ACTA NEUROBIOLOGIAE EXPERIMENTALIS

Acta Neurobiol Exp 2006, 66: 55-68

Prosodic pitch accents in language comprehension and production: ERP data and acoustic analyses

Stefan Heim[1,2] and Kai Alter[3]

[1]Institute of Medicine, Research Centre Jülich, 52425 Jülich, Germany; [2]Brain Imaging Center West, 52425 Jülich, Germany; [3]School of Neurology, Neurobiology and Psychiatry, Medical School, Framlington Place, University of Newcastle, Newcastle upon Tyne NE2 4HH, UK

Abstract: We used event-related potentials (ERPs) and acoustic analyses to investigate the processing of prosodic pitch accents as a function of their position in a sentence. Accents in sentence-medial positions were characterized by a higher fundamental frequency (F_0) and an increased duration. They elicited two different negative ERP components around 400 ms, depending on the predictability of the accent. When the accent was predictable, the negativity was fronto-laterally distributed and identified as the previously known Expectancy Negativity. Unpredictable accents elicited a more broadly distributed N400 with a central maximum, reflecting difficulties in semantic processing. For sentence-initial pitch accents, words had a higher F_0 but of the same duration as sentence-initial words without pitch accents. These pitch accents elicited a P200 but no negativity in a 400 ms time window. The P200 was modulated by the onset latency of the F_0 peak rather than its magnitude. We discuss the possibility of a delayed processing of sentence-initial accents when the actual occurrence of an F_0 peak can be identified by comparing the F_0 of the sentence-initial word to a reduced F_0 of a word occurring later in the sentence.

The correspondence should be addressed to S. Heim, Email: s.heim@fz-juelich.de

Key words: prosody, pitch accent, event-related potentials, ERP, language, production, comprehension, speech

INTRODUCTION

In spoken language, information is not only carried by words, but also by the speech melody (prosody). The term prosody, originally denoting "song sung with instrumental music" in ancient Greek (Friedrich 2003), today refers to suprasegmental speech information. This includes acoustic properties such as fundamental frequency (F_0), loudness (amplitude), and duration of a speech signal, among other acoustic parameters related to voice recognition (e.g., Warren et al. 2005) and affective prosody (e.g., Besson et al. 2002, Schirmer et al. 2002). Comprehensive reviews of the linguistic functions of prosody in human communication can be found in Beckmann (1996), Hirschberg (2002), Hirst and Di Cristo (1998), Ladd (1996), Nespor and Vogel (1986), and Selkirk (1984). From a prosodic point of view, two types of prosodic/suprasegmental information have been investigated in recent behavioural and electrophysiological studies: (1) the processing of prosodic breaks (cf. Isel et al. 2005, Pannekamp et al. 2005, Steinhauer et al. 1999), and (2) the processing of so-called highlighted, pop-up words (see Hruska and Alter 2004, for German, Magne et al. 2005, for similar phenomena in French, Johnson et al. 2003, for English). In this paper, we focus on the processing of (2), namely the processing of constituents that are highlighted/accented by prosodic means.

Highlighting words on sentence level is connected to a special meaning that has an impact on the underlying syntactic and semantic processing in intonational languages such as German, Dutch and English. In these languages, highlighted and accented information is emphasized by pitch accents. In a hypothetical dialogue situation the preceding wh-question of speaker A indicates that speaker B has conveyed the information status of speaker A in answering. In this special situation, speaker B will highlight the new information by means of prosodic patterns. This can be realized by moving the main accent position to the constituent considered to be new in a sentence, indicated in the example below by capitals. The speaker's focus in the answer is therefore related to the constituent previously asked for as exemplified in the following question-answer pair:

(A) Who ate an apple?
(B) ANNA ate an apple.

Thus, focus reflects the status of the information structure (IS). The ongoing research on IS has produced several theoretical definitions (Lambrecht 1996, Liedtke 2001, Prince 1981, Steube 2000). The main description of IS refers to the given/new status. The focus of a sentence is semantically/pragmatically the most salient information and it has been pointed out that these aspects are emphasized as opposed to given or presupposed information (e.g., Halliday 1967, Jackendoff 1972, Rooth 1985). Several psycholinguistic studies using behavioral measures (acceptability judgments, reaction times) revealed that speech comprehension is facilitated when focused information is accented and already given background information is de-accented (Birch and Clifton 1995, 2002, Bock and Mazzella 1983, Brown 1983, Cutler et al. 1997, Dahan et al. 2002, Most and Saltz 1979, Nooteboom and Kruyt 1987, Terken and Nooteboom 1987). Moreover, prosodic information might influence sentence interpretation even in cases when homophonous sentences, i.e. sentences containing the same word order but realized with a different prosody are presented to listeners. The following pair of sentences with different accentuation might illustrate such effects on sentence interpretation.

(C) ANNA ate an apple.
(D) Anna ate an APPLE.

In (C), the sentence might result from a situation as exemplified above (question A followed by answer C), or might provide a correction. In (D), the sentence might also be correction to a specific, preceding context (sentence D proceeded by question E).

(E) Did Anna eat a banana?

Most importantly, such situations need to be embedded in contexts. In recent work on the influence of IS, small dialogues were used to demonstrate the impact of emphasizing single constituents by assigning pitch accents. In a few studies on dialogue processing, matched and mismatched conditions have been employed. For instance, an appropriate dialogue would be the example in (A/B). In contrast, a mismatch would be a combination of (A) and (D):

(A) Who ate an apple?
(D) Anna ate an APPLE.

In this case, the mismatch in answer (D) is twofold. First, there is a missing accent on "Anna", second, there is a superfluous accent on "apple". For the processing of such dialogues, a number of studies showed effects for missing or superfluous accents (Hruska et al. 2001, Johnson et al. 2003, Magne et al. 2005). However, these effects were not congruous. Whereas the studies of Hruska and coauthors (2001) and Johnson and coauthors (2003) yielded negativities (albeit with different scalp distributions), Heim and Alter (accepted)[1] and Magne and coauthors (2005) observed positive-going difference waves for inappropriate vs. appropriate pitch accents. As Magne and coauthors (2005) and Heim and Alter (accepted) argue, this is most probably due to position of the accented word in the sentence. Inappropriate accents on sentence-medial words elicited more positive-going potentials, whereas violations of accents on sentence-final words elicited negative effects. The significance of these positive and negative deflections is still poorly understood. The discussed cognitive processes possibly reflected by these components are surprise when encountering an unexpected accent (positivity) and increased processing demands when integrating the information at sentence-final positions (negativity).

One important question related to the processing of pitch accents still remains unanswered: How are pitch accents processed in isolated sentences without explicitly preceding context? In the studies presented above, this question was related to an indirect processing of shared knowledge by the participants of the communication. The present ERP studies aim to investigate the processing of accents related to single sentence processing, i.e. to the processing of sentences presented without explicitly provided contextual information. In such isolated sentences, pitch accents do not refer to some information given earlier. Therefore, at the beginning of an isolated sentence, the presence of a pitch accent should be confusing since it cannot be related to some existing IS. In contrast, pitch accents occurring later in the sentence can be interpreted in the context of the preceding part of the sentence. This implies that, in isolated sentences, the processing of pitch accents in sentence-initial positions should differ from that of pitch accents in sentence-medial or sentence-final positions where the context provided by the sentence itself may have created some expectancy for the occurrence of a pitch accent.

In the present paper we report two ERP studies addressing this issue. We investigated the processing of prosodic pitch accents in auditory language comprehension as a function of production parameters (F0, duration, onset latency) and their position in a single sentence without a preceding context. Given the above discussed data on accent processing in contexts, one might therefore formulate the following expectations. For unexpected accents on words occurring early in the sentence, there might be an N400/P600 effect indicating integration difficulty. Alternatively, the surprise to encounter an accent at all might be related to a P300 as observed by Magne and coauthors (2005). Prosodic accents occurring later in the sentence might be expected from the context created by the sentence itself and thus evoke no effect at all or the Expectancy Negativity reported by Hruska and Alter (2004).

EXPERIMENT 1

Materials and Methods

The design of Experiment 1 is shown in Example 1. Pitch accents are indicated by capital letters. We used the same materials as in Heim and Alter (accepted). By cross-splicing sentences (1a) and (1b) after the verb, we systematically manipulated the presence of a pitch accent on the first NP (NP1) and/or the second NP (NP2) (1a-d).

(1a) P*eter verspricht sogar ANNA zu arbeiten und das Büro zu putzen.*
(Peter promises even Anna to work and the office to clean.)
(1b) *PETER verspricht sogar Anna zu arbeiten und das Büro zu putzen.*
(Even Peter promises Anna to work and the office to clean.)
(1c) *Peter verspricht sogar Anna zu arbeiten und das Büro zu putzen.*
(1d) *PETER verspricht sogar ANNA zu arbeiten und das Büro zu putzen.*

The interaction of an accent on NP1 (ACC1) with an accent on NP2 (ACC2) and their relationship to the focus particle *sogar* ("even") are discussed in detail by Heim and Alter (accepted). In the present paper, we will focus on the main effects of ACC1 and ACC2 as operationalizations of sentence-initial and sentence-medial accents.

For each of the four conditions, 48 sentences were recorded on a digital tape with a trained female native German speaker in a sound proof chamber at a 44.1 kHz sampling rate and 16-bit resolution.

[1] Heim S, Alter K. Focus on focus: the brain's electrophysiological response to focus particles and accents in German. In: Sentence and Context (Steube A, ed.). De Gruyter, Berlin (book in preparation).

PROCEDURE

Subjects were seated in a dimly-lit room in front of a computer screen (approximate distance 1 m). Stimuli were presented acoustically *via* loudspeakers from a distance of approximately 1.5 m. After a short training block of 10 trials, subjects completed six blocks with 48 sentences each. The proportion of sentences per condition was kept parallel in each block, and the sentences were presented in a pseudo-randomized order. During the presentation of the sentence, a fixation cross was shown in the middle of the screen, which appeared synchronously to the onset of the auditory stimulus. After each sentence, the subjects performed a delayed probe verification task (cf. Isel et al. 2005). A name was presented on the screen in white capital letters on a black background. After a go signal (6000 ms after sentence offset), the subjects had to indicate whether this name had been in the sentence by pressing the left or right button of a response box. All subjects were instructed to make eye-blinks only after they had pressed the response button. YES and NO responses were balanced for each subject, and left or right button presses for the YES/NO responses were balanced across subjects. This task was chosen for several purposes. First, since the probes were only names, subjects had to listen alertly to the sentences and attend the two NPs on which the prosodic manipulation was made. However, they were not instructed to make prosodic judgments. Thus, the task did not interfere with the manipulation. Second, the probe was given after, not before the presentation of the stimulus. Thus, there was no memory load for the subjects while listening to the stimulus that might interfere with the perception of the sentence.

PARTICIPANTS

32 volunteers (16 female; mean age 24.8 years, range 18–34 years) participated in the experiment. They were all right-handed and had normal or corrected-to-normal vision. None of the subjects had a known history of neurological or psychiatric disorder. Each subject was paid for participation. Informed written consent was obtained from all subjects. The experimental standards were approved by the local ethics committee of the University of Leipzig. The data were handled confidentially.

RECORDINGS

The electroencephalogram (EEG) was recorded with 25 Ag-AgCl electrodes (electrocap) from FP1, FP2, F7, F3, FZ, F4, F8, FT7, FC3, FC4, FT8, T7, C3, CZ, C4, T8, CP5, CP6, P7, P3, PZ, P4, P8, O1, O2 (nomenclature as proposed by the American Electroencephalographic Society 1991), each referred to the left mastoid. Bipolar horizontal electrooculogram (EOG) was recorded between electrodes above and below the subject's right eye. Electrode resistance was kept under 5 kW. The signals were recorded continuously with a bandpass filter between DC and 70 Hz and digitized at a rate of 250 Hz.

DATA ANALYSIS

The EEG recorded from single electrode sites was averaged for four regions of interest (ROIs) that were defined as follows. Anterior-left (AL): F7, F3, FT7, FC3; Anterior-right (AR): F8, F4, FT8, FC4; Posterior-left (PL): T7, CP5, C3, P7, P3; Posterior-right (PR): T8, CP6, C4, P8, P4. Average amplitudes of the ERP, starting 200 ms before and lasting 1200 ms after the onset of NP2 ("Anna") were computed for each ROI. Trials containing ocular and amplifier saturation artifacts (EOG rejection ± 40 μV) were excluded from the averages. Averages were aligned (referenced) to a 200 ms pre-stimulus baseline. In order to describe the onsets and length of the ERP effects in reasonable detail, an analysis was carried out in which the data were statistically evaluated in 24 time windows, which had a length of 50 ms each (Gunter et al. 2000). If there were significant effects in more than one consecutive time windows, the analysis was then performed again for the total time window in which there were significant effects in all of the contiguous 50 ms time windows. We used a repeated-measures ANOVA with within-subject factors ACC1 (accent on NP1: present/absent: ACC+/ACC-), LR (hemisphere: left/right), AP (position: anterior/posterior), and ACC2 (accent on NP2: present/absent: ACC+/ACC-). No main effects of or interactions between topographical factors will be reported. If the variables ACC1 or ACC2 revealed a significant interaction ($P<0.05$) with one or both of the topological factors (LR, AP), a further analysis was conducted on the lowest level. The Greenhouse-Geisser correction (Greenhouse and Geisser 1959) was always applied when evaluating effects with more than one degree of freedom in the numerator.

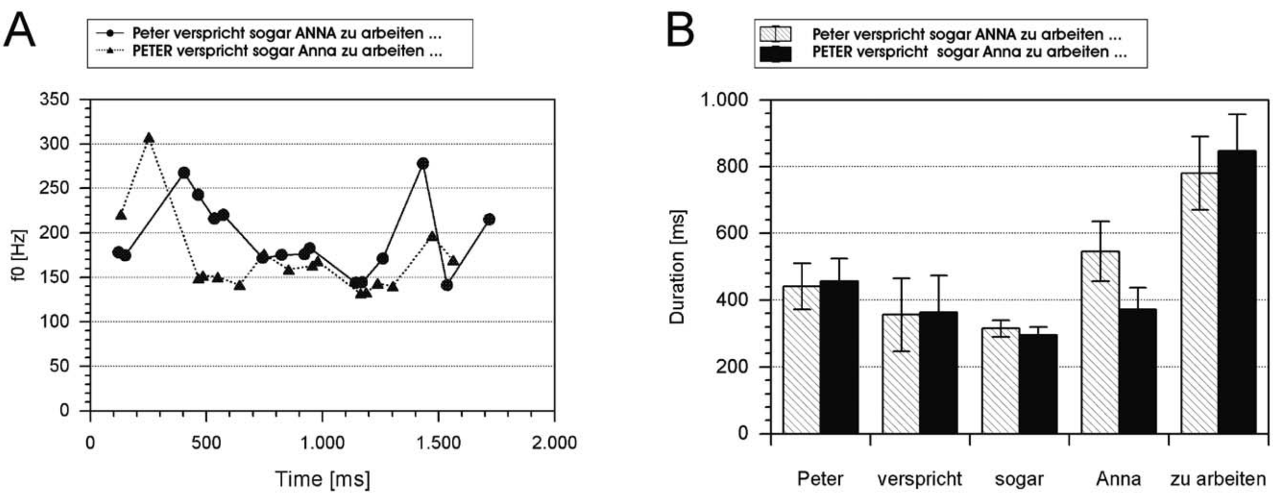

Fig. 1. Acoustic analyses of the stimuli used in Experiment 1. (A) Mean fundamental frequency (F_0 in Hz) of the two basic conditions (1a, 1b). (B) Mean durations (in milliseconds) of each of the first five constituents of the sentences as a function of sentence type.

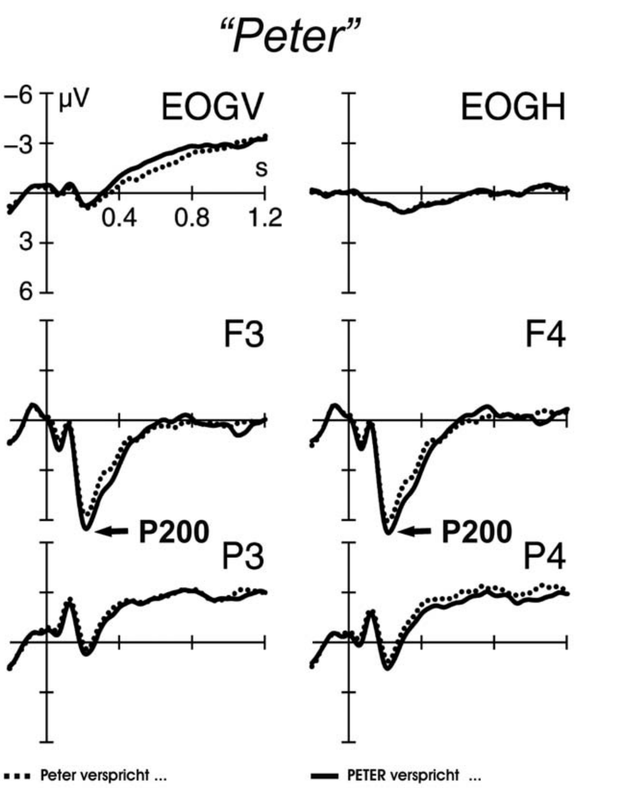

Fig. 2. Mean ERPs from Experiment 1 on NP1 ("*Peter*") at four electrode sites – (F3) left anterior; (P3) left posterior; (F4) right anterior; (P4) right posterior) – as a function of ACC1 (accent present – solid lines; no accent – dotted lines) on NP1.

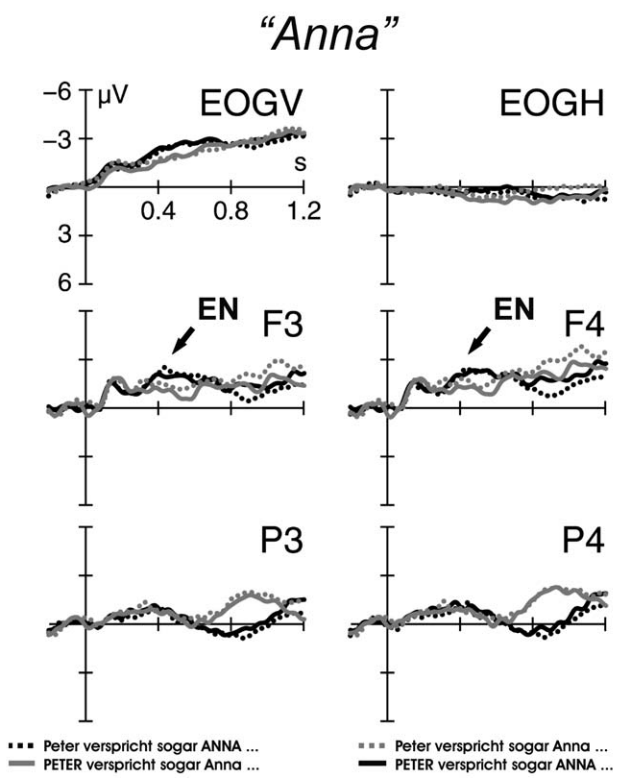

Fig. 3. Mean ERPs from Experiment 1 on NP2 ("*Anna*") at four electrode sites – (F3) left anterior; (P3) left posterior; (F4) right anterior; (P4) right posterior – as a function of ACC1 (accent on NP1 "*Peter*": dotted lines – no accent; solid lines – accent) and ACC2 (accent on NP2 "*Anna*": grey lines – no accent; black lines – accent).

Table I

Mean ERP amplitudes (in µV) in the four regions of interest as a function of ACCENT [(ACC+) pitch accent present; (ACC-) pitch accent absent] on NP1 ("*Peter*") in Experiment 1

	LA	LP	RA	RP
ACC-	2.80	0.14	3.58	0.38
ACC+	3.58	0.53	4.28	0.89

Abbreviations: (LA) left anterior; (LP) left posterior; (RA) right anterior; (RP) right posterior

Table II

Mean ERP amplitudes (in µV) in the four regions of interest as a function of ACCENT [(ACC+) pitch accent present; (ACC-) pitch accent absent] on NP2 ("*Anna*") in Experiment 1

	LA	LP	RA	RP
ACC-	-2.00	-0.93	-2.00	-1.06
ACC+	-1.89	-0.91	-2.14	-1.19

Abbreviations: (LA) left anterior; (LP) left posterior; (RA) right anterior; (RP) right posterior

Results

ACOUSTIC ANALYSES OF THE PRODUCTION DATA

The results of the acoustic analyses for the two basic sentence types (1a and 1b), from which the other two types were generated, can be seen in Fig. 1. The accented constituents had a locally higher fundamental frequency than non-accented constituents but equal duration. For both NP1 and NP2, the F_0 peak in the condition with pitch accent was prior to that in the condition without pitch accent. The accented NP2 had a longer duration than the non-accented NP2.

ERP DATA

NP1 (*"Peter"*)

In an early time window (250-350 ms), there was a significant main effect of ACC1 ($F_{1,31}$=8.89; P<0.006; ACC+ > ACC-), and a significant interaction ACC1 × AP ($F_{1,31}$=9.44; P<0.004). The *post-hoc t*-tests revealed an positive effect for ACC1 (ACC+ > ACC-) in the following regions of interest (ROI): left anterior (LA: t_{31}=-3.51, P<0.001), right anterior (RA: t_{31}=-3.21, P<0.003), and right posterior (RP: t_{31}=-2.38, P<0.023). These effects are shown in Fig. 2, the top panel of Fig. 8, and in Table I.

NP2 (*"Anna"*)

From 400 ms to 600 ms, there was a main effect of ACC2 ($F_{1,31}$=9.19; P<0.005; ACC+ < ACC-) and an interaction ACC2 × AP ($F_{1,31}$=14.69; P<0.001). *Post-hoc t*-tests showed an effect of ACC2 (ACC+ < ACC-) in the LA (t_{31}=3.22; P<0.003), RA (t_{31}=3.74; P<0.001), and RP ROI (t_{31}=2.11; P<0.043). The effects are presented in Fig. 3, the top panel of Fig. 8, and in Table II.

Discussion

The sentence-medial pitch accent on NP2 ("*Anna*") elicited a mostly frontally distributed negativity in the time window between 400–600 ms. This effect is comparable to the one observed by Hruska and Alter (2004) for correct pitch accents, yielding a frontally distributed negativity. We will return to the question of the nature of the process reflected by this component in the General Discussion.

In contrast to the negativity observed on NP2, the sentence-initial pitch accent on NP1 ("*Peter*") elicited an early positivity between 250–350 ms. According to its topography, which is maximally frontal, and its latency about 300 ms, this deflection could be interpreted as a P3a/Novelty P3 or as a late P200. We tend to take this component as a P200 rather than a P3a, for the following reasons. First, the P3a as described by Squires and coauthors (1975) is elicited by task-irrelevant, rare stimuli. None of these characteristics apply to the present paradigm in which stimuli in both conditions and with the same probability of occurrence elicit this component. Second, the significant difference between the conditions reveals that the amplitude is positively modulated by the presence of a pitch accent, i.e., by physical properties of the stimulus. However, as Polich (1998, 1999, cf. Hruby and Marsalek 2003) demonstrated, the physical energy of a stimulus does not influence the P3. In contrast, such a variation of a potential with physical properties was previously reported for the P200 by Carrillo-de-la-Pena and coauthors (1999). We therefore interpret this early positivity as a P200 component showing up for both conditions (1a and 1b) at the beginning of the sentence when both a visual stimulus (the fixation cross) and an acoustic stimulus (the sentence) are switched on. The increase for the accented condition may be either due to the higher F_0 or due to the earlier peak in the F_0 contour. As further evidence for our argument as to which factor influenced the increase of the amplitude in the accented condition the data of Friedrich and coauthors (2001) should be considered. These authors also found a P200 which was stronger for initially unstressed as compared to initially stressed words. The analysis of the acoustic parameters of the Friedrich and coauthors (2001) study (their Fig. 1) reveals that the initially unstressed condition has a peak in the F_0 contour that is smaller than the one in the initially stressed condition but precedes it. This finding substantiates the interpretation of the early frontal positivity in Experiment 1 as a P200 component. It is driven by the first peak in F_0 in the speech signal rather than the magnitude of the F_0 change.

To summarize, there were different effects of pitch accent on NP1 and NP2. This pattern of results suggests that the position of a pitch accent (sentence-initial vs. sentence-medial) really seems to matter for the processing of pitch accents. Comparable data were reported by Magne and coauthors (2005) and Heim and Alter (accepted) for inappropriate accents. This issue was further investigated in Experiment 2 where we disentangled the position of the first accent in the sentence from the visual and acoustic effect of the onset of the stimulation.

EXPERIMENT 2

Materials and Methods

In Experiment 2 we changed the position of the first pitch accent to the first verb (VP1) instead of NP1. Examples for the new conditions are given in (2a–d). Again, conditions (2c) and (2d) were obtained by cross-splicing the sentences of the first two conditions after VP1.

(2a) *Peter verspricht sogar ANNA zu arbeiten und das Büro zu putzen.*

(2b) *Peter VERSPRICHT sogar Anna zu arbeiten und das Büro zu putzen.*

(2c) *Peter verspricht sogar Anna zu arbeiten und das Büro zu putzen.*

(2d) *Peter VERSPRICHT sogar ANNA zu arbeiten und das Büro zu putzen.*

By moving the first accent in the sentence to a more sentence-medial position, we were able to analyse the effects of sentence onset, first accent, and later accent separately. Accordingly, ERP results are given for NP1, VP1, and NP2.

PARTICIPANTS

32 volunteers (16 female; mean age 24.0 years, range 21–28 years) participated in the experiment. They were all right-handed and had normal or corrected-to-normal vision. None of the subjects had a known history of neurological or psychiatric disorder. Informed written consent was obtained from all subjects. The experimental standards were approved by the local ethics committee of the University of Leipzig. The data were handled confidentially. Each subject was paid for participation. None of the volunteers had participated in Experiment 1.

RECORDINGS AND DATA ANALYSIS

The recordings and data analysis were identical to Experiment 1.

Results

ACOUSTIC ANALYSES OF THE PRODUCTION DATA

The results of the acoustic analyses for the two basic sentence types (2a and 2b), from which the other two types were generated, can be seen in Fig. 4. All accented constituents had a locally higher F_0. For NP1, there was an earlier peak in the F_0 in the condition with accent on VP1 than in the condition without accent on VP1. The accented constituents VP1 and NP2 were also characterized by longer durations. This effect was significant for NP2 and showed a trend in VP1.

ERP DATA

NP1 (*"Peter"*)

For the first constituent, there was an early effect (150–250 ms) of ACC1 ($F_{1,31}$=4.88; P<0.035; ACC+ >

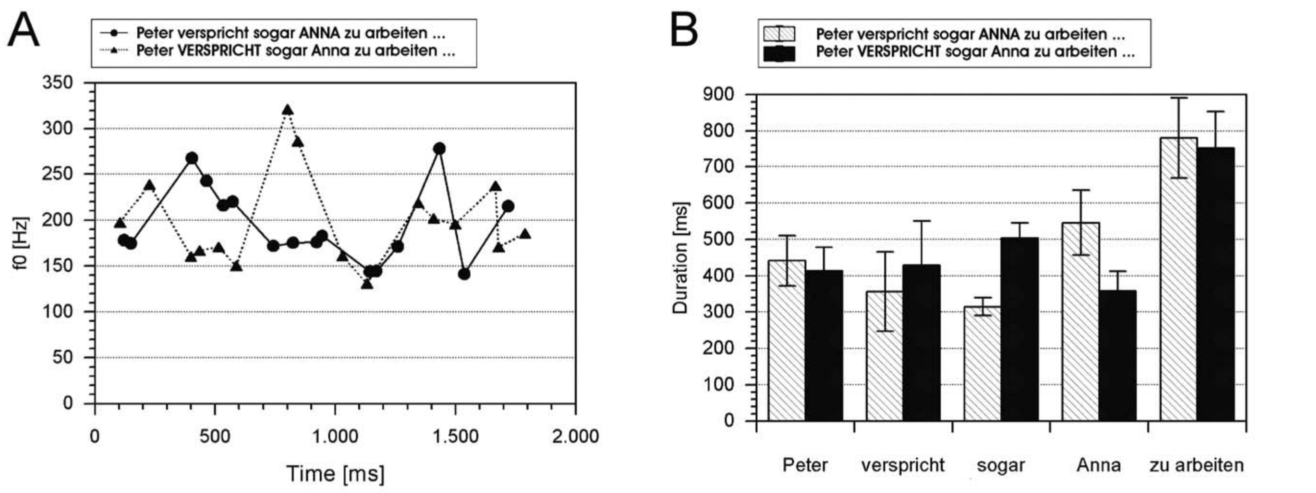

Fig. 4. Acoustic analyses of the stimuli used in Experiment 2. (A) Mean fundamental frequency (F_0 in Hz) of the two basic conditions (2a, 2b). (B) Mean durations (in milliseconds) of each of the first five constituents of the sentences as a function of sentence type.

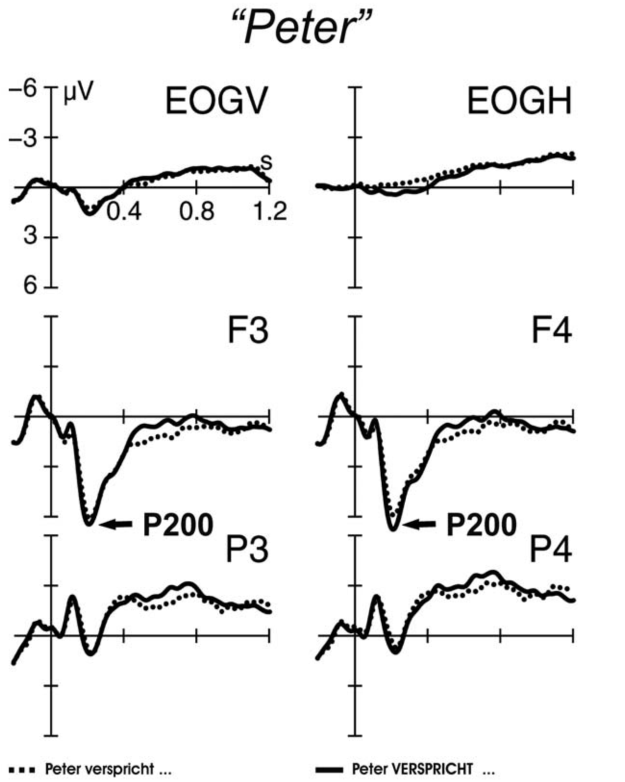

Fig. 5. Mean ERPs from Experiment 2 on NP1 ("*Peter*") at four electrode sites – (F3) left anterior; (P3) left posterior; (F4) right anterior; (P4) right posterior) as a function of ACC1 (accent present – solid lines; no accent – dotted lines) on the verb (VP1: "*verspricht*").

Table III

Mean ERP amplitudes (in μV) in the four regions of interest as a function of ACCENT [(ACC+) pitch accent present; (ACC-) pitch accent absent] on NP1 ("*Peter*") in Experiment 2

	LA	LP	RA	RP
ACC-	4.57	1.67	4.52	1.33
ACC+	4.70	1.77	4.95	1.67

Abbreviations: (LA) left anterior; (LP) left posterior; (RA) right anterior; (RP) right posterior

Table IV

Mean ERP amplitudes (in μV) in the four regions of interest as a function of ACCENT [(ACC+) pitch accent present; (ACC-) pitch accent absent] on VP1 ("*Verspricht*") in Experiment 2

	LA	LP	RA	RP
ACC-	-1.82	-1.00	-2.41	-1.69
ACC+	-2.57	-1.79	-3.49	-2.75

Abbreviations: (LA) left anterior; (LP) left posterior; (RA) right anterior; (RP) right posterior

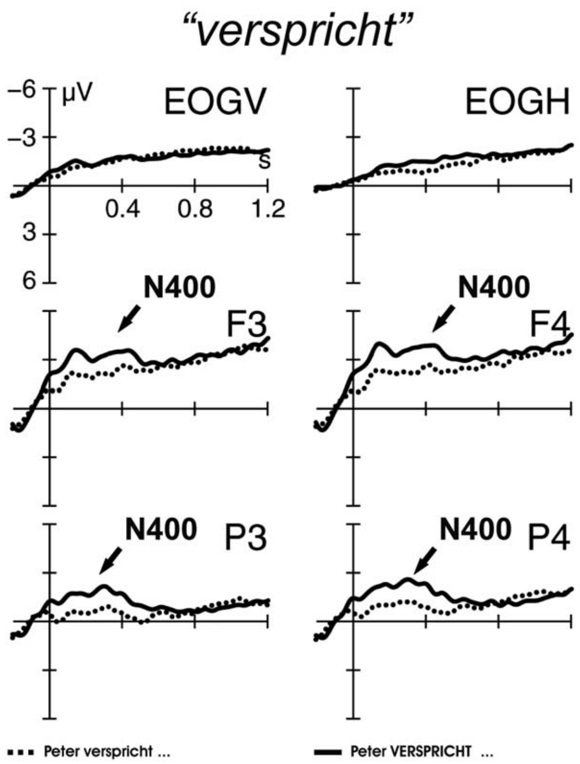

Fig. 6. Mean ERPs from Experiment 2 on VP1 ("*verspricht*") at four electrode sites – (F3) left anterior; (P3) left posterior; (F4) right anterior; (P4) right posterior – as a function of ACC1 (accent present – solid lines; no accent – dotted lines) on VP1.

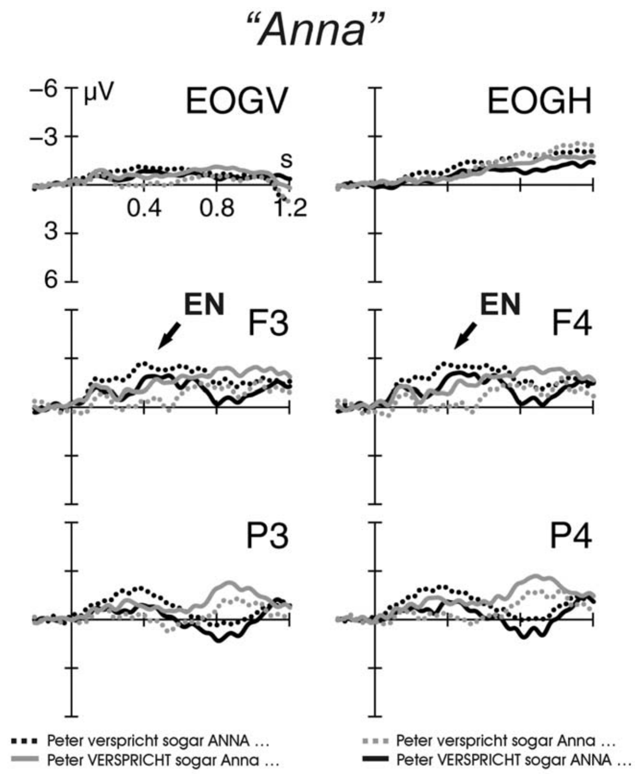

Fig. 7. Mean ERPs from Experiment 2 on NP2 ("*Anna*") at four electrode sites – (F3) left anterior; (P3) left posterior; (F4) right anterior; (P4) right posterior – as a function of ACC1 (accent on VP1 "*versprichti*": dotted lines – no accent; solid lines – accent) and ACC2 (accent on NP2 "*Anna*": grey lines – no accent; black lines – accent).

ACC-) and an interaction ACC1 × LR ($F_{1,31}$=8.44; P<0.007). The *post-hoc t*-tests revealed an influence of ACC1 (ACC+ > ACC-) in the right hemisphere (RA: t_{31}=-2.86, P<0.008;

RP: t_{31}=-2.68, P<0.012) (cf. Fig. 5, the bottom panel of Fig. 8, and Table III).

VP1 (*"verspricht"*)

In a time window ranging from 100-550 ms, the main effect of ACC ($F_{1,31}$=26.78; P<0.001; ACC+ < ACC-) and the interaction ACC1 × LR ($F_{1,31}$=5.19; P<0.030) were significant. The *post-hoc t*-test showed a significant effect of ACC1 (ACC+ < ACC-) in all ROIs (LA: t_{31}=4.06, P<0.001; LP: t_{31}=4.77, P<0.001; RA: t_{31}=5.14, P<0.001; RP: t_{31}=4.75, P<0.001) (cf. Fig. 6, the bottom panel of Fig. 8, and Table IV).

NP2 (*"Anna"*)

In a time window between 100-750 ms, effects were observed for ACC1 ($F_{1,31}$=6.70; P<0.015; ACC+ < ACC-), ACC2 ($F_{1,31}$=23.49; P<0.001; ACC+ < ACC-), ACC1 × AP ($F_{1,31}$=64.83; P<0.001), ACC2 × AP ($F_{1,31}$=43.68; P<0.001), and ACC1 × ACC2 × AP ($F_{1,31}$=22.46; P<0.001). The *post-hoc t*-tests revealed effects of ACC1 (ACC+ < ACC-) in the anterior ROIs (LA: t_{31}=4.83; P<0.001; RA: t_{31}=3.53; P<0.001). ACC2 yielded effects (ACC+ < ACC-) in the LA (t_{31}=5.88; P<0.001), LP (t_{31}=2.73; P<0.010), and RA ROI (t_{31}=5.84; P<0.001) (cf. Fig. 7, the bottom panel of Fig. 8, and Table V).

Discussion

In Experiment 2, we replicated the negativity elicited by the accent on NP2, which was most pronounced over anterior sites. As discussed for Experiment 1, this effect is in line with the findings by Hruska and Alter (2004) for correct pitch accents in question-answer pairs. More interestingly, the accent on VP1, which

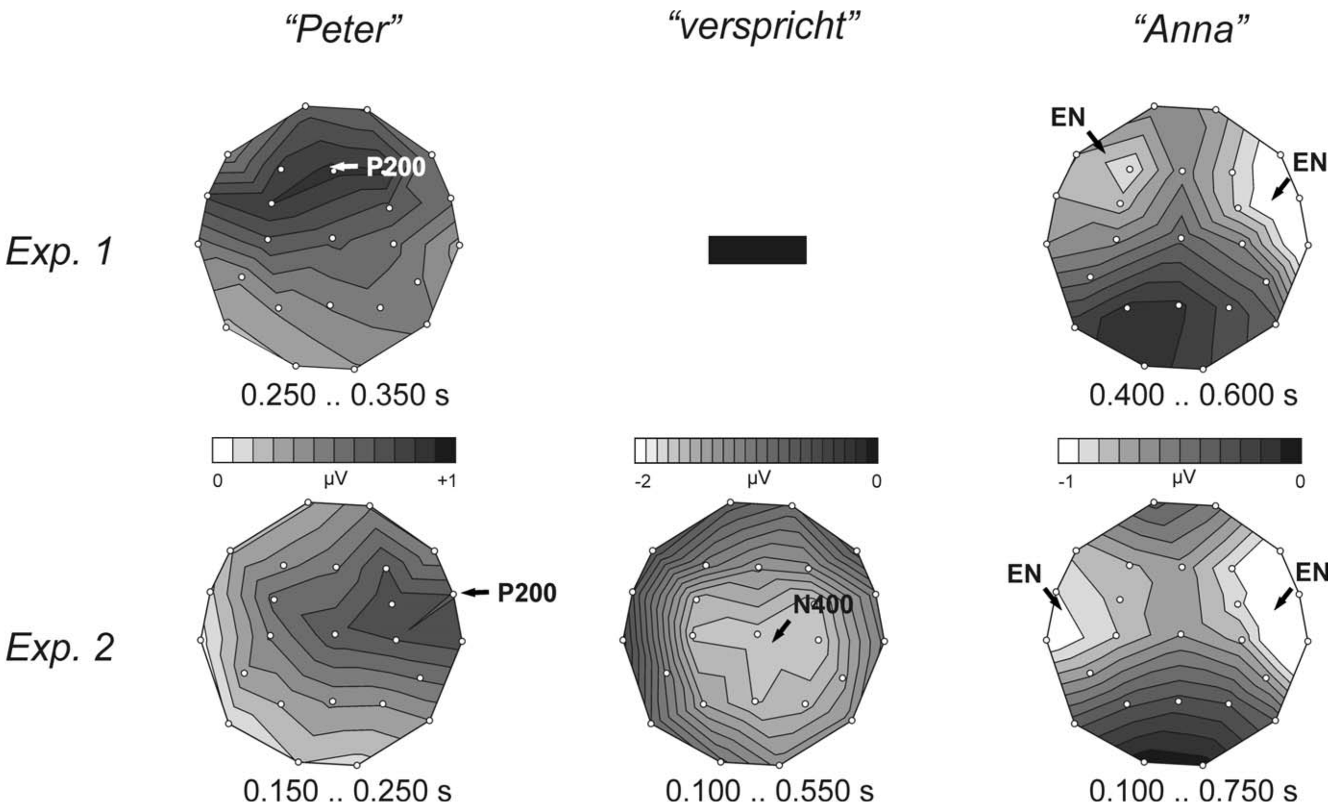

Fig. 8. Difference maps of the significant effects in Experiment 1 (upper row) and Experiment 2 (lower row) for NP1 ("*Peter*"), VP1 ("*verspricht*"), and NP2 ("*Anna*"). Anterior electrode sites are displayed in the upper part of the picture, left electrode sites on the left. Abbreviations: (EN) expectancy negativity.

also is in a sentence-medial position, also elicits a negativity in a comparable time window but with a broader topography. These effects at first sight support the notion that the processing of correct sentence-medial accents in isolated sentences is reflected by a negative brain potential. This will be further elaborated in the General Discussion.

Table V

Mean ERP amplitudes (in µV) in the four regions of interest as a function of ACCENT [(ACC+) pitch accent present; (ACC-) pitch accent absent] on NP2 ("Anna") in Experiment 2

	LA	LP	RA	RP
ACC-	0.22	-0.76	-0.12	-1.29
ACC+	-0.51	-0.53	-0.87	-0.92

Abbreviations: (LA) left anterior; (LP) left posterior; (RA) right anterior; (RP) right posterior

In contrast to these negativities, and as a replication of the findings of Experiment 1, there was again an early frontal positivity in both conditions. In Experiment 2, this effect was significant around 200 ms, which is further evidence for our interpretation of the component as a P200. Again, the P200 was more pronounced for the condition that showed the earlier peak in the F_0 contour (cf. Fig. 4). The effect was not positively correlated with the duration, which showed a tendency towards being shorter for the condition inducing a larger P200 effect.

GENERAL DISCUSSION

In two ERP experiments we investigated the effects of processing prosodic pitch accents in sentence-initial and sentence-medial positions. The results can be summarized as follows. Sentence-medial accents elicit fronto-central negativities which are maximal at about 400 ms post stimulus onset. In contrast, sentence-initial accents elicit a P200 which is modulated by the latency of the first peak in the F_0 contour rather than the amplitude of this peak or the duration of the constituent. The impact of these findings will now be discussed.

The Functional Significance of the Negativities: Expectancy Negativity vs. N400

As mentioned earlier, Hruska and Alter (2004) observed a frontal negativity when pitch accents were encountered in focused positions in a sentence. The authors labeled this negativity "Expectancy Negativity" (EN) since the pitch accent was expected because it was carried by words in focus, which had been assigned by the preceding context question. This is demonstrated in Examples 3 and 4.

3. Context questions

3a. *Wem verspricht Peter zu arbeiten und das Büro zu putzen?* (narrow focus)

(Whom does Peter promise to work and to clean the office?)

3b. *Was verspricht Peter Anna zu tun?* (broad focus)

(What does Peter promise Anna to do?)

4. Answers (pitch accents indicated by capital letters)

4a. *Peter verspricht ANNA zu arbeiten und das Büro zu putzen.* (narrow focus)

(Peter promises Anna to work and to clean the office)

4b. *Peter verspricht Anna zu ARBEITEN und das Büro zu putzen* (broad focus)

Could our sentence-medial accents be expected? The answer is "yes" for the accents on NP2. According to Büring and Hartmann (2001), a focus particle (such as *sogar* ("even") in our materials) assigns focus to its right-adjacent constituent. This focus is to be realized by a pitch accent. Thus, the presence of a prosodic accent would have been expected for NP2 in both experiments, resulting in comparable negative deflections with maxima at fronto-lateral sites (cf. Figs 3, 7, and 8).

In contrast, no such expectancy was created for the sentence-medial accent on VP1 which was placed before the focus particle. A closer look at the scalp distribution reveals that indeed the effect differs from that on NP2 (cf. Fig. 8). It was significant in all four ROIs and shows a central maximum. Thus, this negative deflection could represent a different process. Given its topography, latency, and polarity, it can be identified as a N400 component. The N400 was reported for difficulties in semantic processing on the sentence level (Holcomb and Neville 1991, Kutas and Hillyard 1984) and in lexical access to or semantic integration of single words (Chwilla et al. 1995, Hayashi et al. 2001). Such difficulties might arise because a pitch accent is encountered in an unusual position in a sentence (cf. Bock and Mazella 1983, Cutler et al. 1997, Nooteboom and Kruyt 1987, Terken and Nooteboom 1987). It should be noted, however, that this early accent is not entirely inappropriate in the sense that it was superfluous. Therefore, it does not elicit a positive deflection in the ERP (cf. Magne et al. 2005, Heim and Alter, accepted) but rather a N400 component expressing the difficulties of semantic processing and integration in the sentence.

The P200 – Are Sentence-Initial Accents Processed at all?

In both experiments we observed a P200 component in both conditions. As noted above, the amplitude of this component was modulated by the onset latency of the first F_0 peak in the acoustic signal, i.e., the elicited effect was the stronger the earlier the F_0 peak was encountered (cf. Friedrich et al. 2001). Most interestingly, as Figs 1 and 4 demonstrate, the amplitude of the F_0 peak had no systematic influence: The P200 was stronger for the condition with a higher F_0 peak in Experiment 1 but lower for the condition with the higher F_0 peak in Experiment 2. Moreover, the stronger P200 effect was not related to an increase of duration. Hence, none of the classical production parameters constituting a prosodic pitch accent had any influence for the processing of NP1. Does this finding imply that sentence-initial accents have no relevance at all?

Several points need to be considered here. (1) Our data have repeatedly shown that the processing of sentence-initial accents in fact differs from the processing of both expected and unexpected sentence-medial accents. The latter elicit various negative ERP deflections which are absent for the former. Thus, sentence-initial accents obviously do not have the same significance as sentence-medial accents. (2) However, they may have *some* significance. It could be that a pitch accent is only processed as a relative increase in F_0. For this to happen, the system needs a reference. If the pitch accent is on the sentence-initial word, there is no reference available before the accent. Accordingly, in this case, the word after the accented word is the first baseline available. Following this reasoning, there should be an effect of ACC1 on the second word (VP1 "*verspricht*") in Experiment 1. To test this, we analyzed the ERPs for VP1 in Experiment 1. In a time window from 100–450 ms, there were significant main effect for ACC1 ($F_{1,31}$=10.62, P<0.003; ACC+ < ACC-), and a significant interaction ACC1 × AP ($F_{1,31}$=17.91, P<0.001). The interaction ACC1 × LR × AP showed a trend towards significance ($F_{1,31}$=4.10, P<0.052). The *post-hoc t*-tests revealed significant effects for ACC1 (ACC+ < ACC-) in the LA, LP, and RA ROI (LA: t_{31}=3.62, P<0.001; LP: t_{31}=2.13, P<0.041; RA: t_{31}=4.03, P<0.001). This effect could be taken as evidence that the cognitive processing of the sentence-initial pitch accent is delayed until the F_0 can be compared to some reference (for a similar account cf. Isel et al. 2005). This issue clearly needs further investigation, e.g. on the basis of a synthetic parametric manipulation of the F_0 of the sentence-initial word instead of naturally spoken stimuli. (3) There is one further argument in favor of the processing of sentence-initial prosodic accents. In Experiment 2, where there was no explicit manipulation of the F_0 on the first word, the P200 effect was confined to the right hemisphere. In contrast, in Experiment 1, where the absolute F_0 on NP1 is higher than in Experiment 2, the effect is also significant in the left anterior ROI. Yet, at present, we have no clue what the functional implication of this result might be. Available imaging studies stress the influence of the right frontal rather than left frontal areas in the processing of prosodic information. (Hesling et al. 2005, Meyer et al. 2002, 2004, cf. Friederici and Alter 2004, for a review). Further research combining electrophysiology and neuroimaging will have to address this question.

CONCLUSIONS

In language production, prosodic pitch accents are realized by an increase of the F_0. In contrast to sentence-initial accents, sentence-medial accents tend to go along in addition with a longer duration of the accented phrase. In language comprehension, the processing of prosodic pitch accents in isolated sentences varies as a function of the position of the accented words. Sentence-medial accents are processed depending on whether they are expected or not, revealed by two different negative deflections (Expectancy Negativity vs. N400). In contrast, sentence-initial accents are recognized early, indicated by the P200 for the first available F_0 peak, but probably processed only in relation to the additional acoustic information becoming available later in the sentence.

REFERENCES

American Electroencephalographic Society (1991) Guidelines for standard electrode position nomenclature. J Clin Neurophysiol 8: 200–202.

Beckman ME (1996) The parsing of prosody. Lang Cogn Proc 1: 17–67.

Besson M, Magne C, Schon D (2002) Emotional prosody: Sex differences in sensitivity to speech melody. Trends Cogn Sci 6: 405–407.

Birch S, Clifton C (1995) Focus, accent, and argument structure: Effects on language comprehension. Lang Speech 38: 365–391.

Birch S, Clifton C (2002) Effects of varying focus and accenting of adjuncts on the comprehension of utterances. J Mem Lang 47: 571–588.

Bock JK, Mazella JR (1983) Intonational marking of given and new information: Some consequences for comprehension. Mem Cognit 11: 64–76.

Brown G. (1983) Prosodic structure and the given/new distinction. In: Prosody: Models and Measurements (Ladd DR, Cutler A, eds.). Springer, Berlin, p. 67–78.

Büring D, Hartmann K (2001) The syntax and semantics of focus-sensitive particles in German. Natural Lang Ling Theory 19: 229–281.

Carrillo-de-la-Pena M, Rodriguez Holguin S, Corral M, Cadaveira F (1999) The effects of stimulus intensity and age on visual-evoked potentials (VEPs) in normal children. Psychophysiology 36: 693–698.

Chwilla DJ, Brown C, Hagoort P (1995) The N400 as a function of the level of processing. Psychophysiology 32: 274–285.

Cutler A, Dahan D, van Donselaar W (1997) Prosody in the comprehension of spoken language: A literature review. Lang Speech 40: 141–201.

Dahan D, Tanenhaus MK, Chambers CG (2002) Accent and reference resolution in spoken-language comprehension. J Mem Lang 47: 292–314.

Friedrich C (2003) Prosody and spoken word recognition: Behavioral and ERP correlates. MPI Series in Cognitive Neuroscience No. 36. Max Planck Institute of Cognitive Neuroscience.

Friedrich C, Alter K, Friederici AD (2001) An electrophysiological response to different pitch contours in words. Neuroreport 12: 3189–3191.

Friederici AD, Alter K (2004) Lateralization of auditory language functions – the dynamic dual pathway model. Brain Lang 89: 267–276.

Greenhouse S, Geisser S (1959) On methods in the analysis of profile data. Psychometrika 24: 95–112.

Gunter TC, Friederici AD, Schriefers H (2000) Syntactic gender and semantic expectancy: ERPs reveal early antonomy and late interaction. J Cogn Neurosci 12: 556–568.

Halliday MAK (1967) Intonation and Grammar in British English. Mouton, The Hague.

Hayashi R, Imaizumi S, Mori K, Niimi S, Ueno S, Kiritani S (2001) Elicitation of N400m in sentence comprehension due to lexical prosody incongruity. Neuroreport 12: 1753–1756.

Hesling IH, Clément S, Bordessoules M, Allard M (2005) Cerebral mechanisms of prosodic integration: Evidence from connected speech. Neuroimage 24: 937–947.

Hirschberg J (2002) Communication and prosody: Functional aspects of prosody. Speech Communication 36: 31–43.

Hirst D, Di Cristo A (1998) Intonation Systems. A Survey of Twenty Languages. Cambridge Univ. Press.

Holcomb PJ, Neville HJ (1991) The electrophysiology of spoken sentence processing. Psychobiology 19: 286–300.

Hruby T, Marsalek P (2003) Event-related potentials – the P3 wave. Acta Neurobiol Exp (Wars) 63: 55–63.

Hruska C, Alter K (2004) How prosody can influence sentence perception. In: Information Structure: Theoretical and Empirical Aspects (Steube A, ed.). De Gruyter, Berlin, p. 211–226.

Hruska C, Alter K, Steinhauer K, Steube A (2001) Misleading dialogues: Human's brain reaction to prosodic information. In: Oralité et Gestulité. Interactions et comportements multimodaux dans la communication (Cavé C, Guaitella I, Santi S, eds.), L'Harmattan, Paris.

Isel F, Alter K , Friederici AD (2005) Processing of syntactic and prosodic information in German particle verbs: Evidence from ERPs. J Cogn Neurosci 17: 154–164.

Jackendoff R (1972) Semantic interpretation in generative grammar. MIT Press, Cambridge MA.

Johnson SM, Clifton C, Breen M, Morris J (2003) An ERP investigation of prosodic and semantic focus. J Cogn Neurosci 14 (Suppl): 174.

Kutas M, Hillyard SA (1984) Brain potentials during reading reflect word expectancy and semantic association. Nature 307: 161–163.

Ladd DR (1996) Intonational Phonology. Cambridge University Press.

Lambrecht K (1996) Information structure and sentence form: Topic, focus, and the mental representations of discourse referents. Cambridge University Press.

Liedtke F (2001) Information structure, text, and discourse (in German). In: Pragmatische Syntax (Liedtke F, Hundsnurscher F, eds.). Tübingen, Niemeyer, p. 73–95.

Magne C, Astésano C, Lacheret-Dujour A, Morel M, Alter K, Besson M (2005) On-line processing of "pop-out" words in spoken French dialogues. J Cogn Neurosci 17: 740–756.

Meyer M, Alter K, Friederici AD, Lohmann G, von Cramon DY (2002) Functional MRI reveals brain regions mediating slow prosodic manipulations of spoken sentences. Hum Brain Mapp 17: 73–88.

Meyer M, Steinhauer K, Alter K, Friederici AD, von Cramon DY (2004) Brain activity varies with modulation of dynamic pitch variance in sentence melody. Brain Lang 89: 277–289.

Most RB, Saltz E (1979) Information structure in sentences: New information. Lang Speech 22: 89–95.

Nespor M, Vogel I (1986) Prosodic Phonology. Dortrecht, Foris.

Nooteboom SG, Kruyt JG (1987) Accents, focus distribution, and the perceived distribution of given and new information: An experiment. J Acoust Soc America 82: 1512–1524.

Pannekamp A, Toepel U, Alter K, Hahne A, Friederici AD (2005) Prosody-driven sentence processing: An ERP study. J Cogn Neurosci 17: 407–421.

Polich J (1998) P300 clinical utility and control of variability. J Clin Neurophysiol 15: 14–33.

Polich J (1999) P300 in clinical applications. In: Electroencephalography: Basic Principles, Clinical Applications and Related Fields (Niedermayer E, Lopes de la Silva F, eds.). Urban and Schwarzenberg, Munich. p. 1073–1091.

Prince EF (1981) Taxonomy on the given and new status. In: Radical Pragmatics (Cole P, ed.). New York, Academic Press, p. 223–255

Rooth ME (1985) Association with Focus. Dissertation, University of Massachusetts at Amherst.

Schirmer A, Kotz SA, Friederici AD (2002) Sex differentiates the role of emotional prosody during word processing. Brain Res Cogn Brain Res 14: 228–233.

Selkirk E (1984) Phonology and Syntax: The Relation Between Sound and Structure. MIT Press.

Squires NK, Squires KC, Hillyard SA (1975) Two varieties of long-latency positive waves evoked by unpredicable auditory stimuli in man. Electroencephal Clin Neurophysiol 39: 387–401.

Steinhauer K, Alter K, Friederici AD (1999) Brain potentials indicate immediate use of prosodic cues in natural speech processing. Nat Neurosci 2: 191–196.

Steube A (2000) A cognitive model for information structuring (in German) In: Von der Philologie zur Grammatiktheorie. P. Suchsland zum 65. Geburtstag. (Römer Ch, Bayer J, eds.). Niemeyer, Tübingen, p. 213–238.

Terken J, Nooteboom SG (1987) Opposite effects of accentuation and deaccentuation on verification latencies for given and new information. Lang Cognit Proc 2: 145–163.

Warren JD, Jennings AR, Griffiths TD (2005) Analysis of the spectral envelope of sounds by the human brain. Neuroimage 24: 1052–1057.

Received 30 August 2005, accepted 4 January 2006