gibson [15, 16]) assumes that the prosody-syntax mapping is performed *locally*, immediately upon encountering a strong prosodic boundary.

(1) The PVH assumes that both (weak) ip and (strong) IPh boundaries immediately group the preceding constituents; 'visible' attachment sites within the same prosodic phrase should be preferred. (2) According to the IBH, syntactic preference relies on the relative strength of the final boundary compared to that of the preceding boundaries. (3) The AAH assumes only IPh boundaries trigger syntactic closure (although two IPh boundaries will cancel each other's closure effect out (Watson, personal comm.), re-establishing the default syntactic preference.

1.3. Limitations of previous research

Previous research has examined these theories using global attachment ambiguities (e.g., *you can touch #1 the hat #2 with the feather*), which can be parsed in either one of two grammatical ways (e.g., high and low attachment), regardless of prosodic bias. Moreover, when using globally ambiguous structures, even strong prosodic cues simply modulated (but did not override) the initial syntactic bias towards one structure (Carlson, et al. [1]; Lee & Watson, [7]). Little evidence comes from temporarily ambiguous garden-path structures, such as Early and Late Closure (**EC/LC**), where particular prosodic patterns can override initial preferences and lead to an ungrammatical parse, thus resulting in much stronger prosodic effects (e.g., Kjelgaard & Speer [6]; Pauker, et al. [8]).

Methodologically, the common approach to distinguishing between boundary sizes has been strictly categorical, i.e., studies only contrasted one type of weak (ip) and one type of strong (IPh) boundary (Carlson, et al. [1]). However, recent work suggests that *gradient quantitative boundary size* may be more appropriate to explain the role of prosodic boundaries in parsing decisions (Wagner & Crivellaro [14]).

2. THE PRESENT EXPERIMENTAL APPROACH

The present approach (a) parametrically manipulates the strength of (b) multiple competing boundaries in (c) *locally* ambiguous garden path sentences (EC/LC), and (d) combines behavioral and ERP measures.

2.1. A behavioral study

The main goals of our behavioral study were: **(a)** to contrast the predictions of the three theories using EC/LC ambiguities, and **(b)** to test whether boundaries have a strictly categorical effect or yield a gradient effect.

Sample sentence:

(1) Whenever a bear was approaching **#1** *the people* **#2**

a. (LC) ... *the dogs would run away*

b. (EC) ... *would run away*

Methods. We recorded 42 EC/LC pairs with 2 ip boundaries (H-L) each (see example in (1)). We then manipulated each boundary by adding 320 ms or 80 ms, to create IPh-compatible (H-L-L) and intermediate size boundaries. Full permutation of boundary strengths resulted in 9 prosodic conditions for both EC and LC sentences. Twelve native English speakers rated sentence acceptability on a scale from 1-7 (1=worst; 7=best).

Behavioral Results. Data showed significant main effects of syntax and prosody as well as a significant syntax x prosody interaction ($p < .0001$). As illustrated in Figure 1, we found evidence for a general advantage for EC over LC and a gradient pattern of acceptability that mirrors the parametric manipulations of both boundary 1 and boundary 2. Data are in partial agreement and disagreement with all three theories (Table 1), but support a boundary gradient rather than strict categories account.

Figure 1: Difference in acceptability between Early Closure and Late Closure structures as a function of **prosodic boundary strengths** (N=12 young adults). X-axis: prosodic pattern (3_1= initial strong IPh boundary followed by a weak ip boundary; 2_2 = intermediate boundary followed by intermediate boundary; 1_3 = weak ip followed by strong IPh boundary). Y-axis: EC-acceptability minus LC-acceptability for each prosodic structure. The data illustrate a general, but graded EC advantage in all conditions: **the shorter the first boundary (thick red arrow) and the longer the second boundary (thin black arrows)**, the weaker the EC preference.

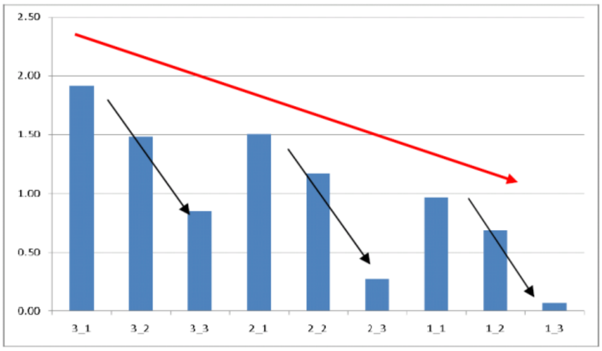
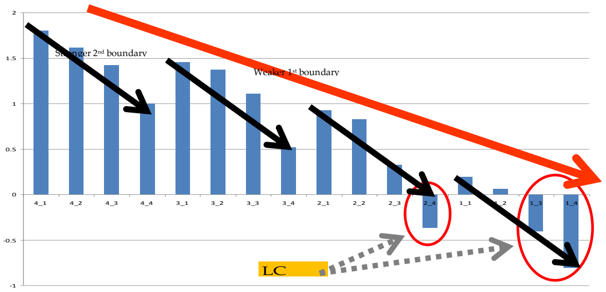


Table 1: Some predictions for the three theories for different prosodic boundary patterns. (1>2: boundary 1 is stronger than boundary 2 in EC/LC sentences, as illustrated in Example (1) above).

Pros.	AAH	PVH	IBH
1>2	EC-pref; IPh-dependent	EC pref (strong)	EC pref
1< 2	LC-pref (default)	EC preference (weaker)	LC pref
1 = 2	LC-pref (default)	EC preference (intermed.)	LC pref or no pref

A follow-up behavioral study included 4 (instead of 3) levels of boundary strength at each position (a total of 16 combinations), some of which strongly support LC interpretation. As predicted, these data overcome the overall EC preference of our first study and provided even more fine-grained detail on the interaction of multiple competing boundaries. As illustrated in Figure 2, we replicated the graded acceptability pattern of our previous study reflecting each single difference in boundary strength at each of the two boundary positions. In addition, this pattern now ranges from a strong preference for EC structures (especially with strong early boundaries) to a clear preference for LC structures (with weak early and strong late boundaries).

Figure 2: Difference in acceptability between Early Closure and Late Closure structures as a function of **prosodic boundary strengths** in our second behavioral study. Unlike in our first study (Figure 1), our follow-up study compared 4 rather than 3 levels of boundary strength at both boundary positions (N=12 young adults). Most importantly, as intended, combining a weak boundary in position 1 and a strong boundary in position 2 resulted in a clear preference for LC (indicated by circles). For further details see caption of Figure 1and running text.



2.2. Event-related brain potentials (ERPs)

The same design used in our follow-up behavioral study has now been tested with ERPs, providing fine-grained *online data* of boundary processing and its impact on sentence interpretation. So far, we have collected ERP data from 38 young adults and are in the process of analyzing them.

Previous work has shown that ERP measures reliably reflect both boundary processing and garden-path effects. Prosodic boundaries elicit a closure positive shift (CPS), whose amplitude and latency vary with the acoustic markers in the speech signal (Steinhauer (et al.), [11-13]; Pauker [8]) as well as additional information influencing boundary strength (e.g., predictability of boundaries; Itzhak, et al. [4]). Garden path effects are reflected by N400 and P600 ERP components, depending on the strength of processing difficulties (e.g., Pauker, et al. [8]). This is illustrated in Figures 3 and 4.

Figure 3: Illustration of a closure positive shift (CPS) and a preceding negativity at prosodic boundaries (from Pauker, et al. [8]).

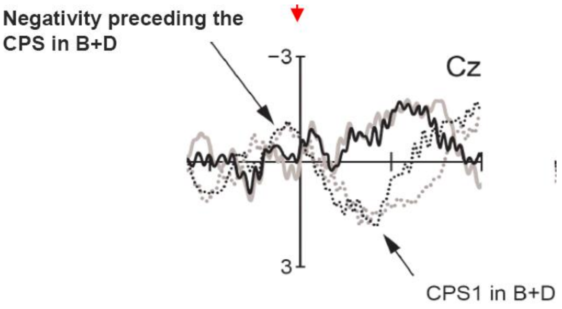
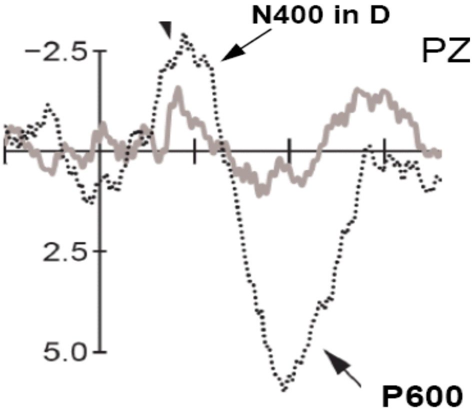
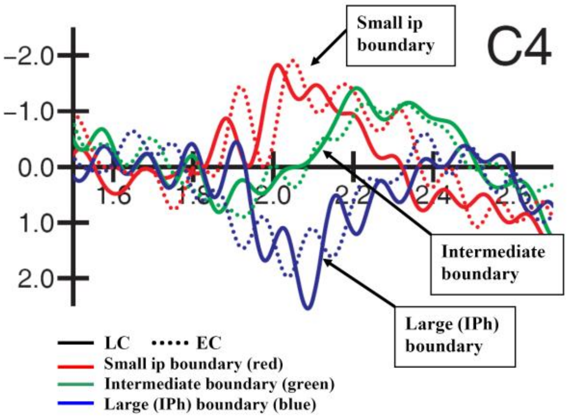


Figure 4: Illustration of prosody-driven ‘reverse’ garden-path effects in an LC sentence, resulting from a superfluous early boundary in position #1 (see Example (1) above; Figure adopted from Pauker, et al. [8]).



Preliminary ERP results. First ERP data of our new study are displayed in Figure 5. These plots show preliminary grand average ERPs at the first boundary position, based on all 38 data sets. Note that these ERPs are time-locked to sentence onset (not to boundary onset) and, therefore, are influenced by the variability in sentence length (which affects the position of the boundary relative to sentence onset). However, even these data strongly suggest a gradient CPS pattern reflecting the parametric manipulation of boundary strength, in both EC and LC sentences. More sophisticated analyses of the CPS (also at boundary position 2) and of the garden path effects will be presented at the conference.

Figure 5: Illustration of graded CPS amplitudes at the first boundary position at electrode C4 (N=38 subjects). These data from our new ERP study show that the CPS varies parametrically as a function of boundary strength and is largest for the strongest boundary (blue lines) and smallest (or absent) for the weakest boundary (red lines). This pattern is strikingly similar in both LC sentences (solid lines) and EC sentences (dotted lines).



3. CONCLUSION

The present approach is expected to provide high-resolution behavioral and ERP data elucidating the real-time processing of multiple competing prosodic boundaries of varying strengths and their impact on syntactic parsing and sentence interpretation. Both behavioral and ERP data will be discussed in relation to current theories of prosodic processing (e.g., Table 1).

4. REFERENCES

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