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Sentence processing in the visual and auditory modality: Do comma and prosodic break have parallel functions? ☆

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ABSTRACT

Two Event-Related Potential (ERP) studies contrast the processing of locally ambiguous sentences in the visual and the auditory modality. These sentences are disambiguated by a lexical element. Before this element appears in a sentence, the sentence can also be disambiguated by a boundary marker: a comma in the visual modality, or a prosodic break in the auditory modality. Previous studies have shown that a specific ERP component, the Closure Positive Shift (CPS), can be elicited by these markers. The results of the present studies show that both the comma and the prosodic break disambiguate the ambiguous sentences before the critical lexical element, despite the fact that a clear CPS is only found in the auditory modality. Comma and prosodic break thus have parallel functions irrespective of whether they do or do not elicit a CPS.

1. Introduction

The majority of ERP research on sentence processing has been carried out in the visual domain (see for reviews: Kutas and Schmitt, 2003; Osterhout et al., 2004). By contrast, only a relatively small number of studies on connected speech have been conducted. On the whole similar ERP signatures for semantic and syntactic anomalies have been observed in the visual and auditory domain (Friederici et al., 1993; Hagoort and Brown, 2000; Holcomb and Neville, 1991; Osterhout and Holcomb, 1993). Even less frequent than auditory studies on sentence processing are direct comparisons of sentence processing in the visual and the auditory domain.

To our knowledge there are only two studies on sentence processing that directly compare ERPs across modalities, one in Dutch (Hagoort and Brown, 2000), and one in Italian (Balcony and Pozzoli, 2005). Both studies looked at ERPs elicited by syntactic violations. They reported similar P600 effects for the visual and the auditory modality. In particular, for Dutch, the language used in the present article, Hagoort and Brown (2000) observed similar P600 effects in terms of both the overall scalp distribution (though the auditory effect showed a more anterior distribution) and the timing of the effect. From this they concluded that core aspects of parsing operations are identical across the two domains of input.

In the present paper, we focus on a direct comparison of ERP correlates in the visual and the auditory domain while participants process locally ambiguous sentences. In contrast to the studies mentioned above, the sentences in the present experiment are correct sentences and do not contain syntactic or

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semantic violations. Rather, we will compare the effects of the signaling of a syntactic break in locally ambiguous sentences across modalities. In the visual domain, the presence or absence of a syntactic break can be signaled by the presence or absence of a comma. A potential analog in the auditory domain concerns the presence or absence of a prosodic break.

Before turning to a more specific discussion of the type of ambiguity used in the present study, we will first provide an overview of language-related ERP components. The most important ERP component for the semantic domain is a negative wave peaking at about 400 ms, called the N400 (Kutas and Hillyard, 1984). A well-established view is that modulations in N400 amplitude reflect the ease with which a word is integrated into the current context, be this a single word (Chwilla et al., 1998), a sentential context (Friederici, 1995), or a discourse context (van Berkum et al., 1999).

For the syntactic domain, two main ERP components have been identified (for an overview, see Friederici, 1995). The first component is an anterior distributed negative potential, which typically occurs to words that render the sentence incorrect (Friederici et al., 1993; Neville et al., 1991; Rösler et al., 1993). Although the topography of this negativity varies somewhat between studies, it often shows a left anterior maximum and therefore is called the Left Anterior Negativity (LAN) (Friederici, 1995). The timing of this negativity has been proposed to differ as a function of the kind of syntactic violation involved. In particular, phrase structure violations (i.e., word category errors) elicit an immediate effect between 100 to 300 ms after stimulus onset (Hahne and Friederici, 2002), whereas morphosyntactic violations (e.g., subject–verb agreement errors) elicit an effect between 300 to 500 ms after stimulus onset. With respect to the functional significance, it has been proposed that the LAN reflects a syntactic process (Friederici, 2002). It has also been suggested that the LAN reflects a general index of working-memory load[1] (King and Kutas, 1995).

The second syntax-related ERP component is a late centro-parietally distributed positive potential starting at about 500 ms and typically extending up to at least 800 ms. This positivity is usually referred to as P600. An increase in P600 amplitude has been observed in response to various kinds of syntactic violations like phrase structure violations (Friederici et al., 1996; Neville et al., 1991; Osterhout and Holcomb, 1992, 1993), subjacency violations (McKinnon and Osterhout, 1996; Neville et al., 1991) and agreement violations (for an overview, see Vos et al., 2001). P600 effects have also been observed in locally ambiguous sentences at the disambiguating lexical element (Friederici et al., 1999; Osterhout and Holcomb, 1992; Osterhout et al., 1994). While the P600 effect to syntactic violations shows a posterior scalp distribution (Coulson et al., 1998), a more anterior or a broader scalp distribution of the P600 effect has been reported in locally ambiguous sentences at the disambiguating element (Friederici et al., 1996; Hagoort et al., 1999; Osterhout and Holcomb, 1992; van Berkum et al., 1999). The P600 is generally conceived of as reflecting processes of revision and repair in sentence processing. It should be noted, however, that recent evidence suggests that the N400 and the P600 are not necessarily distinct, in the sense that they only occur within their own semantic or syntactic domain (e.g., Kim and Osterhout, 2005, and Schlesewsky and Bornkessel, 2006).

In the present study, we use locally ambiguous sentences that allow for two different syntactic analyses up to a certain point in the sentence after which the sentence becomes disambiguated by a lexical element, as exemplified in (1) and (2). These sentences are ambiguous up to and including the noun phrase *the policeman*, and they are disambiguated at the word following this noun phrase (in (2)) or at least at the end of the sentence (in (1)). In (1), the prepositional phrase *in front of the statue* suggests that the coordinated noun phrase *the squatter and the policeman* is the object of the verb *interviewed* (noun phrase coordination; NP-coordination), because it is more likely for *in front of* to set the scene in which the action is taking place than indicating the place at which only the policeman (but not the squatter) is located. In (2), the verb *interrupted* indicates that the noun phrase *the policeman* is the subject of a new sentence (sentence coordination; S-coordination).

(1) The reporter interviewed the squatter and the policeman in front of the statue in the centre of the city.
(2) The reporter interviewed the squatter and the policeman interrupted the interview right away.

In the present paper, we study the processing of the Dutch equivalents of locally ambiguous sentences as (2) (henceforth called ambiguous sentences). In written Dutch, these sentences can also be disambiguated at an earlier point, namely at the NP *the squatter*. When this noun phrase is followed by a comma, this excludes the possibility that the sentence will be resolved as an NP-coordination (for details see below). For the auditory domain, one could hypothesize that a prosodic break after the noun phrase *the squatter* has the same disambiguating function as the comma in the visual domain. It should be noted that this hypothesis does not imply that syntax and prosody are isomorphic. Not all aspects of syntax are expressed in the prosodic structure, and identical syntactic structures can lead to different prosodic structures (see Shattuck-Hufnagel and Turk, 1996) for a review).

The combination of the modality manipulation with this ambiguity allows us to test whether readers and listeners are able to use the information contained in a comma or a prosodic break as a means of an early disambiguation, that is, a disambiguation at a point in time at which the lexical element that disambiguates the sentence (i.e., the prepositional phrase *in front of the statue* versus the verb *interrupted*) has not yet been processed. Furthermore, it allows us to test whether comma and prosodic break have a parallel function in the visual and auditory modality, respectively. Such a parallel function of a prosodic break and a comma could be because the processing of a comma is mediated through prosodic processing as suggested in the implicit prosody hypothesis (see Fodor, 2002). Alternatively, such a parallel function could be because a prosodic break and a comma are processed differently, while nevertheless having the same consequence for the disambiguation of the sentence.

[1] One argument in favor of the latter view is that lexically ambiguous words like *bank* have been reported to elicit very similar anterior distributed negativities (Ischebeck et al., 2008). Such ambiguities are not syntactic but can be assumed to tax verbal working memory more heavily than sentences without lexical ambiguities.

An example of the Dutch materials in the visual domain is given in (3) and (4) (literal English translation is given in italics). The sentences only differ with respect to the absence in (3) or the presence in (4) of a comma after the NP *de boer* (*the farmer*). Sentence (3) is ambiguous until the disambiguating verb. Sentence (4), by contrast, is disambiguated by the comma following *de boer* (*the farmer*). Both sentences are lexically disambiguated as S-coordinations on the verb *verdedigde* (*defended*).

(3) De sheriff beschermde de boer en de knecht verdedigde dapper de ranch tegen Johnson's bende. *The sheriff protected the farmer and the farm hand defended bravely the ranch against Johnson's gang.*
(4) De sheriff beschermde de boer, en de knecht verdedigde dapper de ranch tegen Johnson's bende. *The sheriff protected the farmer, and the farm hand defended bravely the ranch against Johnson's gang.*

The present study builds on a previous study on the coordination ambiguity in Dutch by Hoeks, Vonk, and Schriefers (Hoeks et al., 2002). In a reading study, they compared temporarily ambiguous S-coordination sentences as in (3) (comma absent) with unambiguous S-coordinated control sentences as in (4) (comma present). In Dutch, there are no strict rules regarding the placement of a comma in S-coordinated sentences (Geerts et al., 1984; Renkema, 2004). There is, however, a general habit of not putting commas before *and* in conjoined sentences (Sanders and Metselaar, 2000, pag 163–164), and it is definitely not acceptable to place a comma in cases where two NPs are conjoined. So the absence of a comma does not provide much useful information regarding the structure of a sentence, whereas its presence signals that an S-coordination (or a VP-coordination, for that matter) is very likely and excludes the possibility that the sentence will turn out to be an NP-coordination. The results of a self-paced reading experiment and an eye-movement experiment by Hoeks et al. (2005) showed, for sentences in isolation, that reading times in the disambiguating region (*defended*) were longer in the absence of a comma after the noun phrase *the farmer* (see (3)) than in the presence of a comma at this position (see (4)). Thus, in the absence of a comma, the sentence is initially analyzed as an NP-coordination, and this initial analysis has to be revised when reading the verb *defended*. By contrast, when a comma is present, the sentence is right away (from the comma onwards) analyzed as an S-coordination and thus no processing difficulty occurs at the verb *defended* as no reanalysis is necessary (see also Frazier, 1987).

With respect to the potential impact of a prosodic break as an auditory analog of a comma, the starting point for the present research was the discovery of an ERP signature to intonational phrase (IPh) boundaries, here referred to as prosodic breaks. Steinhauer and colleagues (Steinhauer, 2003; Steinhauer et al., 1999; Steinhauer and Friederici, 2001) demonstrated that a prosodic break reliably elicits a positive shift, termed the Closure Positive Shift (CPS; see also Bögels et al., submitted for publication; Kerkhofs et al., 2007; Mietz et al., 2008; Toepel et al., 2007). In a first series of studies, Steinhauer et al. (1999) presented sentences with and without a prosodic break. They found that a CPS was elicited by sentences with a prosodic break relative to sentences without a prosodic break. In addition, they tested whether a prosodic break could induce garden path effects. To this aim, they constructed sentences in which the prosodic information and the syntactic information either were in line (both a prosodic break and a syntactic clause boundary were present at the same point in the sentence, or neither a prosodic break nor a syntactic clause boundary was present) or were in conflict with each other (a prosodic break was present, whereas there was no syntactic clause boundary). When the prosodic structure did not match the syntactic structure of the sentence, processing difficulty was observed at the point at which the disambiguating syntactic information (which occurred some words after the prosodic break) was encountered. With respect to the functional significance, Steinhauer and colleagues proposed that the CPS is tightly linked to the cognitive process of structuring the incoming speech signal: A CPS occurs immediately when a prosodic break is perceived and is used to guide syntactic parsing decisions.[2]

In a second series of studies, Steinhauer and Friederici (2001) explored whether the CPS is a universal marker for prosodic phrasing during listening and reading. They tested whether punctuation, which also serves the role of structuring the input, gives rise to a CPS-like ERP component. Steinhauer and Friederici made the assumption that if punctuation is mediated by subvocal prosody (an "internal voice"), then its processing may resemble that of overt prosody. To test this they presented sentences with a comma and without a comma. The main result was that a small but reliable CPS to the comma occurred for readers with strict punctuation habits but not for readers without strict punctuation habits. The difference between the two groups suggests a correspondence of punctuation habits and the impact of comma information on on-line sentence processing, which is reflected in the ERPs.

From this, Steinhauer and Friederici concluded that comma perception during reading involves processes similar to the perception of prosodic breaks in spoken language. The main difference between modalities was that the auditory CPS is larger and more extended in time than its visual counterpart. Steinhauer proposed that this difference is most likely due to the fact that phonological representations are more strongly activated during listening than during silent reading (Steinhauer, 2003).

Although Steinhauer and Friederici (2001) discuss the patterns at the occurrence of a comma for both lax and strong punctuation groups, they do not report the findings at the syntactically disambiguating region in detail for these two groups of participants. Therefore, it remains unclear whether the presence of a comma has different effects on how the syntactically disambiguating region of the sentence is processed by the participants with strict and with lax punctuation habits.

In the present article, we combine what is known about the processing of the coordination ambiguity in the visual domain with what is known from ERP research on the processing of commas and prosodic breaks. In the visual domain, we presented sentences like (3) and (4) visually while recording the Electroencephalogram (EEG). For the auditory domain, we presented auditory versions of the same sentences with either a prosodic break or no prosodic break between the noun phrase *the farmer* and *and the farm hand,* while recording the EEG.

[2] Recent results from Toepel et al. (2007) suggest that a CPS is also elicited by the stress pattern of focus prosody.

For the visual modality, the predictions are as follows. As described above, we know from the literature that the presence of a comma is used for the early disambiguation of these sentences towards an S-coordination analysis (Hoeks et al., 2002). A corresponding pattern should also be found in the present ERP experiment with visual stimuli. However, it should be recalled that the evidence for a CPS in response to a comma is not that general. As pointed out above, Steinhauer and colleagues only found a CPS in response to a comma for the group of readers with strict punctuation rules, but not for readers with lax punctuation rules. Because in Dutch punctuation rules are not as strict as in German, it is not clear in advance whether a CPS will be elicited by a comma in Dutch readers. This leads to the following predictions. If there is a CPS in response to the presence of a comma, we can be certain that the comma has been processed, and thus we should find a P600-effect at the disambiguating verb *defended* in the condition without a comma relative to the condition with a comma. By contrast, when there is no CPS, this could be either because the comma did not elicit a CPS, or because participants did not notice the comma. In the first instance we should find a P600-effect at the disambiguating verb *defended* in the condition without a comma relative to the condition with a comma. In the second instance we should not find any difference at the disambiguating verb.

For the auditory sentences, we expect a CPS at the prosodic break relative to the condition without a prosodic break. If the presence of a prosodic break leads the listener to adopt an S-coordination analysis right at or shortly after the prosodic break, this should in addition be reflected in the ERPs at the disambiguating verb (*defended*). More specifically, in the absence of a prosodic break, the verb *defended* will signal the need for a reanalysis of the initially preferred NP-coordination analysis while no such reanalysis would be necessary in the case of the same sentence with a prosodic break. In terms of the ERP components introduced above, we would thus expect a P600-effect in the condition without a prosodic break relative to the condition with a prosodic break. By contrast, if the presence of a prosodic break does not lead to the adoption of an S-coordination analysis right at or shortly after the prosodic break, listeners should adopt the preferred NP-coordination analysis in both conditions. In this case, there should be no differences in the ERP signatures between the two conditions (prosodic break present versus absent) at the disambiguating verb as in both conditions a reanalysis would become necessary.

In the following we will test these predictions in two ERP experiments, one in the visual domain (Experiment 1) and one in the auditory domain (Experiment 2). Both experiments were set up such that each half of the experiment comprised a complete design in order to have the possibility to track potential changes in effects over the course of experiments. This may be particularly relevant for the experiment in the visual modality given the between-participant differences in the processing of a comma as a function of strict versus lax punctuation habits as reported in Steinhauer and Friederici (2001). As comma rules are not very strict in Dutch (see above), it could be the case that our participants may adopt strategies in the course of the experiment.

2. Results

2.1. Experiment 1 — visual modality

2.1.1. Data analysis

The data were filtered with a low-pass filter of 30 Hz. EEG and EOG records were examined for artifacts and for excessive EOG amplitude during the epochs from 150 ms preceding the onset of the NP with or without a comma (hereafter NP2, i.e., *the farmer* in (3) and (4)) and of the verb (i.e., *defended* in (3) and (4)) until 1000 ms after the respective onsets. We used a 150 ms period preceding the onset of the critical word as a baseline. Only trials in which the EOG did not exceed 75 μV, and in which no artifacts (EEG>100 μV) occurred, were included in the analysis. The data from two participants were excluded from the analyses due to excessive artifacts, leaving the data of a total of 30 participants.

Two kinds of analysis were performed on these pre-processed data. First, we used relatively broad windows to quantify the ERP effects. Based on the 500 to 650 ms time-windows of Steinhauer and Friederici (Steinhauer and Friederici, 2001, p. 277) and visual inspection of the waveforms we used the 400 to 800 ms window after NP2 onset to quantify a possible CPS at the comma. In order to quantify reflections of potential processing difficulty at the disambiguating verb, the P600 to verb onset was measured in the 600 to 900 ms window (Hagoort et al., 1999). In addition, visual inspection of the waveforms revealed a more negative going deflection from 350 to 450 ms after verb onset for the condition without a comma relative to the condition with a comma (e.g., electrodes aF7, aF3, and F3). We used the 350 to 450 ms time-window to quantify this negativity.

To further investigate the onset and duration of the effects, we performed additional time-course analyses. To this aim the average amplitude of the EEG was computed from 0 to 1000 ms in steps of 100 ms after the onset of NP2 and after the onset of the disambiguating verb. The data from these analyses are only presented if they provide additional information that is not already contained in the analyses of the broad time-windows.

The mean amplitudes of these windows were entered into a MANOVA repeated measures analysis. The multivariate approach to repeated measurements was used to avoid problems concerning sphericity (Vasey and Thayer, 1987). Two kinds of MANOVA were performed, one for the midline electrodes, and one for the lateral electrodes. The MANOVA for the midline electrodes had the factors Comma (present/absent) and Midline Electrode (aFz/Fz/Cz/Pz/Oz). The MANOVA for the lateral electrodes had Comma (present/absent) as factor, using a Hemisphere by Region of Interest (ROI) by Electrode design. The factors Hemisphere and ROI divided the scalp into 4 quadrants: left anterior (aF7, F7, aF3, and F3), right anterior (aF8, F8, aF4, and F4), left posterior (P7, PO7, P3, and PO3), and right posterior (P8, PO8, P4, and PO4).

To check whether the participants performed differently through the course of the experiment, additional analyses for the standard windows were performed which included the factor Part of Experiment (first/second half of the experiment).

2.1.2. CPS: NP2 with and without comma

Grand average waveforms time-locked to the onset of NP2 (which contains the noun with or without a comma) are presented in

Fig. 1. The presentation of NP2 elicited the for visual stimuli typical ERP response, that is, an N1-P2 complex. Inspection of the waveforms suggests that no CPS was elicited by the comma. For some electrodes, the Comma condition appeared to be even more negative (rather than positive) than the No Comma condition (e.g., PO8 between 550 and 600 ms and aF4 between 750 and 800 ms).

The absence of a CPS was confirmed by the statistical analysis for the CPS window (400–800 ms) for the midline electrodes, which did not yield an effect of Comma ($F<1$), nor an interaction of this factor with Midline Electrode ($F<1$). Also for the lateral electrodes neither an effect for Comma ($F<1$) nor interactions of Comma with ROI, Hemisphere or Electrode were present (all $Fs<1$).

One could argue, however, that the 400 to 800 ms time-window is too long to detect a potentially small CPS. However, also the time-course analyses on consecutive epochs of 100 ms for the CPS-window did not yield reliable effects of Comma neither in the midline analyses ($Fs<1$ for the 100 ms time-windows between 400 and 700 ms; $F[1,29]=2.94$, $p=.096$ from 700 to 800 ms) nor in the lateral analyses ($Fs<1$ for the 100 ms time-windows between 400 and 700 ms; $F[1,29]=3.46$, $p=.067$ from 700 to 800 ms). Furthermore, no interactions of Comma with Midline Electrode for the midline analyses were found (all $Fs<1$). Likewise, for the lateral analyses no effects of Comma or relevant interactions were present (all $ps>.075$). Thus, there appears to be no clear and statistically reliable CPS in response to the comma. Additionally, the negative-going effects for the Comma condition described at the visual inspection were not statistically reliable. Time-course analyses on 100 ms consecutive time-windows outside the 400 to 800 ms window (i.e., the windows between 0 and 400 ms and between 800 and 1000 ms) did not show any effects of Comma, nor any interactions with this factor (all $ps>.12$).

Finally, the Part of Experiment-analyses for the midline and for the lateral electrodes also did not reveal an interaction between Part of Experiment (first versus second half of the experiment) and Comma (all $ps>.20$), nor any other relevant interactions (all $ps>.084$), indicating that the same pattern of results was found across the course of the experiment. In sum, the results of all analyses for the CPS converge in that no CPS was found in the visual modality.

2.1.3. *Negativity and P600 effects: Disambiguating verb*

To test for reflections of a processing difficulty at the disambiguating verb, the signals were time-locked to verb onset. Grand average waveforms are presented in Fig. 2. Inspection of Fig. 2 suggests the presence of a biphasic pattern for the No comma condition relative to the comma condition: a negative-going effect around 400 ms at bilateral anterior electrodes (e.g., aF3, aF4, F3, and F4) and a P600-like effect starting at about 600 ms at the midline (see aFz and Fz) and bilateral anterior sites.

The midline analysis for the 350–450 ms window did not disclose an effect of Comma ($p>.10$), nor an interaction between Comma and Midline Electrode ($F<1$). However, in the lateral analysis an effect for Comma was obtained ($F[1,29]=4.33$; $p<05$). This main effect showed that mean amplitudes were more negative-going for the sentences without a comma (i.e., ambiguous sentences) than for the sentences with a comma (i.e., unambiguous sentences). No interactions with ROI, hemisphere or electrode were found (all $ps>.19$), indicating that the negativity was broadly distributed across the scalp and not restricted to (left) anterior sites.

In the midline analysis for the P600 window (600–900 ms) no effect of Comma was obtained ($p>.10$). There was an interaction of Comma with Midline Electrode ($F[4,26]=3.24$; $p<.05$). Follow-up analyses revealed P600-like effects at two anterior sites (aFZ and Fz; both $ps<.05$), but not at more posterior sites (all $ps>.10$). The analyses for the lateral electrodes for the P600 window did not yield an effect of Comma ($F<1$). Instead, an interaction between Comma and ROI ($F[1,29]=9.16$; $p<.01$) was

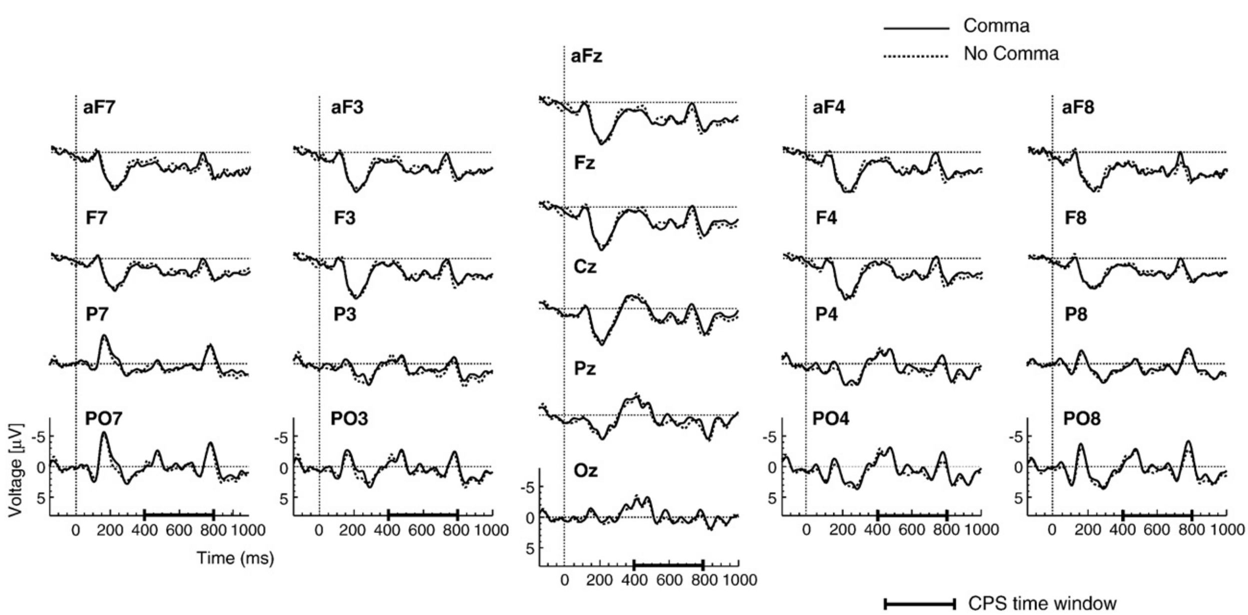

Fig. 1 – Grand average waveforms over participants ($n=30$), time-locked to the onset of NP2, for the S-coordination sentences with a comma (solid line) and the S-coordination sentences without a comma (dotted line) in Experiment 1.

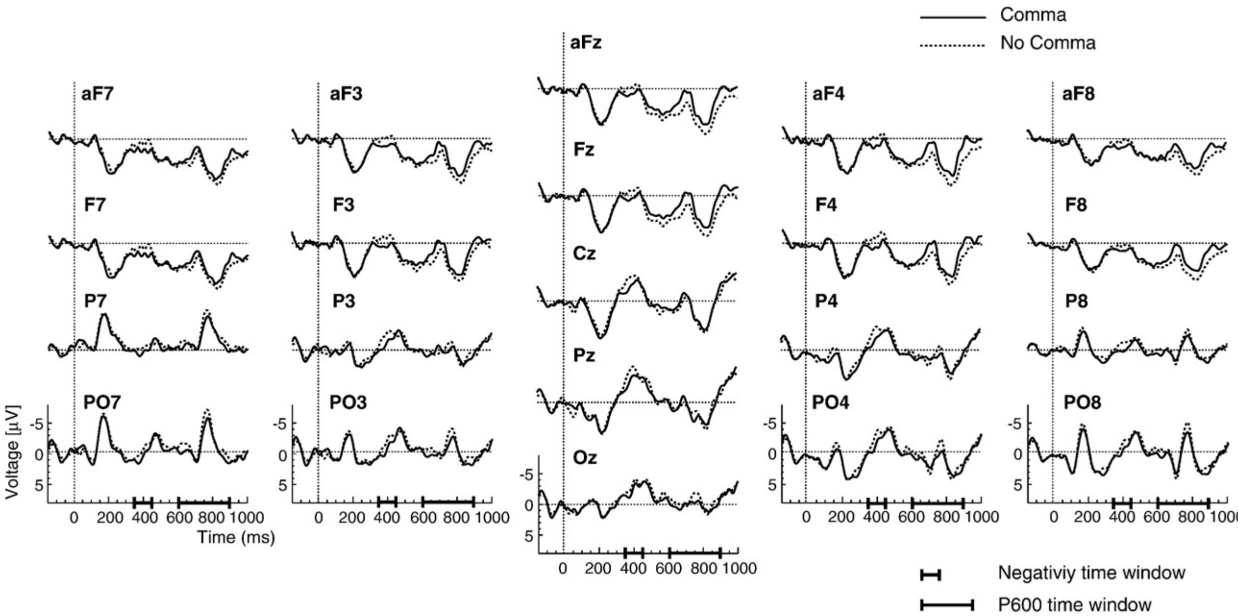

Fig. 2 – Grand average waveforms over participants (n = 30), time-locked to the onset of the disambiguating verb, for the S-coordination sentences with a comma (solid line) and the S-coordination sentences without a comma (dotted line) in Experiment 1.

found. Separate analyses for the two levels of ROI showed an effect of Comma for the anterior ROIs ($F[1,29] = 4.89$; $p < .05$), but not for the posterior ROIs ($p > .20$). A four-way interaction between Comma, Electrode, Hemisphere, and ROI was also present ($F[3,27] = 3.03$; $p < .05$). Follow-up t-tests for all lateral electrodes revealed P600 effects at the following sites of the right hemisphere: aF8, aF4, and F8 (all $ps < .05$), and at a single site over the left hemisphere: PO7 ($p < .05$). The time-course analyses yielded essentially the same pattern of results as the window analyses. In sum, the analyses for the disambiguating verb indicated that a P600 effect was present at the anterior sites of both the midline and the right hemisphere.

Finally, both the midline analysis and the lateral analysis containing Part of Experiment as a factor did not yield interactions between Part of Experiment and Comma, or other relevant interactions. This indicated that the participants' brain responses to the materials remained the same during the experiments.

2.1.4. Discussion Experiment 1

In Experiment 1, no significant CPS was obtained after the comma. This is in contrast to Steinhauer and Friederici, who demonstrated a CPS in response to a comma (Steinhauer and Friederici, 2001). However, Steinhauer (2003) also showed that the occurrence of a CPS in response to the presence versus absence of a comma depends on the degree to which participants did or did not follow punctuation rules (also see Introduction).

One possible explanation for the apparent discrepancy between the results of the present study and that of Steinhauer and Friederici (2001) is a difference in design. Our materials did not include any punctuation errors, while in Steinhauer and Friederici half of the critical materials and a proportion of the filler items (Experiment 1) or only a proportion of the filler items (Experiment 2) contained punctuation errors. This makes it likely that participants were more aware of the comma manipulation in Steinhauer and Friederici's experiment than in the present experiment.

The reason that we do not find a CPS in the visual modality may be that the CPS only occurs when participants' attention is focused on punctuation. Following this line of reasoning, one could argue that our data do not show a CPS because the participants were not paying particular attention to punctuation. Possibly, the participants from Steinhauer and Friederici with low punctuation knowledge also did not show a CPS because they were unaware of at least some proportion of comma errors, and thus were not as focused on punctuation as the participants with high punctuation knowledge.

A second possible explanation for the difference in results relates to the language that was tested. In Dutch, in contrast to German, language users are in general sloppy with punctuation. This could mean that our participants are similar to the participants with low punctuation knowledge from Steinhauer and Friederici (2001). It might be that these participants simply ignore the comma. However, the results at the disambiguating verb reveal that this was not the case. If the comma had not been processed at all, the unambiguous S-coordinations with a comma and the ambiguous S-coordinations without a comma should have shown identical results at the disambiguating verb. Clearly, this is not the case. The comparison of the two conditions shows a biphasic ERP pattern, that is, a negativity followed by a P600-like effect for the ambiguous S-coordinations relative to the unambiguous S-coordinations. As these two conditions only differ with respect to the presence versus absence of the comma, we can conclude that the comma must have been processed, despite the fact that it did not elicit a CPS.

Based on the timing, the negativity of the biphasic pattern at the disambiguating verb can either be an N400 or it can be a LAN. However, the scalp distribution of this effect does not match that of the LAN, which typically shows a left-anterior or anterior distribution. Instead, the broad distribution of the effect – including posterior and anterior sites – would fit better with the distribution of an N400. Note that Steinhauer et al. (1999) in response to a prosody–syntax mismatch also observed a biphasic N400–P600 pattern.

The P600 effect in Experiment 1 did not show the centro-parietal scalp distribution that is usually found in response to syntactic violations, but an anterior distribution. However, as pointed out in the introduction, previous studies on locally ambiguous sentences (as opposed to sentences with syntactic violations) have also reported an anterior scalp distribution of the P600 effect (Friederici et al., 1996; Hagoort et al., 1999; Osterhout and Holcomb, 1992; van Berkum et al., 1999). Based on these differences in topography, some authors (Friederici et al., 2002; Hagoort et al., 1999) have proposed that the posterior distributed P600 effect indicates a failure of a parse and/or the resulting repair processes, whereas the frontally distributed P600 effect reflects processing difficulty related to revision processes in the case of (locally) ambiguous sentences. It is important for our present purposes that the finding of an anterior distributed P600 effect to locally ambiguous sentences is consistent with previous ERP studies.

2.2. *Experiment 2: Auditory modality*

Having established in Experiment 1 that the presence of a comma is used by readers to arrive at an early disambiguation of locally ambiguous sentences, Experiment 2 was conducted to test whether a prosodic break can have a parallel function in spoken sentence processing. The same sentences as in Experiment 1 were presented, but now in the auditory modality.

2.2.1. *Data analysis*

In Experiment 2 the waveforms were time-locked to the offset of NP2 (e.g., *the farmer* in (3) and (4)), and to the uniqueness point of the disambiguating verb (e.g., *defended* in (3) and (4); for details about the determination of the uniqueness point see the Results section of Experiment 2 below). The data of three participants were excluded from the analyses; two due to excessive artifacts, one due to a software error, leaving the data of a total of 24 participants.

Based on visual inspection of the ERP waveforms, we used the time-window from 400 to 800 ms to quantify the CPS in the auditory modality. At first sight, this seems to contradict the time-windows used in earlier auditory CPS studies (Steinhauer, 2003; Steinhauer et al., 1999; Steinhauer and Friederici, 2001). However, it has to be pointed out that the time-locking procedure in the present study differed from that used in other auditory CPS studies. In the present study, we use the standard ERP methodology of time-locking each individual trial to a specific critical event and normalize the waveforms in a 150 ms interval directly preceding that event. For the auditory materials, we defined this critical event as the offset of the second noun (and thus the onset of the pause in the condition with a prosodic break). Previous CPS studies (Steinhauer, 2003; Steinhauer et al., 1999; Steinhauer and Friederici, 2001) time-locked and normalized the waveforms to the onset of the sentences, computing an average ERP-waveform over the entire sentences. The location of a prosodic break in the auditory signal was then determined by computing the average location of the pause of the prosodic break in the auditory signal. The latency of the CPS is estimated by comparing the point in time at which the prosodic break condition and the no prosodic break condition begin to differ with the average position of the prosodic break. Clearly, this latter procedure has the disadvantage of "considerable latency variability across trials" (Steinhauer, 2003, p. 151) with respect to the onset of the pause of the prosodic break, a problem that does not occur when time-locking the ERPs to the offset of the word preceding the pause. On the other hand, the procedure used in the present study has the disadvantage that it does not take into account potential contributions of other acoustic aspects of the prosodic break that precede the pause, such as the prefinal lengthening and pitch rise of the boundary tone. Due to these procedural differences in time-locking and averaging, the time-windows in which a CPS is found in the present study cannot be compared directly with the time-windows from the previous studies (Steinhauer, 2003; Steinhauer et al., 1999; Steinhauer and Friederici, 2001).

Studies that use a similar time-locking procedure as in the present study also report a time-course that is similar to the time-course in the present experiment. For instance, Toepel et al. (2007) used a similar time-locking procedure and report a CPS with a latency of 500 to 800 ms. Knösche et al. (2005) find a CPS from 500 to 600 ms in the EEG and from 400 to 700 ms in the MEG as a response to musical phrase boundaries. Finally, for the visual modality Steinhauer and Friederici (2001) investigated the CPS by time-locking to the word that either has a comma attached or has no comma attached. They report a CPS within the 550 to 650 window following comma onset. In addition to the different time-locking points for the CPS, one has to keep in mind that differences in the acoustic realizations of the prosodic break between different studies might also affect the latency of the CPS.

For the P600 at the disambiguating verb, the same window was used as in Experiment 1. In the Part of Experiment-analyses contrasting the first and the second half of the experiment, the windows for the analyses were determined by visual inspection: from 200 to 400 ms for the first half of the experiment, and from 600 to 700 ms for the second half of the experiment.

For each window, two kinds of MANOVA were performed. The midline MANOVA had the factors Prosodic Break (break/no break) and Midline Electrode (Fz/Cz/Pz). The MANOVA for the lateral electrodes had Prosodic Break (prosodic break/no prosodic break) as a factor, using a Hemisphere by Region of Interest (ROI) by Electrode design. The factors Hemisphere and ROI divided the scalp into 4 quadrants: left anterior (aF7, F7, FC3, and F3), right anterior (aF8, F8, FC4, and F4), left posterior (CP5, P7, PO7, and P3), and right posterior (CP6, P8, PO8, and P4)[3]. Also the time course analyses were carried out in the same way as for Experiment 1.

2.2.2. *CPS: NP2 with and without prosodic break*

Grand average waveforms time-locked to the offset of NP2 are presented in Fig. 3. Inspection of the waveforms suggests that

[3] Note that in Experiment 2, a different electrode montage was used than in Experiment 1. This was done because, in addition to traditional language-related areas, the auditory modality was expected to give different scalp distributions than the visual modality (see Experimental Procedures section).

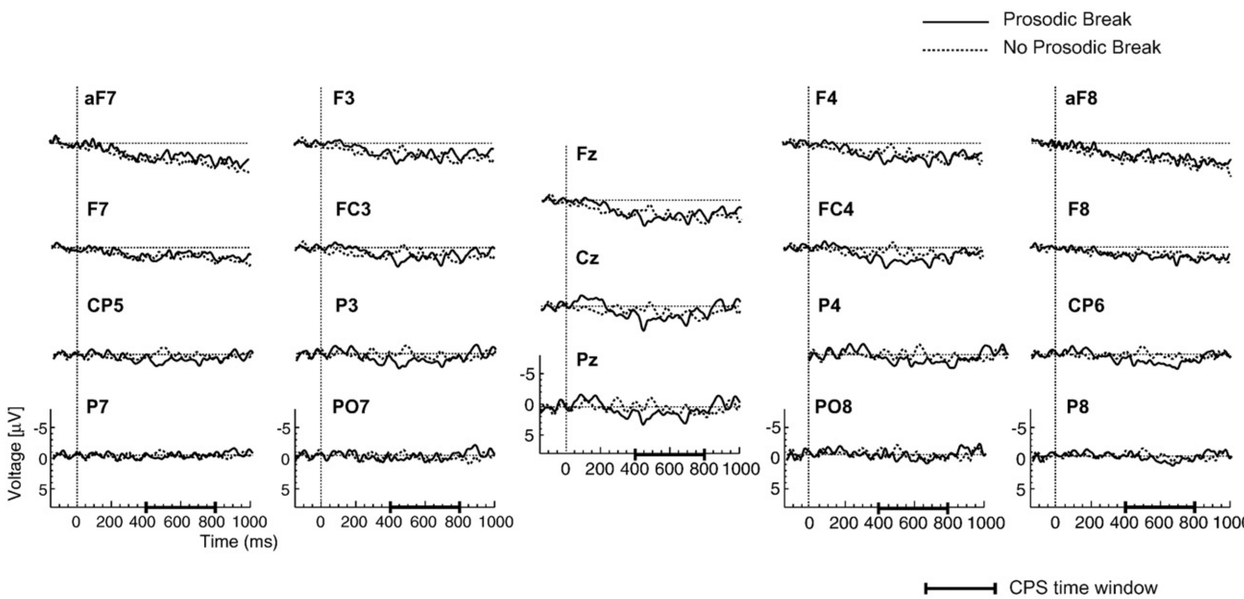

Fig. 3 – Grand average waveforms over participants ($n=24$), time-locked to the offset of NP2, for the Prosodic Break condition (solid line) and the No Prosodic Break condition (dotted line) in Experiment 2.

the prosodic break gave rise to a CPS (e.g., at CP5 and CP6). Furthermore, the CPS appears to be preceded by a negativity between 100 and 300 ms (e.g., electrodes Fz and Cz).

In the analysis for the 400 to 800 ms window for the midline electrodes, no effect of Prosodic Break ($F<1$), and no interaction between Prosodic Break and Midline Electrode ($F<1$) was present. Although the lateral analysis did not yield a main effect of Prosodic Break ($F<1$), a three-way interaction between Prosodic Break, ROI, and Electrode was found ($F[3,21]=8.20$; $p<.01$). Separate analyses for the two levels of ROI did not yield a main effect of Prosodic Break, neither for the anterior nor for the posterior ROI (both $ps>.19$). However, for the posterior ROI a Prosodic Break by Electrode interaction was found ($F[3,21]=4.85$; $p<.01$). This interaction showed a trend towards significance at the anterior ROI ($F[3,21]=3.02$; $p=.057$). Follow-up analyses for the single sites in the posterior ROI revealed a CPS effect at bilateral centroparietal sites (CP5 and CP6; $p<.05$).

The time-course analyses revealed that in the 400 to 500 ms window a CPS was obtained not only for the lateral electrodes but also for the midline electrodes. In particular, the midline analysis in this time-window yielded an effect for Prosodic Break ($F[1,23]=7.51$; $p<.05$). The interaction between Prosodic Break and Midline Electrode was not significant ($F<1$) indicating that a CPS effect was broadly distributed across the midline. Likewise, the lateral analyses in the 400 to 500 ms window revealed an effect of Prosodic Break ($F[1,23]=5.10$; $p<.05$) and an interaction between Prosodic Break, ROI and Electrode ($F[3,21]=7.20$; $p<.01$). Follow-up analyses showed that a CPS effect was present at the following sites: FC3, FC4, CP5, CP6, P3, and P4 (all $ps<.05$). The time-course analyses thus revealed that a CPS effect was elicited at bilateral anterior and posterior sites.

With respect to the early negativity that was described in the visual inspection of the signals, the time-course analyses revealed a trend towards a significant effect of Prosodic Break for the midline analysis of the 100 to 200 ms time-window ($F[1,23]$ 3.42; $p=.078$).

The results for the midline analysis and the lateral analysis for the CPS-window containing Part of Experiment as a factor did not show any interactions between Prosodic Break and Part of Experiment (both $Fs<1$) or any other relevant interactions (all $ps>.091$).

2.2.3. *Negativity and P600 effect: Uniqueness point of the disambiguating verb*

To examine the effects at the verb, averages were computed time-locked to the onset of the disambiguating phoneme of the disambiguating verb. This point was determined using the phonological representations from the CELEX database (Baayen et al., 1993). The verbs were matched against a database of words from those syntactic categories that allowed for a syntactically well-formed continuation of the sentence, but which did not lead to an S-coordination structure. The database therefore contained all plural verbs, present tense verbs, all nouns, all determiners, and all infinitives. The point of disambiguation was defined as the point at which the verb shares no more phonemes with another word in this database. The uniqueness point of the disambiguating verb was chosen for the time-locking of the averaging of the EEG signals because of the left-to-right temporal nature of the speech signal which implies that the actual verbs will be recognized at quite different points in time when using the onset of the verb as reference for time-locking. As has been pointed out by van Berkum et al. using the onset of a spoken word for time-locking introduces undesirable jitter in the signal (van Berkum et al., 2003).

Grand average waveforms time-locked to the onset of the disambiguating phoneme of the verb are presented in Fig. 4. Visual inspection of the waveforms suggests that no P600 effect was present.

Consistent with this, for the P600 window (600–900 ms) no effect of Prosodic Break ($ps>.10$) or relevant interactions were present neither for the midline nor for the lateral analyses ($ps>.20$).

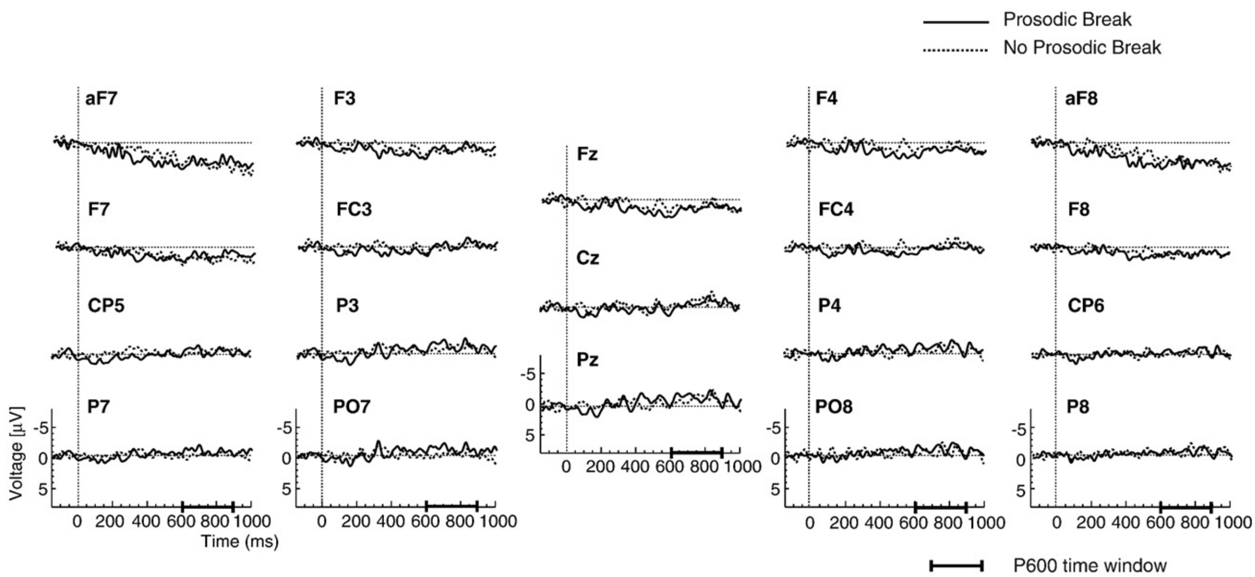

Fig. 4 – Grand average waveforms over participants ($n=24$), time-locked to the onset of the disambiguating phoneme of the disambiguating verb, for the Prosodic Break condition (solid line) and the No Prosodic Break condition (dotted line) in Experiment 2.

Grand average waveforms, time-locked to the onset of the disambiguating phoneme of the disambiguating verb, for the first and the second half of the experiment are presented in Figs. 5 and 6, respectively. Inspection of the figures suggests that the patterns for the first and the second half of the experiment differ. In the first half, a negative effect for the No Prosodic Break condition relative to the Prosodic Break condition seems to be present from about 200 to 400 ms at left anterior electrodes (e.g., aF7 and F3 in Fig. 5), and between 500 and 600 ms (e.g., aF8 and F8 in Fig. 5). In contrast, for the second half, a P600-like effect seemed to be present at more posterior sites (e.g., CP5 and P3 in Fig. 6).

This descriptive pattern was confirmed in corresponding time-course analyses. The midline time-course analyses of the first half of the experiment for the negativity (epochs 200–300 and 300–400 ms) did not yield an effect of Prosodic Break ($ps<.19$) or an interaction with Midline Electrode ($ps>.075$). The lateral analysis for the first epoch (200 to 300 ms) yielded a main effect for Prosodic Break ($F[1,23]=4.37$; $p<.05$) and a Prosodic Break by Electrode interaction ($F[3,21]=5.59$; $p<.001$) in the absence of interactions with ROI ($Fs<1$). Follow-up analyses for the single electrodes indicated that a LAN-like effect was present at the following sites: aF7, aF8, F3, FC3, and CP5 (all $ps<.05$). The analyses for the 300 to 400 ms window for the lateral sites yielded an interaction between Prosodic Break, Hemisphere, ROI, and Electrode ($F[3,21]=5.72$; $p<.01$). Follow-up analyses, however, indicated that no other effects or interactions were obtained, except for a trend towards an

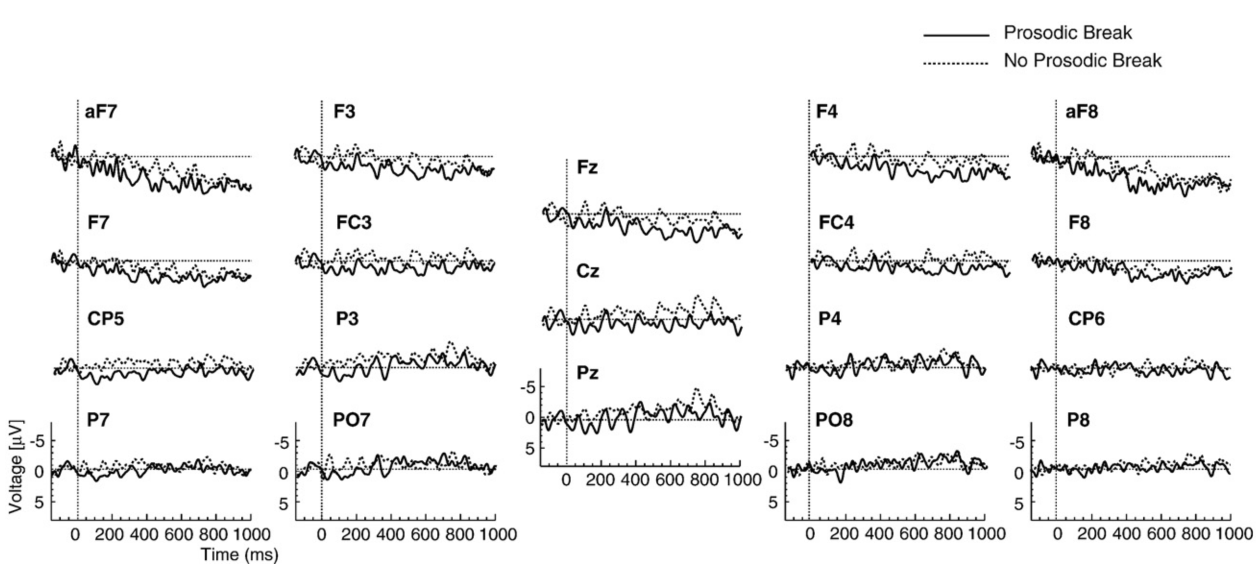

Fig. 5 – Grand average waveforms over participants ($n=24$), time-locked to the onset of the disambiguating phoneme of the disambiguating verb, for the Prosodic Break condition (solid line) and the No Prosodic Break condition (dotted line) for the first half of the experiment in Experiment 2.

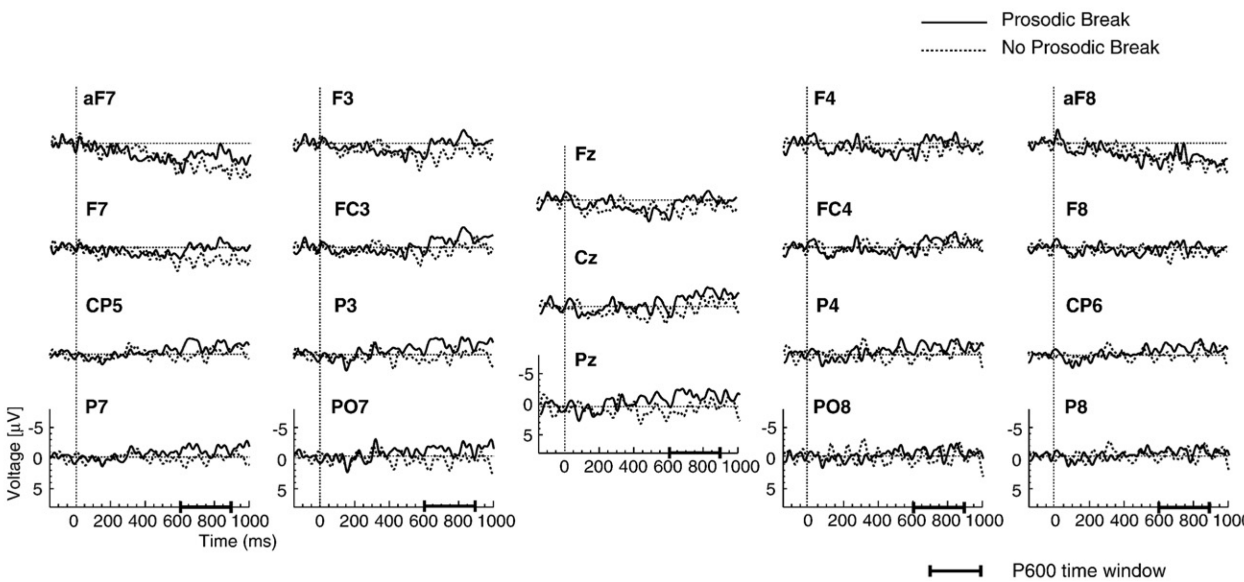

Fig. 6 – Grand average waveforms over participants (n=24), time-locked to the onset of the disambiguating phoneme of the disambiguating verb, for the Prosodic Break condition (solid line) and the No Prosodic Break condition (dotted line) for the second half of the experiment in Experiment 2.

effect of Prosodic Break for the left-posterior ROI ($F[1,23]=4.16$; $p=.057$).

Further time-course analyses for 100 ms consecutive time-windows across the entire 1000 ms revealed a trend towards a main effect of Prosodic Break from 100 to 200 ms ($F[1,23] = 4.07$; $p=.056$) in the lateral analysis. The negativity from 500 to 600 ms showed a trend towards a main effect of Prosodic Break both in the midline analysis ($F[1,23]=3.77$; $p=.065$) and the lateral analysis ($F[1,23]=3.54$; $p=.073$) in the time-window 500 to 600 ms.

Statistical analyses for the second half of the experiment revealed a P600-like effect for the 600 to 700 ms epoch. Although the midline and lateral analyses did not yield effects of Prosodic Break (ps>.10) or interactions with Electrode (ps>.60), the lateral analyses did reveal a Prosodic Break by Hemisphere interaction ($F[1,23]=7.71$; $p<.05$). Separate analyses for the two hemispheres indicated that a P600-like effect was present for the left hemisphere ($F[1,23]=5.91$, $p<.05$), but not for the right hemisphere ($p>.30$). The time-course analyses for the 100 ms consecutive time windows spanning the entire 1000 ms did not reveal any reliable differences between conditions (all ps>.10).

2.2.4. *Discussion Experiment 2*

Taken together, the data at the prosodic break replicate the findings of Steinhauer et al. (1999), and show that also for Dutch a CPS is elicited by a prosodic break. Visual inspection of the signals suggested that a small negativity preceded the CPS, but no significant effects were found. Note that other CPS-studies have also observed a small negativity preceding the CPS (e.g., Bögels et al., submitted for publication and Kerkhofs et al., 2007).

At the disambiguating verb, the data show a difference between the S-coordination sentences without a prosodic break and with a prosodic break. This difference indicates processing difficulty at the disambiguating verb for sentences without a prosodic break relative to sentences with a prosodic break. However, this processing difficulty took a different form in the two halves of the experiment. In the first half of the experiment, an early increase in negativity for the S-coordination sentences without a prosodic break was observed. The time course analyses revealed that this effect was significant in the 200 to 300 ms time window after the onset of the uniqueness point of the disambiguating verb. Given the timing (200–300 ms) and the anterior scalp distribution of the effect we take this effect to reflect a LAN effect. The trend towards significance in the 100 to 200 ms window does not contradict this interpretation, as this effect falls into the time window in which LAN effects for phrase structure violations have been reported (100 to 300 ms after stimulus onset). We will come back to this point in the General Discussion. In the second half of the experiment, the LAN effect disappeared and instead a P600-like effect was found for the S-coordination sentences without a prosodic break.

In order to understand the differential pattern in the two halves of the experiment at the disambiguating verb, it is useful to have a closer look at the potential functions of the presence or absence of a prosodic break. The presence of a prosodic break presumably functions in the same way as the comma in the visual modality: It signals an S-coordination. By contrast, the absence of a prosodic break may have two different functions. It may indicate the presence of an NP-coordination, or it may function as a neutral cue, i.e., it does not lead to any specific expectation of an NP- or S-Coordination.

Given these two potential functions of the absence of a prosodic break, one could hypothesize that in the first half of the experiment the absence of a prosodic break is used to predict an NP-coordination. This turns out to be correct for the experimental filler sentences (NP-coordination sentences without a prosodic break; see Materials section, below), but not for the critical S-coordination sentences without a prosodic break. Actually, for the S-coordination sentences without a prosodic break a double violation takes place. First, the expectation based on the absence of a prosodic cue is violated and second, the default NP-coordination preference is violated.

In the course of the experiment, however, listeners will learn that the absence of a prosodic break should not be taken as a reliable cue for an upcoming NP-coordination. Thus, they will treat the absence of the prosodic break as neutral (i.e., as not implying any specific upcoming syntactic structure). The standard NP-coordination preference will start to dominate, and thus syntactic processing difficulty will be reflected in a P600 effect at the disambiguating verb. Obviously this raises the question of why a comparable pattern was not obtained in the visual domain. We will come back to this question in the General discussion.

3. General discussion

We presented two experiments, one in the visual and one in the auditory modality. In order to compare the two modalities, the same sentences were presented in both experiments.

In the visual study, no significant CPS occurred at the comma, but the N400/P600 effect at the verb shows that the comma has nevertheless been used to disambiguate the ambiguous S-coordination sentences. In the discussion of the visual study it was hypothesized that the absence of a CPS was due to the fact that participants did not pay specific attention to the comma. This suggests that the CPS in the visual modality does not reflect the mere detection of a comma, and thus of a syntactic break. It remains an open question as to what the CPS in the visual modality does reflect. We would suggest that it primarily reflects conscious processing of the comma. Such conscious processing can occur when part of the experimental materials contain explicit punctuation errors, as in the studies of Steinhauer (2003), Steinhauer et al. (1999), and of Steinhauer and Friederici (2001). That attention has an effect on the CPS is also consistent with a recent MEG study in the auditory modality of Knösche et al. (2005). They observed an MEG correlate of phrase structure in music perception that resembled the CPS in terms of timing and scalp distribution. Source localization suggested that structures in the limbic system, in particular, anterior and posterior cingulate as well as posterior mediotemporal cortex were the likely generator of this magnetic counterpart of the CPS. These brain structures have been shown to be involved in memory and attention processes (Cabeza and Nyberg, 2000) (for further evidence on the localization of the CPS see Ischebeck et al., 2008).

In contrast to the absence of a CPS in the visual study, Hoeks et al. *did* find a difference between NP2 with and without a comma in an eye-movement experiment in which they tested similar materials (Hoeks et al., 2005). Reading times on NP2 with a comma were slower than reading times on NP2 without a comma. These data show that the presence or absence of a comma can lead to behavioral differences, even though these differences do not show up in the ERPs.

At the disambiguating verb in the visual modality we found a negativity followed by a P600 for the sentences without a comma. Based on the broad anterior/posterior scalp distribution of the negativity it was classified as an N400. The P600 effect showed an anterior scalp distribution which has been reported before in studies using ambiguous sentences (Hagoort and Brown, 2000). The observation of a biphasic N400/P600 pattern to a prosody–syntax mismatch is in line with a previous study of Steinhauer et al. (1999).

In the auditory experiment, the prosodic break did elicit a CPS. This replicates previous findings showing that a CPS is elicited by the occurrence of a prosodic break (Bögels et al., submitted for publication; Isel et al., 2005; Kerkhofs et al., 2007; Mietz et al., 2008; Pannekamp et al., 2005; Steinhauer, 2003; Steinhauer et al., 1999; Steinhauer and Friederici, 2001; Toepel et al., 2007). The presence of a prosodic break led to disambiguation of the S-coordination sentences: In sentences without a prosodic break reflections of a processing difficulty at the disambiguating verb were found. However, the reflections of processing difficulty in the first half of the experiment took on a different form than those in the second half of the experiment. In the first half of the experiment, we found a LAN-effect, whereas in the second half of the experiment we found a P600-effect. As described in the introduction, a LAN is associated with word category violations. If we assume that in the first half of the experiment the absence of a prosodic break is taken as a cue for an NP-coordination interpretation, the S-coordination sentences without a prosodic break contain both a violation against the default NP-coordination expectation and a violation against the additional expectation induced by the prosodic cue. This should lead to an extremely strong expectation of an NP-coordination. Therefore, the occurrence of a verb after NP3 (i.e., *defended* following the *farm hand* in (3) and (4)) will be picked up as a word category violation. This interpretation is consistent with the early timing of the LAN effect in the first half of the auditory study (200–300 ms following the uniqueness point of the disambiguating verb) which corresponds well with the time window in which LAN effects to word category violations have been observed (100–300 ms; see, e.g., Friederici et al., 1996).

In the course of the auditory experiment, however, the function and use of the absence of a prosodic break might change. The sentences without a prosodic break turn out to be NP-coordination sentences in two thirds of the cases. Thus, in one third of the sentences the absence of a prosodic break is not a cue for an NP-coordination. Participants might eventually learn during the first half of the experiment that the absence of the prosodic break is not a reliable cue. If this is the case, participants will stop using the absence of a prosodic break as a cue. When the participants have learned to ignore the absence of a prosodic break, only the default NP-coordination preference plays a role. This will result in a less extreme violation of the expectations of the participants when the verb is encountered. This violation is thus not picked up as a word category violation anymore, but rather induces a syntactic reanalysis, which will result in a P600, as observed in the second half of the experiment.

The topography of this P600 effect in the auditory study differed from that in the visual study. Specifically, the auditory P600 effect was widely distributed over the left hemisphere (including anterior and posterior sites), while in the visual study it was restricted to anterior areas. This finding is at odds with the claim that frontally distributed P600 effects are associated with processing difficulty related to the revision processes for ambiguous sentences. There is one other visual study, by Kaan and Swaab (2003), that did not find an anterior positivity for non-preferred continuations in ambiguous sentences. In this study, both non-preferred and ungrammatical continuations elicited a posterior-distributed P600 effect.

Based on this study, Kaan and Swaab proposed that revision is not a sufficient condition to evoke a frontally distributed P600 effect. Future studies are needed to further determine the antecedent conditions for eliciting the frontal P600 component.

We have been proposing that the negativity in the first half of the auditory experiment reflects an extreme processing difficulty due to a double violation of the expectation of an NP-coordination. But why is there no corresponding negativity in the first half of the visual experiment? According to Dutch punctuation rules, NP-coordination sentences are written without a comma. S-coordination sentences are usually also written without a comma, but the placement of a comma after the second noun (although infrequent) disambiguates the coordination as an S-coordination. This means that the absence of a comma is a neutral cue as it can signify both an NP-coordination sentence and an S-coordination sentence. Thus, there is no double violation in the visual experiment. And therefore, the pattern does not change over the two halves because the absence of a comma is a neutral cue right from the beginning of the experiment, and remains so throughout the experiment.

In the auditory experiment, it appears as if the same word can be picked up as an outright (word-category) violation or as a signal for a need of syntactic reanalysis, depending on how strong the syntactic expectation or preference is. This proposal is similar to related work by Kim and Osterhout who showed that one and the same violation can lead to different ERP signatures depending on the strength of a syntactic expectation. Kim and Osterhout showed that in sentences like "The meal was devouring", the semantically anomalous "devouring" elicited a P600 effect (Kim and Osterhout, 2005). Additional experiments (Kim, personal communication) showed that when the same target sentences were preceded by semantically and syntactically correct sentences with the same syntactic structure (i.e., "NP was VERB-ing"), the P600 effect was eliminated. Put differently, it appears that the strength of the expectancy of a specific syntactic structure modulates the way in which a given violation is processed.

The argumentation put forward for the different patterns of results in the first and the second half of the auditory experiment follows a similar line. In the first half of the experiment the absence of a prosodic break is taken as a strong cue for an upcoming NP-coordination, and thus the disambiguating verb (*defended* in (3) and (4)) will be picked up as a word category violation. In the second half of the experiment, the absence of a prosodic break is not taken anymore as a cue for an upcoming NP-coordination, and thus the disambiguating verb will be picked up as signaling the need for syntactic reanalysis.

The present experiments show that a CPS is elicited by a prosodic break, while a comma does not necessarily elicit a CPS. Why was a CPS elicited by a prosodic break in Experiment 2, whereas no CPS was elicited by a comma in Experiment 1? We propose that whether a CPS is elicited at a boundary marker depends on how salient this marker is. Presumably a prosodic cue is more salient than a comma (at least in a language with lax punctuation rules like Dutch). If this is the case, it is more likely for a CPS to occur after a prosodic break than after a comma. This implies that the CPS cannot simply be the reflection of the processing of any boundary cue. Rather, in order to elicit a CPS, the boundary cue either has to be very salient as in the case of a prosodic break or, in case of a less salient cue like a comma, has to attract attention.[4]

Regardless of whether a CPS was elicited at the boundary marker, both comma and prosodic break led to an early disambiguation at the comma or the prosodic break, hereby overriding the default NP-coordination preference. This establishes that comma and prosodic break have a parallel function as a boundary marker.

4. Experimental procedures

4.1. *Methods Experiment 1*

4.1.1. *Participants*

The participants were 32 undergraduate students from the University of Nijmegen, 10 male and 22 female (aged 21 to 32, mean age 23.9). All participants were right-handed. Hand dominance was assessed by an abridged version of the Edinburgh Inventory (Oldfield, 1971). The participants were paid for their participation.

4.1.2. *Materials*

The stimulus materials consisted of 60 S-coordination sentences in two conditions, 60 NP-coordination experimental fillers and 144 other fillers. The 60 NP-coordination experimental fillers were included to have an equal number of sentences that turn out to be S-coordination sentences and sentences that turn out to be NP-coordination sentences. The other filler sentences contained a subject/object relative clause ambiguity. The S-coordination sentences either were (locally) ambiguous (as in (3) repeated here as (5a)) or were disambiguated by a comma between *the farmer* and *and* (as in (4) repeated here as (5b)). The S-coordination sentences without a comma (5a) were identical with respect to syntactic word categories to the NP-coordination experimental fillers as in (6) up to the disambiguating region (*defended* in (5a) and *on* in (6)). None of the 60 NP-coordination experimental fillers contained a comma, and thus there were no sentences in the experiment that violated Dutch punctuation rules. The S-coordination sentences were lexically disambiguated by the second verb in the sentence (*defended* in 5). The NP-coordination sentences were in principle disambiguated at the end of the sentence. However, in the construction of the NP-coordination sentences, care was taken to choose PPs following NP3 that did not fit NP3 as a continuation. For example in (6) it is unlikely that … *in front of the statue* is a PP modifying the NP *the policeman*, but rather provides the location of the entire scene. As a result our NP-coordination sentences were disambiguated at the PP following NP3 (*on the square* in 6). Note that the actual lexical disambiguation point for NP-coordinations is not critical for our data as the NP-coordinations only served as filler materials.

[4] Note that this can also explain the occurrence of a CPS in hummed sentences as reported in (Mietz et al., 2008). In these sentences the structuring information (i.e., the prosodic breaks) is very salient because in these sentences the prosodic information presumably is the main type of structuring information availabe.

(5) a. De sheriff	beschermde	de boer	en	de knecht	verdedigde
The sheriff	*protected*	*the farmer*	*and*	*the farm hand*	*defended*
NP1	verb1	NP2	and	NP3	Verb2
dapper	de ranch	tegen Johnson's bende.			
bravely	*the ranch*	*against Johnson's gang.*			
Adverb	*NP*	*PP*			
b. De sheriff	beschermde	de boer,	en	de knecht	verdedigde
The sheriff	*protected*	*the farmer,*	*and*	*the farm hand*	*defended*
NP1	verb1	NP2,	and	NP3	Verb2
dapper	de ranch	tegen Johnson's bende.			
bravely	*the ranch*	*against Johnson's gang.*			
Adverb	*NP*	*PP*			
(6) De journalist	interviewde	de kraker	en	de agent	voor het standbeeld
The reporter	*interviewed*	*the squatter*	*and*	*the policeman*	*in front of the statue*
NP1	*verb1*	*NP2*	*and*	*NP3*	*PP*
in het centrum van de stad.					
in the centre of the city.					
PP					

In addition to these materials, 20 sentences for a training block and 12 starter sentences were constructed. These sentences were representative for the materials that were used in the actual experiment. The sentences were pre-tested in a self-paced reading experiment. The data confirmed that the comma disambiguated the S-coordination sentences as reflected by a processing difficulty at the disambiguating verb in (5a) relative to (5b).

4.1.3. *Design*

The 60 experimental sentences (S-coordination sentences with and without a comma), 60 experimental filler sentences (NP-coordination sentences), the 144 other filler sentences, and 12 starter sentences, 276 in total, were divided into 6 blocks of 46 items. The actual design of the experiment only concerns the 60 S-coordination sentences, with the experimental factor Comma (present/absent). A pseudo-random order of all 276 items was generated, such that the maximum number of S-coordination sentences in a row was 3. Furthermore, each block started with 2 starter sentences. We constructed two versions of this order, such that each version contained 30 S-coordination sentences without a comma and 30 S-coordination sentences with a comma. Within each version, each of the 60 S-coordination sentences occurred only once. Half of the participants read version one and the other half read version two. Therefore, across participants, each S-coordination sentence contributed to each of the two levels of the experimental factor Comma equally often, but each participant saw each S-coordination sentence in only one of the two conditions. Furthermore, the pseudo-random order was constructed in such a way that the first and the second half of the experiment also followed these constraints. Thus each of the two halves also comprised a complete design. The 20 training sentences were combined into a training block. Also for this block the list was generated in a pseudo-random fashion, such that the maximum number of S-coordination sentences in a row was 3.

4.1.4. *Apparatus*

The EEG was recorded from 27 tin electrodes mounted in an elastic electrode cap. Of these 27 electrodes, 21 were included in the analyses (see paragraph 2.1.1). The electrode positions were a subset of the international 10% system which has been used in other studies on sentence processing in the visual modality (e.g., van Herten et al., 2005). The left mastoid served as reference during the recording, but before the EEG was analyzed, the signal was re-referenced to software linked mastoids. Electrode impedance was less than 3 KΩ. Vertical EOG was recorded bipolary by placing electrodes above and below the right eye. Horizontal EOG was recorded bipolary by placing electrodes beside the left and beside the right eye. The electrode impedance of the EOG electrodes was less than 5 kΩ. EEG and EOG channels were amplified (time constant = 10 s, bandpass = .02–100 Hz). All signals were digitized on-line with a sampling frequency of 500 Hz using a 16-bit A/D converter.

4.1.5. *Procedure*

The participants were tested in a soundproof and dimly lit room. The sentences were presented using Rapid Serial Visual Presentation (RSVP), centered (with a fixed left margin) on a computer screen. Each word of the sentence was presented separately for 300 ms, followed by 300 ms of blank screen, before the next word appeared. In the case of very short words (like articles or prepositions), an entire constituent or a part of a constituent was shown (e.g., [de ranch] (*the ranch*) and [tegen Johnson's bende.] (*against Johnson's gang.*) in example (7)). The comma was presented together with NP2 (e.g., [de boer,] (*the farmer,*).

(7) [De sheriff] [beschermde] [de boer] [en] [de knecht] [verdedigde] [dapper] [de ranch] [tegen Johnson's bende.]

A trial started with the presentation of a fixation cross in the center of the screen for 300 ms. The first word of the sentence was presented 600 ms after the onset of the fixation cross. The participants were asked not to blink while reading a sentence. In order to determine whether participants were paying attention to the sentences, 20% of all sentences (experimental and all filler sentences) were followed by a question. For instance, the question for the sentence in (3) was: "Did the farmer defend the ranch?", for which the "no" answer would have been appropriate.

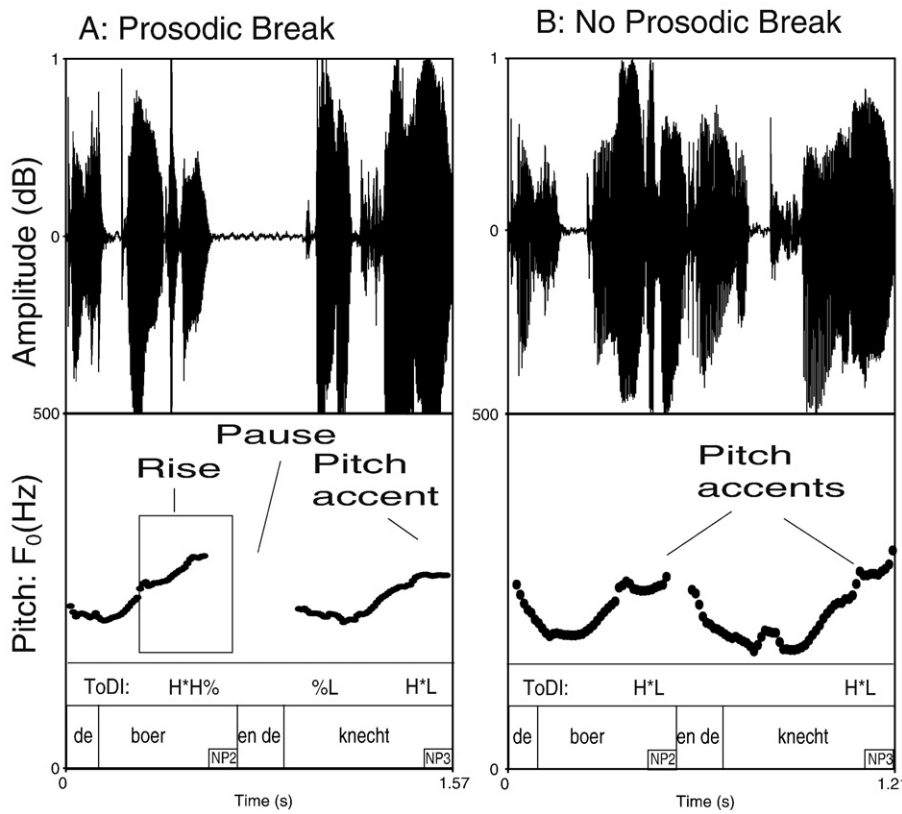

Fig. 7 – Acoustic properties of a typical critical region of the target sentence. The upper boxes show the amplitude of the speech signal in the Prosodic Break condition (Panel A) and in the No Prosodic Break condition (Panel B). The middle boxes show the pitch-track of the speech signal in both conditions. The lower boxes show the transcription in ToDI (Gussenhoven, 2004) and in words of the speech signal.

Before each question, the word "VRAAG" (*question*) was presented in upper case. Participants had to answer the question by pressing a button on a button box with the right index finger ("yes" response) or the left index finger ("no" response).[5] After 1500 ms following the offset of the last word of a preceding trial, or following the button press after a question, the fixation cross for the next trial appeared.

4.2. *Methods Experiment 2*

4.2.1. *Participants*

The participants were 27 undergraduate students from the University of Nijmegen, eight male and 19 female (aged 19 to 28, mean age 22.8) who fulfilled the same criteria as those in Experiment 1 and had not participated in Experiment 1.

4.2.2. *Materials*

The materials used for the recording session were constructed as follows. For each S-coordination sentence used in the visual ERP study (e.g., example (5) repeated here as (9)), a second sentence was constructed with an NP-coordination structure (e.g., example (10)). This was accomplished by modifying the S-coordination sentences by replacing the Verb Phrase of the S-coordination sentences (from defended to the end of the sentence in (9)) with two or more Prepositional Phrases (PPs; *in front of the shed* in (10)). This resulted in 60 NP-coordination experimental fillers which were identical to their S-coordination counterparts up to the second verb (*defended*), or PP (*in front of the shed*). In addition, the same 60 NP-coordination experimental filler sentences, 144 unrelated filler sentences, 14 training block items, and 12 starter items were used as in Experiment 1.

(9) De sheriff beschermde de boer en de knecht verdedigde dapper de ranch tegen Johnson's bende. *The sheriff protected the farmer and the farm hand defended bravely the ranch against Johnson's gang.*

(10) De sheriff beschermde de boer en de knecht voor de schuur waar een gevecht plaatsvond. *The sheriff protected the farmer and the farm hand in front of the shed where a fight was fought.*

A female speaker recorded these materials. The speaker was instructed to first read the sentences for herself, and then to read the sentences out loud. She was asked to produce the NP-coordination sentences twice with a clear continuation intonation (without a prosodic break), and to produce the S-coordination sentences four times, twice with a prosodic break after *farmer*, and twice with as little prosodic marking as

[5] Only 6.5 % of the questions was answered incorrectly, indicating that the participants had been paying attention to the meaning of the sentences.

possible (neutral). The materials were recorded in blocks of ten items in a row, alternating between 10 S-coordination items and 10 NP-coordination items. This resulted in 2*60 S-coordination sentences with a prosodic break, 2*60 S-coordination sentences with a neutral intonation, 2*60 modified to NP-coordination sentences (such as (10)) with an NP-coordination intonation, 2*60 NP-coordination experimental fillers, 144 unrelated filler sentences containing a subject relative/object relative clause ambiguity, 14 training block items, and 12 starter items.

From these recorded materials, the experimental sentences and filler sentences were constructed as follows. First, from the two recordings of the same sentence the second recording was discarded, except when the first had an artifact in it (e.g., a cough from the speaker). Second, for the experimental S-coordination sentences, the neutral intonation S-coordination sentences were duplicated, creating a set of two identical sentences with neutral intonation. Finally, for each of these two duplicates, a first target sentence was constructed by cross-splicing the coordination part (*the farmer and the farm hand*) from sentences such as (9) over the coordination part in the first neutral sentence. A second target sentence was constructed by cross-splicing the coordination part from sentences such as (10) over the coordination part in the neutral sentence. This resulted in pairs of S-coordination target sentences with the two sentences of a pair only differing with respect to the intonation in the coordination part (prosodic break present versus prosodic break absent). Like in the visual experiment, the NP-coordination experimental fillers did not contain a boundary marker (prosodic break).

The prosodic structure of the constructed target sentences was transcribed by two independent judges using the ToDI system (Gussenhoven, 2004) (see ToDI line in Fig. 7). Acoustic analyses of the target sentences showed clear differences between the Prosodic Break and the No Prosodic Break conditions. The pattern from Fig. 7, panel A (the prosodic break condition) consists of a pitch accent without a low target (H*) followed by a high boundary tone (%H), a pause, a low boundary tone (%L) and a pitch accent on the third noun (H*L). This pattern occurred in 65% of the sentences with a prosodic break. In addition to this pattern, a pattern in which the first pitch accent preceding the pause had a low target was observed in 35% of the sentences with a prosodic break (as denoted by the H*L in H*L %H %L H*L). The average length of the pause was 343 ms (sd: 59 ms; min: 216 ms; max 499 ms).

In the No Prosodic Break condition (Fig. 7, panel B), these features were not present. Instead there were pitch accents (H*L) on NP2 (*farmer*) and NP3 (i.e., the third noun phrase: *farm hand*). The pattern from Fig. 1 Panel B was observed in 82% of the sentences without a prosodic break. In addition to this structure, instances in which the second pitch accent was smaller than the first pitch accent (as denoted by !H*L in H*L ! H*L) occurred in 15% of the sentences without a prosodic break. Finally in 3% of the sentences without a prosodic break, the pitch accent on the first of the two NPs was lower than the pitch accent on the second NP (!H*L H*L).

In summary, these analyses reveal clear differences between the two prosodic conditions: The prosodic break items all had a pause that was preceded by a boundary tone, the no prosodic break items contained a pitch accent on each noun, but did not contain boundary tones or a pause.

4.2.3. *Design*

Apart from the main experimental factor, the design was identical to that of Experiment 1. The main experimental factor was Prosodic Break (prosodic break/no prosodic break). The same two versions as in Experiment 1 were used.

4.2.4. *Apparatus*

The apparatus was the same as in Experiment 1 with two exceptions. First, we used a somewhat different electrode montage, as used earlier in auditory ERP studies (e.g., Steinhauer, 2003). The auditory cap featured 25 electrodes, of which 19 were included in the analyses (see paragraph 2.2.1). The electrode positions were a subset of electrodes from the 10% system featuring electrodes over traditional language-related sites. In addition the electrode cap for the visual modality featured more electrodes over the visual cortex, whereas the cap for the auditory modality featured more electrodes over the temporal lobes. Second, the time constant of the amplifier in Experiment 2 was 8 s instead of 10 s in Experiment 1.

4.2.5. *Procedure*

The participants were tested in a soundproof room. The sentences were presented over headphones. A trial started with a warning beep of 100 ms. The auditory presentation of a sentence started 500 ms after offset of the warning beep. Following the offset of each sentence there was a 4000 ms interval before the onset of the warning beep of the next trial. Because eye movements distort the EEG-signal, the participants were asked to look at a fixation point. They were trained to avoid eye-blinks during the presentation of the items during a training block of 14 items that preceded the actual experiment. The participants were instructed to listen carefully to each story. In contrast to Experiment 1 they were not given an additional task. We did not use an additional task because we assume that the auditory materials are salient enough to ensure processing (see also (van Berkum et al., 2003).

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