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Research report

Syntax-related ERP-effects in Dutch

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Abstract

In two studies subjects were required to read Dutch sentences that in some cases contained a syntactic violation, in other cases a semantic violation. All syntactic violations were word category violations. The design excluded differential contributions of expectancy to influence the syntactic violation effects. The syntactic violations elicited an Anterior Negativity between 300 and 500 ms. This negativity was bilateral and had a frontal distribution. Over posterior sites the same violations elicited a P600/SPS starting at about 600 ms. The semantic violations elicited an N400 effect. The topographic distribution of the AN was more frontal than the distribution of the classical N400 effect, indicating that the underlying generators of the AN and the N400 are, at least to a certain extent, non-overlapping. Experiment 2 partly replicated the design of Experiment 1, but with differences in rate of presentation and in the distribution of items over subjects, and without semantic violations. The word category violations resulted in the same effects as were observed in Experiment 1, showing that they were independent of some of the specific parameters of Experiment 1. The discussion presents a tentative account of the functional differences in the triggering conditions of the AN and the P600/SPS.

Theme: Neural basis of behavior

Topic: Cognition

Keywords: Language; Syntactic processing; (L)AN; N400; P600/SPS; ERP

1. Introduction

Most language-related ERP research has concentrated in some way or another on aspects of semantic and syntactic processing during language comprehension (for recent reviews, see [7,23]. The discovery by Kutas and Hillyard [32] of an ERP component that seemed especially sensitive to semantic manipulations marked the beginning of a growing effort to find and exploit language-relevant ERP components. Kutas and Hillyard observed a negative-going potential with an onset at about 250 ms and a peak around 400 ms (hence the N400), whose amplitude was increased when the semantics of the eliciting word (i.e. *socks*) mismatched with the semantics of the sentence context, as in *He spread his warm bread with socks*. Since 1980, much has been learned about the processing nature of the N400 (for extensive overviews, see [34,49]). The N400 is usually largest over posterior scalp sites with a slight right hemisphere preponderance in reading but no laterality effects with spoken input. It has been found that most word types (e.g. nouns, verbs, etc.) in the language elicit an N400 (cf. [31]). As such the N400 can be seen as a marker of lexical processing. The amplitude of the N400 is most sensitive to the semantic relations between individual words, or between words and their sentence and discourse context. The better the semantic fit between a word and its context, the more reduced the amplitude of the N400. Modulations of the N400 amplitude are quite generally viewed as directly or indirectly related to the processing costs of integrating the meaning of a word into the overall meaning representation that is built up on the basis of the preceding language input [6,47]. This holds equally when the preceding language input consists of a single word, a sentence, or a discourse [4].

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Linguists and psycholinguists alike have argued that next to semantic processing other types of information are involved in deriving an overall interpretation for the input string of words. For instance, Jackendoff [25,26] proposes a tripartite architecture of the language faculty, in which conceptual/semantic structures, phonological structures, and syntactic structures are crucial in language processing. In relation to language, the N400 amplitude modulations have been reliably linked to the processing of conceptual/semantic information. Other ERP effects have been observed in relation to phonological processing [5,9,21,56]. In addition, recent years has seen quite a few ERP studies devoted to establishing ERP effects that can be related to the processing of syntactic information. The two most salient syntax-related effects are an anterior negativity, also referred to as LAN, and a more posterior positivity, here referred to as P600/SPS.

LAN. A number of studies have reported negativities that are different from the N400, in that they usually show a more frontal maximum (but see [39]), and are sometimes larger over the left than the right hemisphere. Moreover, *prima facie* the conditions that elicit these frontal negative shifts seem to be more strongly related to syntactic processing (but see below) than to semantic integration. Usually, LAN effects occur within the same latency range as the N400, that is between 300 and 500 ms post-stimulus [14,30,47,38,54]. But in some cases the latency of a left-frontal negative effect is reported to be much earlier, somewhere between 125 and 180 ms [13,15,42].

The LAN effects are to be distinguished from the N280 that is reported in relation to the processing of closed- vs. open-class words. The N280 is an ERP component that is seen in an averaged waveform to words of one or more types. For instance, in the averaged waveform for closed-class words one can easily identify a component with a maximal amplitude at around 280 ms (see [8,29,41,43,40,46,53]). The LAN, however, refers to the amplitude *difference* between two conditions. It is identified by comparing the averaged waveforms of two conditions. That is, in one condition one sees an increased negativity in comparison with another condition. This negative increase is usually largest over (left) frontal sites.

In some studies LAN effects have been reported to violations of word-category constraints [14,38]. That is, if the syntactic context requires a word of a certain syntactic class (e.g. a noun in the context of a preceding article and adjective), but in fact a word of a different syntactic class is presented (e.g. a verb), early negativities are observed. Friederici and colleagues (e.g. [12,14]) have tied the early negativities specifically to the processing of word-category information. However, in other studies similar early negativities are observed with number, case, gender, and tense mismatches [37,38]. In these violations the word category is correct but the morphosyntactic features are wrong. Friederici [13] has recently attributed the very early negativities that occur between 100 and 300 ms (ELAN) to violations of word category, and the negativities between 300 and 500 ms to morphosyntactic processing.

The functional interpretation of LAN effects is not yet agreed upon. One possibility is that within the context of language processing this effect is specifically syntactic in nature. Along these lines it has been proposed that LAN effects are functionally related to matching word-class information against the requirements of the constituent structure derived from the earlier lemmas in the sentence [12]. The word-class information might have some temporal precedence over other lexical information in generating a syntactic structure for the incoming string of words [14]. However, as we argued above, this would explain only a subset of the reported LAN effects.

LAN effects have also been related to verbal working-memory [30,10]. Such an account is compatible with the finding that both lexical and referential ambiguities seem to elicit very similar frontal negativities ([19,3]; see also King and Kutas [28]). These cases refer to the processing of words with more than one meaning (e.g. *bank*) and to the processing of nouns that have more than one antecedent in the preceding discourse. Such ambiguities are clearly not syntactic in nature, but can be argued to tax verbal working-memory more heavily than sentences in which lexical and referential ambiguities are absent. This account denies a special relation of LAN effects to syntactic processing, but relates them to the general resource requirements for language comprehension. Presumably, anterior negative shifts consist of a family of effects with subtle topographic differences and functional distinctions, some of which are related to aspects of syntactic processing.

P600/SPS. A second ERP effect that has been related to syntactic processing is a later positivity, nowadays referred to as P600/SPS [10,52]. One of the antecedent conditions of P600/SPS effects is a violation of a syntactic constraint. If, for instance, the syntactic requirement of number agreement between the grammatical subject of a sentence and its finite verb is violated (see (1), with the critical verb form in italics), a positive-going shift is elicited by the word that renders the sentence ungrammatical [22]. This positive shift starts at about 500 ms after the onset of the violation and usually lasts for at least 500 ms. Given the polarity and the latency of its maximal amplitude this effect was originally referred to as the P600 [48] or, on the basis of its functional characteristics, as the Syntactic Positive Shift (SPS; [22]).

* The spoilt child *throw* the toy on the ground. (1)

An argument for the independence of this effect from possibly confounding semantic factors is that it also occurs in sentences where the usual semantic/pragmatic constraints have been removed [19]. This results in sentences like (2a) and (2b) where one is semantically odd but grammatically correct, whereas the other contains the same agreement violation as in (1):

a. The boiled watering-can *smokes* the telephone in the cat.
b. * The boiled watering-can *smoke* the telephone in the cat. (2)

If one compares the ERPs to the italicized verbs in (2a) and (2b), a P600/SPS effect is visible to the ungrammatical verb form. Despite the fact that these sentences do not convey any conventional meaning, the ERP effect of the violation demonstrates that the language system is nevertheless able to parse the sentence into its constituent parts.

Similar P600/SPS effects have been reported for a broad range of syntactic violations in different languages (English, Dutch, German), including phrase-structure violations [22,42,47], subcategorization violations [1,51,46], violations in the agreement of number, gender, and case [10,22,39,45,50], violations of subjacency [42,36], and of the empty-category principle [36]. Moreover, they have been found with both written and spoken input [15,20,48].

This study. The purpose of this study was to investigate the nature of syntax-related ERP effects to word category violations. These violations have been reported to elicit left anterior negativities as well as a P600/SPS. However, in some cases the reported effects showed a left-hemisphere preponderance, in other cases the effects were bilateral. We sought to establish for Dutch the nature and topography of the ERP effects elicited by a purely syntactic violation. In addition, this study differed from most other studies on the effects of word category violations in two ways. One relates to the word position of the violation. In most studies (but not all, e.g., [14]) reporting word category effects, these effects are picked up to words in sentence-final position. For various reasons, presenting the critical words in sentence-final position can impact the overall morphology of the ERP waveform, especially for other than N400-effects. By consequence, the comparison with results obtained to words in other than sentence-final positions is complicated. It is well-known in the reading-time literature that apart from local effects, the sentence-final words are often strong attractors of global processing factors related to sentence wrap-up, decision, and response requirements (e.g., [55]). For example, in sentences that subjects judge as unacceptable, final words seem to elicit an enhanced N400-like effect, regardless of whether the unacceptability is semantic or syntactic in nature [22,47,48]. Osterhout [45] found that syntactic anomalies were more likely to elicit a noticeable anterior negativity when placed at the end of the sentence than when embedded within the sentence. The ERP effects of the local violation and the more global ERP effects of sentence processing thus tend to overlap most strongly in sentence-final position, thereby affecting the resulting ERP waveforms for the local effect particularly in this position. Cross-study comparisons would thus be made easier if words that realize the critical experimental manipulation were not in sentence-final position.

The second methodological difference is that in the materials of this study the likelihood of the critical word in the correct version of the sentence was made equal to its counterpart in the syntactic violation condition. This is often not controlled for. For instance, Friederici, Hahne, and Mecklinger [14] presented word category violations in sentence-internal positions, as in this study. They presented the German equivalents of sentences such as 'The sauce is being refined/refinement by the host whom few greeted.' Given the sentence context a verb form ('refined') is allowed, but a noun ('refinement') is syntactically unacceptable. If one wants to study the consequences of presenting the wrong word category (i.e. noun instead of verb) in its purest form, other factors should be excluded as much as possible. One such factor is cloze probability, which is known to affect the amplitude of the N400 [33]. That is, if in the context of the preceding words a particular item has a higher probability of occurrence than some other item, the N400 amplitude elicited by these items will differ. More in particular, words with a higher cloze probability elicit a smaller N400 than words with a lower cloze probability (cf. [19]). This, however, is not a syntactic effect, and not a consequence of word category per se. Crucially, in the case of a semantically conventional sentence, it is likely that the cloze probability of the correct word form (i.e. 'refined') is higher than zero, whereas the incorrect word form ('refinement') with certainty equals zero. As a result, the effect of the syntactic violation is potentially partly confounded with an effect of cloze probability. Therefore, in this study we decided to make the cloze probability of the critical word in both correct and syntactically illegal sentences identical, namely zero. In this way ERP effects of the word category violation were not polluted by the consequences of a difference in cloze probability. In addition, the lemma frequencies of nouns and verbs in critical word position were matched.

Two experiments were performed to study the consequences of syntactic word category violations in sentence-internal positions and with a close match in cloze probability and in the semantics of the syntactic violation and its correct counterpart. In addition to the word category violation, Experiment 1 also contained semantic violations. The semantic violation condition was merely added to see whether with the same subjects the standard sentence-final semantic anomalies resulted in a classical N400 effect with a posterior maximum. If such a standard effect is not obtained, the syntax-related effects could be due to spurious aspects related to the specific group of subjects or to the language studied (Dutch).

2. Method

2.1. Subjects

Twelve college-aged students participated in the experiment. Participants were paid for their participation. All subjects had normal or corrected-to-normal vision and were right-handed according to an abridged Dutch version of the Oldfield Handedness Inventory [44]. Three of the twelve young subjects reported familial left-handedness. None of the subjects had any known neurological impairment.

3. Materials

The stimuli consisted of a list of 308 visually presented Dutch sentences. Of these sentences 272 were the critical sentences for the experiment. The remaining sentences were used as practice trials (16) and warm-up trials (5 at the start of each of the four blocks).

The materials for the syntactic condition consisted of 96 sentence pairs. Next to the correct version of each sentence, a version was created that contained a word category violation. In this version a verb was placed at a position where this was grammatically incorrect given the syntactic context. To guarantee that the observed ERP effects could be ascribed to the syntactic violation alone, two additional constraints were used during the construction of the materials. The first one was that apart from word category (noun vs. verb) the Critical Words (CWs) in the correct and incorrect version of the sentences were maximally alike. This was done by using noun–verb pairs that are semantically strongly related (*the cook* vs. *to cook*). Second, to prevent differences in transition probabilities (expectancy) from context to CW, this probability was made zero in both correct and incorrect versions. In the correct version this was done by adding an adjective before the noun that made the sentence pragmatically very unlikely. An example is given in Table 1. The zero cloze probability was verified in a pretest. In the pretest subjects were given the sentence context up to, but not including the Critical Word. Subjects were instructed to continue the sentence with one or more words. Twelve subjects participated in the pretest. All subjects filled in a noun at the Critical Word position. However, this was never the actual noun used in the experimental materials.

The mean sentence length for the syntactic violation condition was 8.8 words (range: 7–11 words). The mean lemma frequencies of the CWs were 908 (nouns) and 922 (verbs). The frequency counts were based on the Dutch Celex corpus (cf. [2]), which contains over 42 million tokens.

For the semantic condition we selected 40 sentence pairs from the materials of a study by Swaab, Brown and Hagoort [57]. One member of each pair consisted of a sentence that ended with a critical word that matched the sentential-semantic constraints. The other sentence of these pairs ended with a word that violated the sentential-semantic constraints. An example is given in Table 1. The full set of experimental items is available on request to the first author. The 40 semantically congruent and semantically anomalous critical words (CWs) were matched for lemma frequency (with an average of 1872 for congruent CWs, and an average of 1873 for anomalous CWs). Congruent and anomalous items were matched for syntactic structure. The mean sentence length for both the congruent and the anomalous items was 7.5 words (range: 5–10 words).

On the basis of these materials we created two experimental lists. Subjects were equally distributed over the two lists. For the first list, all the semantically congruent and semantically anomalous sentences, and all sentences with and without a word-category violation were distribut-

Table 1
Examples of the stimulus materials

Experiment 1:	
Syntactic condition:	
Correct:	De houthakker ontweek de ijdele **schroef** op dinsdag. (The lumberjack dodged the vain **propeller** on Tuesday.)
Violation:	De houthakker ontweek de ijdele **schroeft** op dinsdag. (The lumberjack dodged the vain **propelled** on Tuesday.)
Semantic condition:	
Correct:	De timmerman kreeg een compliment van zijn **baas**. (The carpenter got a compliment of his **boss**.)
Violation:	Het meisje stopte een snoepje in haar **bloem**. (The girl put a sweet in her **flower**.)
Experiment 2:	
Context sentence:	Er waren eens een houthakker en een bruine beer. (Once upon a time there were a lumberjack and a brown bear.)
Correct:	De houthakker ontweek de ijdele **schroef** op dinsdag. (The lumberjack dodged the vain **propeller** on Tuesday.)
Violation:	The houthakker ontweek de ijdele **schroeft** op dinsdag. (The lumberjack dodged the vain **propelled** on Tuesday.)

The Critical Words are in bold.

ed over four blocks, such that the congruent/correct items and their anomalous/incorrect counterparts were separated by one intervening block. The critical sentences were pseudo-randomly presented such that a particular trial type never occurred more than four times in a row. The second list was derived from the first by changing the presentation order of the blocks: (list 1: block 1,2,3,4; list 2: block 3,4,1,2). Each experimental list was preceded by a practice list of 16 sentences.

4. Procedure

Subjects were tested individually in a dimly illuminated sound-attenuating booth. They were seated in a comfortable reclining chair, and were instructed to move as little as possible. Participants were told that they would be presented with a series of sentences. They were asked to process each sentence for comprehension.

At the beginning of each trial a horizontal rectangle was displayed for 3 s, to inform the subjects that they were allowed to blink and move their eyes. After its offset, an asterisk was displayed for 400 ms to warn the subjects that they had to fixate their eyes on the center of the screen. The asterisk was followed by the visual presentation of the sentence. Sentences were presented on the center of a computer screen, word-by-word in white lowercase letters (font: Arial; font size: 21) against a dark background. Viewing distance was approximately 100 cm and the stimuli subtended a visual angle of 3° horizontally and 0.5° vertically. Each word was presented for 400 ms, followed by a blank screen for another 400 ms. The final word was presented together with a period, followed by a blank screen for 1 s before the next trial began.

The testing session began with a short practice block. The experimental trials were presented in four blocks of approximately 10 min each. Subjects were given short breaks between the blocks. To make sure that the subjects were actually reading the sentences, at the end of some randomly determined trials the experimenter asked the subjects a question about the content of the sentence that was just presented. Subjects knew that questions would be asked, but not after which trials. Subjects were asked whether a particular noun had occurred in the sentence or not (e.g., 'Did the word violin occur in the last sentence?'). Half of the nouns that were presented to the subjects had been present in the preceding sentence, half were nouns that had not been presented. The total number of questions was sixteen, equally distributed over the four blocks. No additional task demands were imposed.

4.1. EEG-recording and data analysis

Continuous EEG was recorded from 29 sintered Ag/AgCl electrodes in an electrode cap, each referred to the left mastoid. Twenty-three electrodes (Fz, FCz, Cz, Pz, Oz, AF3, AF4, F7, F8, F3, F4, FT7, FT8, FC3, FC4, C3, C4, CP3, CP4, P3, P4, PO7, PO8) were placed according to the 10% standard system of the American Electrophysiological Society. Six electrodes were placed over non-standard intermediate locations: a temporal pair (LT and RT) placed 33% of the interaural distance lateral to Cz; a temporo-parietal pair (LTP and RTP) placed 30% of the interaural distance lateral to Cz and 13% of the inion–nasion distance posterior to Cz; a parietal pair (LP and RP) midway between LTP/RTP and PO7/PO8. Vertical eye movements were monitored via a supra- to suborbital bipolar montage. A right to left canthal bipolar montage was used to monitor for horizontal eye movements. Activity over the right mastoid bone was recorded on an additional channel to determine if there were differential contributions of the experimental variables to the presumably neutral mastoid site. No such differential effects were observed.

The EEG and EOG recordings were amplified by a SynAmp™ Model 5083 EEG amplifier system, using a band-pass filter of 0.02–30 Hz. Impedances were kept below 3 kΩ. The EEG and EOG signals were digitized on-line with a sample frequency of 200 Hz.

5. Results

Prior to off-line averaging, all single trials waveforms were screened for electrode drifting, amplifier blocking, muscle artifacts, eye movements and blinks. This was done over an epoch that ranged from 150 ms before onset of the word immediately preceding the Critical Word (CW) to 2000 and 2200 ms after CW, for the semantic and word-category violation respectively. Trials containing artifacts were rejected. The overall rejection rate was 10.1%.

Per subject and per condition, average waveforms were computed across all remaining trials. This was done after normalizing the waveforms of the individual trials on the basis of a 150-ms pre-CW baseline. Several latency windows were selected for statistical analysis. These included for the semantic violation condition: 300–500 ms after onset of CW; for the word-category violation condition 300–500 ms and 600–800 ms after onset of CW. In addition, to test for possible ELAN effects, word category violations were also analyzed in a 100–300-ms latency window [13]. Subsequent ANOVAs used mean amplitude values computed for each subject, condition, and electrode site in the selected latency windows. In the analyses reported below, different subsets of electrodes were taken together to investigate the topographical distribution of the ERP-effects. For purposes of brevity we use the following labels: Anterior Left (AL: AF3, F3, F7, FC3, FT7), Anterior Right (AR: AF4, F4, F8, FC4, FT8), Posterior Left (PL: CP3, LTP, P3, LP, P07), Posterior Right (PR: CP4, RTP, P4, RP, P08). Omnibus ANOVAs with Condition and Site (4 quadrants: AL, AR, PL, PR) as within-subject factors will be reported first, followed by ANOVAs on more specific Regions of Interest.

Fig. 1 shows the results for the word category violation. This violation results in two distinct ERP effects. The one is a negative shift in the latency range of 300–500 ms, with a maximal amplitude at about 425 ms. This effect is largest over anterior sites, and has an equal distribution over the left and right hemisphere. The Anterior Negativity (AN) is followed by a positive shift over posterior scalp sites. The onset of this positivity is at about 600 ms, and lasts until approximately 900 ms over the centro-posterior sites. This effect is the P600/SPS that has been reported before in relation to syntactic violations. Over posterior sites there is an indication of a negativity around 100 ms.

The ELAN, the AN, and the P600/SPS were analyzed in separate repeated measures ANOVAs on the mean amplitudes in the 100–300-ms latency range, the 300–500-ms latency range, and the 600–800-ms latency range, respectively. The Greenhouse–Geisser correction was applied when evaluating effects with more than one degree of freedom in the numerator [17,60].

The omnibus ANOVA for the 100–300-ms window did not result in a significant effect of Grammaticality ($F < 1$). However, the Grammaticality by Site interaction was significant ($F(1,11) = 6.86$; $MSe = 0.85$; $P < 0.05$). This was due to the fact that the negativity was only visible over posterior sites. However, an analysis restricted to the posterior electrode sites failed to reach significance ($F(1,11) = 2.86$; $MSe = 7.9$; $P = 0.12$). Thus, no ELAN effects were obtained.

For the 300–500 ms latency window, the omnibus ANOVA only showed a marginally significant effect of Grammaticality ($F(1,11) = 3.46$; $MSe = 19.45$; $P = 0.09$). Since negativities elicited by word category violations are reported to have a strict frontal distribution [13], an additional ANOVA was done on the mean amplitude values for the left and right anterior electrode sites. This analysis resulted in a significant effect of Grammaticality ($F(1,11) = 5.01$; $MSe = 7.66$; $P = 0.047$). However, no significant Grammaticality by Hemisphere interaction was obtained ($F < 1$), indicating that the Anterior Negativity was equally distributed over both hemispheres.

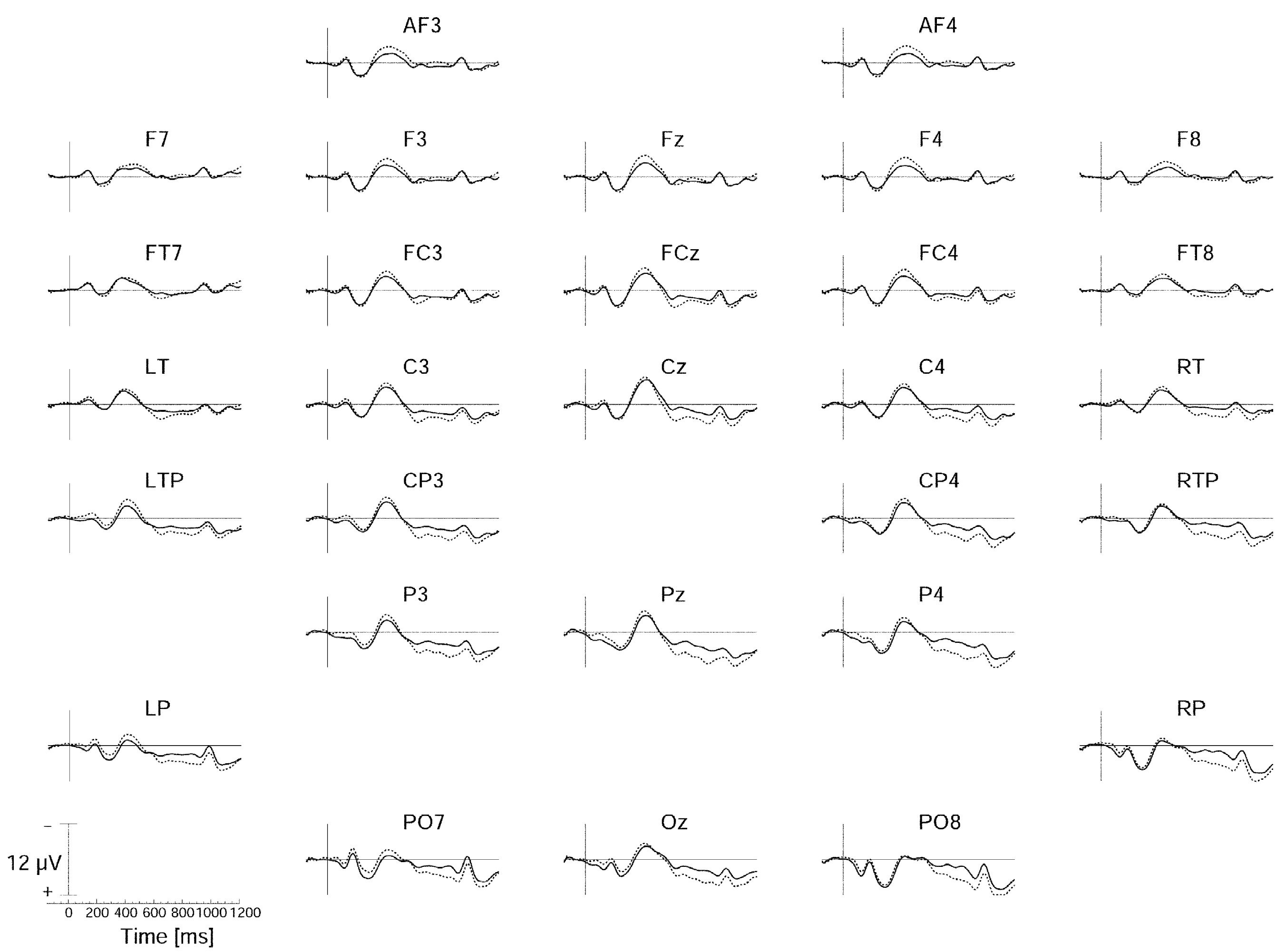

Fig. 1. Grand average waveforms for 29 electrode sites for the word category (syntactic) violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the syntactic violation.

In the 600–800-ms latency window the omnibus ANOVA resulted in a marginally significant effect of Grammaticality ($F(1,11) = 3.65$; $MSe = 18.59$; $P = 0.083$), and a highly significant Grammaticality by Site interaction ($F(1,11) = 9.66$; $MSe = 1.61$; $P < 0.01$). The interaction was due to the posterior topography of the P600/SPS. Since the posterior topography of the P600/SPS has been reported before in relation to syntactic violations [13,20], the Region of Interest analysis focused on the posterior electrode sites (quadrants PL and PR). This analysis resulted in a significant Grammaticality effect ($F(1,11) = 15.29$; $MSe = 7.27$; $P = 0.002$). No significant Grammaticality by Hemisphere interaction was obtained ($F < 1$), indicating that the effect was not different between hemispheres.

Fig. 2 shows the results for the semantic condition. As can be seen, the sentence-final semantic violation resulted in a substantial N400-effect. This effect shows the standard characteristics, in that it starts at about 250 ms after the onset of CW, and has its maximal amplitude at about 400 ms. Although the effect is widely distributed, it has a clear centro-posterior maximum. Moreover, it is clearly visible over both hemispheres, with the slight right-hemisphere preponderance that is regularly reported for visual N400-effects. Especially over left-posterior sites the increased N400 is followed by a late positivity for the sentence-final semantic violations.

The semantic violation effect was tested in an omnibus ANOVA on the mean amplitudes in the 300–500 ms latency range. This analysis resulted in a highly significant main effect of Semantic Violation ($F(1,11) = 62.7$; $MSe = 29.54$; $P = 0.000$). However, the Semantic Violation by Site interaction failed to reach significance ($F(1,11) = 1.80$; $MSe = 6.13$; $P > 0.10$). An additional ANOVA over the midline sites obtained both a significant main effect of Semantic Violation ($F(1,11) = 74.8$; $MSe = 10.25$; $P = 0.000$), and a significant interaction with Electrode ($F(1,11) = 7.54$; $MSe = 1.13$; $P < 0.05$). This interaction was due to the fact that the Semantic Violation effect increased from Fz to Pz.

To test whether the topographic distributions of the Anterior Negativity and the N400-effect were indeed

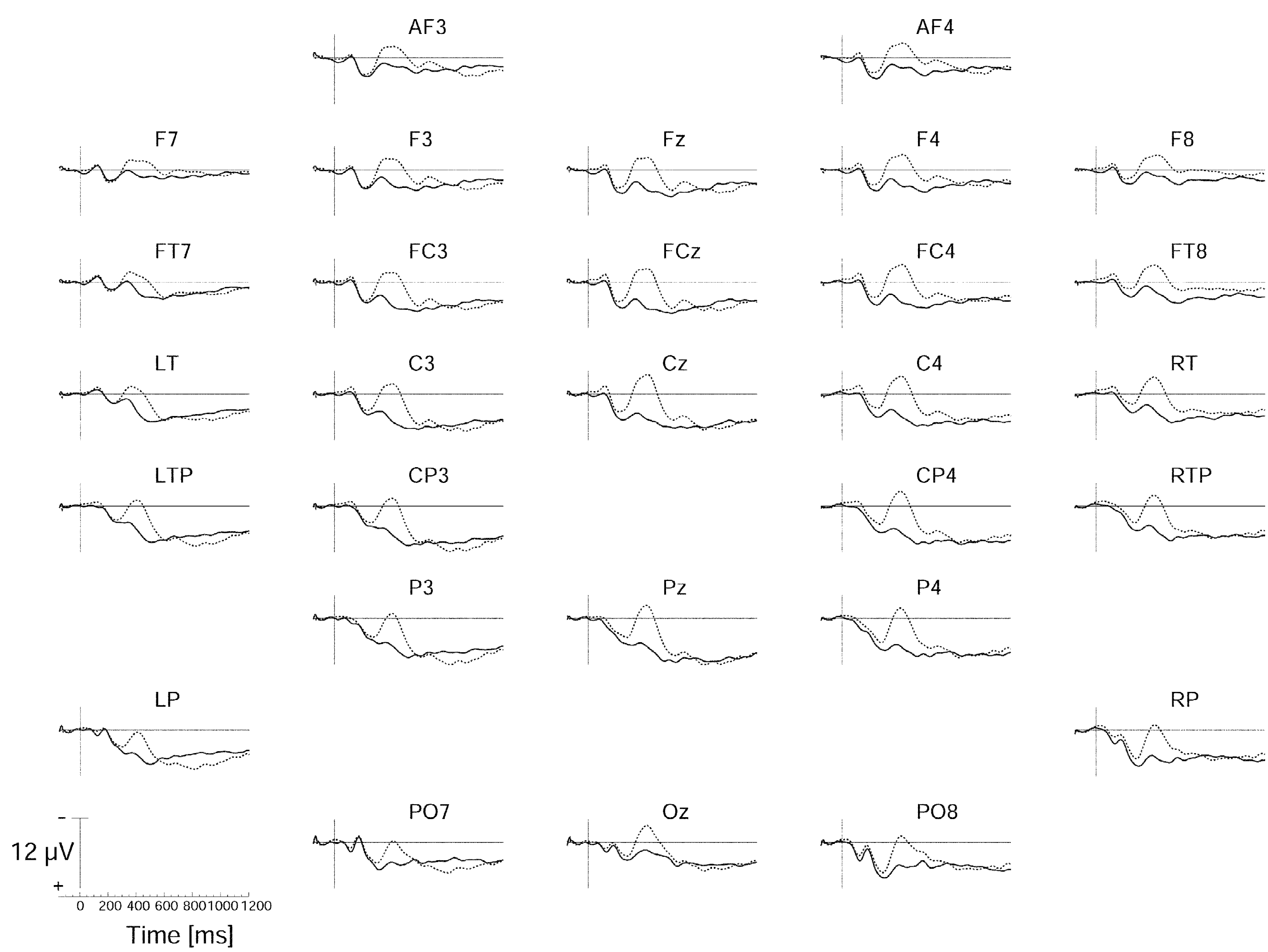

Fig. 2. Grand average waveforms for 29 electrode sites for the semantic violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the semantic violation.

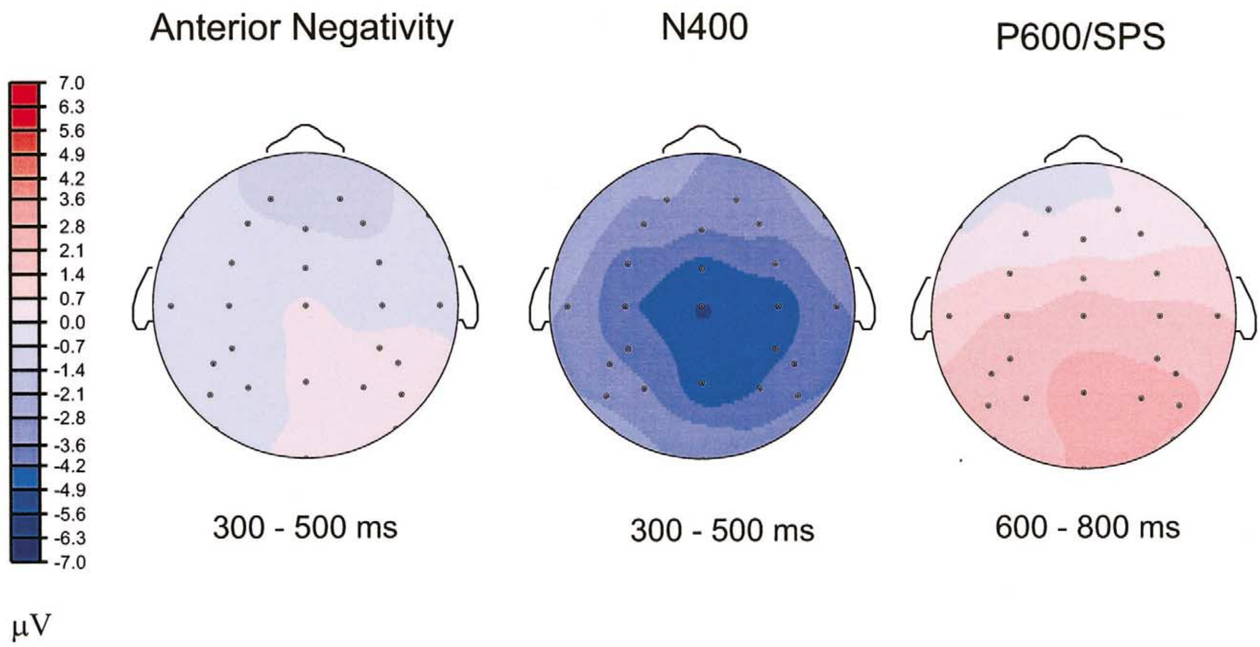

Fig. 3. Isopotential voltage maps of the Anterior Negativity (AN), the N400-effect, and the P600/SPS. Maps are based on difference waveforms that resulted from subtracting the correct condition from the violation condition. To reduce the consequences of a slight baseline problem in left posterior electrode sites for the AN (see Fig. 2), the maps were based on a normalization of the waveforms relative to a 0–150-ms baseline.

different, we entered the mean amplitude effects in the 300–500 ms latency range into an overall ANOVA with Type of Violation as the additional factor. This resulted in a significant Type of Violation by Electrode interaction ($F(1,11) = 6.79$; $MSe = 1.60$; $P < 0.05$), which remained after normalization according to the procedure recommended by McCarthy and Wood [35]. The presence of this interaction substantiates the claim the AN has a more frontal distribution than the classical N400-effect, and therefore depends on the contribution of generators that are, at least to some degree, non-overlapping with the neural generators that are responsible for the semantic violation effect.

Fig. 3 presents the topographic distributions for the semantic violations effect (the N400-effect) and the two syntactic violation effects (the AN and the P600/SPS).

The behavioral data showed that the subjects adequately responded to the questions that were asked after a subset of the trials. The average percentage of correct responses was 95%. This guaranteed that subjects were engaged in actively processing the sentences.

6. Discussion

The results of this experiment can be summarized as follows. A clear N400-effect was observed for semantic violations. This N400-effect had the usual centro-posterior maximum. In contrast, the syntactic word category violation resulted in a qualitatively different pattern of results than the semantic violation. First, an Anterior Negativity was observed in a latency range very similar to that of the N400-effect. However, the topographic distribution of the Anterior Negativity was clearly more frontal than the N400 distribution. The Anterior Negativity was followed by the P600/SPS that was most clearly seen over posterior electrode sites. For none of these effects any significant hemispheric differences were observed. Finally, no ELAN effects, sometimes reported for word category violations, were obtained.

Before discussing the implications of these results, a follow-up experiment was done in which a few parameters of design and presentation were changed. Since Experiment 1 was designed with the purpose to test not only young healthy subjects, but also aphasic patients, the SOA was relatively long (800 ms). In addition, for the same reason, all subjects saw each item in the correct and the violation condition, albeit that the order of presentation was counterbalanced among subjects. To test whether for the syntactic violation the same results could be obtained with a more standard SOA in ERP research on language, and without repeating the item in its two conditions within individual subjects, we decided to run a control experiment in which these aspects were changed.

7. Experiment 2

The major differences between this experiment and Experiment 1 was that in Experiment 2 subjects only saw one version of each sentence pair, and the presentation of the sentences was speeded up to an SOA of 600 ms. That is, each word was presented for 300 ms, followed by a blank screen for another 300 ms. The main purpose of this experiment was a different one than testing the consequences of word category violations. For this reason, each item started with a lead-in sentence. For the sentences with a word category violation this lead-in sentence did not have any consequence for the syntactic manipulation of the target sentence. Apart from the addition of a lead-in sentence, the word category violations were identical to the ones in Experiment 1 (see Table 1). In addition to the 96 target sentences, the materials consisted of 210 filler sentences. The materials of this experiment did not contain semantic violations. In this experiment materials were distributed over two versions such that each subject saw only one version of each sentence pair. Each version contained 5 blocks of items, and each block started with 3 start-up items. A total of 38 right-handed subjects participated in Experiment 2. The testing session began with the presentation of 30 practice items. Experimental trials were presented in five blocks of about 10 min each. Other aspects of the procedure were the same as in Experiment 1. Relative to Experiment 1, ERPs were recorded from a more restricted set of 13 electrodes, including three midline sites (Fz, Cz, Pz) and five pairs over the left and right hemisphere (F7, F8, FT7, FT8, LT, RT, LTP, RTP, PO7, PO8).

8. Results

Artifact rejection was done in the same way as in Experiment 1. The overall rejection rate was 7.8%. The grand averaged waveforms are presented in Fig. 4 for two representative anterior electrode sites (F7, F8) and two representative posterior electrode sites (LTP, RTP). As can be seen in Fig. 4, results were very similar as in Experiment 1. A bilaterally distributed anterior negativity was obtained in the latency range of 300–500 ms. Over posterior sites a positive shift was seen starting at about 600 ms after onset of the word category violation, which was slightly larger over the right than left hemisphere.

Results were analyzed as before in an omnibus ANOVA and in an analysis for specific regions of interest. The Anterior Negativity was tested on the mean amplitudes in the 300–500 ms latency range. The omnibus ANOVA did not result in a significant effect of Grammaticality ($F(1,37) = 2.17$, $MSe = 7.09$; $P = 0.15$). This was due to the focal nature of the effect. However, a Region of Interest analysis over the set of frontal electrodes (Fz, F7, F8) revealed a significant effect of Grammaticality ($F(1,37) = 5.82$; $MSe = 3.10$, $P = 0.021$). The word category violation resulted in an increased anterior negativity. No hemispheric differences were obtained ($F < 1$).

The P600/SPS was tested in an omnibus ANOVA on the mean amplitude in the 600–800 ms latency range. This analysis resulted in a significant main effect of Gram-

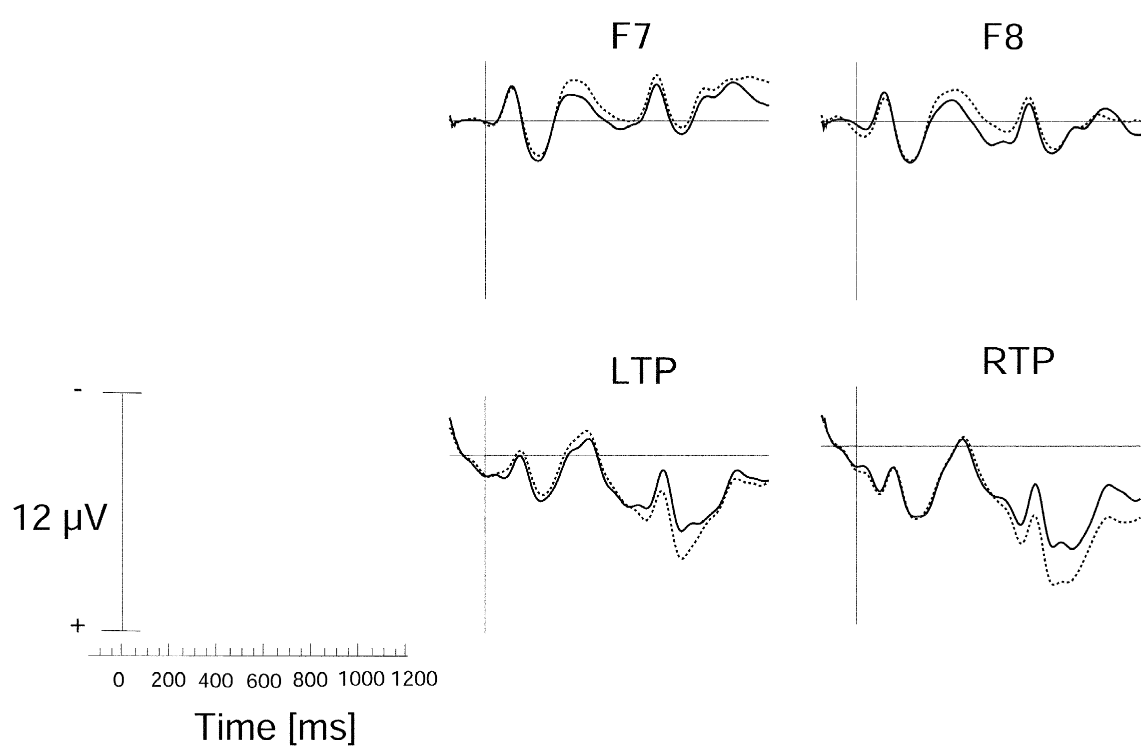

Fig. 4. Grand average waveforms for two representative frontal electrode sites (F7, F8) and two representative posterior electrode sites (LTP, RTP) for the word category (syntactic) violations (dotted line) and their correct counterparts (solid line). The *X*-axis specifies time in milliseconds, the *Y*-axis specifies the amplitude in μV. Zero on the time axis marks the onset of the word presentation that instantiates the violation.

maticality ($F(1,37) = 6.12$; $MSe = 14.0$; $P = 0.018$), as well as a significant Grammaticality by Electrode interaction ($F(1,37) = 5.0$; $MSe = 1.11$; $P < 0.05$). The interaction was due to the posterior distribution of the P600/SPS. A Region of Interest analysis over posterior electrode sites (Cz, Pz, LT, LTP, RT, RTP) resulted in a significant effect of Grammaticality ($F(1,37) = 8.91$, $MSe = 9.24$, $P = 0.005$) with an increased positivity for the word category violation.

9. General discussion

The results of these two experiments were clear-cut. Word category violations in sentence-internal positions resulted in two distinct ERP-effects. The one effect is an anterior negativity between 300 and 500 ms. This negative shift over frontal areas is of equal size over the left and the right hemisphere. Most likely, this AN has to be distinguished from the Left Anterior Negativity that is related to working memory operations [30]. The latency of the AN is very similar to the latency of the N400 effect. However, the distribution of the AN was more frontal than the distribution that is standardly observed for the N400 when words and sentences are visually presented [34]. This classical N400-effect with a posterior distribution was obtained in Experiment 1 for semantic violations. Despite changes in presentation parameters, and filler materials, Experiment 2 resulted in the same pattern of effects for the syntactic violation as was found in Experiment 1. This testifies the robustness of the results.

The other effect observed to the word category violation is a posteriorly distributed P600/SPS. This effect has an onset at about 600 ms and carries over into the processing epoch of the following word. This P600/SPS has been found to a large number of syntactic violations, but it also occurs in relation to syntactic ambiguities (e.g., [23,51] and it varies with syntactic complexity [27]. The interesting aspect about word category violations is that in this case AN and P600/SPS co-occur.

The co-occurrence of AN and P600/SPS might also have created a potential problem of overlapping components. That is, the frontal distribution of the AN might in fact be due to an overlap in time and space of the posterior P600/SPS, thereby reducing the negativity over posterior sites. We consider this possibility, however, unlikely for two reasons. First, the latency windows of the two effects seem to be adjacent rather than overlapping. Second, in an experiment in which we combined semantic and syntactic violations, we observed an N400 effect with a classical posterior distribution together with a P600/SPS. This makes us believe that the frontal distribution of the AN is real and not a spurious consequence of overlapping components.

The word category violations in this study did not result in very early negativities (ELAN) that are sometimes reported for this type of violation (see [13] for an overview). One condition that is claimed to be necessary for ELAN effects is that the syntactic anomalies are true syntactic violations, and not dispreferred syntactic structures. In our case the materials embodied outright syntactic violations for which no acceptable grammatical reading was possible. In this sense, they fulfilled the requirements for eliciting an ELAN. One alternative interpretation is that in fact our violations were morphosyntactic violations rather than word category violations, since processing the inflectional suffix added to the stem is required to assign the word category ‘verb’. However, in many cases derivational and inflectional morphemes carry the information that assigns word class to a particular lexical item. In some cases, syntactic morphemes code for within-class features such as number (e.g., car vs. cars). However, in other cases, they mark the transition from one word class to the other (e.g., refined vs. refinement). The materials used in this study were of the latter type. Therefore, the type of violations we used has to be classified as word category violations. The reason why we do not find an ELAN effect where other studies have reported this effect, might have to do with the fact that word class in this study was determined by the suffix, whereas in other studies [16,24] this word class assignment could be based on the prefix or the onset consonants of the critical word. So, it seems that only under very special circumstances the effects of word category violations are earlier than the latency range observed in this study.

Before making a few remarks about the functional interpretation of AN and P600/SPS, it is important to reiterate that the syntax-related ERP effects in this study were obtained in other than sentence-final positions, and after matching both the cloze probability and the semantics of the Critical Words in the sentences with and without a syntactic violation. On purpose, in both the syntactically correct and the syntactic violation conditions, the cloze probability of the critical word was made zero. So far, in all published studies on word category violations, cloze probabilities most likely differed between conditions. Therefore the effect of the word category violation might be partly due to differences in cloze probability. To avoid this, we constructed sentences in which both for the syntactically correct and the syntactically incorrect condition, the critical word was semantically odd given the preceding context. This guaranteed the zero cloze probability. However since the semantic oddity was present in both control and violation condition, the difference (that is, the effect) cannot be semantic in nature. The only difference between the two conditions is the syntactic violation. An interpretation of the grammaticality effects in terms of the semantic consequences of the word category violation is, therefore, highly unlikely. Since the sentence contexts were constructed such that the expectation for the critical words was zero, the N400 itself might have been clearly present in the ERPs elicited by the critical words. However, crucially, under these conditions no differential N400s are to be expected. Moreover, the semantics of verbs and nouns were matched as closely as possible. The only semantic difference between the noun (the cook) and the verb (to cook) is that the one refers to an agent and the other to an action. This difference, however, is strongly correlated with the syntactic word class distinction. In short, due to the design characteristics of this study, chances were minimized that the ERP effects for the syntactic violation were 'polluted' by either sentence-final N400-like wrap-up effects, or by N400-effects resulting from a difference in cloze probability.

Since word class was the only feature in which the critical words in the correct condition and the syntactic violation condition differed, one possibility is that the ERP effects were due to word class rather than to the syntactic violation. However, this explanation is highly unlikely in the light of the fact that in a series of ERP studies on the processing of word class in Dutch, the ERP waveforms for the nouns and verbs were not significantly different over anterior sites in the 300–500 ms latency range ([8,58, but see [11] for different results). Moreover, the nature of the effects obtained in this study is in line with other studies on syntactic violation effects.

In summary, both the Anterior Negativity and the P600/SPS seem to be syntax-related ERP effects within the domain of language processing. This latter qualification is crucial. For neither of these effects one can claim that they are language-specific. Most likely they are not. However, within the domain of language processing they seem to honor the distinction between at least semantic and syntactic processing. What is still an unsolved issue is which aspects of syntax-related processing trigger the AN, and which the P600/SPS. For this one needs an explicit account of parsing operations.

Hagoort [18] developed an explicit account of syntax-related ERP effects based on a computational model of parsing developed by Vosse and Kempen [59], here referred to as the Unification Model. According to this model each word form in the lexicon is associated with a structural frame. This structural frame consists of a three-tiered mobile specifying the possible structural environment of the particular lexical item. The top layer of the frame consists of a single phrasal node (e.g., NP). This so-called root node is connected to one or more functional nodes (e.g., Subject, Head, Direct Object) in the second layer of the frame. The third layer contains again phrasal nodes to which lexical items or other frames can be attached. This parsing account is 'lexicalist' in the sense that all syntactic nodes (e.g., S, NP, VP, N, V, etc.) are retrieved from the mental lexicon. There are no syntactic rules that introduce additional nodes. In the on-line comprehension process, structural frames associated with the individual word forms incrementally enter the unification workspace. In this workspace constituent structures spanning the whole utterance are formed by a unification operation. This operation consists of linking up lexical frames with identical root and foot nodes. The resulting binding links between lexical frames are formed dynamically, which implies that the strength of the binding links varies over time until a state of equilibrium is reached. Due to the inherent ambiguity in natural language, at any point in the parsing process usually alternative binding candidates will be available. That is, a particular root node (e.g., PP) often finds more than one identical foot node (i.e. PP) with whom it can form a binding link. Ultimately, one phrasal configuration results. This requires that among the alternative binding candidates only one remains active. The required state of equilibrium is reached through a process of lateral inhibition between two or more alternative binding links (for the details, see [59]). The advantage of the model is that (i) it is computationally explicit, (ii) accounts for a large series of empirical findings in the parsing literature, (iii) belongs to the class of lexicalist parsing models that have found increasing support in recent years. This model also account nicely for the two syntax-related ERP-effects reported in this and many other studies. The P600/SPS is reported in relation to syntactic violations, syntactic ambiguities, and syntactic complexity. The AN, in contrast, has so far only been observed to syntactic violations. In the Unification Model, binding (Unification) is prevented when either the root node of a syntactic building block does not find another syntactic building block with an identical foot node to bind to, or when the agreement check finds a serious mismatch in the grammatical feature specifications of the root and foot nodes. The claim is that an anterior negativity (AN) results from a failure to bind, as a result of a negative outcome of the agreement check or a failure to find a matching category node. In the context of the model, we claim that the P600/SPS is related to the build-up of the strength of the binding links. This strength and the time it takes to build up the binding links is affected by ongoing competition between alternative binding options (syntactic ambiguity), by syntactic complexity, by recovery operations in the case of syntactic violations, and by semantic influences. Momentarily, more specific claims of this parsing model in relation to AN and P600/SPS are under empirical investigation.

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