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Distinct Neurophysiological Patterns Reflecting Aspects of Syntactic Complexity and Syntactic Repair

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Aspects of syntactic complexity and syntactic repair were investigated by comparing the event-related (brain) potentials (ERPs) for sentences of different syntactic complexity to those containing a syntactic violation. Previous research had shown that both aspects of syntactic processing are reflected in a late positivity (P600). Results from the present reading experiment demonstrate, however, that although both processing aspects elicit a late positivity, they are different in distribution. The repair-related positivity preceded by a negativity displayed a centroparietal distribution, whereas the complexity-related positivity showed a frontocentral scalp distribution. These data indicate that the P600 is not a unitary phenomenon. Moreover, the distributional differences strongly suggest that different neural structures underlie the two aspects of processing, namely syntactic repair and syntactic integration difficulties, most evident when processing syntactically complex sentences.

KEY WORDS: sentence processing; ERP; P600; syntactic complexity.

INTRODUCTION

The investigation of language processes by means of neurophysiological measures has identified a number of distinct markers for different aspects of language, such as phonology, semantics, and syntax. The processing of semantic information has been investigated extensively by means of event-related (brain) potentials ERPs over the last two decades. In this paper, we

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focus on syntactic processes. We examine whether different ERP signatures can be found for different aspects of syntactic processing, such as dealing with syntactic complexity and syntactic violations. Before we turn to this particular issue, we briefly introduce the ERP method and its potential to differentiate different processing aspects.

Event-related potentials (ERPs) are small voltage differences within the spontaneous electrical activity of the brain that are time-locked to a particular event. ERP components are characterized by their polarity (positive or negative), latency, and scalp distribution. Functionally, they are specified by the particular event or experimental condition by which they are evoked. The ERP technique is potentially powerful because it provides more than one dimension of information, allowing a better differentiation between different processing aspects than can be obtained with a one-dimensional measure. The observation of different ERP patterns can provide information about the degree of activity of a given neuronal structure and differences between different neuronal structures. A purely quantitative difference is more likely to reflect different levels of engagement of the same neural structure and functional processes. In contrast, qualitative differences either in the spatial distribution or the polarity suggest the involvement of different neural structures and thereby different functional processes (Rugg & Coles, 1995). Previous ERP studies in the domain of language comprehension have identified distinct ERP components differing in latency, polarity, and topography for lexical-semantic and syntactic processes.

Electrophysiological studies have provided evidence for a separation between lexical-semantic and syntactic processes. Lexical-semantic processes are reflected in an ERP component that can be described as a broadly distributed negativity between 350 and 500 ms, peaking at 400 ms. It is therefore called N400 (Kutas & Hillyard, 1980; for a review, see Kutas & Van Petten, 1994). For the processing of syntactic information two different ERP patterns have been identified: the P600 and left anterior negativities. Garden-path sentences and complex sentences elicit a positive-going wave for the disambiguating word and the (ambiguous) critical word, respectively, between 300 and 900 ms. This positivity was labeled P600 (Osterhout & Holcomb, 1992). Incorrect sentences often elicit an early anterior negativity between 150 and 400 ms, followed by a late positivity (e.g., Friederici, Pfeifer, & Hahne, 1993; Münte, Heinze, & Mangun, 1993; Neville *et al.*, 1991; Coulson, King & Kutas, 1998a; Hahne & Friederici, 1999; Hahne & Jescheniak, 2001). Thus, the positivity between 300 and 900 ms is found in response to different aspects of syntactic processes, such as reprocessing, which becomes necessary when revising an initially persued syntactic structure, and repair processes, which are necessary when confronted with syntactically incorrect input. More recently, a late positivity was also reported for the processing of syntactically complex sentences (Featherston, Gross, Müute, & Clahsen, 2000; Kaan, Harris, Gibson, & Holcomb, 2000). We discuss each of these aspects in turn.

Reanalysis-related Positivity

Osterhout and Holcomb (1992, 1993) found that the critical disambiguating word in garden-path sentences evoked a late positivity of around 600 ms, which they called P600. The observation of a P600 response to required revisions has been reported for different types of syntactic constructions in English (Osterhout & Holcomb, 1992; Osterhout, Holcomb, & Swinney, 1994).

Mecklinger, Schriefers, Steinhauer, & Friederici (1995), investigating German subject and object relative clauses, also found a positivity as a function of required reanalysis, however, with a shorter latency (P345). The brief latency was attributed to the case of revision from a subject relative clause to an object relative clause construction in German and to the experiment containing only subject and object relative clause sentences. In a follow-up study, relative clause constructions were presented together with complement clause constructions (Friederici, Steinhauer, Mecklinger, & Meyer, 1998; Friederici, Mecklinger, Spencer, Steinhauer, & Donchin, 2001). In this study, we observed again a P345 for the relative clauses, which, however, was followed by a later small positivity of around 600 ms. These data were taken to suggest that two aspects of the revision process may be differentiated, namely the process of diagnosing the need for re-analysis and the actual re-analysis itself; the former is reflected in the early positivity, the latter in the later positivity. The finding of a P345 effect only in the Mecklinger *et al.* study was assumed to be a reflection of a process of diagnosis that includes the immediate availability of the alternative structure, possibly due to the constraints of the experimental setting. Fodor and Inoue (1994) have argued that diagnosis includes the availability of the alternative structure in any case (and not just under constraint of experimental conditions).

Repair-related Positivity

Late positivities during language processing, however, are not only observed in correlation with processes of structural reanalysis but also with processes of repair, which become necessary when the system is confronted with a syntactic violation (Neville *et al.*, 1991; Friederici *et al.*, 1993; Coulson *et al.*, 1998a; Münte, Heinze, Matzke, Wieringa, & Johannes, 1998). The positivity in correlation to syntactic violations has its maximum around 600 ms. It has been observed in response to phrase structure violations, verb argument, and morphosyntactic violations. Thus the late positivity was not only interpreted to reflect processes of reanalysis (in the case of structural ambiguities) but also to reflect processes of repair (Friederici, 1998). Brown, Hagoort, & Osterhout (1999), reviewing the relevant P600 studies, point out that there may be a distributional difference between the P600 evoked by ambiguity resolution (reanalysis–related P600) and the P600 elicited by syntactic violations (repair-related P600). While the former may be more frontally distributed (e.g., Osterhout & Holcomb, 1992), the latter may be characterized by a centroparietal scalp distribution (e.g., Coulson *et al.,* 1998a).

Taken together the different observations with respect to the late positive component reveals that there may be three different subcomponents embedded in the late positive component. The first subcomponent is the P345, which is assumed to reflect diagnosis and immediate recovery from a nonpreferred structure. These processes are taken to be fast and automatic, because the P345 has been proven to be uninfluenced by semantic aspects (Mecklinger *et al.,* 1995), probability variation (Steinhauer, Mecklinger, Friederici & Meyer, 1997) and additional memory load (Vos, Gunter, Schriefers & Friederici, 2001). The second subcomponent is the reanalysis–related P600 with a frontocentral distribution, which is taken to reflect processes of structural reanalysis. Because this subcomponent was found to be sensitive to probability variation (Steinhauer *et al.,* 1997) and to additional memory load (Vos *et al.,* 2001) it is taken to reflect processes that are not autonomous. The third subcomponent is the repair-related P600. This component has a centroparietal distribution and is affected by semantic variables (Gunter, Friederici & Schriefers, 2000) and probability variation (Hahne & Friederici, 1999), again suggesting a reflection of processes that are not autonomous.

Complexity-related Positivity

In addition to these findings, a P600 has been reported recently as a function of syntactic complexity (Kaan *et al.,* 2000). In this study, the P600 was evoked by a lexical element in a complex syntactic structure (not requiring reanalysis) compared to the same element in a less complex structure. This result was used to argue against an interpretation of the P600 as a marker of reanalysis or repair. Rather, the P600 was interpreted to reflect processes of syntactic integration.

Domain-general Positivity

A more general interpretation of the late positivity has been proposed by Coulson *et al.* (1998a). They claim that the late positivity is a reflection of a general, non–domain-specific context-updating process that is evoked by unexpected events. Under this interpretation, a lexical element either causing an error or requiring a re-analysis is unexpected, and, therefore, elicits a late positivity similar in distribution to the well-known electrophysiological marker of unexpectedness, the P300 (Donchin & Coles, 1988). For a discussion of the domain specificity or the generality of the positivities observed in language studies, see Osterhout, McKinnon, Bersick & Corey (1996), Osterhout & Hagoort (1999), and Coulson *et al.* (1998a, b).

According to the different findings, the P600 has received the following functional interpretations. Osterhout and colleagues (Osterhout & Holcomb, 1992, 1993; Osterhout *et al.*, 1994) interpreted the P600 as a reflection of costs due to reprocessing. Friederici and colleagues (Friederici *et al.*, 1993, 1996; Hahne & Friederici, 1999) interpret the P600 to reflect processes of reanalysis (in case of garden-path sentences) and repair (in case of incorrect sentences) and, thus, take this component to indicate secondary syntactic processes, in contrast to the early anterior negativity, which is taken to reflect first-pass parsing processes. Hagoort *et al.* (1993) take this P600 to reflect syntactic processes per se, and call it *syntactic positive shift*, whereas Kaan *et al.* (2000) interpret the P600 to mark difficulties in syntactic integration in general.

Several observations reported here speak against a unitary functional view of the late positivity. First, the analysis of Friederici *et al.* (2001) suggests that there are already two functionally distinct aspects, namely diagnosis and reanalysis, housed in the late positivity, which are characterized by a different distribution. Second, Brown *et al.* (1999) reviewing some of the relevant literature point out that there may be a distributional difference between the reanalysis–related and the repair-related positivity. Third, the finding that a late positivity was observed as a function of syntactic complexity in sentences containing neither a disambiguating element nor a violating element is not compatible with the view that the P600 is a reflection of perceiving an unexpected event.

The Present Study

The goal of the present study was to investigate whether a positivity elicited by a syntactic violation can be differentiated from one elicited by syntactically complex constructions that requires on-line revisions. A difference in their distribution would indicate that different generators and, therefore, different processes underlie the two positivities. A similar distribution would suggest that the same neuronal generators are involved when processing either a syntactic violation or a syntactically complex sentence (Rugg & Coles, 1995).

A comparison between syntactic violation and syntactic complexity was possible using the following German constructions.

(1) correct, minor complexity:
Dem Vater trug er den Mantel.
The $_{\text{DAT}}$ *father carried* $_{\text{PAST TENSE, SINGULAR}}$ *he* $_{\text{SINGULAR}}$ *the coat.*
(*He carried* $_{\text{SINGULAR}}$ *the coat for the father.*)

(2) correct, major complexity:
Dem Vater getragen hat er den Mantel.
The$_{\text{DAT}}$ *father carried* $_{\text{PARTICIPLE}}$ *has he the coat.*
(*He has carried the coat for the father.*)

(3a) incorrect, minor complexity:
**Dem Vater trugen er den Mantel.*
The $_{\text{DAT}}$ *father carried* $_{\text{PAST TENSE, PLURAL}}$ *he* $_{\text{SINGULAR}}$ *the coat.*
(*He carried* $_{\text{PLURAL}}$ *the coat for the father.*)

(3b) incorrect, major complexity:
**Dem Vater getragen er den Mantel.*
The $_{\text{DAT}}$ *father carried* $_{\text{PARTICIPLE}}$ *he the coat.*
(*He carried* $_{\text{PARTICIPLE}}$ *the coat for the father.*)

Sentence (1), despite starting with a dative DP, is a fairly conventional German clause and is both intuitively and analytically less complex than sentence (2). In sentence (1), the verb has been fronted to second position (C^0), as is required in German simple main clauses and the dative DP "*dem Vater*" has been fronted to first position in the sentence (Spec CP). The subject pronoun and the direct object of the verb have not been displaced. In sentence (2), the auxiliary "*hat*" has been fronted to second position (C^0) as is required in German participial constructions; however, unlike sentence (1), first position (Spec CP) is occupied by the fronted VP which contains the dative DP. In addition, the fronted VP constituent in sentence (2) must contain an empty category corresponding to the direct object, the accusative DP "*den Mantel*," which occurs in sentence final position.

Sentences (3a) and (3b) are ungrammatical counterparts to (1) and (2), respectively. The participle form "*getragen*" requires an auxiliary, which is present in (2), i.e., "*hat*," but not in (3b). This causes sentence (3b) to be incorrect at the pronoun "*er*." In (3a) subject-verb agreement is violated; the plural marked verb is associated with a singular subject pronoun. Thus sentence (3a) is incorrect at the pronoun '*er*' as well.

Under any structural description, sentences (1) and (2) differ in their syntactic complexity. We adopt the descriptive apparatus of Chomsky's Government and Binding Theory and later works (Chomsky, 1981) and define "complexity" in terms of the type of displacement relations that must be computed for a successful parse.

(1) *Dem Vater trug er den Mantel*

$[_{CP}$ $[_{DP}$ dem Vater$]_{i}$ $[_{C'}$ $[_{V\text{-}Infl}$ trug$]_{K}$ $[_{IP}$ $[_{DP}$ er$]$ $[_{I'}$ $t_K]$ $[_{VP}$ $[_{V'}$ $[t_i]$ $[_{V'}$ $[_{DP}$ den Mantel$]$ $t_K]]]$

In the derivation above, the verb has been raised out of the VP to INFL, and the V-Infl complex has been raised to C^0. In addition, the Dative NP in the VP has been raised to Spec CP.

(2) *Dem Vater getragen hat er den Mantel*

$[_{CP}$ $[_{VP}$ $[_{DP}$ dem Vater$]$ $[_{V'}$ $[t_g]$ $[_{v}$ getragen$]]_{r}$ $[_{C'}$ $[_{Infl}$ hat$]_{q}$ $[_{IP}$ $[_{DP}$ er$]$ $[_{I'}$ $t_q]$ $[_{VP}$ $[_{DP}$ den Mantel$]_{g}$ $[_{VP}$ $t_r]]]$

Sentence (2) may be more complex than (1) in terms of its grammatical representation. In the derivation of (2), the auxiliary "*hat*" raises to C^0. The Dative DP plus the verb must be fronted as a constituent to Spec CP. To accomplish this, the Accusative DP has been scrambled out of the inner VP, leaving a trace in the accusative argument's position next to the verb. Thus the VP containing the trace of the accusative argument movement is fronted to derive (2). This construction type is an example of so called Germanic remnant movement: a constituent from which movement has taken place is itself moved (Müller, 1996).

The derivations of both sentence types (1) and (2) contain displacements, but only (2) contains the displacement of a constituent containing a trace of a displacement. Therefore, (2) must be considered to be more complex than (1).

Sentences like (2) pose special challenges to the parser beyond sentences like (1). The occurrence of an initial Dative DP is not problematic in German. On the basis of simplicity and economy, the parser that has identified the Dative DP may predict a structure as in (1). Thus, in (1), the parser assigns the Dative DP to Spec CP and expects a simple tensed verb ("*trug*") to associate with C^0. In (2) the parser also initially encounters a Dative DP. Upon encountering the participle form, the parser first discovers that there is a verb as expected, but morphological analysis determines that it is a participle form that cannot occupy C^0 but must be part of a VP constituent containing the Dative DP. This requires revision of the content of Spec CP from DP to VP. Upon subsequent analysis of the verb participle, the parser discovers that the verb assigns an accusative argument (instead of dative argument only, as in *Dem Vater geholfen hat er/He has helped the father*). An empty category must therefore be posited in the VP, requiring further structural revision. The occurrence of the auxiliary confirms the VP fronting analysis, and the auxiliary can be assigned to C^0.[4]

From this descriptive analysis, a number of predictions follow. First, correct sentences like (1) should be easier to parse than sentences like (3), which are incorrect, and sentences like (2), which are more complex and require a number of on-line revisions. Incorrect sentences, like (3), should elicit a negativity preceding a late positivity. Complex but correct sentences, like (2), may elicit a late positivity. Second, if processes dealing with repair and processes dealing with complexity are based on the same neuronal generators, no difference should be observed for the distribution of the late positivity found for (2) and (3). If, however, different generators underlie these two aspects of syntactic processing, we should observe a distributional difference between the late positivity for (2) and (3).

METHOD

Participants

Twenty-four right-handed subjects (all students of the University of Leipzig, 13 female; age range, 20 to 31; mean age, 23) participated in the study. All participants were German native speakers and had normal or corrected-to-normal vision. Subjects were paid for their participation.

Materials

There was a total number of 360 sentences, i.e., 120 sentences of minor complexity type (1), 120 sentences of major complexity type (2), and 120 incorrect sentences (3), half of type (3a) and half of type (3b). Within sentence types (1) and (2), half of the sentences contained a singular and half a plural subject NP, with which the verb agreed.

The 360 sentences were divided into six blocks with 60 items each. Each block contained 20 items of conditions (1), (2), and (3). The six blocks were pseudo-randomized independently, ensuring that no more than

[4] The occurrence of an empty category before a potential antecedent is, in and of itself, costly, because the unassigned variable must be carried forward during the parse until an associate for this variable is found. In the current constructions, this will result in a further parsing conflict since the first potential associate is the subject pronoun (*er*). This element is clearly marked nominative, whereas the parser is looking for an accusative argument. Because of the presence of the auxiliary in sentences like (2), a direct comparison between sentences (1) and (2) at the subject pronoun is not considered here.

3 items of one condition and no more than five incorrect sentences occurred in direct succession. These six blocks were presented in six different presentation lists. The sequence of the blocks within a list was determined by a random Latin square. The six presentation lists were realized equally often across participants.

Procedure

Participants were seated in a comfortable chair approximately 100 cm (40 inches) in front of a computer screen. Sentences were presented visually in a word-by-word manner. Each trial was structured as follows: A fixation point appeared on the screen for 500 ms. Then each word was presented for 500 ms and directly followed by the next word. After the terminal word of the sentence, the screen was blank for 800 ms, until a response sign appeared and participants were asked to judge the correctness of the sentence. The response sign disappeared after a response had been registered or a timeout of 2 seconds. After an interstimulus interval of 1500 ms, the next trial began.

ERP Recording

The EEG was recorded with 59 tin electrodes secured in an elastic cap (Electro Cap International) and placed in the following locations: FP1/2, AF7/8, AF3/4, F9/10, F7/8, F5/6, F3/4, FT9/10, FT7/8, FC5/6, FC3/4, T7/8, C5/6, C3/4, TP9/10, TP7/8, CP5/6, CP3/4, P9/10, P7/8, P5/6, P3/4, PO7/8, PO3/4, O1/2, FPZ, FZ, FCZ, CZ, CPZ, PZ, POZ, OZ (Sharbrough *et al.*, 1991). The vertical electrooculogram (EOGV) was recorded from electrodes placed above and below the right eye. The horizontal EOG (EOGH) was recorded from positions at the outer canthus of each eye. The recordings were referenced against the left mastoid. The activity over the right mastoid was actively recorded and did not reveal any condition-specific variation. The AFZ electrode served as ground. Electrode impedance was kept below 5 kΩ. The biosignals were amplified within a bandpass from DC to 40 Hz and digitized at 250 Hz.

Data Analysis

ERPs were computed separately for each participant and experimental condition, starting 200 ms before and lasting 1200 ms after the onset of the critical word, which in case of sentence type (1) and (3) was the pronoun and in sentence type (2) was the auxiliary. The averages were aligned to a 200 ms prestimulus baseline. The comparison between the sentence types (1) and (3) allows to measure the ERP on identical targets (pronouns). For the comparison between sentence types (1) and (2), the targets, although not identical, belong to the same word class. Less than 5% of the trials had to be excluded from the averages because of ocular artifacts (EOG rejection criterion, ± 50 μV standard deviation within a 200 ms moving window) or amplifier saturation. These were equally distributed across conditions [(1), 4.25%; (2), 4.74%; (3), 3.9%].

For the statistical analysis of the behavioral data, error rates were computed separately for each condition. For a statistical evaluation of the ERP effects, the average voltage amplitudes in three defined time windows relative to onset of the target were computed. The following time windows were defined: 350 to 450 ms for the negativity in the incorrect condition, 500 to 700 ms for the frontal positivity, and 800 to 1100 ms for the late positivity in the complex condition. The centroparietal positivity in the incorrect condition was analyzed in the same time windows as the two positivities in the complex condition, i.e., 500 to 700 ms and 800 to 1100 ms. The selection of these time windows was based on a visual inspection of the grand averages.

All dependent variables were quantified using repeated-measure ANOVAs with the within-subject variables condition (simple-complex or simple-incorrect), ant_pos (anterior, central, posterior) and hemisphere (left, right). The variables ant_pos and hemisphere were completely crossed. For the three levels of the variable ant_pos, twelve anterior electrode positions (F7/8, F5/6, F3/4, FT7/8, FC5/6, FC3/4), twelve central positions (T7/8, C5/6, C3/4, TP7/8, CP5/6, CP3/4), and twelve posterior positions (P7/8, P5/6, P3/4, PO7/8, PO3/4, O1/2) were selected while the electrodes for the variable hemisphere were F7, F5, F3, FT7, FC5, FC3, T7, C5, C3, TP7, CP5, CP3, P7, P5, P3, PO7, PO3, O1 (left) versus F8, F6, F4, FT8, FC6, FC4, T8, C6, C4, TP8, CP6, CP4, P8, P6, P4, PO8, PO4, O2 (right). The Geisser-Greenhouse correction was applied when evaluating effects with more than one degree of freedom in the numerator (Geisser & Greenhouse, 1959).

RESULTS

Behavioral Data

The error rates in the grammaticality judgment task were 2.1% for the simple condition, 1.3% for the complex condition, and 4.2% for the incorrect condition. A multivariate analysis of variance revealed a significant main effect of condition ($F(2,22) = 5.34$, $p < .05$) and a Neuman-Keuls test showed that participants made significantly more errors in the incorrect condition than in the two other conditions.

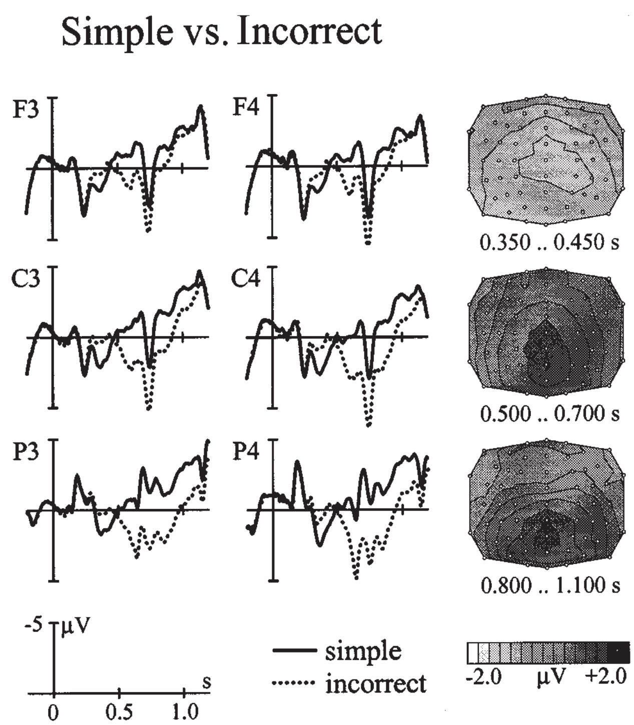

Fig. 1. *Left,* Grand average ERP waveforms for six selected electrode positions for the simple and the incorrect condition. *Right,* Topographic maps of the differences between the ERP response to the incorrect and the simple condition for three time windows. Dark areas indicate positive differences between conditions, and bright areas indicate negative differences. Electrode positions are marked by small circles.

ERP Data

The ERPs for the three conditions, i.e., minor complexity, major complexity, and incorrect, are displayed in Figures 1 and 2. Incorrect sentences (3) compared to simple correct sentences (1) elicited a centrally distributed negativity between 350 and 450 ms, followed by a centroparietal positivity between 500 and 1100 ms (Fig. 1).[5] Syntactically complex sentences (2) compared to simple sentences (1) evoked a small frontally distributed positivity

[5] A first analysis was conducted to test for possible differences between the two incorrect conditions (3a) and (3b). No main effect of condition was found. Interactions of condition and topographic factors did not prove to be significant in subsequent analyses. Therefore, items of (3a) and (3b) were collapsed for all further analyses.

between 500 and 700 ms and a second positivity between 800 and 1100 ms, which was widely distributed (Fig. 2).

Simple versus incorrect condition: 350–450 ms

The analysis of the simple (1) compared to the incorrect (3) condition in the time window of 350 to 450 ms after target onset revealed a highly significant main effect of condition ($F(1,23) = 24.60$, $p < .001$) with a larger amplitude for the complex compared to the simple condition, as well as a reliable interaction of condition and ant_pos ($F(2,46) = 5.17$, $p < .02$). Analyses for each of the three levels of ant_pos revealed significant condition effects for each of the three regions (anterior: $F(1,23) = 9.98$, $p < .01$; central: $F(1,23) = 28.20$, $p < .001$; posterior: $F(1,23) = 28.92$, $p < .001$), demonstrating a widely distributed negativity for the incorrect sentences (3) compared to the simple correct sentences (1) in the early time window.

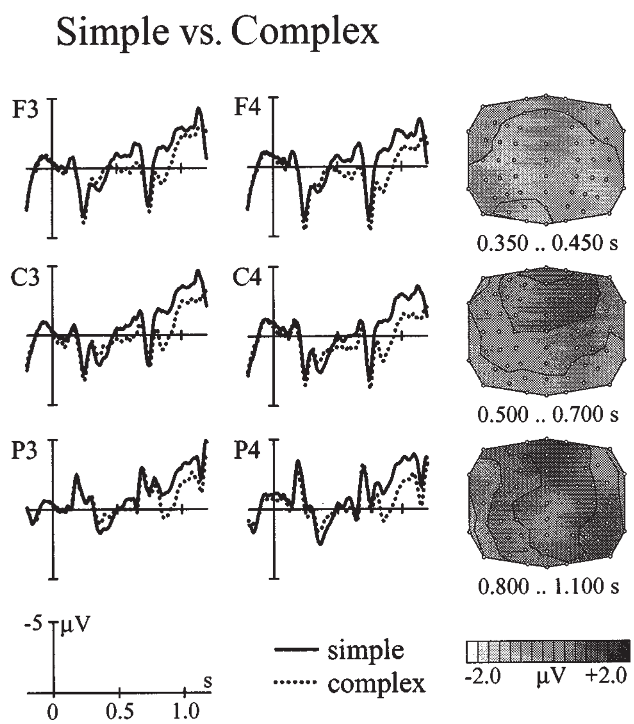

Fig. 2. *Left,* Grand average ERP waveforms for six selected electrode positions for the simple and the complex condition. *Right,* Topographic maps of the differences between the ERP response to the complex and the simple condition for three time windows.

Simple versus incorrect condition: 500–700 ms

For the time window of 500 to 700 ms, the analyses of the simple compared to the incorrect condition revealed a highly reliable main effect of condition ($F(1,23) = 29.24$, $p < .001$) as well as a significant interaction of condition and ant_pos ($F(2,46) = 4.35$, $p < .05$). Analyses conducted for each of the three levels of ant_pos showed that the incorrect condition was more positive than the simple condition in each of the three regions, with a maximum over centroparietal regions (anterior: $F(1,23) = 15.00$, $p < .001$; central: $F(1,23) = 27.12$, $p < .001$; posterior: $F(1,23) = 35.96$, $p < .001$).

Simple versus incorrect condition: 800–1100 ms

For the late time window of 800 to 1100 ms, a highly reliable main effect of condition ($F(1,23) = 34.35$, $p < .001$), a significant interaction of condition and ant_pos ($F(2,46) = 26.69$, $p < .01$), and a marginally significant interaction of condition, ant_pos and hemisphere ($F(2,46) = 2.99$, $p < .07$) existed. Analyses conducted for each of the six regions of interest showed that the incorrect condition was more positive than the simple condition over centroparietal regions (left central: $F(1,23) = 27.92$, $p < .001$; right central: $F(1,23) = 24.35$, $p < .001$; left posterior: $F(1,23) = 72.54$, $p < .001$; right posterior: $F(1,23) = 51.86$, $p < .001$) and extended to right anterior sites (left anterior: $F(1,23) = 2.09$, $p < .17$; right anterior: $F(1,23) = 4.70$, $p < .05$).

Simple versus complex condition: 500–700 ms

Analyses comparing the simple (1) and the complex condition (2) in the time range 500 to 700 ms revealed a marginal significant condition effect ($F(1,23) = 2.91$, $p = .10$), a highly significant interaction of condition and ant_pos ($F(2,46) = 11.43$, $p < .01$) as well as a marginal interaction of condition, ant_pos and hemisphere ($F(2,46) = 2.73$, $p < .10$). Therefore, we evaluated the condition effects for each level of ant_pos and hemisphere independently. These analyses showed that condition was significant for the left anterior ($F(1,23) = 8.47$, $p < .01$) and the right anterior region ($F(1,23) = 5.74$, $p < .03$), as well as for the left central region ($F(1,23) = 5.71$, $p < .03$). However, no other regions revealed a significant condition effect (right central: $F(1,23) = 1.23$, $p < .28$; left and right posterior: $F < 1$), demonstrating that the positivity between 500 and 700 ms was restricted to anterior electrode positions.

Simple versus complex condition: 800–1100 ms

The analyses of the late time window (800 to 1100 ms) showed a highly significant effect for the variable condition ($F(1,23) = 20.48$, $p < .001$) and an interaction of condition and hemisphere ($F(1,23) = 4.62$, $p < .05$), i.e., complex sentences elicited a more positive waveform than simple sentences. This effect was slightly more pronounced over the right hemisphere. Separate analyses for the two levels of hemisphere revealed highly significant condition effects over both hemispheres (left: $F(1,23) = 22.10$, $p < .001$; right: $F(1,23) = 18.00$, $p < .001$).

Complex versus incorrect condition: 800–1100 ms

To evaluate whether the topography of the two positivities elicited in the late time window in the complex (2) and in the incorrect condition (3) differed from each other, we conducted additional analyses on normalized data that compared these two conditions (McCarthy & Wood, 1985). These analyses revealed a highly significant interaction of condition and ant_pos ($F(2,46) = 10.16$, $p < .01$), suggesting that the topography of the two positivities in the time window of 800 to 1100 ms differs between the two conditions, with the incorrect condition having a more posterior distribution.

DISCUSSION

The present study set out to investigate whether and to what extent the processing of syntactically incorrect sentences and of syntactically complex sentences involve the same brain systems. Both types of sentences have been reported to evoke a late positivity, P600, in the ERP. A number of studies showed a P600 in correlation with the processing of syntactically incorrect sentences at the point of incorrectness (Neville *et al.*, 1991; Hagoort *et al.*, 1993; Friederici, Hahne, & Mecklinger, 1996; Münte, Matzke, & Johannes, 1997). Other studies demonstrated a P600 in correlation with the processing of temporary ambiguous but correct sentences at the point at which reanalysis of the initial structure is required (Osterhout & Holcomb, 1992, 1993; Mecklinger *et al.*, 1995), although one study reported a P600 for correct and unambiguous but complex sentences (Kaan *et al.*, 2000).

The Biphasic Pattern: Negativity-Positivity

The experiment compared the processing of syntactically incorrect sentences and syntactically complex sentences in a within-subject design. The ERP pattern observed was the following: The syntactically incorrect sentences elicited a centrally distributed negativity between 350 and 450 ms, followed by a positivity between 500 and 1100 ms, whereas the syntactically complex, but correct sentences elicited a small frontally distributed positivity between 500 and 700 ms, followed by a positivity between 800 and 1100 ms. The present data are partially compatible with earlier findings on the processing of syntactically incorrect sentences (Neville *et al.,* 1991; Münte *et al.,* 1997; Coulson *et al.,* 1998a; Gunter & Friederici, 1999; Friederici & Frisch, 2000; Frisch & Schlesewsky, 2001) that report a biphasic pattern for these sentence types. Moreover, the data are in agreement with earlier studies that report a P600 for sentences that are correct but which either contain a temporary ambiguity requiring syntactic revision or are just syntactically more complex (Osterhout & Holcomb, 1992; Mecklinger *et al.,* 1995; Featherston *et al*., 2000; Kaan *et al.,* 2000).

Although replicating a biphasic ERP pattern for incorrect sentences with a negativity followed by a positivity, the present ERP pattern differs from that of earlier studies in the topography of the syntax-related negativity. The syntax-related negativity usually observed between 300 and 500 ms when stimuli are presented visually (Gunter, Stowe, & Mulder, 1997; Coulson *et al.,* 1998a; Münte *et al.,* 1997) displays a left anterior maximum. Although the distribution sometimes extends to left temporal sites (e.g., Coulson *et al.,* 1998a; Neville *et al.,* 1991; Friederici & Frisch, 2000), the early negativity was seldom reported to be of a central distribution. A closer look at the particular violation types investigated may shed some light on the distributional differences. Most of the earlier studies investigated morphosyntactic violations, i.e., subject-verb agreement errors (e.g., Gunter *et al.,* 1997; Münte *et al.,* 1997) and case marking errors (e.g., Coulson *et al.,* 1998a; Friederici & Frisch, 2000) or phrase structure violations (e.g., Neville *et al.,* 1991) in subject-first sentences. Here, syntactic violations were investigated in object-first sentences with the indirect object topicalized. A similar centrally distributed negativity was reported in correlation with German sentences containing a sentence-initial direct object/indirect object ambiguity by Hopf, Bayer, Bader, & Meng (1998) at the disambiguating verb and with German sentences in which subject and object NPs were either both case-marked as nominative or both case-marked as accusative (Frisch & Schlesewsky, 2001). The distribution of these syntax-related negativities resemble that of a classical N400, indicating lexical-semantic integration processes rather than the distribution of the negativity usually observed with syntactic violations. At the moment we can only speculate which factor may influence the distribution of the syntax-related negativity in some German constructions.

Frisch and Schlesewsky (2001) attribute their own findings for the incorrect double case-marking to the specifics of German free word order. They assume expectancy-based procedures to come into play once a partial structure has been built on the initial case marked NP. This may lead to a set of expectations about the upcoming noun phrase, which upon nonfulfillment lead to lexical or thematic integration problems and, thus, to an N400. A similar expectation-based strategy may have been active in the present case in which the sentence initial NP is marked for dative case, which predicts a structure compatible with a three-place verb. This view is supported by a recent ERP study in German in which it was shown that the parser builds up expectations about a particular verb class (one-place versus two-place argument verbs) on the basis of case-marked arguments presented before the verb. A mismatch between the verb's class and the expected number of arguments also leads to a N400–like activation pattern that is followed by a late positivity (Friederici & Frisch, 2000). Further research is needed to determine if this is a possible interpretation.

The Distributional Difference of the Positivity

The distributional difference between the two positivities, with the repair-related positivity for the syntactically incorrect sentences being more centroparietal and the positivity for the syntactically complex sentences being more frontally distributed, is taken to indicate that the brain systems involved in the two positivities and the processes they reflect are different. While the processes involved in parsing incorrect sentences are assumed to reflect repair functions, those involved in processing syntactically complex sentences seem to reflect aspects of on-line syntactic revision. The simple and the complex sentences used in this study both involve displaced arguments; they only differ in the structural complexity associated with the displacements. Therefore, the positivity observed for the complex sentences can be taken as a marker of processing syntactic complexity. This latter result is in agreement with the claim by Kaan *et al.* (2000) who argue that the P600 reflects processes of syntactic integration in principle.

The present data, however, clearly indicate that the late positivity is not a unitary component. They rather suggest that there are at least two types of positivity—a more frontally distributed one and a centroparietally distributed one, each reflecting different aspects of syntactic processing. Moreover, the distributional difference between the two positivities indicates that different neural structures support the processing of syntactically complex sentences and processes of syntactic repair.

Given these suggestive results, one can further ask if it is possible to discriminate different types of syntactic complexity with respect to the late positivities and the biphasic pattern. The construction used in sentences like (2) are more complex than those in sentences like (1) along two parameters.

1. Sentence (2) has a VP in first position (Spec CP) with its attendant argument structure, whereas (1) has only a DP.

2. The fronted VP in sentence (2) contains a trace corresponding to the direct object. This variable must be maintained until an associate is found.

Only one of these conditions may be sufficient to give rise to the complexity-related positivity, but this is beyond the scope of the present study.

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