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 parsing 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) x SYNTAX (correct vs. incorrect) yielding four experimental conditions (see Table 1). Additionally two fully correct filler 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 each containing sentences for all six conditions resulting in a total of 288 sentences.
- All four experimental conditions were constructed by a careful splicing 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 (underlined) were disyllabic 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 rates (percentage of correct answers)
- EEG: sampling rate 250 Hz, 23 Ag/AgCl cap-mounted electrodes (offline re-referenced to linked mastoids), EOG recorded for artifact control
- ERPs were computed for two different time epochs (both epochs were calculated with a 100 ms pre-stimulus baseline):
  - I) time-locked to the onset of the critical word (-100 to 1600 ms) (see Figure 2),
  - II) time-locked to the onset of the critical word's suffix (-100 to 1200 ms) (see Figures 3a,b) in order to reduce jittering of possible effects of the experimental manipulation at the suffix.

Data analyses

- time epoch (I): omnibus-analyses (PROSODY x SYNTAX), time windows (TW): 300-500, 600-800 and 800-1200 ms (see Figure 2).
- time epoch (II): 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

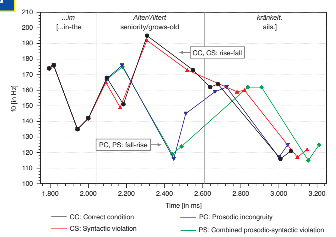
Recorded source sentences for the experimental conditions.

[1]*Maria weiß, dass der Rentner im* Alter *kränkelt*.
[2]Maria weiß, dass der Rentner im *Alte*rk kränkelt.
[3]Maria weiß, der Rentner kränkelt im *Alte*rk.
[4]Maria weiß, dass der Rentner im Alte*r* kränkelt.
[5]Maria weiß, dass der Rentner im Alte*rt* kränkelt.
[6]Maria weiß, der Rentner kränkelt im Alte*r*.
[7]Maria weiß, dass der Rentner ungern alte*rt*.

Splicing procedure

Con	*Example sentence* [with literal English translations]	Prosody	Syntax
CC	*Maria weiß, dass der Rentner im*[1] | *Alte*[2] | *r*[4] | *kränkelt.*[1] [Maria knows that the pensioner in-the seniority ails.]	congruent	correct
CS	* *Maria weiß, dass der Rentner im*[1] | *Alte*[2] | *rt*[5] | *kränkelt.*[1] [Maria knows that the pensioner in-the grows-old ails.]	congruent	incorrect
PC	# *Maria weiß, dass der Rentner im*[1] | *Alte*[3] | *r*[6] | *kränkelt.*[1] [Maria knows that the pensioner in-the seniority ails.]	incongruent	correct
PS	* # *Maria weiß, dass der Rentner im*[1] | *Alte*[3] | *rt*[7] | *kränkelt.*[1] [Maria knows that the pensioner in-the grows-old ails.]	incongruent	incorrect

1



Results

1. Performance data

Participants showed excellent performance in the grammaticality judgment 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).

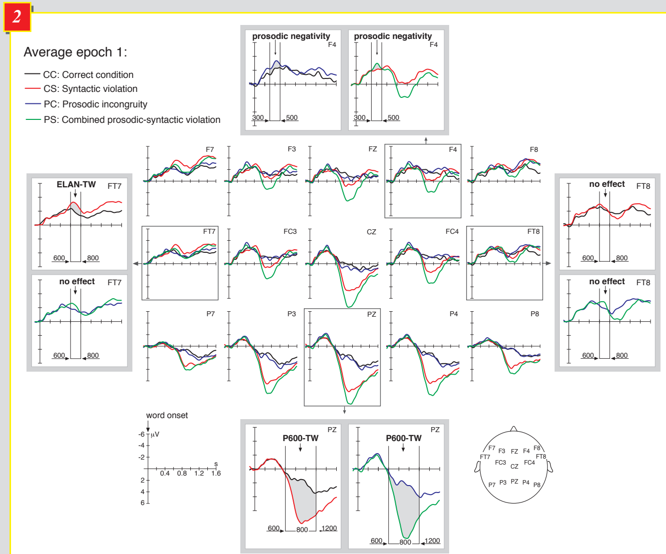
- 200-400 ms: a left-temporal negativity.
- 400-800ms: a left-temporal negativity and a posterior positivity.

PC vs. PS (see Figure 3a):

- 200-400 ms: a negativity at temporal regions of both hemispheres
- 400-800ms: a posterior positivity

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

2



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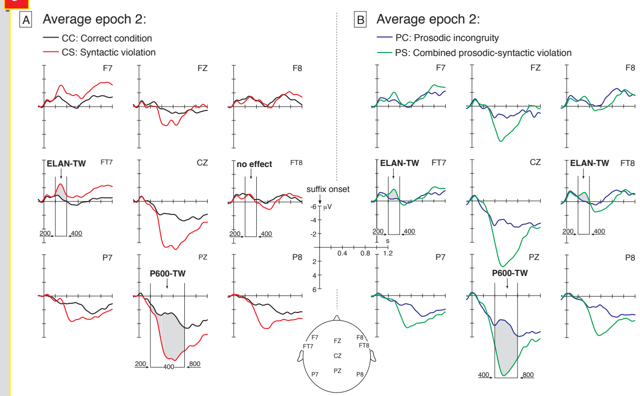

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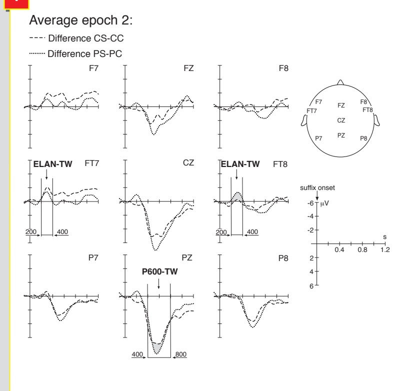

Discussion

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-syntactic 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 thereby 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

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