Neurophysiological Evidence for an Immediate Interaction of Prosody and Syntax in Speech Processing

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Introduction
In psycholinguistic literature it has been claimed that prosody and syntax interact at a very early stage of language processing. However, as most studies used off-line methods, they could not rule out the possibility that the interaction might take place after an initial processing stage. Using event-related potentials (ERPs), a method with excellent time resolution, the present study with German sentences provides neurophysiological evidence that prosody and syntax indeed interact at an initial stage. A general challenge in the investigation of the timing of syntactic and prosodic processing is that they may not be perfectly synchronized in time [1]. Therefore, we disentangled both variables in time by manipulating prosody at the stem and syntax at the suffix of the same critical word.

Methods
Design
• PROSODY (congruent vs. incongruent) × SYNTAX (correct vs. incorrect) yielding four experimental conditions (see Table 1). Additionally, two fully correct conditions were included.
• prosodic incongruity: critical word prosodically marked for sentence end, syntactic violation: phrase structure error at the suffix which disambiguated the critical word as a verb.
• 48 blocks containing sentences for all six conditions resulting in a total of 288 sentences.
• All four experimental conditions were constructed by a careful辑ting procedure to create correct sentences as well as the prosodic and syntactic violations. Source sentences were naturally spoken by a trained female speaker (recorded at 44kHz and 16 bit) (see Table 1).
• All critical words conditionally were isilabic with a trochaic stress pattern.

Participants
24 native speakers of German (12 females), all right-handed, age 19-29 years (mean 22.6).

Acoustical analyses of the stimuli
Concerning fundamental frequency (f0), the critical words in CC and CS showed a rise-fall pattern (see Figure 1), while in PC and PS they demonstrated a fall-rise pattern typical for the sentence end (see e.g. [2]).

Procedure
• All sentences were presented via loudspeakers in a pseudo-randomized order.
• Task: grammaticality judgement after each sentence.

Dependent variables
• Performance ratio (percentage of correct answers).
• ERP: sampling rate 250 Hz, 23 Ag/AgCl cup-shaped electrodes (inflated to exclude linked moieties), EEG recorded for artifactual control
• ERPs were computed for two different time epochs (both epochs were calculated with a 100 ms pre-stimulus baseline; 1) time-locked to the onset of the critical word (-100 to 1600 ms) (see Figure 2).
• 2) time-locked to the onset of the critical word’s suffix (-100 to 1200 ms) (see Figures 4a-d) in order to reduce jmitting of possible effects of the experimental mani-pulation at the suffix.

Data analyses
• time epoch 1: omnibus analyses (PROSODY × SYNTAX), time windows (TW): 300-500, 600-800 and 800-1200 ms (see Figure 2).
• time epoch 2: pairwise comparisons (see Figures 3a and 3b) yielding effects of SYNTAX (as CC and CS vs. PC and PS differed in the baseline), TWs: 200-400 and 400-800 ms.

Table 1

Results
1. Performance data
Participants showed excellent performance in the grammaticality judgement task (98.0% correct answers, no difference between conditions).

2. ERP data
(I) time-locked to critical word onset (see Figure 2):
- 300-500ms: a broadly distributed negativity for both prosodically incongruent conditions (PC, PS) independent of syntax.
- 600-800ms: a reliable left-temporal negativity for syntactically incorrect sentences only present when prosody was congruent (CS vs. CC), but not when prosody was incongruent (PS vs. PC).
- 800-1200ms: a posterior positivity for the syntactic and the combined violation condition indicating interaction of syntax and prosody (overadditive relation, based on difference waves)

(II) time-locked to critical word onset:
- CC vs. CS (see Figure 3a):
  - 200–400 ms: a left-temporal negativity.
  - 400–600 ms: a left-temporal negativity and a posterior positivity.
- PC vs. PS (see Figure 3b):
  - 200–400 ms: a negativity at temporal regions of both hemispheres.
  - 400–800ms: a posterior positivity

Direct contrast between left-temporal negativity CC-CS and bilateral temporal negativity PS-PC (see Figure 4a): difference at the right-temporal region significant, at the left-temporal region marginally (based on difference waves).

Discussion
Prosodic negativity
- reflects a mismatch between prosodic expectations for the sentence continuation built up on line and their disconfirmation.
- in a former study observed with a clear right anterior focus ("RAN") [3]. This topographical difference might be attributed to the level of linguistic information contained in the prosodically incongruent speech input according to the "Dual pathway model" [4] (right hemisphere dominant for prosody, left hemisphere more engaged the more linguistic content a stimulus provides).

Early temporal negativity:
- An early temporal negativity (interpreted as an ELAN-component) was observed over the left hemisphere for mere syntactic violation, but showed up bilaterally for the combined prosodic-syntax-violation (precise time-locking critical).
- This distributional change indicates an early interaction of prosody and syntax during the stage of initial phrase structure building.
- The prosodic influence density seems to be realized by additional recruitment of the right hemisphere. This might explain differing results observed by several ERP-studies concerning the topography of the ELAN-component (see [3] for an overview).

Late positivity
- Prosody and syntax also interact during a late processing stage as indexed by the P600 (confirming findings of our earlier study [3]).

The present findings support the assumptions of the "Dual Pathway Model" [4]. Moreover, based on the present results, the time course of the interaction between prosodic and syntactic information can be described precisely.

References