The brain´s response to hummed sentences

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ABSTRACT

The paper at hand investigates the processing of pure prosodic information using electrophysiological measures. Previous experiments showed a specific EEG response, a positive shift, in correlation to Intonational Phrase boundaries (IPh, [5]) in auditorily presented sentences [7]. This component is called Closure Positive Shift (CPS) and interpreted as a reflection of the processing of intonational boundaries in the speech signal. However, up to now it is unclear whether the CPS is determined by prosodic information only or whether it also depends on additional structural information contained in the signal. The aim of the present study was to separate prosodic processing from that of syntax and semantics and to investigate the brain's response to isolated prosodic information. We were able to show that isolated prosodic information also elicits a large positive shift at IPh boundaries. These results indicate that even prosody on its own is sufficient to evoke the event-related brain potential Closure Positive Shift (CPS).

1. INTRODUCTION

Spoken language, besides semantic and syntactic information, provides prosodic information such as pitch, duration, intensity, and spectral tilt. Those prosodic properties have so far mainly been investigated in perception as conveying an important role for the interpretation and disambiguation of syntactic structures [2, 9]. These phenomena were recently also studied using event-related potentials, i.e. by computing the online reaction of the brain to certain speech stimuli. Most of these studies so far were concerned with the interfaces between prosody and either syntax or semantics. However, the brain responses mediating the perception of isolated prosodic properties are still to be determined.

A brain response directly correlated to the perception of Intonational Phrase boundaries, as confirmed by acoustic analyses of the underlying sentence material, is the Closure Positive Shift [7]. This effect is a positive-going waveform in the event-related potentials. Following the first description of the CPS, an attempt was made to separate the prosodic properties in spoken language from additional, hence phonemic, syntactic, and semantic information [8]. This was done by filtering the original sentence material with a special procedure (PURR, [6]). The evolved signals then only comprised prosodic parameters. This study confirmed the CPS as prosodically evoked component. However, using the unnatural stimuli, the time-course and amplitude of the effect was different from the results on natural sentence processing.

Hence, the main goal of the present study was to explore the brain response to naturally produced but delexicalized sentences. The method chosen for these purposes was humming the material introduced by Steinhauer et al. [7].

2. METHODS

2.1. Subjects

Twenty-two students (11 female, mean age 24,5 years) participated in the experiment. All subjects were right-handed, and without any hearing disorders.

2.2. Acoustic stimuli

A corpus of non-speech stimuli was created by humming the sentences used in the Steinhauer et al. study [7] (see Table 1). This method assured that the sentences did neither contain syntactic nor semantic information, whereas the overall intonation contour (as measured by the fundamental frequency) was still comparable to the original sentences. Thus, the sentences only contained prosodic information such as intonation, duration, and amplitude.

Examples of the original material, which was analogously hummed, are given in Table 1. Condition A comprised only one IPh boundary, whereas condition B contained two.

Condition A	[Peter verspricht Anna zu arbeiten]$_{IPh1}$ [und das Büro zu putzen.] [Peter promises Anna to work]$_{IPh1}$ [and to clean the office.]
Condition B	[Peter verspricht] $_{IPh1}$[Anna zu entlasten] $_{IPh2}$ [und das Büro zu putzen.] [Peter promises] $_{IPh1}$[to support Anna] $_{IPh2}$ [and to clean the office.]

Table 1: Examples for the original sentences which were hummed

A corpus of 96 hummed sentences (48 in each condition) was constructed. These hummed sentences were recorded with a trained female speaker in a sound-proof room and digitized at 44.1 kHz/ 16 bit/ Mono. All stimuli were normalized in amplitude to 70%. The analysis of the tonal patterns assured that the sentences really differed in their prosodic realization. As visualized in Figure 1, condition B

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conveying two IPh boundaries exhibits a high boundary tone at the end of the proposed first tonal phrase whereas condition A conveying one IPh boundary does not.

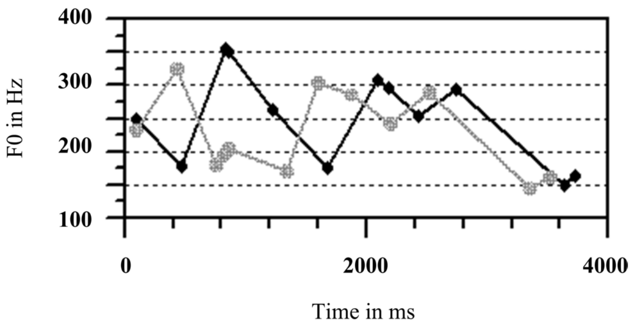

Figure 1: Stylized course of F0 in Hz for condition A (grey) and condition B (black)

The overall sentence length between conditions did not differ significantly (see Figure 2). The only difference between conditions is indeed a pause in condition B after the first tonal phrase (∅ 316ms vs. ∅ 10ms in condition A).

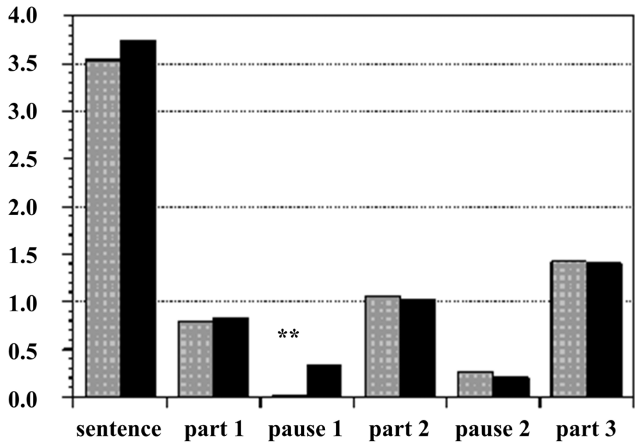

Figure 2: Sentence duration for condition A (grey) and condition B (black), ** $p < 0{,}01$

For experimental reasons, another 96 hummed filler sentences were constructed by splicing real words into the existing hummed versions. The position of these "real words" within the hummed sentences was random to convey the impression that they belong to an entire spoken phrase. These fillers did not enter the data analysis, but only assured the participant's attention throughout the experiment.

2.3 Procedure

Sentences were presented auditorily in a pseudo-randomized order in 8 blocks of 24 trials. Block order was counterbalanced across subjects. A probe detection task was used. For it, a real word was spliced into the hummed fillers (as described above). 50% of the filler sentences contained the probe that was asked for, and 50% did not.

Participants were seated in a sound-proof chamber in front of a PC monitor. Sentences were presented via loudspeakers. Participants were instructed to look at a fixation point in the middle of the monitor throughout the whole experiment and to blink only during the presentation of the probe words.

Each trial started with the auditory presentation of a sentence. After a interstimulus interval (ISI) of 1500 ms the probe followed. Participants had to decide whether the probe had been a part of the preceding sentence or not by pressing a corresponding button as soon as possible.

An experimental session lasted about 1,5 h, including electrode application.

2.4. Data analysis

EEG epochs containing eyeblinks or movement artifacts were rejected and did not enter the ERP averages. Averages were computed for 4500ms across the whole sentence using a 200ms prestimulus baseline.

ANOVAs were computed for the midline and lateral electrodes seperatly. For the midline, a two-way ANOVA was used with the factors condition and electrode. For the lateral electrodes, 6 regions of interest (ROIs) were defined. A three-way ANOVA design with the factors condition, position, and hemisphere was applied.

3. RESULTS

As expected, a large positive waveform (CPS) in correlation to the intonational phrase boundaries was detected. The two conditions elicited significantly different ERP effects due to their varying tonal pattern. Grand-average ERPs across all subjects showed that condition B evoked two positive shifts, corresponding to its two IPh boundaries. In contrast, condition A which only contained one IPh boundary elicited one corresponding positive shift. Grand-average ERPs are displayed in Figure 3.

With regard to the topography of the effects, it is notable that the first CPS for condition B is located bilaterally across the two hemispheres of the brain. The CPS for condition A as well as the second CPS for condition B is most pronounced over posterior electrode positions. Interestingly, statistical analyses showed that the positive shift for condition A and the second positive shift for condition B are strongly lateralized to the right hemisphere.

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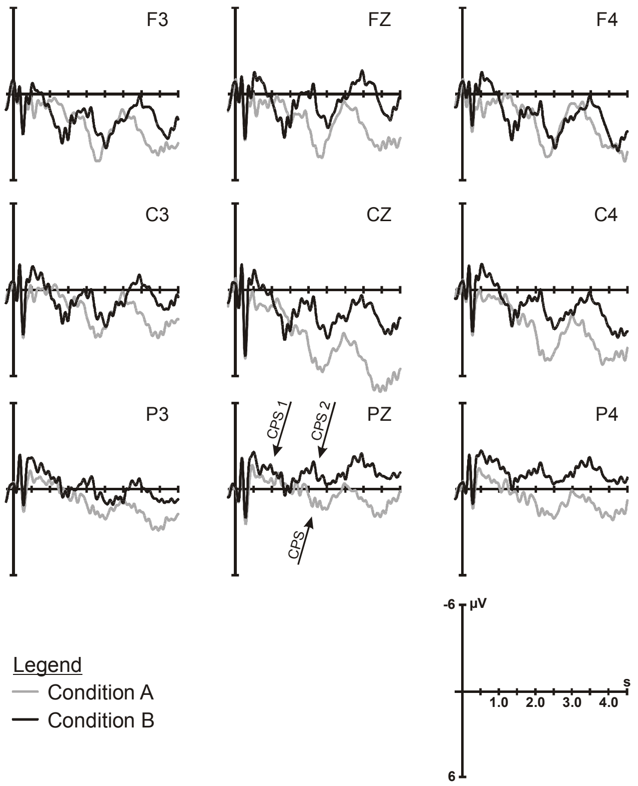

Figure 3: Grand average ERPs for the delexicalized sentences in both conditions at the frontal, central, and parietal electrodes

4. CONCLUSIONS

The present study explored the perception of linguistic prosody in the absence of phonemic, syntactic, and semantic information. It could be shown that even prosody on its own is able to elicit the event-related component CPS which has formerly been found to indicate online prosodic processing in the presence of additional linguistic information.

These results are consistent with the data of Steinhauer & Friederici [8] who investigated the nature of the CPS in filtered delexicalized speech material. They could also show an independence of that ERP component from other linguistic information (i.e. phonemic, syntactic and semantic), hence its reliance on acoustic parameters in the speech stream. The present data show that the Closure Positive Shift is much more pronounced with naturally produced but delexicalized speech. It is also worth noting that the Steinhauer et al. study do not report any lateralization effects with the technically manipulated speech material. The clear lateralization effect in our results is most possibly contributable to the naturally produced stimuli used in the present study. Thus it seems that the human brain is much more effective in understanding and interpreting naturally produced vocalizations in contrast to artificially processed speech.

Furthermore, the lateralization effects for the perception of isolated prosody are in accordance with the results of neuroimaging studies [3, 10] showing an advantage of the right hemisphere for the processing of prosodic parameters. The role of the right hemisphere for the interpretation and production of prosodic parameters, especially for the fundamental frequency has also been manifested by a large amount of patient studies [1, 4].

In conclusion, our data show that prosody in naturally produced but delexicalized speech material evokes a specific ERP component in correlation to the intonational phrase boundaries. This component which has previously only being found in correlation to the IPh boundaries in naturally produced sentences including also syntactic and semantic information is the Closure Positive Shift (CPS). Thus prosodic information is sufficient for elicitation of this electrophysiological marker.

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