Electrophysiological Evidence for Two Steps in Syntactic Analysis: Early Automatic and Late Controlled Processes

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Abstract

■ In this study we examined the properties of the processes involved in the structural analysis of sentences using event-related brain potential measures (ERP). Previous research had shown two ERP components to correlate with phrase structure violations: an early left anterior negativity (ELAN), which is assumed to reflect first-pass parsing processes, and a late parietally distributed positivity (P600), assumed to reflect second-pass parsing processes. We hypothesized that the first-pass parsing processes are highly automatic, whereas second-pass parsing processes are more controlled. To test this hypothesis we varied the proportion of correct sentences and sentences containing phrase structure violations with incorrect sentences being either of a low (20% violation) or a high (80% violation) proportion. Results showed that the early left anterior negativity was elicited and equally pronounced under both proportion conditions. By contrast, the late positivity was elicited for a low proportion of incorrect sentences only. This data pattern suggests that first-pass parsing processes are automatic, whereas second-pass parsing processes are under participants' strategic control. ■

INTRODUCTION

Comprehending sentences involves a variety of subprocesses computed in a restricted amount of time. Therefore models attempting to give a plausible description of language comprehension not only have to isolate the necessary subcomponents but also explore their properties and temporal coordination. Recent work on these issues using on-line behavioral measures has led to two main accounts: the serial and the interactive account. Serial models hold that initial parsing processes are restricted to syntactic knowledge such as word category information and phrase structure rules and are independent of semantic and pragmatic information (Frazier & Fodor, 1978; Rayner, Carlson, & Frazier, 1983; for a review see Frazier, 1987; Gorrell, 1995; see also O'Seaghdha, 1997, for recent empirical support). According to the second view, the interactive approach, these different aspects interact continuously during comprehension (MacDonald, 1993; Marslen-Wilson & Tyler, 1980; McClelland, St. John, & Taraban, 1989).

Those researchers who assume autonomy of syntactic processes do so for processes of initial structure building, that is, first-pass parsing processes (Frazier, 1987; Gorrell, 1995) but not necessarily for second-pass parsing processes, which may include processes of reanalysis (Fodor & Inoue, 1994; Frazier, 1987; Inoue & Fodor, 1995). To test whether the assumptions of automatic first-pass parsing processes and more controlled second-pass parsing processes are valid, it is of particular interest to explore the functional properties and the exact timing of the two subprocesses involved.

During the last years more traditional approaches to language comprehension research (in particular reaction time studies) have been fruitfully complemented by studies using event-related brain potentials (ERPs) as a dependent variable. Most research on language processing using ERPs has focused on semantic aspects of comprehension. In this domain the so-called *N400 component* has been identified to correlate systematically with processes of semantic integration (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995; for a review on N400-research see Kutas & Van Petten, 1994). Less work has been concerned with the processing of *structural* information. These studies have identified either a *left anterior negativity,* a *late centroparietal positivity,* or a combination of both to correlate with syntactic processing. A late positivity (also called the *P600 component*) has been found to covary with a variety of syntactic anomalies such as garden-path sentences and other syntactically nonpreferred structures (Friederici, Hahne, & Mecklinger, 1996; Hagoort, Brown, & Groothusen, 1993; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995; Osterhout & Holcomb, 1992, 1993; Osterhout, Holcomb, & Swinney, 1994), outright phrase structure violations (Friederici et al., 1996; Neville, Nicol, Barss, Forster, & Garrett, 1991; Osterhout & Holcomb, 1992, 1993), subjacency violations (Neville et al., 1991;

McKinnon & Osterhout, 1996) and agreement violations (Coulson, King, & Kutas, 1998; Friederici, Pfeifer, & Hahne, 1993; Gunter, Stowe, & Mulder, 1997; Hagoort et al., 1993; Osterhout & Mobley, 1995). Left anterior negativities have been observed in correlation with phrase structure violations (Friederici et al., 1993, 1996; Münte, Heinze, & Mangun, 1993; Neville et al., 1991; Osterhout & Holcomb, 1992, 1993), with the processing of subcategorization information (Osterhout & Holcomb, 1993; Rösler, Friederici, Pütz, & Hahne, 1993), with agreement violations (Coulson et al., 1998; Friederici et al., 1993; Gunter et al., 1997; Osterhout & Mobley, 1995), and even for agreement errors in pseudoword combinations (Münte, Matzke, & Johannes, 1997). Moreover, a left anterior negativity was observed for the processing of function words as compared to open class words (Neville, Mills, & Lawson, 1992; Nobre & McCarthy, 1994). Kluender and Kutas (1993) and King and Kutas (1995) observed a left anterior negativity, also in correlation with the processing of filler-gap assignments, and suggest that the left anterior negativity reflects working memory processes (but see Gunter et al., 1997, who did not observe any effects of working memory load on the left anterior negativity).

With regard to the left anterior negativities described in the literature it seems reasonable to distinguish *early* left anterior negativities (ELAN) with a latency of about 100 to 300 msec and left anterior negativities with a latency of about 300 to 500 msec (LAN). The ELAN thus far has been observed for the processing of phrase structure violations and closed class elements only. This might suggest that the processing of word category information appears to be processed particularly early as compared to, for example, agreement and subcategorization information.

In view of these findings we formulated a model (Friederici, 1995) that partially follows the proposals made by Frazier and colleagues (Frazier, 1987; Frazier & Fodor, 1978; Frazier & Rayner, 1982). The model entails three stages of analysis. During the first phase the parser incrementally assigns the initial syntactic structure on the basis of word category information only. This first-pass parse is presumably reflected in the early left anterior negativity (ELAN). Importantly, this early negativity is only observed in correlation with outright phrase structure violations. Syntactic structures that are infrequent but nevertheless legal do not elicit this early negativity (Friederici et al., 1996; Hagoort et al., 1993). This suggests that during this first-pass parse the parser is only guided by phrase structure rules and does not take the frequency of occurrence of particular structures into account. During the second phase the parser tries to achieve the thematic role assignment. These processes are reflected by negativities around 400 msec. During this stage lexically bound information other than word category information is processed. On the one hand this is lexical-semantic information, which is reflected in the centro-parietally distributed N400-component; on the other hand it is syntactic information such as subcategorization and inflectional morphology, which is reflected in left anterior negativities around 400 msec. During the third phase lexical-semantic and syntactic information are mapped onto each other. In case of an unsuccessful match a reanalysis or repair becomes necessary, which is reflected by the late centro-parietally distributed positivity.

We hypothesize that the first-pass parse reflected in the early anterior negativity is a process characterized by a high degree of automaticity, whereas the P600 is assumed to be of a much more controlled nature. According to two-process theories of information processing, automatic processes are fast-acting, occur without intention or awareness, and do not use limited-capacity resources. By contrast, controlled processes are slower, are under a person's strategic control, and use limited-capacity resources (Posner & Snyder, 1975; Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).[1]

The present study was designed to test the hypothesis of fairly automatic first-pass parsing processes as reflected in the early negativity and fairly controlled later processes of reanalysis and repair as reflected in the P600 component. To test our hypotheses we resorted to a paradigm frequently applied to study the relative amount of automaticity, namely, the systematic manipulation of the proportion of matching and nonmatching information within an experiment. This procedure has been successfully used in behavioral studies of language comprehension (e.g., de Groot, 1984; Deutsch & Bentin, 1994; Fischler & Bloom, 1979; Neely, 1977; Stanovich & West, 1983). It was also applied in ERP language research to examine the nature of the N400 (Chwilla et al., 1995; Holcomb, 1988). The rationale of the proportion manipulation is to influence the participant's expectations concerning the frequency of particular types of stimuli and thereby his or her strategic behavior. If the ERP component correlated with a specific process is influenced by the proportion manipulation (i.e., affected by strategies) this process is assumed to be under active control. By contrast, if the ERP component is *not* affected by the varying proportion, the underlying process is assumed to be fairly automatic.

In our study we varied the proportion of correct and syntactically incorrect sentences across two experimental sessions. In one session 20% of the sentences contained a phrase structure violation, whereas in the other session there were 80% phrase structure violations. Correct sentences consisted of a noun phrase, an auxiliary, and a past participle (*Das Baby wurde gefüttert—The baby was fed*). Syntactically incorrect sentences contained a word category error. In these sentences a preposition appeared after the auxiliary and was directly followed by a past participle (*Die Gans wurde im gefüttert—The goose was in the fed*). Because the preposition indicates the beginning of a prepositional phrase necessarily consisting of a preposition and a noun phrase, this sequence of words creates a clear phrase structure violation. We predicted that if the early left anterior negativity reflects an automatic process, it should be present and equally pronounced under both proportion conditions because an automatic process should not be influenced by strategic behavior as induced by the varying proportion of incorrect sentences. We additionally predicted that if the late positivity reflects a more controlled process of secondary parsing, it would diminish in the case of a high proportion of incorrect sentences compared to a low proportion of incorrect sentences. Unlike a situation in which only a few sentences are incorrect (20%) and in which attempts to repair the—rarely occurring—incorrect structures may be a useful strategy for overall successful comprehension, participants may refrain from second-pass parsing processes in a situation with 80% incorrect sentences because they quickly realize that within such an experimental session the possibility of overall successful comprehension is clearly diminished. Thus, if the P600 reflects processes of syntactic repair that are under participant's control, the amplitude of this component should be remarkably reduced in the 80% violation session.

RESULTS

Behavioral Data

Participants had no difficulties in judging the correctness of the sentences (error rate < 1%). There were no differences between conditions ($F < 1$).

ERP

The ERPs elicited by correct sentences and by phrase structure violations for the two proportion conditions are shown in Figures 1 and 2. As can be clearly seen, phrase structure errors elicited an early anterior negativity that was more pronounced over the left than over the right hemisphere. Importantly, this effect was independent of the proportion of incorrect sentences. By contrast, the proportion manipulation clearly affected the late positive component. Syntactic violations in the 20% violation condition elicited a late parietally distributed positivity, whereas this effect seemed to be reversed in the 80% violation condition (see Figure 3). These descriptive findings were supported by the subsequent statistical analyses.

Because the present study focuses on the effects of proportion on the processing of phrase structure violations, only effects involving the factor Sentence Type will be reported (see Methods for a description of the procedure in statistical analysis). In a multivariate analysis of variance (MANOVA) performed on the lateral electrode sites for the first time window (100 to 300 msec) there was a significant interaction of Sentence Type and Region ($F(1, 19) = 4.54, p < 0.05, MSE = 15.45$) reflecting the fact that the negativity was most pronounced at anterior sites. Importantly, there was not even a tendency for an interaction of Proportion × Sentence Type ($F < 1$), and none of the other interactions reached significance. To further analyze the interaction of Sentence Type × Region we performed separate analyses for each quadrant. These analyses revealed a significant main effect of Sentence Type only for the left anterior quadrant[2] ($F(1, 19) = 7.08, p < 0.02, MSE = 14.78$). The right anterior quadrant showed a tendency for a Sentence Type effect ($F(1, 19) = 2.65, p < 0.12, MSE = 17.82$), whereas there were no Sentence Type effects for the posterior electrodes (Fs < 1). The interaction of Sentence Type × Electrode did not reach significance in any quadrant. These results show that the early negativity is most pronounced at the left anterior electrode sites. Analyses performed on the three midline electrodes revealed a main effect of Sentence Type ($F(1, 19) = 5.81, p < 0.03, MSE = 8.26$) but no interaction of Sentence Type × Electrode ($F(2, 38) = 1.75, p < 0.28, MSE = 1.47$).

For the second time window (500 to 1000 msec) the analyses performed on the lateral sites revealed no main effect of Sentence Type ($F < 1$), but the interaction of Sentence Type × Proportion only slightly failed to reach significance ($F(1, 19) = 3.99, p < 0.06, MSE = 94.31$) and the interaction Sentence Type × Proportion × Region was significant ($F(1, 19) = 4.57, p < 0.05, MSE = 46.13$) as was the interaction of Sentence Type × Region ($F(1, 19) = 8.87, p < 0.008, MSE = 26.84$). Due to the significant interaction of Sentence Type × Proportion × Region and the nearly significant interaction of Sentence Type × Proportion, the following analyses were conducted separately for the two proportion conditions.

For the low error proportion a MANOVA including the factors Sentence Type, Hemisphere, and Region revealed a significant Sentence Type × Region interaction ($F(1, 19) = 9.14, p < 0.007, MSE = 49.05$) that reflects the fact that the positivity was present at posterior but not at anterior sites. Neither the main effect of Sentence Type ($F(1, 19) = 2.10, p < 0.16, MSE = 107.74$) nor the interaction of Sentence Type and Hemisphere ($F < 1$) reached significance. To further analyze the interaction of Sentence Type × Region we again performed analyses separately for each quadrant. These revealed highly significant main effects for the factor Sentence Type in both posterior quadrants (left posterior: $F(1, 19) = 11.71, p < 0.003, MSE = 35.88$; right posterior: $F(1, 19) = 7.34, p < 0.02, MSE = 33.59$) but no reliable effects of Sentence Type for the anterior quadrants (both Fs < 1). There was also a significant interaction of Sentence Type × Electrode for the right posterior quadrant. *T* tests for the four electrodes in this quadrant showed that the effect of incorrect sentences being more positive than correct sentences was only marginally significant at the electrode locations CP6 ($p = 0.10$) and P8 ($p = 0.06$) but highly significant at P4 ($p = 0.009$) and O2 ($p = 0.003$).

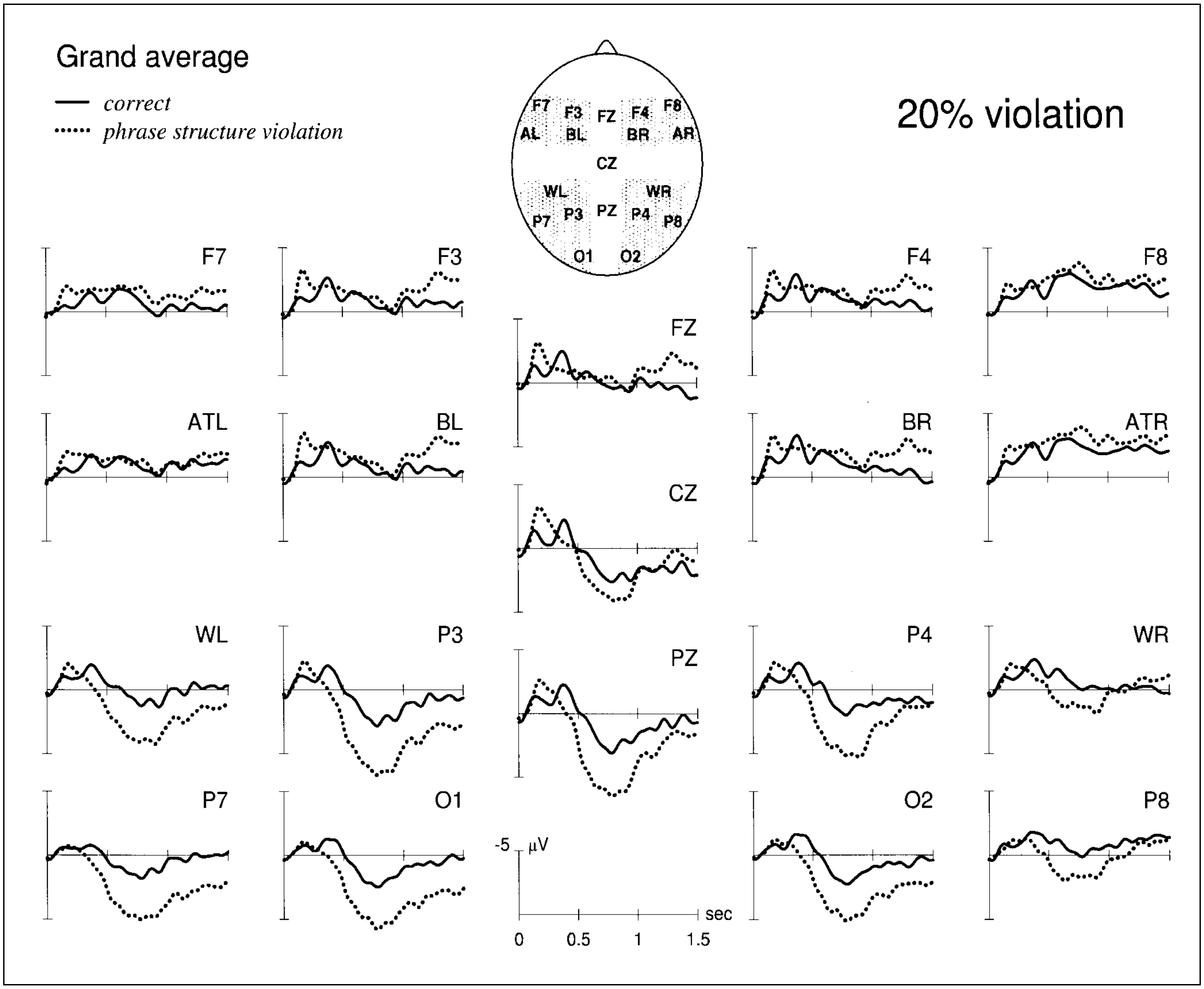

Figure 1. Grand average ERPs for the critical past participle for correct (solid line) and incorrect sentences (dotted line) in the *low* error proportion condition (i.e., 20% of the sentences violated the syntactic phrase structure). Negative voltage is plotted up.

Analyses of the midline electrodes revealed no significant main effect of Sentence Type ($F(1, 19) = 2.20$, $p < 0.15$, $MSE = 33.68$) but a significant interaction of Sentence Type and Electrode ($F(2, 38) = 10.07$, $p < 0.0001$). *T* tests showed that the interaction occurred because there was no reliable difference between correct and incorrect sentences at the locations Fz ($p = 0.86$) and Cz ($p = 0.20$) but a highly reliable effect at Pz ($p = 0.005$). The analyses for the 500- to 1000-msec window for the low error proportion condition clearly support the descriptive result of a posterior-distributed positivity for syntactically incorrect sentences.

The analyses for the high error proportion condition revealed a different picture. Analyses for lateral electrode sites did not reveal any significant effects of Sentence Type. There was a slight tendency for a main effect of Sentence Type ($F(1, 19) = 2.29$, $p < 0.15$, $MSE = 67.38$), but this effect did not interact with any topographical factor (all *F*s < 1). Therefore no further analyses were conducted on the lateral electrode sites. For the midline sites there was a marginally significant main effect of Sentence Type ($F(1, 19) = 3.48$, $p < 0.08$, $MSE = 29.57$) but no interaction with the factor Electrode.

Additional Analyses on the Late Positivity

Additionally we conducted further analyses for the posterior lateral electrodes to explore the observed interaction of Sentence Type and Region in the first analysis of the second time window (cf. Figure 4). This analysis revealed only a marginally significant main effect of Sentence Type ($F(1, 19) = 2.68$, $p < 0.12$, $MSE = 13.95$), which, however, interacted with Proportion ($F(1, 19) = 12.04$, $p < 0.001$, $MSE = 11.95$). *T* tests showed that the difference between correct and incorrect sentences was highly reliable for low error proportion ($t = 3.20$, $p < 0.005$) but that there was no significant difference between correct and incorrect sentences for a high error

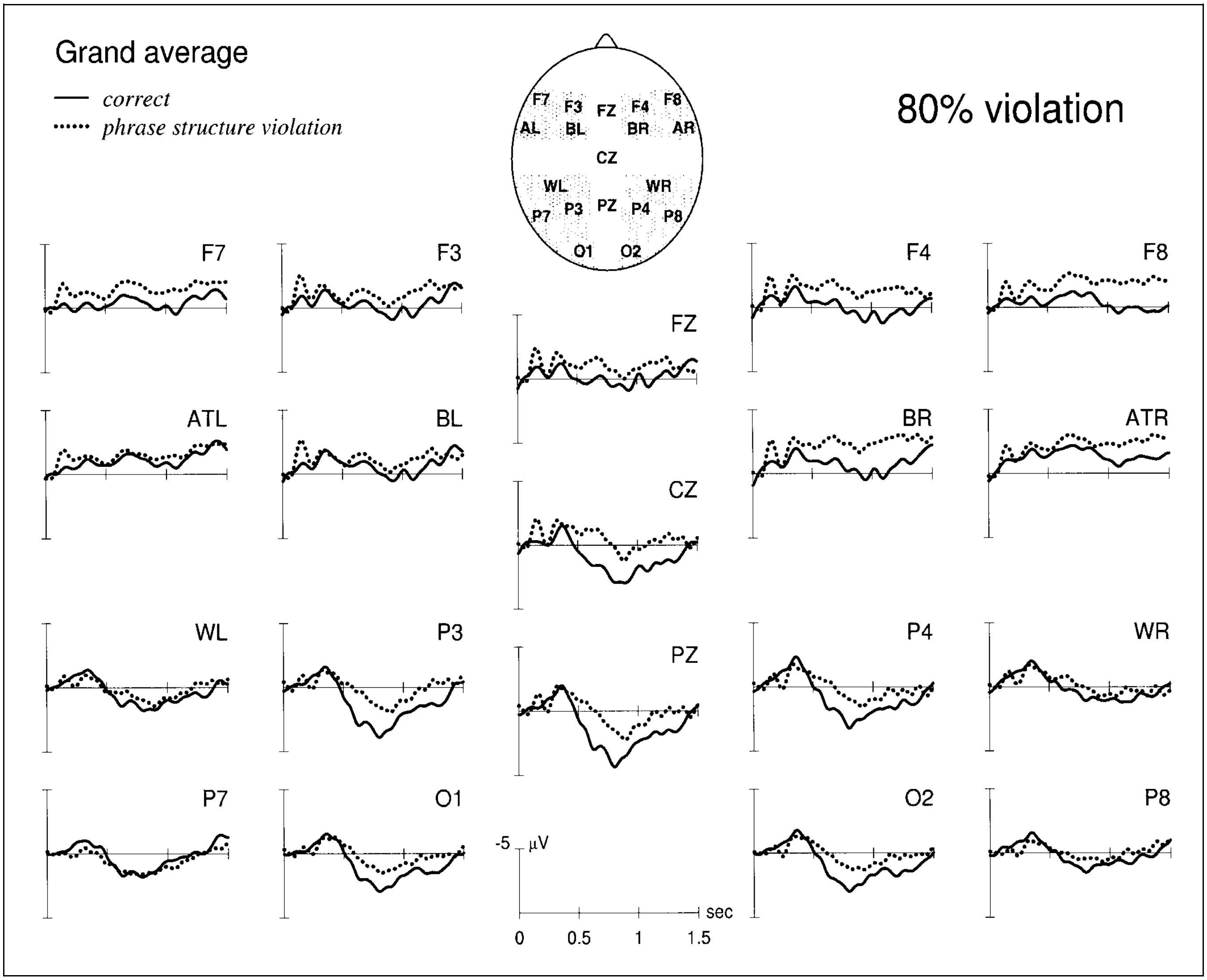

Figure 2. Grand average ERPs for the critical past participle for correct (solid line) and incorrect sentences (dotted line) in the *high* error proportion condition (i.e., 80% of the sentences violated the syntactic phrase structure). Negative voltage is plotted up.

proportion ($t = 1.32, p < 0.20$). A direct comparison of the correct sentences across proportion conditions revealed no significant difference ($t = 1.47, p < 0.16$).

Additional Analyses on Presentation Sequence

One could question whether this overall pattern only occurred because we have tested the same participants in different sessions under both proportion conditions. To check for this possibility we analyzed each participant's first session only. These analyses revealed virtually the same data pattern as the overall analyses. The differences with regard to the first time window (100 to 300 msec) were that the interaction of Sentence Type and Region was more pronounced in the global analysis ($F(1, 19) = 4.54$, $p < 0.05$, $MSE = 15.45$) than in the first session ($F(1, 18) = 2.28, p < 0.14, MSE = 12.50$), whereas the reverse was true for the interaction of Sentence Type, Region, and Hemisphere (global: $F(1, 19) = 1.36$, $p < 0.26$, $MSE = 1.96$; first session: $F(1, 18) = 4.33, p < 0.05$, $MSE = 0.85$), suggesting that the early negativity was more restricted to the left anterior sites in the first as opposed to the second session. The only difference with regard to the second time window was that the interaction of Proportion, Sentence Type, Hemisphere, and Region, which failed to reach significance in the global analysis ($F(1, 19) = 2.33, p < 0.14, MSE = 2.65$) was now significant ($F(1, 18) = 7.52, p < 0.01, MSE = 1.86$).

This correspondence clearly demonstrates that all the effects we discuss were present from the beginning and not carried primarily or exclusively by the second session. We also analyzed each participant's second session and found the early negativity to be equally present in both proportion conditions such as in the global analysis. The late positivity, however, was largely diminished as compared to the global analysis and was no longer reliable.

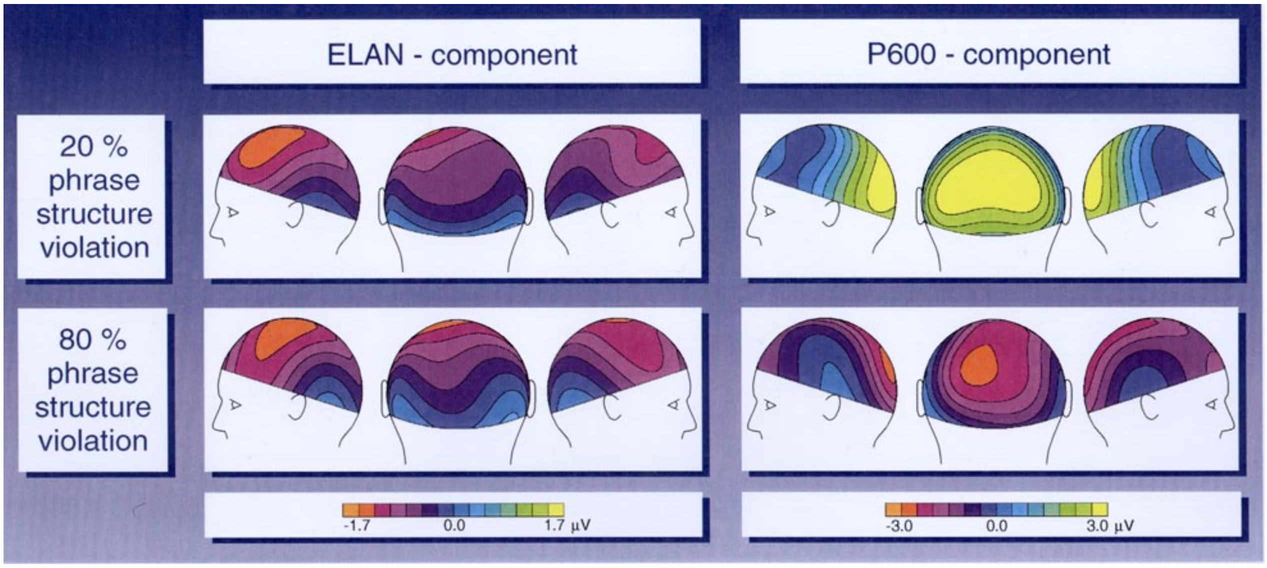

Figure 3. Topography for the early left anterior negativity (ELAN) for the two proportion conditions (average for all 20 participants). The maps show the maximum activation at 140 msec for the ELAN component and the maximum activation at 630 msec for the P600 component. A left anterior negativity is obtained and equally pronounced for both proportion conditions (i.e., independent of the proportion of correct and incorrect sentences), whereas the late positivity is only present for a low proportion of incorrect sentences (20% violation) but not for a high proportion of incorrect sentences (80% violation).

DISCUSSION

The aim of the present study was to examine the properties of the processes involved in the structural analysis of sentences. Previous research had shown two ERP-components to correlate with the processing of phrase structure information: an early left anterior negativity and a late parietally distributed positivity. We hypothesized that the early negativity reflects highly automatic first-pass parsing processes, whereas the late positivity reflects second-pass parsing processes that are of a more controlled nature. To examine our claim concerning different degrees of automaticity we varied the proportion of phrase structure violations in an auditory sentence comprehension study.

The results clearly supported our hypotheses. An early left anterior negativity was elicited and equally pronounced under both proportion conditions, supporting the idea that the early structure-building processes are rather independent of the participants' conscious expectancies and strategic behavior and can therefore be claimed to be automatic in nature. In contrast, we observed a P600-component[3] for a low proportion of syntactically incorrect sentences only. In case of a high proportion of incorrect sentences we did not find a P600 component. For a high error proportion the effect even seemed to reverse, although this effect was not statistically significant. We take these results as evidence that the late positive component reflects processes that are under the control of the participant.

Thus the pattern of results shows a clear dissociation

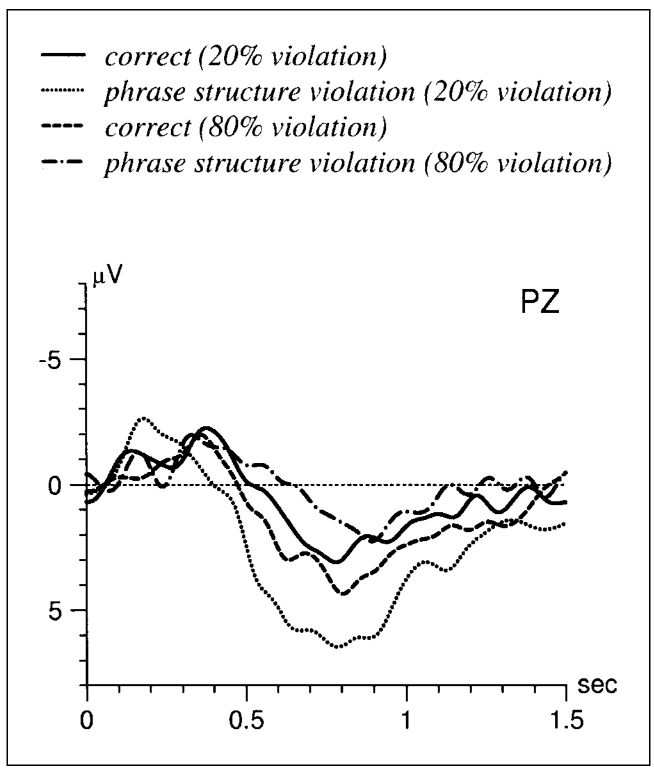

Figure 4. Grand average ERPs for the critical past participle for all four conditions at electrode Pz. A P600 component is elicited only for rarely occurring phrase structure violations.

of the components' dependency on proportion. Although the early negativity seems to be fairly independent of the percentage of incorrect sentences, the late positivity clearly depends on the proportion of incorrect sentences. Furthermore, the order of presentation of the two proportion conditions influenced the late positivity exclusively, leaving the early negativity unaffected. This dissociation strongly suggests that these two components reflect functionally distinct processes of language comprehension. In view of the rationale underlying our experimental paradigm, this data pattern leads to the conclusion that the processes reflected in the ELAN component are fairly automatic in nature, and the late positivity reflects processes that are at least to a great extent under the participant's control.

Earlier research suggested that the processes reflected by the ELAN can be specified as first-pass parsing processes (Friederici et al., 1996). The processes reflected by the P600 were defined as the parser's attempt to map the initial syntactic structure onto lexical-semantic information, including processes of reanalysis (Friederici, 1995). The view that the P600 reflects these types of second-pass parsing processes is supported by a study by Münte et al. (1997), who did not find a P600 for morphosyntactic violations in pseudoword sentences.

The late positivity observed in the present study may be discussed in light of a recent debate about whether the P600 is a member of the P300 family or, to be more precise, identical to the P3b component or not. This idea seems reasonable because these components have similar topography and timing. Because the P3b clearly depends on the variation of proportion, any possible dependency of the P600 on proportion must be considered as a relevant argument in this debate. Our data showed a clear dependency of the P600 on the proportion manipulation, further supporting the view that the P600 behaves very similarly to the P3b. This confirms recent results by Coulson et al. (1998) and Gunter et al. (1997), who both found the P600 to covary with proportion manipulations of agreement errors (but see Osterhout, McKinnon, Bersick, & Corey, 1996, who did not find any such dependency). However, the proportion manipulation did not influence the ERP responses to correct sentences, which could be predicted for the 80% violation condition in view of a P3 account. Such a prediction, however, is not necessarily valid for the following reason. Unlike in P3 experiments defining arbitrarily which stimuli are the high or low frequent ones, participants in language experiments have a referential system independent of the laboratory context that makes a correct sentence a highly probable event as opposed to a syntactically incorrect sentence. Therefore, the high proportion of incorrect sentences might not suffice to turn a correct sentence into an oddball event within the experiment.

Whatever the ultimate outcome of the P3/P600 debate might be, we fully agree with Gunter et al. (1997) and Osterhout et al. (1996) that the late positive component is a valuable tool in examining language comprehension processes, in particular, as it has been shown to vary in amplitude as a function of syntactic reprocessing (Osterhout et al., 1994) and in latency as a function of the complexity of syntactic reanalysis (Friederici, 1997). Furthermore, this debate does not affect our main conclusion concerning the automatic versus controlled status of the two processing stages in language comprehension reflected by the early negativity and the late positivity because the P3b component is usually interpreted as an index of the allocation of cognitive processing resources (Israel, Wickens, Chesney, & Donchin, 1980; Sirevääg, Kramer, Coles, & Donchin, 1989; Strayer & Kramer, 1990; Wickens, Kramer, Vanasse, & Donchin, 1983). Thus, independent of whether the P600 is a member of the P3 family or not, the observed dissociation in the dependency on proportion of the ELAN on the one hand and the P600 on the other hand suggests that the two processes underlying these components vary in their degree of automaticity.

One might wonder whether the task to be performed by the participants has had an influence on the result pattern. Judging the grammatical correctness of a sentence may reinforce controlled processes and thereby potentially influence the ERP components. Thus the observed ELAN component might not be attributed to automatic processes alone. Although we restrict our claims only to *relative* automaticity (see Note 1), it might be worthwhile to consider a potential influence of task. Considering other tasks we find that the ELAN component has been reported also with a probe detection task (Friederici et al., 1993, 1996). Moreover, Hahne and Friederici (1998) showed that shifting the participant's attention to semantic aspects of the sentences by instruction did not influence the ELAN but did affect the P600. Thus the ELAN component, but not the P600 component, seems to be rather independent of the participant's task.

The present data are fully compatible with structure-driven serial accounts of language parsing (Frazier, 1987; Gorrell, 1995), which assume a first-pass parse during which the parser automatically assigns the initial syntactic structure on the basis of word category information and a second parsing stage during which structural reanalysis (Frazier, 1987) or repair (Fodor & Inoue, 1994) takes place. This latter stage appears to be more controlled in nature. Thus it seems reasonable to assume that the automatic first-pass parse is reflected in the left anterior negativity, whereas the second parsing stage is reflected in the late positivity.

The data are neutral with respect to interactive models because they do not test the interaction of lexical-semantic and syntactic processes (for this issue see Hahne & Friederici, 1998). They do contribute, however, to the specification of the temporal and functional structure of syntactic parsing. The electrophysiological approach with its high temporal resolution allowed us to clearly separate early and late processes in parsing and to specify which of two subprocesses involved in parsing is affected by proportion manipulations, namely, the late process that is under participants' strategic control and the early process that is unaffected by proportion manipulations and is automatic.

METHODS

Participants

Twenty right-handed students from the Free University of Berlin (8 male, age range 20 to 29 years, mean 24 years) participated in the experiment. They were all native speakers of German and were either paid or received course credit. All of them had normal or corrected to normal vision and no known hearing deficit.

Materials

There were two types of experimental sentences, correct sentences and syntactically incorrect sentences. Correct sentences consisted of a noun phrase, an auxiliary, and a past participle (*Das Baby wurde gefüttert—The baby was fed*). Syntactically incorrect sentences contained a phrase structure error. In these sentences a preposition appeared after the auxiliary and was directly followed by a past participle (*Die Gans wurde im gefüttert—The goose was in the fed*). Because the preposition indicates the beginning of a prepositional phrase necessarily consisting of a preposition and a noun phrase, this sequence of words creates a clear word category violation.

Each of 40 critical past-participle forms appeared exactly once in a correct sentence and once in an incorrect sentence, yielding 40 sentence pairs. These 40 sentence pairs were randomly assigned to two base lists so that one sentence of each pair appeared in each list, and each list consisted of 20 correct sentences and 20 incorrect sentences, respectively (see Table 1).[4]

Each of the two base lists was supplemented by 80 additional filler items, each presented twice to establish the proportion manipulation, resulting in a total of 200 items per list. Apart from the correct sentences described above, each list consisted of a second type of correct sentences, namely, sentences with a complete prepositional phrase (*Die Kuh wurde im Stall gefüttert—The cow was in the barn fed*). This was necessary to ensure that participants were not able to anticipate the violation when encountering the preposition. Filler sentences with the same item number (e.g., 041/corr, 041/c_pp, 041/syn) shared the participle (as in our example, the word *fed*) but contained different preceding content words (*baby, goose, cow*). These filler sentences were distributed over the two base lists as illustrated in Table 1, resulting in eight different presentation lists. Within one list the number of the two types of correct sentences was identical (i.e., there were 80 sentences of this type in the 20% violation condition and 20 sentences in the 80% violation condition; see Table 1). All

Table 1. Schema of the experimental design. Ten percent of the items correspond to 20 items. Critical items (1 to 40) were included only once per list, whereas filler items (41 to 120) were included twice.

Items	*%*	*Proportion condition*[a]							
		20% violation condition				*80% violation condition*			
Base list		*A*	*A*	*B*	*B*	*A*	*A*	*B*	*B*
Presentation list		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Critical items									
1–20	10	corr	corr	syn	syn	corr	corr	syn	syn
21–40	10	syn	syn	corr	corr	syn	syn	corr	corr
Filler items									
41–60	10	c_pp	syn	c_pp	syn	c_pp	syn	c_pp	syn
61–80	10	syn	c_pp	syn	c_pp	syn	c_pp	syn	c_pp
81–100	10	corr	c_pp	corr	c_pp	syn	syn	syn	syn
101–120	10	c_pp	corr	c_pp	corr	syn	syn	syn	syn
41–80	20	corr	c_pp	corr	c_pp	syn	syn	syn	syn
81–120	20	c_pp	corr	c_pp	corr	syn	syn	syn	syn

[a] corr = correct sentences ("Das Baby wurde gefüttert"); syn = phrase structure violations ("Die Gans wurde im gefüttert"); c_pp = correct sentences including a prepositional phrase ("Die Kuh wurde im Stall gefüttert").

participles were regular German verb forms starting with the morpheme *GE-*.

The items were pseudorandomized with the critical items appearing at the same positions in the two experiments. The critical items were equally distributed across the whole experiment. Within each list there were no repetitions of critical items. The repetition of filler items with the same item number (i.e., same participle) was separated by at least a lag of 15 items. For each of the two base lists two different basic randomizations were created. Note that the grand average ERPs on the critical items were based on exactly the same items. Any difference between the two proportion conditions therefore must be caused by the composition of the filler sentences set resulting in a dominance of either correct or incorrect sentences within the whole experiment.

All sentences were spoken by a female speaker. The sentences were digitized and the onset of the critical past participle was determined by careful visual and auditory inspection of the speech wave to allow for a precise time-locking of the ERP in each sentence. To avoid possible prosodic or other acoustic cues prior to the presentation of the critical word in the syntactic violation condition, the speaker initially produced a correct sentence with a noun after the preposition. In a second step this noun was spliced out of the digitized speech signal using a speech-editing tool. To ensure that this splicing procedure would not be impaired by coarticulation phenomena, we used nouns for which the phonological transitions from preposition offset to noun onset and from noun offset to participle onset were identical. Two colleagues, both familiar with digital speech processing, who listened to our spliced sentences and visually inspected the corresponding waveforms, did not detect any striking acoustic or visual deviations from an ordinary, unspliced speech sample. Furthermore, after the experimental sessions the participants were asked whether they had noticed any acoustic oddness of these spliced sentences, but none of them had done so.

The proportion manipulation was realized within-subjects in different sessions. The order of participation in the 20% versus 80% violation session was counterbalanced across subgroups of participants. The two sessions were separated by at least 1 week but not more than 2 weeks. Each participant received different randomizations across sessions. Although there were no repetitions of critical sentences, the same critical past-participle forms were presented in both sessions, once in a correct sentence and once in an incorrect sentence.

Electrophysiological Recording

The electroencephalogram (EEG) was recorded with 19 tin electrodes secured in an elastic cap (Electro Cap International). The specific locations were Fz, Cz, Pz, F7, F3, FT7, FC3, CP5, P3, P7, O1, F8, F4, FT8, FC4, CP6, P4, P8, O2 (cf. Sharbrough, 1991). The vertical electrooculogram (EOG) was recorded from electrodes placed above and below the right eye. The horizontal EOG was recorded from electrodes positioned at the outer canthus of each eye. All recordings were referenced to the left mastoid. Activity over the right mastoid bone was actively recorded. This recording was not systematically affected by any of the experimental factors. Off-line all recordings were re-referenced to the linked mastoid. Electrode impedance was kept below 2 kΩ. The electrical signals were amplified within a bandpass from direct current to 40 Hz and were digitized with a sampling rate of 250 Hz.

Procedure

Participants were seated in a comfortable chair and listened to the stimuli via headphones. During the presentation of the sentences participants were instructed to fixate on a small star in the middle of a CRT screen placed in front of them and to avoid blinks during the presence of the fixation star. The fixation marker appeared on the screen 500 msec prior to the beginning of the auditory sentence presentation and remained visible until 3000 msec after sentence offset. Then a response sign appeared on the screen for 2000 msec and the participant was asked to indicate via pushbuttons whether the sentence was correct or incorrect. The next trial started after an interstimulus interval of 1000 msec.

Data Analyses

Prior to averaging, trials with eye movement or other artifacts were rejected (about 10% of all trials, range per condition: low error proportion: 0 to 6 trials for correct sentences and 0 to 8 trials for the incorrect sentences; high error proportion: 0 to 10 trials for correct sentences and 0 to 6 trials for incorrect sentences). Event-related potentials were computed for each participant in each experimental condition for 1500 msec time-locked to the onset of the critical past participle relative to a 100-msec poststimulus baseline.[5] Only trials on which participants responded correctly were included in the averaging procedure.

Statistical analyses were performed on the mean amplitude within two time windows: one ranging from 100 to 300 msec, and the other ranging from 500 to 1000 msec. These latency windows were chosen because they roughly correspond to the latency ranges of the components observed for phrase structure violation as described in the literature and because the visual inspection of the grand averages revealed the strongest condition effects within these time windows. All analyses were quantified using the multivariate approach to repeated measurement (O'Brian & Kaiser, 1985; Vasey & Thayer, 1987). In statistically analyzing our data, we employed a hierarchical analysis schema: Data from midline and lateral electrode sites were treated separately to allow for quantification of hemispheric differences. In a first step the analyses for the midline sites included three factors: Proportion (20% versus 80% violation), Sentence Type (correct versus syntactic violation) and Electrode (Fz, Cz, Pz). Instead of the factor Electrode, the analyses for the lateral electrode sites included two topographical factors that were completely crossed: Hemisphere (left versus right) and Region (anterior versus posterior). The eight electrodes chosen for the two levels of the factor Hemisphere were F7, F3, FT7, FC3, CP5, P3, P7, O1 versus F8, F4, FT8, FC4, CP6, P4, P8, O2. The two levels of the factor Region were F7, F3, FT7, FC3, F8, F4, FT8, FC4 versus CP5, P3, P7, O1, CP6, P4, P8, O2. Interactions of Sentence Type and Proportion led to separate analyses for each session. If the factor Sentence Type revealed a significant interaction with either the factor Proportion or a topographical factor, we further examined this interaction at a lower level. Reliable interactions of Sentence Type and topographical factors were further analyzed by conducting analyses of Sentence Type and Electrode separately for each of the four quadrants. In the case of reliable interactions of Sentence Type and Electrode, we performed t tests for each electrode within that quadrant.

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Notes

1. Meanwhile, the strict dichotomy of the two processes has been challenged. Recent views hold that processes may vary in their degree of automaticity (i.e., ought to be viewed as more or less automatic and more or less controlled; Friedrich, Henik & Tzelgov, 1991; Hoffman & MacMillan, 1985; Kahneman & Chajczyk, 1983). By using the term *automatic* we follow this latter view (i.e., we do not assume that automatic processes are *totally* capacity-free).
2. For this quadrant, which is of particular interest, an additional analysis was conducted that revealed that even in this quadrant there was no interaction of Sentence Type and Proportion ($F < 1$).
3. This positivity was observed across a time window from 500 to 1000 msec, which is in the time range of the late syntactic positivity usually referred to as P600. For reasons of consistency we use the term P600, although the component does not peak at 600 msec.
4. Although 20 trials are less than the number of trials usually recommended for ERP language experiments to achieve good signal-to-noise-ratio (which is > 25 trials, cf. Kutas & Van Petten, 1994), this fact is compensated for by the relatively high number of participants. Also, the clear results of the statistical analyses clearly demonstrate that our obtained ERPs are highly reliable.
5. Because a prestimulus baseline calculated from the onset of the critical word would cover different word types (auxiliary versus preposition), we decided to use this poststimulus baseline (see Friederici et al., 1996; Neville et al., 1991; Osterhout et al., 1994, for a similar procedure). Although prepositions are mostly classified as being closed class words and are therefore comparable to auxiliaries, it has been demonstrated that the processing of different types of prepositions differs. Although obligatory prepositions behave like closed class words, lexical prepositions show the same effects as open class words (Friederici, 1983, 1985). Because our prepositions were lexical prepositions, it seems reasonable to prefer a poststimulus baseline rather than a prestimulus baseline. Statistical analyses of the baseline time window did not reveal any systematic differences between conditions. Furthermore, we conducted additional statistical analyses with a 100-msec prestimulus baseline, treating the two baselines as a within-subject factor. None of the effects reported in this paper interacted with the baseline factor (all Fs < 1), indicating that the effects are not influenced by the baseline chosen here.

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