

# First-Pass versus Second-Pass Parsing Processes in a Wernicke's and a Broca's Aphasic: Electrophysiological Evidence for a Double Dissociation

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The present paper is a first attempt to integrate the classical brain lesion behavioral impairment approach of functional neuroanatomy and the electrophysiological brain mapping approach in the domain of syntactic processing. In a group of normal age-matched controls we identified three electrophysiological components previously observed in correlation with language comprehension processes: an early left anterior negativity normally seen in correlation with syntactic first-pass parsing processes (ELAN), a centroparietal negativity seen in correlation with processes of lexical-semantic integration (N400), and a late centroparietal positivity observed in correlation with secondary syntactic processes of reanalysis and repair (P600). The early left anterior negativity was absent in a patient with an extended lesion in the anterior part of the left hemisphere sparing the temporal lobe, although the late centroparietal positivity and the centroparietal N400 were present. In a patient with a left temporal-parietal lesion the early left anterior negativity was found to be present, whereas the N400 component was absent. These findings suggest that first-pass parsing and secondary processes are subserved by distinct brain systems.

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## INTRODUCTION

The debate concerning the underlying deficit in Broca's aphasia is still ongoing. In the mid 1980s it became clear that most Broca patients although agrammatic in their output as well as in their comprehension<sup>1</sup> possessed a

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<sup>1</sup> There are, however, rare cases with agrammatic output but intact comprehension (Miceli, Menn, & Goodglass, 1983).

surprising amount of grammatical knowledge (Linebarger, Schwarz, & Safiran, 1983; Wulfeck, 1988; Friederici & Kilborn, 1989). Subsequent research tried to specify the deficit in terms of a computational deficiency. While some researchers assumed that reduced memory capacities were responsible for the observed agrammatic comprehension (Kolk & van Grunsven, 1985) others hypothesized that the deficit was a reflection of an alteration in the temporal structure of either access or integration processes (Friederici, 1988; Hagoort, 1990; Prather, Zurif, Stern, & Rosen, 1992).

In one of these proposals (Friederici, 1988, 1995) the temporal structure of language processing is assumed to be altered due to a slower access to specifically syntactic information in a two stage parsing model. Such a two stage parsing mechanism had been proposed by Frazier (Frazier, 1978; Frazier & Fodor, 1978) to describe normal parsing. She assumed a first stage during which the parser assigns an initial syntactic structure to the input and a second stage during which thematic role assignment takes place. The initial first-pass parsing stage supposedly operates quite fast and automatic mainly on the basis of word category information building local phrase structure, whereas the second stage during which syntactic and lexical-semantic information are mapped onto each other for interpretation may involve controlled processes as well (Gorrell, 1995). Under these assumptions, slower access to syntactic information results in an inefficient first-pass parse.

Although there is some debate as to whether the initial stage is purely structure driven (Frazier, 1978; Ferreira & Clifton, 1986; Gorrell, 1995) or may also consider lexically encoded information such as verb-argument structure (McClelland, St. John, & Taraban, 1989; Shapiro, Nagel, & Levine, 1993) we will assume an initial stage of structure building that is primarily structure driven and working in a highly automatic fashion. This stage may guarantee the ease with which normals parse the incoming linguistic information. If this initial processing stage is slowed down efficient on-line parsing may no longer be possible.

This assumption was supported by behavioral studies showing that Broca's aphasics with comprehension problems are delayed in their on-line syntactic processes (Friederici, 1985; Friederici & Kilborn, 1989). It was demonstrated that Broca's aphasics' performance improved when more time was given to process the relevant information, for example, by increasing the interstimulus interval between the sentence prime and the target in a syntactic priming task (Haarmann & Kolk, 1990). Additional support for the view that these patients may have lost the automaticity of the syntactic processes came from a syntactic priming study in which normal controls and Broca's aphasics were required to ignore the sentence prime. Broca's aphasics who did demonstrate a syntactic priming effect with a considerable delay under normal priming conditions were able to attentionally ignore the prime whereas normal controls were not (Kilborn & Friederici, 1994). This strongly suggests that Broca's aphasics, in contrast to normals, process syntactic informa-

tion in a controlled way. On the basis of these findings the hypothesis was formulated that the Broca's area and adjacent areas support the fast and automatic syntactic processes necessary for efficient on-line parsing (Friederici, 1995).

A different way of exploring the assumed language-brain relationship is to register brain activity in a normal brain while presenting language stimuli. From the different methods available such as SPECT, PET, fMRI, MEG, and EEG only the latter two allow monitoring of language processes on line, millisecond by millisecond. This may be the reason why most studies on syntactic processing have used event-related brain potential (ERP) measurements.<sup>2</sup> From an overview of recent ERP studies focusing on syntactic processes in normals it is evident that there are two components which are observed in correlation with syntactic parsing, an early left anterior negativity (ELAN) present around 200 ms or later after the critical stimulus and a late positive component present around 600 ms (P600) after the critical stimulus (Friederici, 1995).

#### *The Early Negative ERP Component*

The early negativity which has its localized maximum over the anterior part of the left hemisphere was observed in correlation with the processing of phrase structure errors (Neville, Nicol, Barss, Forster, & Garrett, 1991; Friederici, Pfeifer, & Hahne, 1993; Münte, Heinze, & Mangun, 1993; Friederici, Hahne, & Mecklinger, 1996) as well as with the processing of function words in correct sentences (Neville, Mills, & Lawson, 1992; Nobre & McCarthy, 1994). An ERP component sensitive to syntactic word class around 200 ms was also reported by Samar and Berent (1986) in a principle component analysis also suggesting early syntactic operations.<sup>3</sup> A left anterior negativity that emerged around 400 ms was observed in correlation with errors of inflectional morphology (Gunter, Vos, & Mulder, 1995; Coulson, King, & Kutas, 1998; Penke, Weyers, Gross, Zander, Münte, & Clahsen, 1997). Thus the latency for this left anterior negativity seems to vary across studies.

However, those studies which are comparable with respect to presentation mode and stimulus material show consistent results. Both these factors may influence the component's latency. Let us first consider the presentation mode. Note that the ERP is usually time locked to the word onset. Thus we

<sup>2</sup> But see Mazoyer, Tzourio, Frak, Syrota, Murayama, Levrier, Salamon, Dehaene, Cohen, and Mehler (1993) for a recent PET study including a syntactic condition in a variety of conditions that were subtracted from each other and Stromswold, Caplan, Alpert, and Rauch (1996) for a PET study which focuses on syntactic processing as such.

<sup>3</sup> In this principle component analysis they identified one component at 140 ms that was sensitive to syntactic phrase structure violations and one at 220 ms that was sensitive to word category information.

may not only expect general differences between the visual (holistic) and auditory (left-to-right) presentation of the critical stimulus, but also between auditorily presented words whose word category decision point (e.g., verb vs. noun) appears in the word stem of the critical item (e.g., *eat* vs. *meal*) and those whose word category decision point appears at the suffix (e.g., *refined* vs. *refinement*). It has been shown that in the auditory domain the latency of the left anterior negativity observed for phrase structure violations including the latter type of words is longer (Friederici, Hahne, & Mecklinger, 1996) than that for phrase structure violations including the former type of words (Friederici, Pfeifer, & Hahne, 1993). Second, latency variations may be influenced by the different types of syntactic violation, namely, phrase structure violation on the one hand versus inflectional violation on the other, as these differ functionally. According to Frazier (1978) first-pass parsing processes consist of structure building processes on the basis of category information, be it for lexical elements (e.g., N = noun, V = verb, etc.) or for functional elements (e.g., INFL = inflection). This information is sufficient to build up a phrase structure tree. Lexical specification of these categories [e.g., N → meal, refinement, etc.; INFL → -Ø (3. person singular), -s (3. person plural)] is only required later during the process. Therefore, violations of word category information should be detected earlier than violations of agreement indicated by particular inflectional forms. Thus, inflectional errors, in contrast to word category errors, lead to a left anterior negativity around 400 ms. This negativity is followed by a late positivity in some studies (in Dutch: Gunter, Vos, & Mulder, 1995; Gunter, Stowe, & Mulder, 1997; in English: Coulson, King, & Kutas, 1998; in German: Penke et al., 1997; but see Hagoort et al., 1993; and Osterhout & Mobley, 1995).

### *The Late Positive ERP Component*

The late positivity was found in correlation with syntactic anomalies either requiring a reanalysis as in garden-path sentences (Osterhout & Holcomb, 1992, 1993; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995) or a repair as in syntactically incorrect sentences (Neville et al., 1991; Hagoort, Brown, & Groothusen, 1993; Gunter, Vos, & Mulder, 1995; Coulson, King, & Kutas, 1998; Osterhout & Mobley, 1995). This late positive component is widely distributed over centroparietal areas and is usually observed with an onset around 500 ms and a duration of several hundred milliseconds (labeled P600). It has been correlated with the cost of reprocessing during sentence comprehension (Osterhout & Holcomb, 1992).

If one tries to characterize those syntactic anomalies that elicit a biphasic ERP pattern (left anterior negativity followed by a late positivity) and those that only elicit a late positivity it appears that syntactic errors realized as a phrase structure violation or as an agreement violation are correlated with

a biphasic pattern.<sup>4</sup> Whereas syntactic anomalies realized as garden-path sentences usually elicit a positivity only.

On the basis of the available literature it was hypothesized that the early left anterior negativity may reflect first-pass parsing processes during which an initial syntactic structure is built and that the late positivity might reflect secondary syntactic processes including processes of structural reanalysis and repair (Friederici, 1995).<sup>5</sup>

A recent paper by McKinnon and Osterhout (1996) suggests an interesting specification of this view. In their study, they investigate structural violations of long distance dependencies, i.e., structural violations that span across clauses. As they found a late positivity as the only component correlated with the violation, their study may suggest that the early left anterior negativity must be viewed as a component reflecting on-line processes of local phrase structure building. Violations that span across clauses may not be reflected in this component.

We take the two ERP components, i.e., the ELAN and the P600, observed in correlation with syntactic processes to reflect different stages of syntactic parsing (Friederici, 1995; Friederici & Mecklinger, 1996; Friederici et al., 1996). The early negativity observed over left anterior sites (ELAN) is viewed to reflect a first-pass parsing stage responsible for local phrase structure building. The late centroparietal positivity (P600) is assumed to reflect a second stage responsible for thematic role assignment including processes of syntactic reanalysis and repair.

### *The N400 Component*

In addition to these two syntactic components a number of studies have identified a particular component in correlation with lexical-semantic processes (Kutas & Hillyard, 1980; for review see Kutas & Van Petten, 1994). This lexical-semantic component can be described as a negativity present around 400 ms after the onset of the critical stimulus distributed over the posterior parts of both hemispheres. Due to its polarity and temporal structure this component is called N400.

The N400 component was investigated most recently in aphasic patients with different lesion sites. Revonsuo and Laine (1996) present a case with

<sup>4</sup> But see Hagoort, Brown, and Groothusen (1993) for an exception.

<sup>5</sup> There is, however, some debate about the nature of the left anterior negativity. While most researchers take it to reflect syntactic processes (Neville et al., 1991; Friederici et al., 1993; Münte et al., 1993), Kluender and Kutas (1993) argue that it should be considered as a working memory component. This argument is based on the finding that the left anterior negativity is observed in correlation with sentence types including a filler-gap relation, i.e., sentences in which a particular element has been moved out of its initial position as for example in *wh*-questions. The argument, however, ignores at least some of the data in the literature, especially those early left anterior negativities reported in correlation with the processing of syntactic errors.

an "extensive infarction in the left frontotemporal areas . . . the lesion encompassed the Broca's area, part of the Wernicke's area, insula, and underlying white matter" (p. 31).<sup>6</sup> One week postonset the patient was diagnosed as a global aphasic. The patient, however, was only tested in the ERP experiment 2½ months postonset. No independent neuropsychological or language examination was carried out at that time. In this ERP experiment semantically congruous and incongruous sentences were presented auditorily to the patient. The patient was required to listen to the sentences attentively. Similar to normals he showed an N400 component for the incongruous words.<sup>7</sup>

Hagoort, Brown, and Swaab (1996) report ERP results from a group of Broca's ( $N = 13$ ) and a group of Wernicke's aphasics ( $N = 7$ ). For semantically incongruous sentences they observed a significant N400 component for Broca's aphasics and a reduced N400 component for Wernicke's aphasics. Lesion data from these patients are presented averaged over Broca's aphasics and Wernicke's aphasics, respectively. The figures indicate that Wernicke's aphasics' lesions are mostly restricted to the left posterior regions, whereas Broca's aphasics' lesions included anterior *and* posterior regions. Due to this grouping based on clinical aphasia types independent of lesion site, conclusions about the functional brain topography, unfortunately, are not possible.

### *The Present Study*

Based on the functional and neurotopographical specification of the language related ERP components we set out to investigate the patterns of brain activity during sentence comprehension in a Broca patient with a left anterior lesion and a Wernicke patient with a left posterior lesion. Based on earlier reaction time studies we hypothesized that Broca's aphasics have lost the fast and highly automatic first-pass parsing mechanism, but that they may be able to access grammatical knowledge by more controlled mechanisms. This was based on the finding that Broca's aphasics do show a syntactic priming effect during sentence comprehension, however, with considerable delay (Friederici & Kilborn, 1989; Haarmann & Kolk, 1991, 1994). The priming effect must be taken as an indication that these patients do have access to syntactic information during sentence processing. Moreover, these patients' syntactic ability in grammaticality judgment tasks was demonstrated by Linebarger, Schwartz, and Saffran (1983). The finding that Broca's aphasics, unlike normal controls, are able to ignore sentence fragments in a syntactic priming experiment and perform a lexical decision task on the target uninfluenced by the prime (Kilborn & Friederici, 1994) is taken to sup-

<sup>6</sup> From the displayed CAT scan of this patient 4 days postonset, however, extension of the lesion to Wernicke's area cannot be seen.

<sup>7</sup> In addition for 10% of the experimental sentences the patient was required to give an acceptability judgment. For these he showed chance level performance. The combined data were taken to indicate semantic processing without conscious understanding.

port the notion that these patients' syntactic processes are subject to the individual's control. We predicted that if the Broca's area supports this early parsing mechanism we should not be able to observe the early syntactic component (ELAN) in a patient with a lesion including Broca's area, but possibly the late syntactic component (P600) and the semantic component (N400). Wernicke patients who have been shown to demonstrate some on-line syntactic capacities (Friederici, 1985; Blumstein, Milberg, Dworetzky, Rosen, & Gershberg, 1991) in the absence of lexical and sentential comprehension are expected to differ in their brain activity from a Broca's aphasic. We predicted that a patient with a circumscribed lesion in the Wernicke's area should show the early syntactic component (ELAN), but no or a reduced component reflecting lexical-semantic integration or thematic role assignment (N400).

In the present experiment we examined one Broca patient and one Wernicke patient in addition to eight normal controls. We recorded their event-related brain potentials while they were listening to sentences including lexical-semantic and syntactic violations presented as connected speech.

## METHODS

### *Participants*

In this study two aphasic patients and eight normal age-matched controls were tested.

### *Aphasic Cases*

The individual patient histories of the two aphasic cases are displayed in Table 1.

*Case W.S.* The first case, W.S., is a 62-year-old right-handed male who had suffered from a stroke in 1981. He was classified as a Broca's aphasia on the basis of the Aachen Aphasia Test. The test scores of the relevant subtests are displayed in Table 1. He showed the typical agrammatic output seen in agrammatic Broca's aphasia. Lesion site was confirmed by an MRI (see Fig. 1).

On August 17, 1995 (i.e., 14 years/5 months/3 weeks postonset), serial T1- and T2-weighted 6-mm images were obtained parallel and perpendicular to the CA-CP-line. The T1-weighted native horizontal images revealed an extended lesion in the territory of both the left middle and the left anterior cerebral artery.

The continuous lesion area encloses: (1) the superior frontal gyrus, from the frontal pole to the paracentral lobule (not including its posterior fronto-medial cortex); (2) the middle frontal gyrus, except its most rostral portion; (3) the opercular and an adjacent band of the triangular part of the inferior frontal gyrus; (4) the rostral and upper insular (including the external capsules); and (5) the frontodorsal white matter down to the moderately enlarged lateral ventricle.

The following left-sided brain structures are largely spared: (1) the anterior

TABLE 1

Patient	Age	Sex	Etiology	Classification AAT	Comp. AAT	Naming	Token test	Lesion
W.S.	62	m	CVA (1981)	Broca (100%)	114 (100%)	101 (82%)	9 (83%)	Left frontal and insula
G.R.	38	f	CVA (1994)	Wernicke (71,7%)	93 (71%)	111 (96%)	36 (36%)	Left temporoparietal



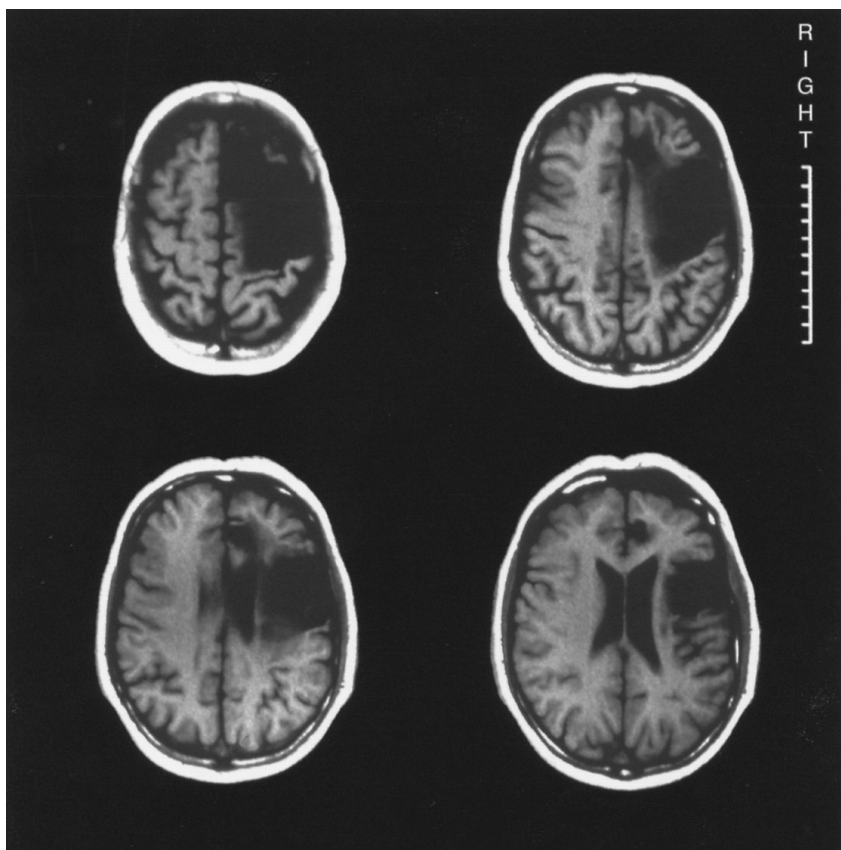


FIG. 1. MR image of patient W.S.

cingulate cortex and the cingular bundle; (2) the caudate nucleus and the putamen; (3) the parietal lobe; and (4) the temporal lobe (and in particular its mediobasal parties).

Taken together, the NMR images show large, pseudocystically transformed infarction in the supply area of the left middle and left anterior cerebral artery. The left middle cerebral artery infarction is centered on the branches of the frontal flank, the left anterior cerebral artery infarction on the internal frontal artery.

With respect to the question at issue the anterior language area (including Broca's area), the anterior arcuate fasciculus and (at least) the anterior supplementary motor area are most likely lesioned, whereas the posterior language area and the subcortical nuclei appear completely intact.

*Case G.R.* The second case G.R. is a 37-year-old right-handed female who suffered from a stroke in 1994. She was classified as a Wernicke's aphasia on the Aachen Aphasia Test. Scores of the relevant subtests are displayed in Table 1. Lesion site was confirmed by CT (see Fig. 2).

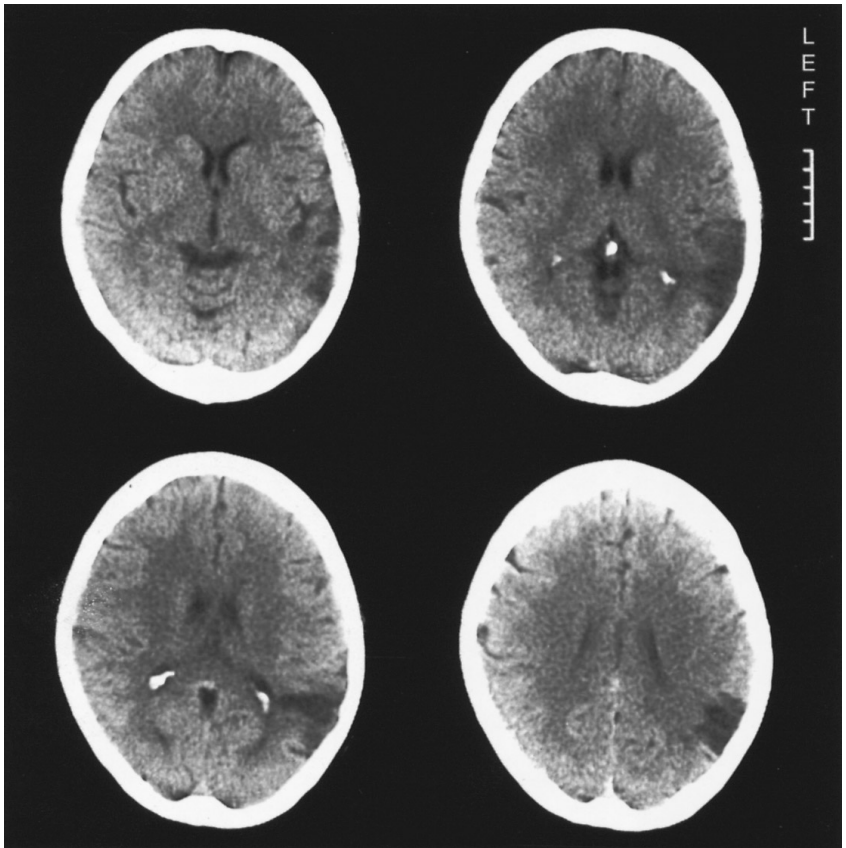


FIG. 2. CT scan of patient G.R.

On October 19, 1994 (20 months/2 weeks postonset), serial axial CT 8-mm images parallel to the orbitomeatal line were obtained.

The images revealed an area of significantly decreased density within the territory of temporal and parietal branches of the left middle cerebral artery. The well-marked lesion area is centered on the posterior third of the upper temporal lobe (presumably on the superior temporal gyrus) and the adjacent portion of the parietal lobe (presumably on the inferior angular and less possibly also on the supramarginal gyrus).

Except for a small strip of tissue between the involved parietal cortex and the not significantly enlarged atrium of the lateral ventricles the temporal-parietal white matter is largely intact. The posterior insula appears spared; the insular cistern, however, is slightly enlarged.

Taken together, the CT images show a mainly cortical, left-sided middle cerebral artery infarction restricted to the territories of posterior temporal

TABLE 2

Material	
(1)	Correct sentence: Der Finder wurde belohnt. <i>The finder was rewarded.</i>
(2)	Semantic violation: Die Wolke wurde begraben. <i>The cloud was buried.</i>
(3)	Phrase structure violation: Der Freund wurde im besucht. <i>The friend was in the visited.</i>
(4)	Morphosyntactic violation: Der Schatz wurde bewache (1. Pers. Sing.). <i>The treasure was guard.</i>

branches and the inferior angular artery. The lesion area encloses a portion of the posterior language cortex and most likely Wernicke's area.

*Normal Controls.* In addition to these two aphasic patients eight right-handed age-matched participants without neuropathological history served as normal controls (NCs). Four served as controls for patient W.S. (Broca-NCs) and four for patient G.R. (Wernicke-NCs). Broca-NCs were chosen to match W.S. in sex, age, and handedness. The four Broca-NCs were right-handed males at a mean age of 61.75 years ranging from 61 to 63 years. Four NCs were chosen to match G.R. in sex, age, and handedness. Wernicke-NCs were right-handed females at a mean age of 36.25 years ranging from 34 to 39 years.

### Material

The material used in the experiment consisted of sentences which were either correct (Sentence Type 1) or incorrect in that the sentence final word did not match the previous sentence context. Examples of each sentence type are displayed in Table 2. Sentence Type 2 was incorrect with respect to lexical-semantic aspects due to a selectional restriction violation. Sentence Type 3 was incorrect with respect to the required phrase structure due to a word category error. Note that German is a verb final language and that the preposition requires a noun and not a verb as a correct continuation. Sentence Type 4 contained a morphosyntactic error due to an incorrect verb inflection.<sup>8</sup>

<sup>8</sup> In all sentences the critical word was at sentence final position. Although the argument may be raised that specific effects may confound with so-called end-of-sentence wrap-up processes (e.g., Osterhout & Holcomb, 1992; Osterhout & Mobley, 1995), results from earlier studies indicated that the specific effects under consideration were present when the critical word was in mid-sentence position (Friederici et al., 1996) or in sentence final position (Friederici et al., 1993).

There was a total of 240 sentences with 40 sentences in each experimental category and 80 filler sentences to balance the amount of correct and incorrect sentences.

### *Procedure*

Participants were seated in a comfortable chair and were requested to carefully listen to sentences which were presented over headphones and to indicate whether the sentence heard was correct or not. Nineteen tin scalp electrodes mounted in an elastic cap (Electro Cap) were used—13 were placed according to the 10–20 system (Jaspers, 1958) and 6 were placed at additional sites over the Broca's area and the Wernicke's area left and the homologous areas at the right side as well as at a left anterior temporal and a right anterior temporal side, i.e., Broca's region (BL was defined in the frontotemporal region as crossing point between T3-Fz and F7-Cz) and the right hemisphere homologue (BR, defined as the crossing point between T4-Fz and F8-Cz) and the Wernicke's region (WL was defined in the posterior-temporal region as crossing point between T3-P3 and C3-T5) and the right hemisphere homologue (W.R., i.e., crossing point between T4-P4 and C4-T6). The left anterior temporal electrode (ATL) was defined as half the distance between F7 and T3 and the right anterior temporal electrode (ATR) corresponding as half the distance between F8 and T4. The EEG was recorded monopolar against linked mastoids.

Vertical electrooculogram (EOG) was recorded from electrodes placed above and below the right eye; horizontal EOG was recorded from electrodes placed beside the left and the right eye.

Electrode impedance was maintained below 5 k $\Omega$ . Biosignals were recorded with a DC-amplifier (low-pass filter settings 40 Hz) and digitized with 4 ms resolution.

ERPs were calculated from the onset of the critical word until 1500 ms hereafter. The onset of the critical word was marked within each sentence to allow the time locking of the ERP. The first 100 ms of the critical word were used as a baseline.

Sentences were presented auditorily. Prior to each sentence a fixation cross was presented on a computer screen for 500 ms. Sentence duration was approximately 1800 ms. The fixation cross was present throughout the sentence presentation and 3200 ms thereafter. Then two faces, a frowning face and a smiling face, were presented to the left and right of the center of the screen. Participants were instructed that a sentence judgment was required and that the frowning face to the left of the center of the screen symbolized an unacceptable sentence and the smiling face to the right of the center of the screen symbolized an acceptable sentence. Judgment response was required by a button press. No special instruction concerning the speed of the response was given; correctness of the response was emphasized. Participants were

TABLE 3

Grammaticality Judgment Performance: Number of Correct Responses of 40 Trials

Participants	Age (years)	No. correct	Sentence type		
			Semantic violation	Phrase structure violation	Morphosyntactic violation
Normal age-matched controls					
Broca-NCs					
A	62	39	39	40	40
B	61	40	39	40	40
C	63	40	40	40	39
D	61	40	39	37	39
Wernicke-NCs					
A	37	35	39	39	40
B	34	40	39	39	40
C	35	40	38	39	40
D	39	38	40	40	39
Aphasics					
Case 1 (W.S.) <sup>a</sup>	62	77	77	80	80
Case 2 (G.R.)	37	21	39	35	38

<sup>a</sup> Due to a high number of eye movement related artifacts case 1 took part in a second session, resulting in an overall trial number of 80 trials.

holding a response panel on their laps with two buttons. The left button (corresponding to the left of the screen) was the *NO/unacceptable* button; the right button (corresponding to the right of the screen) was the *YES/acceptable* button. After 2500 ms the faces disappeared and the screen was blank for 1500 ms before the next trial began.

A total of 240 sentences was presented in six blocks with 40 items each. Experimental and filler items were systematically distributed over the six blocks in a quasi-randomized order. Two different randomizations were constructed and distributed equally across subjects.

## RESULTS

### *Behavioral Data*

The number of correct responses for each condition and subject is displayed in Table 3.

Normal controls as well as W.S. showed a high level of judgment accuracy. G.R., in contrast, classified most of the incorrect sentences correctly as being incorrect, but her performance was at chance level for the correct sentences.

### *ERP Data*

As the ERP data for normal controls were group data while the aphasic data were single case data we treated them differently in the statistical analyses.

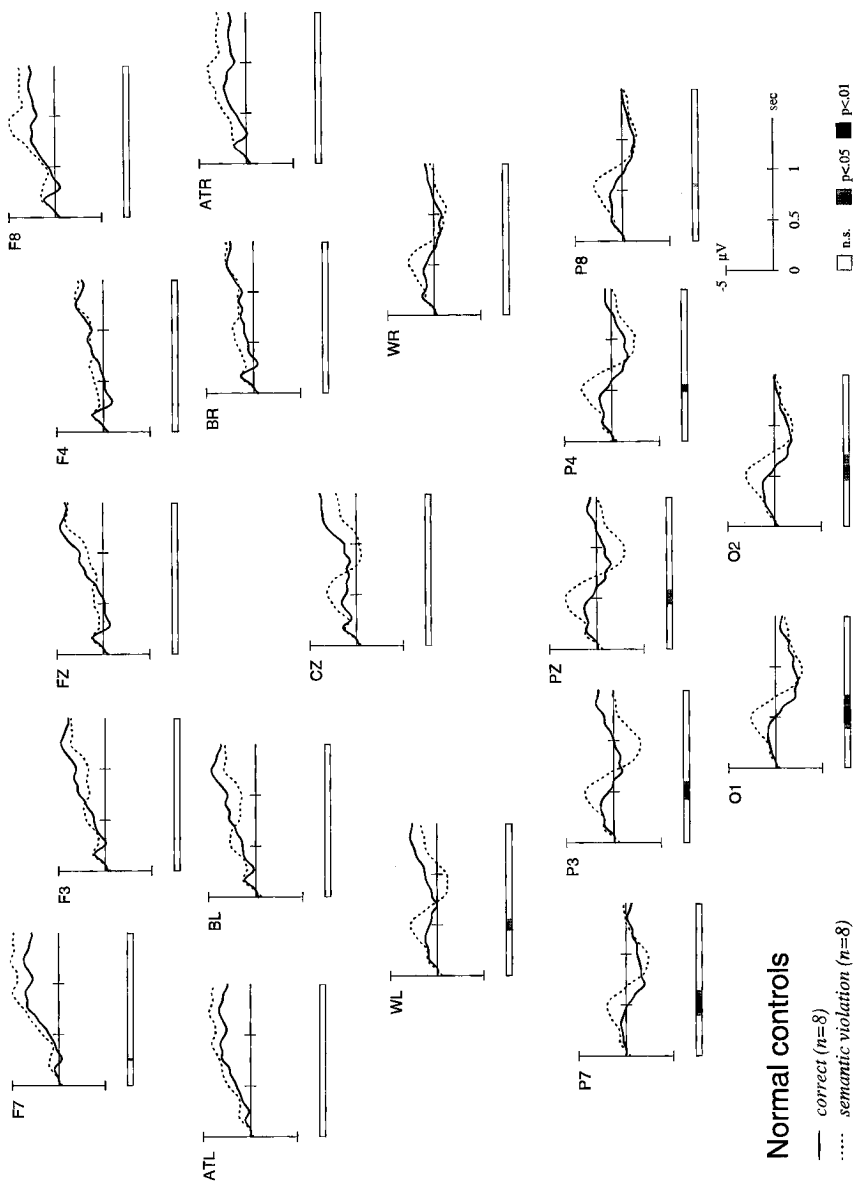
ERPs for normal controls were analyzed using standard analyses of variance (ANOVAs). These analyses focused on the critical components observed in a prior experiment with younger adults using the same stimulus materials and procedure (Friederici, Pfeifer, & Hahne, 1993): (1) a left anterior negativity around 180 ms for the phrasal violation condition, (2) a centroparietal negativity around 400 ms (N400) for the semantic condition, and (3) a centroparietal positivity between 600 and 1500 ms.

For each violation type an ANOVA was calculated including the factors Condition (correct/incorrect) and Group (Wernicke-control/Broca-control). The analysis for the phrasal condition calculated for the time window 100–300 ms over the electrodes in the left anterior quadrant revealed a significant main effect of condition ( $F(1, 6) = 12.01, p < .01, MSe = 0.53$ ), but neither main effect of Group ( $F(1, 6) < 1$ ) nor an interaction of the two variables ( $F(1, 6) = 2.52, p < .16$ ). The analysis for the semantic condition was calculated for the time window 300–500 ms over the electrodes in the two posterior quadrants. It revealed a significant main effect of condition ( $F(1, 6) = 11.07, p < .02, MSe = 0.54$ ), but no main effect of Group ( $F(1, 6) < 1$ ) and no interaction ( $F(1, 6) < 1$ ). The analysis of the morphosyntactic condition for the time window 600–1500 ms over the electrodes of the two posterior quadrants, finally, revealed a main effect of condition ( $F(1, 6) = 13.46, p < .01, MSe = 2.16$ ), but again neither a main effect of Group ( $F(1, 6) < 1$ ) nor an interaction ( $F(1, 6) < 1$ ). Given that no group-related differences were found for the relevant components tested here, the two groups were collapsed to constitute a single group of normal controls.

As we are dealing with single case data for the aphasic participants we were not able to use standard statistical ERP analysis procedures. Therefore we decided to use running *t* tests to test the reliability of the differences between the correct and the incorrect condition for each of the two aphasic patients. These *t* tests were calculated at each sampling point (i.e., every 4 ms) at each electrode site. In the result figures areas in which the conditions differ significantly are plotted below each electrode with gray areas indicating a  $p < .05$  and the black areas indicating a  $p < .01$ .

### *Normal Controls*

The group of normal controls showed an ERP pattern similar to that observed in an earlier study using the same stimulus material (Friederici et al., 1993). As can be seen from Figs. 3–5 no clear N1 and P2 components are visible in the waveforms (this also holds for Figs. 6 to 11). The absence of these components is due to the fact that the critical words were presented



**FIG. 3.** Average of ERPs of normal controls for the semantic violation condition. The waveforms are superimposed for the correct and the violation condition. The vertical lines indicate the onset of the critical word. Below each electrode the significant difference obtained by a running  $t$  test calculated over subjects is displayed.

in a continuous speech stream and not as single words in a word-by-word fashion. Due to this presentation mode no clear offset N1/P2 components are visible.

For the lexical-semantic condition normals showed a negative going wave about 400 ms postonset of the critical word (Fig. 3). This negativity is distributed over centroparietal areas in the left and the right hemisphere as the running *t* test displayed below each electrode indicates. This pattern resembles that of the N400 component observed in correlation with lexical-semantic integration processes (e.g., Kutas & Hillyard, 1983).

For the phrase structure condition the normal participants displayed (Fig. 4) a left anterior negativity between 100 and 300 ms after the onset of the critical word. Moreover, a centroparietal positive going wave was observed between 300 and 700 ms after the word indicating the word category violation. Early negativities (ELAN) similar to the one observed here have been registered in correlation with the processing of word category errors (Neville et al., 1991; Friederici et al., 1993). Centroparietal positivities have been found to correlate with the processing of syntactic errors (Hagoort et al., 1993) as well as with the processing of garden-path sentences (Osterhout, Holcomb, & Swinney, 1994).

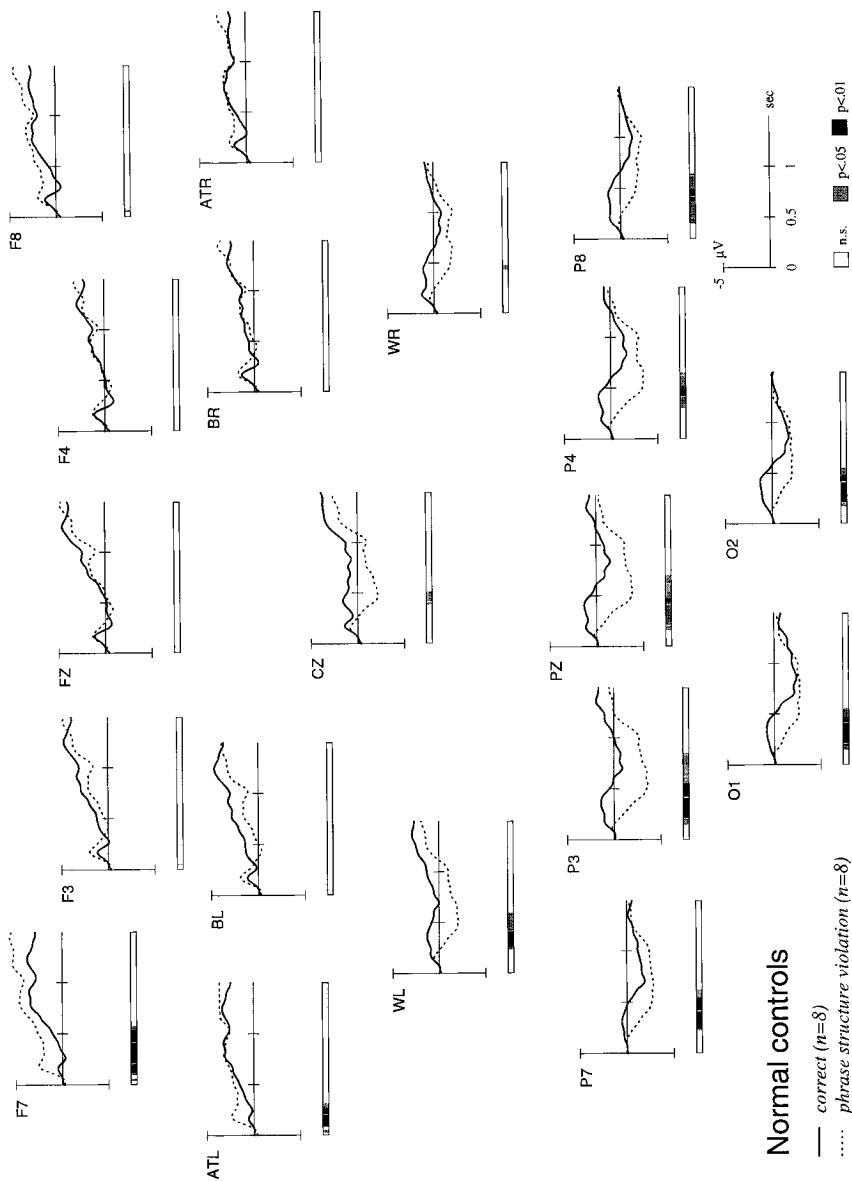
For the morphosyntactic condition the normal participants displayed a centroparietal positive going wave between 600 and 1500 ms (P600) (see Fig. 5). This is in agreement with studies investigating inflectional violations (in Dutch: Hagoort et al., 1993; in English: Osterhout & Mobley, 1995). However, a biphasic pattern consisting of a negative going wave preceding a late positivity has been reported in correlation with the processing of inflectional errors (Friederici et al., 1993; Gunter et al., 1995). An explanation for the observed differences between studies is not available and must await an exploration in future experiments.

The discussion whether the observed positivity reflects primary syntactic processes or processes of reanalysis and repair is still ongoing (Friederici & Mecklinger, 1996; Mecklinger et al., 1995; Osterhout et al., 1994). We take the two components observed in correlation with syntactic processes to reflect the two stages of syntactic parsing (Frazier, 1978), namely, the early stage of initial parsing being reflected in the left anterior negativity and a later secondary stage involving thematic mapping including processes of reanalysis and repair reflected in the late centroparietal positivity (Friederici, 1995).

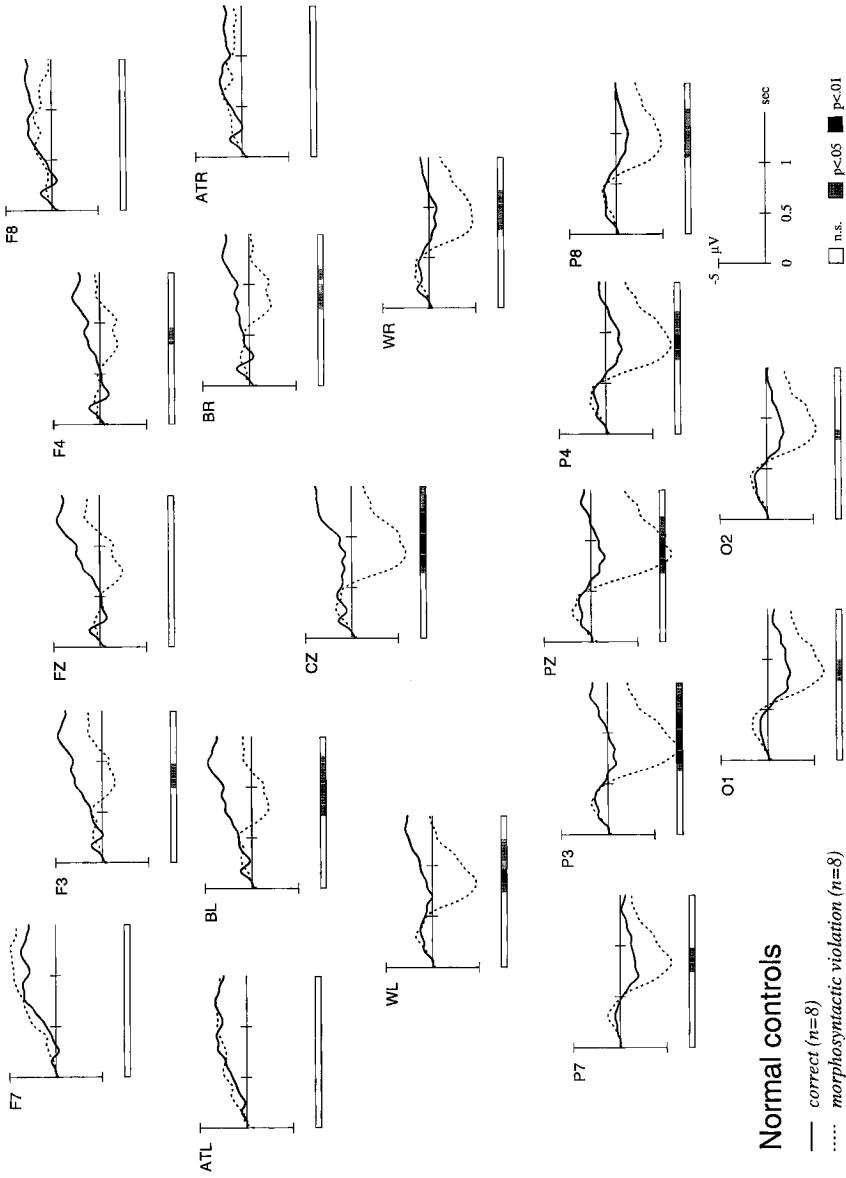
### *Aphasic Cases*

The number of artifact-free trials gathered from the two aphasic cases participating in this study is sufficient to allow a calculation of averages of the correctly answered trial in each condition, even for G.R. who only participated in one session.





**FIG. 4.** Average of ERPs of normal controls for the syntactic, i.e., phrase structure violation condition. The waveforms are superimposed for the correct and the violation condition. The vertical lines indicate the onset of the critical word. Below each electrode the significant difference obtained by a running  $t$  test calculated over subjects is displayed.



**Normal controls**

— correct (n=8)  
 ..... morphosyntactic violation (n=8)

**FIG. 5.** Average of ERPs of normal controls for the morphosyntactic violation condition. The waveforms are superimposed for the correct and the violation condition. The vertical lines indicate the onset of the critical word. Below each electrode the significant difference obtained by a running *t* test calculated over subjects is displayed.

*Case G.R.* Wernicke patient G.R. similar to normals displayed an early left anterior negativity for the phrase structure violation condition. This negativity present between 200 and 350 ms was significant at the left anterior electrode F7 and ATL (Fig. 6). There was also a late positivity with a maximum at Pz which was significant between 1200 and 1500 ms. In contrast to normal controls the onset of this positivity was considerably delayed.

For the semantic violation condition no N400 component was observed (Fig. 7). There was, however, a late posterior positivity starting as late as 1200 ms and which was similar in latency and distribution to the one observed for the phrase structure violation condition. This is in clear contrast to the pattern demonstrated by normal controls in this study and that of normal participants in previous studies. In these studies the processing of sentences with a semantic violation was always correlated with an N400 component, but never with a late positivity.

For the morphosyntactic violation condition (Fig. 8) G.R. again displayed a very late centroparietal positivity present between 1000 and 1500 ms. Given the finding that G.R. showed a similar positivity for the two other conditions it appears that it is not specific to the processing of the morphosyntactic violation.

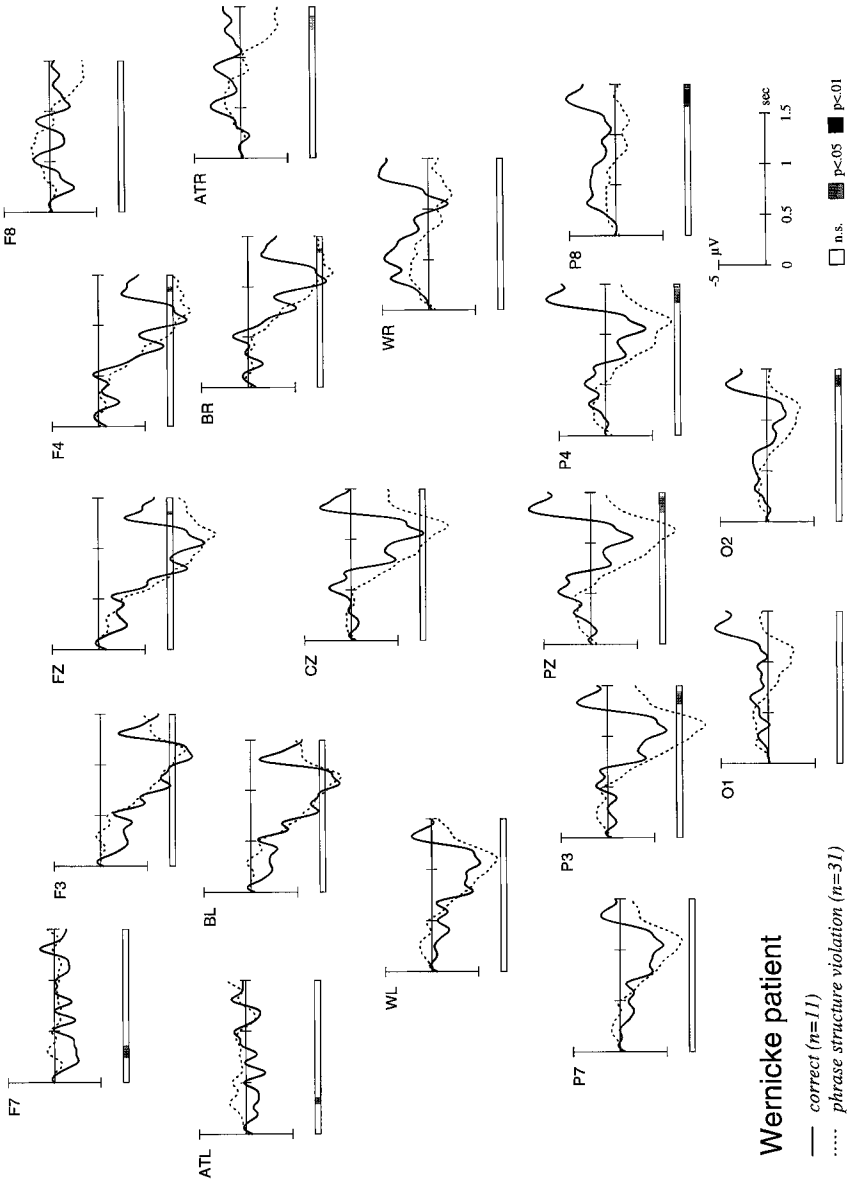
*Case W.S.* Broca patient W.S. unlike both normal controls and unlike G.R. demonstrated no early left anterior negativity (Fig. 9). There was, however, a late positivity between 400 and 1100 ms in correlation with the processing of phrase structure violations. This positivity was not only present over centroparietal sites, but also at frontal sites of the right hemisphere.

Similar to normal controls W.S. showed a negative component between 500 and 950 ms for the semantically incorrect sentence (Fig. 10). Although somewhat delayed the pattern of this negativity resembles that of an N400 component usually seen in correlation with lexical-semantic processes in normals.

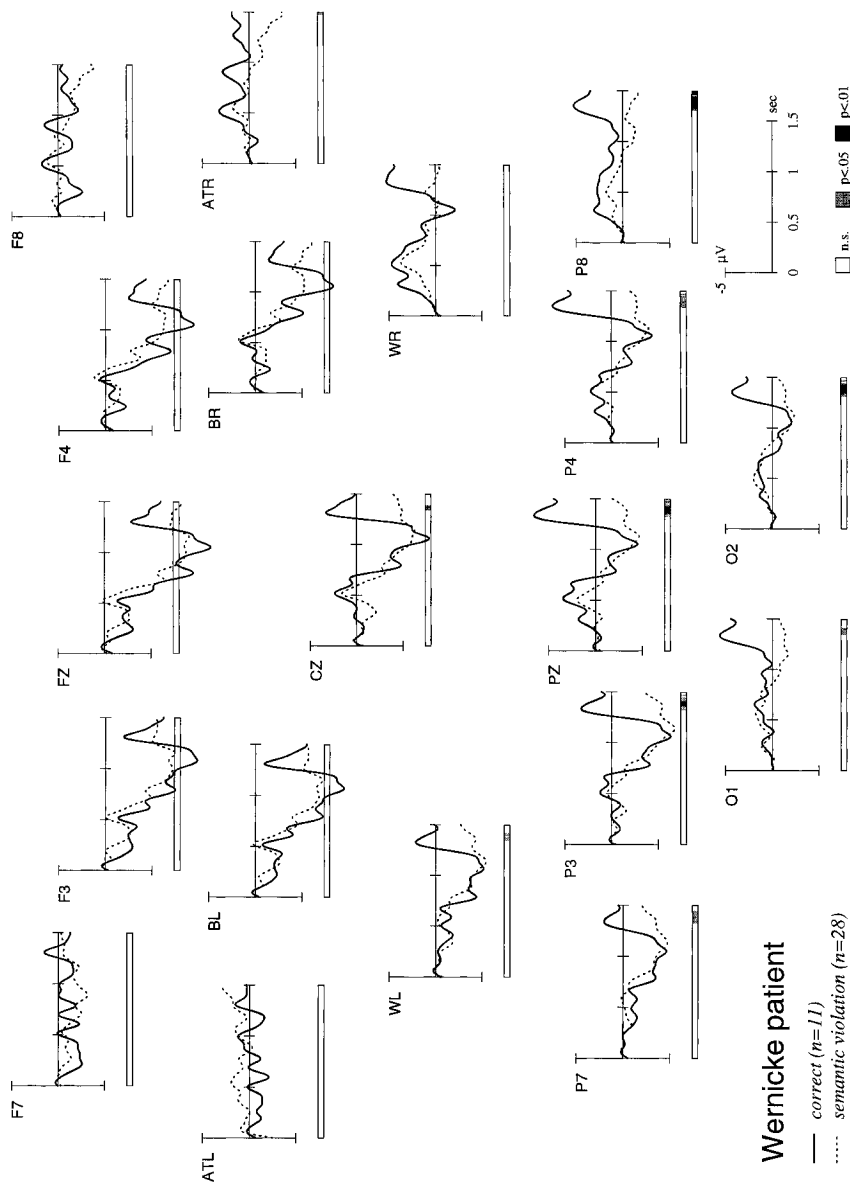
For the morphosyntactic violation condition (Fig. 11) W.S. displayed a positive going wave between 600 and 1200 ms most pronounced over centroparietal areas but also present over frontal sites of the right hemisphere.

## DISCUSSION

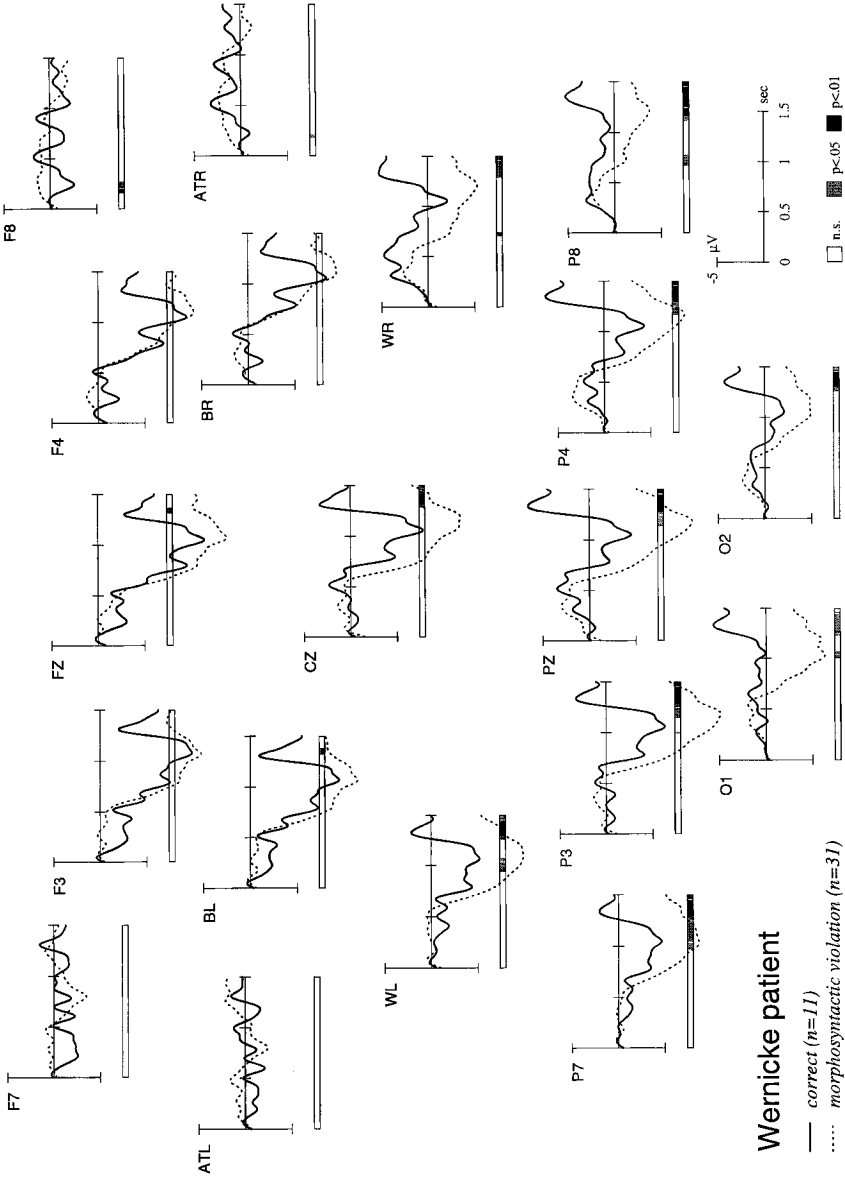
The study investigated lexical-semantic and syntactic processes in two aphasic cases and eight normal age-matched controls using event-related brain potential measures. The results of the normal controls are in agreement with earlier findings, in particular, with those from a study using similar language material in an auditory language comprehension experiment (Friederici et al., 1993). All three components observed in this earlier study in correlation with language processes were present in the normal controls: (1) an early left anterior negativity indicating the disruption of first-pass parsing processes was observed in the condition including a phrase structure



**FIG. 6.** Average of ERPs of Wernicke-patient G.R. for the syntactic, i.e., phrase structure violation condition. The waveforms are superimposed for the correct and the violation condition. The number of trials that were included in the analysis is indicated in the lower left of the figure. These are only those to which a correct judgment was given. The vertical lines indicate the onset of the critical word. Below each electrode levels of significance for a running *t* test calculated over items are displayed.



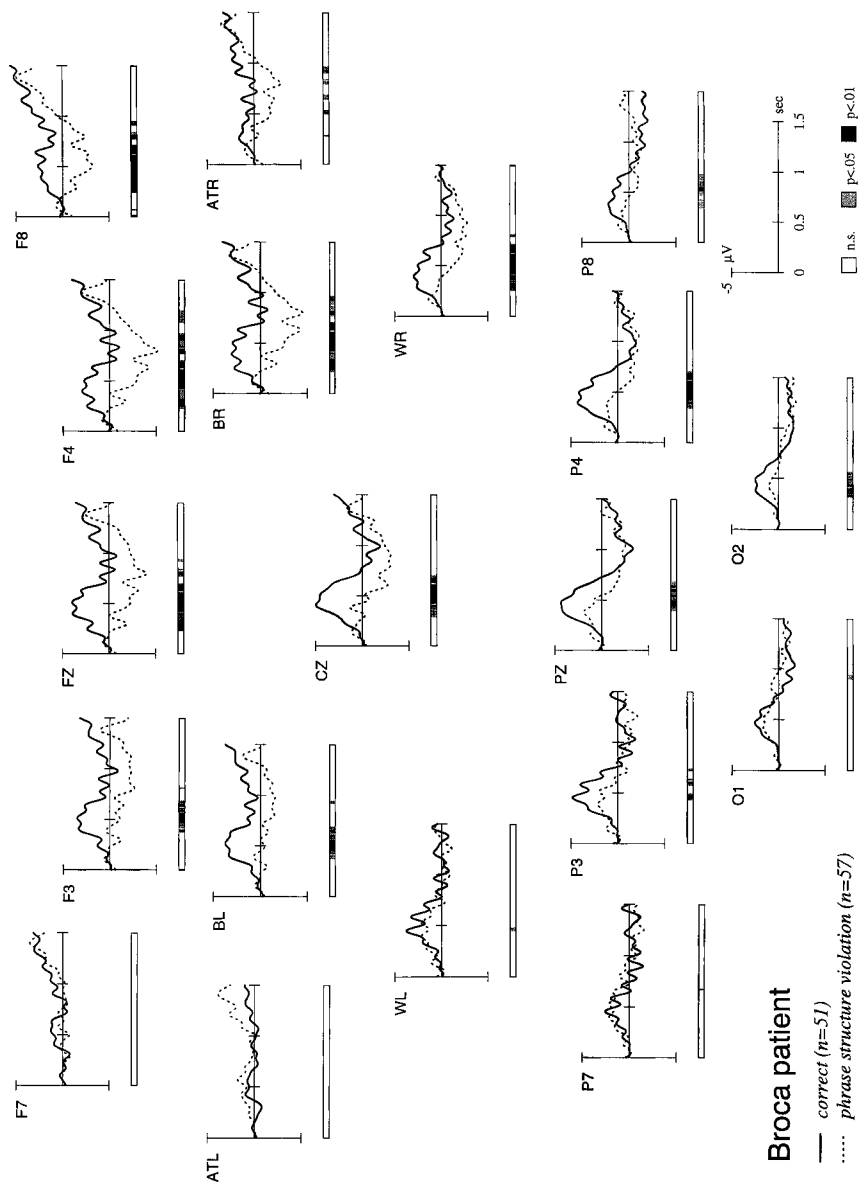
**FIG. 7.** Average of ERPs of Wernicke-patient G.R. for the semantic violation condition. The waveforms are superimposed for the correct and the violation condition. The number of trials that were included in the analysis is indicated in the lower left of the figure. These are only those to which a correct judgment was given. The vertical lines indicate the onset of the critical word. Below each electrode levels of significance for a running  $t$  test calculated over items are displayed.



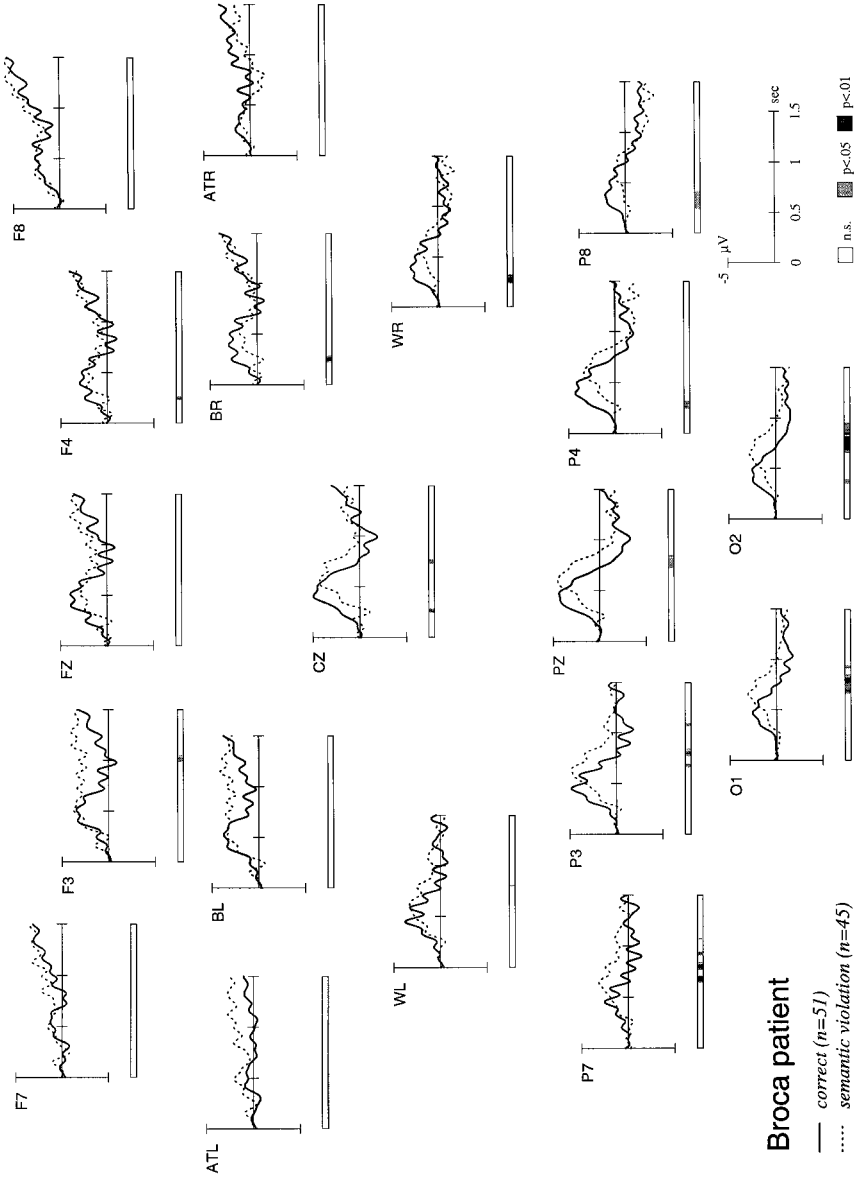
**Wernicke patient**

— correct (n=11)  
..... morphosyntactic violation (n=31)

**FIG. 8.** Average of ERPs of Wernicke-patient G.R. for the morphosyntactic violation condition. The waveforms are superimposed for the correct and the violation condition. The number of trials that were included in the analysis is indicated in the lower left of the figure. These are only those to which a correct judgment was given. The vertical lines indicate the onset of the critical word. Below each electrode levels of significance for a running *t* test calculated over items are displayed.

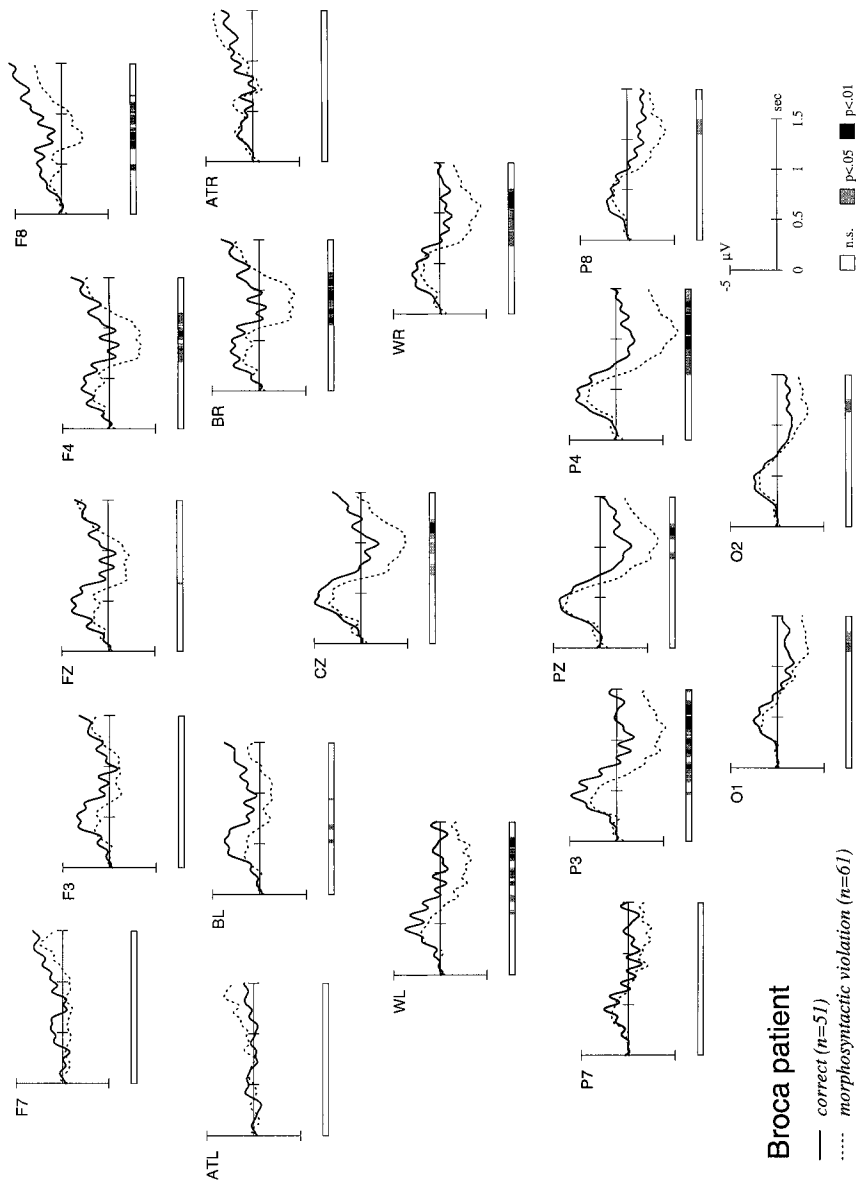


**FIG. 9.** Average of ERPs of Broca-patient W.S. for the syntactic violation condition. The waveforms are superimposed for the correct and the violation condition. The number of trials that were included in the analysis is indicated in the lower left of the figure. These are only those to which a correct judgment was given. The vertical lines indicate the onset of the critical word. Below each electrode levels of significance for a running  $t$  test calculated over items are displayed.



**FIG. 10.** Average of ERPs of Broca-patient W.S. for the semantic violation condition. The waveforms are superimposed for the correct and the violation condition. The number of trials that were included in the analysis is indicated in the lower left of the figure. These are only those to which a correct judgment was given. The vertical lines indicate the onset of the critical word. Below each electrode level of significance for a running *t* test calculated over items are displayed.





**FIG. 11.** Average of ERPs of Broca-patient W.S. for the morphosyntactic violation condition. The waveforms are superimposed for the correct and the violation condition. The number of trials that were included in the analysis is indicated in the lower left of the figure. These are only those to which a correct judgment was given. The vertical lines indicate the onset of the critical word. Below each electrode levels of significance for a running  $t$  test calculated over items are displayed.

error, (2) an N400 component indicating the disruption of lexical-semantic integration processes was present in the condition including a lexical-selection error, and (3) a late positivity taken to reflect secondary processes of syntactic repair was present both for the phrase structure violation and the morphosyntactic violation condition.

Although it is widely accepted that the N400 component reflects lexical-semantic (e.g., Kutas & Hillyard, 1983; Kutas & Van Petten, 1994) and in particular lexical integration processes (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995), it is less clear which subprocesses the two other components observed in correlation with syntactic processing reflect. While Hagoort et al. (1993) take the late positivity to reflect syntactic processes, Osterhout and Holcomb (1992, 1993) view the late positivity to index the cost of reprocessing when confronted with syntactic anomalies, not assigning a functional role to the left anterior negativity observed in some studies. We (Friederici, 1995; Friederici et al., 1996) have tried to specify the functional role of the two ERP components found in correlation with different types of syntactic anomalies by proposing that the early left anterior negativity might reflect primary syntactic processes and the late positivity to reflect secondary processes of syntactic reanalysis and repair. Within this approach primary syntactic processes are defined as first-pass parsing processes responsible for building up the initial syntactic structure on line as it is usually observed in correlation with the processing of local phrase structure errors (Neville et al., 1991; Friederici, Pfeifer, & Hahne, 1993). Results from a recent study investigating syntactic violations of long-distance dependencies that showed no left anterior negativity (McKinnon & Osterhout, 1996) might suggest that the early left anterior negativity (ELAN) may only be elicited by within-clause phrase structure violations, but not by across-clause phrase structure violations. The secondary processes which we assume to be reflected in the late positivity (P600) may include processes of syntactic reanalysis as in the case of syntactically correct garden-path sentences and processes of syntactic repair as in the case of syntactically incorrect sentences.

The present finding that different ERP components identified in normal listeners can be selectively impaired as a function of lesion site and aphasic breakdown supports the view that the different components are generated by different brain systems. In detail, the ERP data from the two aphasic patients suggest the following conclusions: W.S., a patient with the clinical classification of an agrammatic Broca's aphasia and with a large left anterior lesion including Broca's area leaving the posterior language area and subcortical nuclei intact, demonstrated a selective absence of the early left anterior negativity. This component normally seen in correlation with first-pass parsing processes responsible for building up local phrase structure seems to depend upon the intactness of the left anterior cortical regions. It is not clear, however, whether the left anterior cortical areas themselves generate this component or whether these areas are part of a network generating this com-

ponent. Interestingly, this patient who has lost the ability to produce grammatically correct sentences in an on-line fashion and to process sentences during language comprehension on line<sup>9</sup> showed a late positive component indicating that he detected the syntactic violation although presumably on the basis of secondary processing mechanisms. Processing mechanisms that have been discussed involve those of controlled syntactic processes which appear to be separable from automatic first-pass parsing processes (Kilborn & Friederici, 1994). W.S., moreover, demonstrated an N400 component normally seen in correlation with lexical-semantic processes, although with some delay compared to the normal controls. This latter finding is compatible with a recent study by Hagoort, Brown, and Swaab (1996) reporting that Broca's aphasics although somewhat delayed when integrating this type of information into preceding context showed an N400 pattern. A recent ERP study with a case of global aphasia whose CT scan suggest a primarily anterior lesion also displayed a negativity between 300 and 800 ms in response to a semantic anomaly (Revonsuo & Laine, 1996). Thus, the ERP result for the syntactic condition observed for W.S. is compatible with the view that Broca patients have lost the automatic first-pass parsing processes, but may have retained controlled second-pass parsing processes (Friederici & Kilborn, 1989; Haarmann & Kolk, 1994).<sup>10</sup> Furthermore, it is compatible with the view that left anterior brain areas are involved in the cortical network supporting language comprehension (see Neville et al., 1992, for a similar argument on the basis of an ERP study with deaf signers). The role this anterior brain system plays in the comprehension process may be restricted to procedures supporting automatic first-pass parsing processes.

G.R., a patient classified as a Wernicke's aphasic and with a circumscribed lesion centered on the posterior third of the superior temporal gyrus and the adjacent portion of the inferior angular/(supramarginal) gyrus, demonstrated the selective presence of the early left anterior negativity indicating intact first-pass parsing processes. This finding was predicted on the basis of earlier behavioral results indicating the intactness of some aspects of automatic syntactic processes (Friederici, 1985; Blumstein et al., 1991). The absence of

<sup>9</sup> W.S. participated on an on-line sentence comprehension experiment examining patient's on-line sensitivity to inflectional elements as word category markers (noun vs. verb) (Friederici, Wessels, Emmorey, & Bellugi, 1992). In this study W.S. showed no on-line grammatically effect.

<sup>10</sup> Tyler, Ostrin, Cooke, and Moss (1995) have tried to argue against this view showing that four of four agrammatic patients display a sensitivity for subcategorization violation and morphological substitutions. These data, however, do not concern the argument put forward here that first-pass parsing processes are defined to involve structure building on word category information alone. The only relevant test is a patient's sensitivity to word category violations. Only one of four agrammatic patients showed such a sensitivity on line. This patient, however, was a special case as his aphasia resulted from a motorcycle accident which he had when he was 16 years old. It is not clear to what extent brain plasticity at this young age may have allowed functional reorganization.

the N400 component in the semantic condition suggests that lexical-semantic integration processes are impaired. These findings although compatible with earlier behavioral studies reporting lexical-semantic deficits in Wernicke's aphasics seem only partly compatible with a recent ERP study in which a group of Wernicke's patients had shown a reduced N400 effect (Hagoort et al., 1996). However, a direct comparison with this study may not be valid for two reasons. First, in the Hagoort et al. study ERPs were averaged across all correct vs. incorrect sentences, respectively, independent of a control of whether they were processed correctly or not. As in this study no reaction indicating the patient's judgment of the sentence was required; a statement about the reduced presence or absence of the N400 with respect to the correctly answered trials is not possible. A reduced N400 pattern may be the result of averaging over correctly and incorrectly understood sentences. Second, ERPs were averaged over patients with different lesions. On the basis of group data, however, it is difficult to describe whether a single patient with a particular lesion in the temporal-parietal language area may or may not have revealed an N400 component. In addition, it is not unlikely that the presence or absence of the N400 depends not only on the lesion site but on other tissue variables such as type and stage of necrosis or chronicity of the lesion. In the present study G.R. also showed a very late positive component starting around 1200 ms which, however, was present in the semantic as well as in the two syntactic conditions. Given that this component appeared in all three conditions we are hesitant to attribute it to a specific linguistic process. It may rather be taken to reflect a process of a general kind, for example, some nonspecific surprise component (Donchin, 1981) reflecting the patient's "feeling" that there is something wrong with the sentence without being able to specify it.<sup>11</sup>

## CONCLUSION

The ERP pattern for the two patients provides a picture of a double dissociation: Patient G.R. showed a selective presence of the early left anterior negativity in the absence of an N400 component, whereas patient W.S. showed a selective absence of the early left anterior negativity in the presence of an N400 component. When considering the presence of the early left anterior negativity and the absence of the N400 in G.R. in light of the patient's lesion site, we may conclude that the intactness of some part of the posterior language area seems a necessary condition for the generation of an N400 component. The finding of an absence of the left anterior negativity and the presence of an N400 in W.S. in whom anterior brain areas are lesioned suggests that posterior brain areas must be supported by an additional anterior

<sup>11</sup> G.R. reported that she often felt that something was wrong with the sentence presented, but that she was not sure.

cortical regions of the left hemisphere to guarantee the efficiency with which the normal brain processes language on line.

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