AGRAMMATIC COMPREHENSION:

AN ELECTROPHYSIOLOGICAL APPROACH

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AGRAMMATIC COMPREHENSION:

AN ELECTROPHYSIOLOGICAL APPROACH

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Woorden gaan over en
weer, waar de mensen zijn.
Woorden zijn lief en leed,
rouw en geboortepijn.

(H. Oosterhuis)

DANKWOORD

Door de veelheid van raadgevers komt iets tot stand

(Spreuken 15: 22)

Nu ik op onze zolderkamer deze woorden uit Spreuken zit te typen, realiseer ik mij pas goed hoe heerlijk het is om dit dankwoord te kunnen schrijven. Immers, een dankwoord schrijven veronderstelt dat het proefschrift echt af is! Eindelijk is het moment aangebroken waarop ik mijn *veelheid van raadgevers* kan danken voor hun afzonderlijke bijdrage aan de totstandkoming van dit proefschrift.

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INTRODUCTION

CHAPTER 1

If I say the tiger has been killed by the lion,
which animal is dead?`

From: Wings, a drama by Arthur Kopit (1978)[1]

Apart from the treasures *faith, hope and love,* one of the greatest gifts to humanity is the ability to communicate. Not a day passes, but we convey messages and understand messages expressed by others. The relative ease and speed with which we speak and comprehend language makes that we are barely aware of the complex processes that underlie the miracle of speaking and understanding language. However, this situation can dramatically change if someone suffers from aphasia, an acquired language impairment resulting from focal brain damage, such as a cerebro-vascular accident (CVA). The once so natural day-to-day communicative situations can turn into a struggle to understand and to be understood (Doesborgh et al., 2002). The severity of the aphasic impairment can differ from one patient to another. In aphasia, all language modalities can be affected, and problems can arise at different linguistic levels such as phonology, morphology, semantics and syntax. Based on the symptoms patients exhibit, different aphasic syndromes can be distinguished. This dissertation focuses on syntactic comprehension problems in patients with Broca's aphasia from an electrophysiological perspective. Of particular interest is what syntax-related event-related brain potentials (ERPs) can reveal about the nature of the deficit that underlies agrammatic comprehension in patients with Broca's aphasia.

[1] In 1976, the father of the American playwright Arthur Kopit suffered a stroke which left him incapable of speech. The play *Wings* came about as a result of his son's attempt to deal with puzzling and frustrating questions about his father's infirmity: "To what extent was he still intact? *What was it like inside?"*.

In the remainder of this chapter, first the term agrammatic comprehension will be clarified. Next, a brief introduction to the technique of event-related brain potentials is given, accompanied by a succinct report of central findings in the ERP literature on language processing. Subsequently, results of recent studies investigating syntactic processes in Broca patients by means of ERP measurement are summarized. Finally, the general objective of the dissertation and its outline will be sketched.

AGRAMMATIC COMPREHENSION

The ability to process syntactic information is highly important for the understanding of spoken and written language. Consider for instance the following two sentences. “The man congratulates the woman” versus “The man is congratulated by the woman”. To understand that these two sentences express a different content, knowledge in itself about the meaning of the words ‘man’, ‘to congratulate’, and ‘woman’ is insufficient. In order to arrive at the correct interpretation of these sentences, the syntactic structure of the sequences of words needs to be analyzed. In addition, to understand the sentential meanings, it is necessary to map the syntactic information onto the correct thematic roles (‘who is doing what to whom’). Whereas neurologically unimpaired language users scarcely experience any difficulty in processing syntactic information, for some patients suffering from aphasia, syntactic processing is not a straightforward operation anymore. Disorders of syntax resulting from brain damage have most often been studied in patients with *Broca’s aphasia*. The most salient feature of Broca’s aphasia is the slow and effortful speech and the lack of grammatical markers in language production. Typically, the utterances consist mainly of high-frequency content words while many function words and inflections are being omitted, resulting in the characteristic telegraphic-like, *agrammatic* speech, with which the textbook Broca’s aphasia is associated. In severe cases, patients produce nothing more than one-word utterances, whereas in patients with a milder Broca’s aphasia, utterances can be produced with *some* syntactic organization.

Initially, patients with Broca’s aphasia were thought to have intact language comprehension and to have a speech production problem only. Indeed, these patients appear, at a cursory glance, to follow daily conversations with little difficulty and therefore their comprehension problem is less noticeable. However, careful testing starting in the 1970s (e.g.

Caramazza & Zurif, 1976; Heilman & Scholes, 1976; Kolk & Friederici, 1985) has revealed that many Broca patients (but see Miceli, Mazzucchi, Menn, & Goodglass, 1983; Kolk, van Grunsven, & Keyser, 1985; Nespoulous et al., 1988) suffer from *agrammatic comprehension*: they have problems with the comprehension of sentences that require for correct understanding a full analysis of the syntactic structure.

The study of agrammatic comprehension has been often approached by using the so-called sentence-picture matching task (e.g. Caramazza & Zurif, 1976; Caplan & Hildebrandt, 1988). In this task, patients usually see a set of pictures. After some time, a spoken sentence is presented. One of the pictures corresponds to the sentence content; the others are distracters. The patient's task is then to select from this set of pictures the one that best portrays the meaning of the presented sentence. By manipulating the kind of disagreement between the sentence and the distracter pictures, information can be obtained as to which aspects of the language system are affected in the patient.

The sentence-picture matching task has been applied to a variety of sentences of different structural types to probe Broca patients' ability to understand these different types of sentences (Berndt, Mitchum, & Wayland, 1997). This approach has revealed relative patterns of comprehension success and comprehension failure. Broca patients perform usually relatively well on semantically irreversible sentences like "The boy eats an apple" (Apples cannot eat boys). However, they have usually more difficulty with interpreting reversible sentences as "The boy kisses the girl" (Both boys and girls can kiss). Whereas assignment of thematic roles (*who was doing what to whom*) seems to be constrained by real world knowledge in irreversible sentences, these lexical-semantic cues are absent in semantically reversible sentences (Berndt, Mitchum, & Haendiges, 1996). Though, not all reversible sentences are equally difficult: passive reversible sentences are known to be more difficult than active reversible sentences. There has been a lively debate regarding the proportion of Broca patients that actually manifest these patterns of comprehension (Berndt et al., 1996; Zurif & Piñango, 1999; Berndt & Caramazza, 1999; Caramazza, Capitani, Rey, & Berndt, 2001). Nevertheless, the tendency of Broca patients with agrammatic comprehension toward thematic reversals in the comprehension of semantically reversible passive sentences has been frequently observed. Despite indications of an impairment in processing syntactic information, the term a-grammatic comprehension suggests more than in fact is the case, that patients with Broca's aphasia would suffer from a radical loss of syntax. There has been accumulating evidence from different experimental paradigms (including off-line syntactic judgement, on-line syntactic judgement, syntactic priming, word monitoring and sentence-picture matching studies), that agrammatic aphasics have not lost their syntactic knowledge, but that they are impaired in exploiting this knowledge in real time during the construction of a syntactic representation. The observation of Linebarger, Schwartz, and Saffran (1983) that agrammatic aphasics performed much better on grammaticality judgement tasks (although certainly not near one hundred percent correct) than on sentence-picture matching tasks, was the first demonstration of preservation of syntactic knowledge. Another type of evidence suggesting that syntactic knowledge has not been lost, comes from different types of variation that patients exhibit on sentence-picture matching tasks (cf. Kolk & Van Grunsven, 1985): variation of severity (both with-in and between subjects), and between-sentence variation. These findings are difficult to reconcile with the notion of a complete loss of syntactic knowledge, but they strongly favour the view that agrammatic comprehenders have a problem in the *processing* of this type of syntactic knowledge.

A number of hypotheses have been offered to account for Broca patients' syntactic comprehension problems (see for a review, Kolk, 1998). Some proposals approach the comprehension problems from a theoretically based linguistic perspective (e.g. Grodzinsky, 1986, 1995, 2000; Hickok, Zurif, & Canseco-Gonzales, 1993; Mauner, Fromkin, & Cornell, 1993; Beretta, 2001); other accounts highlight processing limitations. In accounts that view the syntactic impairment as a processing deficiency, emphasis has been put either on limitations in the *automaticity* of syntactic processing (Friederici, 1985, 1988; Friederici & Kilborn, 1989), on limitations in processing *capacity* (e.g. Haarmann, Just, & Carpenter, 1997; Miyake, Carpenter, & Just, 1994, 1995) or on changes in the *temporal organization* of the parsing process (Hagoort, 1990): it has been suggested that the activation of grammatical information is *slowed down* (e.g. Friederici, 1988; Friederici & Kilborn, 1989; Haarmann & Kolk, 1991a, 1991b; and more recently, Burkhardt, Piñango, & Wong, 2003) or that syntactic information is subjected to a pathologically *fast decay* (e.g. Haarmann & Kolk, 1994).

For a long time, the study of agrammatic comprehension used experimental methods that were not sensitive to measure temporal aspects of the processes involved in language comprehension. The widely used sentence-picture matching task is an example of this. Such a task is *off-line* in the sense that patients are requested to operate on a final product of the language comprehension process: patients give their responses well after a sentence has been fully presented. Therefore, an off-line task does not give any information on temporal aspects of syntactic processing that results in the overt performance on the task. In contrast to off-line tasks, *on-line* measures tap into the language comprehension process as it unfolds in real time. In the previous two decades, studies of aphasia have began to focus on *on-line* properties of syntactic processing in patients with Broca's aphasia. Examples of such on-line experimental measures are speeded lexical decision and word monitoring. However, when testing aphasic patients, such tasks have the following drawbacks: (i) patients with severe comprehension deficits might not understand the task; (ii) performing the task might interfere with the real-time language processing operations under study. An on-line method with a high temporal resolution in measuring the on-line processing of language that can be applied without any additional task, over and above the natural one of listening to speech, is the event-related brain potential (ERP) method. The experiments reported in this dissertation use this ERP technique.

EVENT-RELATED BRAIN POTENTIALS (ERPs)

Variations in electrical activity of the brain over time can be measured via electrodes placed at the scalp. This registration of voltage fluctuations is known as the electroencaphalogram (EEG). The EEG reflects the summation of the synchronous post-synaptic activity of large populations of cortical pyramidal cells. The brain's spontaneous electrical activity is referred to as background EEG. Changes in background EEG activity reflect large changes in the general state of a person, for example as a function of being awake or asleep. *Event-related brain potentials* (ERPs) differ from the background EEG in that they reflect electrical activity of the brain that is time-locked to a particular sensory, motor or cognitive event (hence the term '*event*-related'). In the context of psycholinguistic experimentation, an example of a cognitive event could be the presentation of certain types of words or sentences. In the following, I will give a brief general introduction on ERPs. For an extensive review of the use of the ERP technique in cognitive psychology see Coles and Rugg (1995). For a detailed discussion of neurophysiological aspects of ERPs the reader is referred to Allison, Wood, &

McCarthy (1986). Kutas & Van Petten (1994) can be consulted for methodological aspects of the use of ERPs in psycholinguistics.

ERPs are substantially smaller in amplitude (1-10 μV) than the spontaneous background EEG (50-100 μV). To increase the signal-to-noise ratio of the ERP relative to the background EEG, the brain signal is time-locked to the onset of the stimulus, and averaged over a number of events of the same type. Figure 1-1 illustrates how ERPs can be extracted from the EEG. The idea behind the averaging procedure is that brain activity that is not related to the processing of the event under study is random with respect to the timing of the stimulus onset, and thus will be averaged out. As a consequence, only fluctuations in electrical activity remain that have a temporal relationship with the presented stimulus. The amplitude of the ERP of interest determines how many trials are needed to get a reliable ERP average. For psycholinguistic experiments, a minimum number of 25-30 trials per condition (that not have been contaminated by artifacts, see below) is required (Kutas & Van Petten, 1994).

The EEG is recorded by attaching electrodes to the scalp. Nowadays the electrodes are usually mounted in an elastic cap, as can be seen in Figure 1-2. The activity of each scalp electrode site is measured in reference to an electrode that is placed at a site that is assumed not to record any neural activity, for instance the mastoid bone behind the ear. Amplification, filtering, and digitization of the signal is done according to a standard protocol (Picton, Lins & Scherg, 1995). Placement and nomenclature of electrodes follows commonly the standard guidelines of the American Electroencephalographic Society (1994). In this system, electrode locations are labeled by a letter and a number. Letters refer to the area of the cortex (e.g. F = frontal, C = central, P = parietal, O = occipital, and T = temporal). Odd numbers refer to the left hemisphere, even numbers to the right hemisphere, and z indicates the midline position. Thus, as an example, Pz defines a midline electrode location over the parietal lobe, whereas F7 defines a left frontal site.

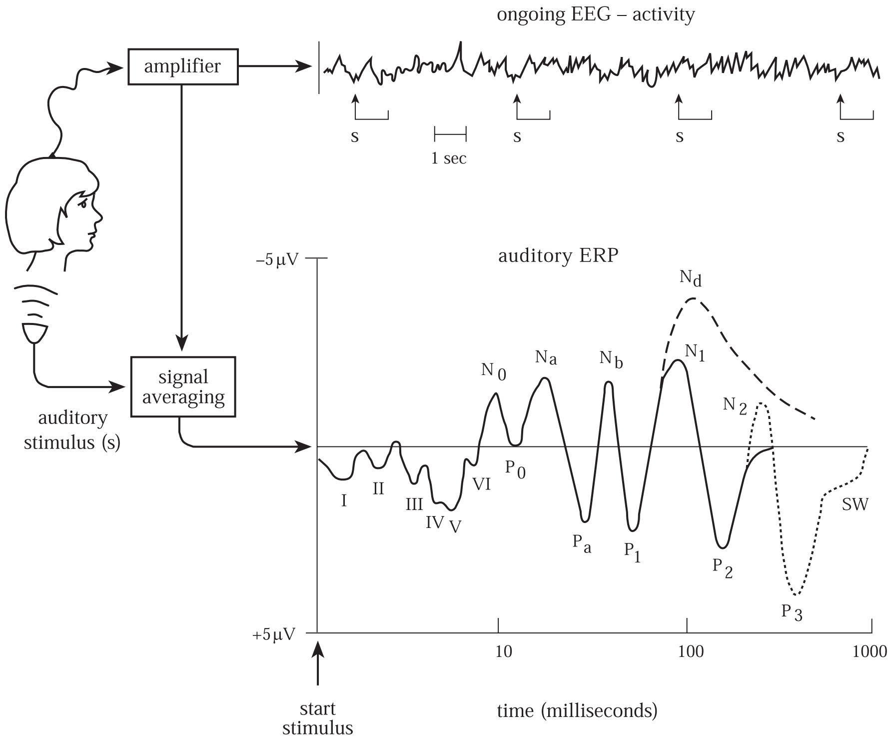

Figure 1-1. *Idealized waveform of the computer-averaged event-related potential (ERP) to an auditorily presented word. The ERP is not recognizable in the raw electroencephalogram (EEG) and is extracted from the EEG by averaging over many presentations from the same stimulus category. The logarithmic time display allows visualization of the early brainstem potentials (Waves I to VI), the middle-latency components (N_0 to N_b), exogenous long-latency components (P_1, N_1, and P_2), and endogenous long-latency components (N_d, N_2, P300, and slow wave). Negative voltages are plotted upwards, and positive voltages downwards. (After Hillyard & Kutas, 1983).*

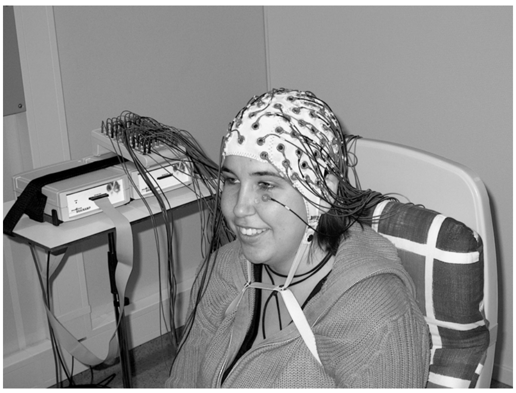

Figure 1-2. *Participant wearing electrode cap during EEG measurement.*

During recording, the EEG signal can be contaminated by artifacts as electro-oculographic artifacts from eye movements and blinks, excessive muscle activity, large electro-cardiographic potentials, and changes in skin conductance. To reduce the occurrence of such artifacts, subjects are usually instructed to sit still, to fixate their eyes at a specific spot, and not to blink during presentation of stimulus materials. To monitor the distortions of the EEG signal by vertical eye movements and blinks, a supra- to sub-orbital bipolar electrode montage is used. To track horizontal eye movements a right to left canthal bipolar montage is applied. Trials containing such artifacts are most often rejected for further analysis. In ERP studies with neurological patients it is not uncommon, if subjects have a substantial number of blinks, to perform a single trial correction procedure as for instance described by Gratton, Coles, & Donchin (1983). This procedure estimates and removes the contribution of eye blinks from the EEG at each electrode site.

The time-locked averaged ERP signal consists of a number of positive and negative voltage peaks with a characteristic latency and with a specific distribution over the scalp, usually referred to as *ERP components*. One should be aware of the fact that an ERP component is usually not simply equivalent to a peak or deflection in the ERP waveform, but it is often defined as a reflection of a particular process that is generated by a specific set of neurons. A distinction can be made between so-called exogenous and endogenous ERP components. ERP components that occur relatively early (roughly within the first 100 ms) after stimulus onset, are considered as exogenous sensory components, because their amplitude and peak latency vary mainly as function of stimulus parameters such as intensity, frequency, and rate of presentation. Within the class of exogenous components a subdivision can be made into early brain stem potentials (occurring at less than 10 ms after stimulus onset) reflecting information processing in primary sensory pathways, and middle latency components (10-100 ms) reflecting thalamic activity and possibly the earliest cortical processing. Thus, exogenous components are evoked by physical characteristics of an external stimulus, and are relatively insensitive to cognitive processes. Of more interest for investigations of higher cognitive functions, are the so-called endogenous components, with latencies beyond 100 ms. It is these endogenous ERP components that are relevant for neurolinguistically oriented ERP research, as in the present dissertation.

Endogenous components are relatively insensitive to variations in physical stimulus characteristics, but are responsive to task demands, instructions, subjects' intentions, decisions, and expectancies, reflecting cognitive aspects of stimulus processing. In ERP research, inferences about the nature of underlying cognitive processes are usually based on modulations in amplitude or latency of an endogenous ERP component as a consequence of some experimental manipulation. It is assumed that the onset latency of an endogenous ERP component can be conceived as an upper limit for estimating the time course of some cognitive operation (Rugg and Coles, 1995; Kutas & Dale, 1997). The amplitude difference of the ERP signal between two different experimental conditions within a certain time interval is referred to as the *ERP effect*.

Polarity of an ERP component and its peak-latency measured from stimulus onset often determines the name that has been given to a component. For instance, P300 stands for a positive peak with a mean peak latency of 300 ms. Components can also be labeled by the combination of their polarity and ordinal position in the waveform (e.g., N1, P1, N2). Alternatively, naming of ERP effects is based on the cognitive function they are assumed to reflect. An example relevant for the present dissertation, is the Syntactic Positive Shift (SPS). Sometimes, ERP effects are referred to with a combination of both types of labeling, for instance P600/SPS.

ERPs have some unique characteristics that are advantageous when studying aphasia (Hagoort & Kutas, 1995). First, ERPs can be recorded without imposing additional, potentially interfering task demands on aphasic patients, other than the natural one of, for instance, listening to spoken language. Second, ERPs provide an on-line and continuous record of neural activity underlying language processing with a temporal resolution in the order of milliseconds. This allows inferences about (changes in) the time course of language processing in aphasic patients. Third, the multiple dimensions of ERPs (i.e., polarity, latency, and scalp distribution) make them suitable to differentiate between qualitatively different processes. In the context of language processing, the distinction between semantics and syntax is reflected in qualitatively different ERP signals (see below). Therefore, ERPs can be informative about the types of linguistic information that patients are (in)sensitive to.

In the following, I will introduce three language-relevant ERP effects before I turn to what ERP studies on syntactic processing in aphasic patients have revealed so far.

ERPs AND LANGUAGE PROCESSING

It is almost 25 years ago that Kutas & Hillyard (1980) published their, by now, legendary and influential paper in which they reported on their discovery of an ERP component, the *N400*, that seemed especially sensitive to *semantic processing*. Unquestionably, this paper formed the starting point to introduce ERPs in the field of psycholinguistics. The ERP component that Kutas & Hillyard observed was a negative-going potential, with an onset at about 200-250 ms and a peak around 400 ms (hence N400). Its amplitude increased when the semantics of an eliciting word did not match with the preceding sentence context, as in “He spread the warm bread with butter and *socks*” (cf. Kutas & Hillyard, 1980). Semantically congruous words elicited the same component, but the amplitude of the negative peak was much smaller compared to the anomalous sentence endings. This modulation of the N400 amplitude by semantic context is known as the N400 effect (see for extensive reviews Kutas & Van Petten, 1994; Osterhout & Holcomb, 1995). Subsequent research has shown that an N400 effect can be elicited, both in the auditory and visual modality, without an outright semantic violation: the N400 amplitude can be modulated by subtle differences in semantic expectancy and semantic relatedness. The N400 is usually largest over posterior scalp sites with a slight right hemisphere preponderance with a visual stimulus presentation. N400 effects can be observed not only in sentential context but also when the preceding language input consists of a single word or a discourse. In sentential contexts, N400 amplitude modulations are generally viewed to index the relative ease of semantic integration (e.g. Brown & Hagoort, 1993; Hagoort & Brown, 2000b); but see Kutas & Federmeier, 2000).

Another exciting finding in language processing ERP research has been the discovery of ERP effects related to *syntactic processing*, that are qualitatively different from the semantics-related N400. This is not to say that these syntax-related ERP effects are syntax-specific. Indeed, for none of the language-relevant ERP effects can it be claimed that they are language-specific. However, this does not limit the significance of ERPs since, under conditions of language input, different ERPs can be exploited to investigate different aspects of language processing (cf. Hagoort, Brown, & Osterhout, 1999).

In recent years, a number of ERP studies have reported two *syntax*-related ERP effects: an anterior negativity also referred to as *LAN (Left Anterior Negativity*) and a more posterior positivity, here referred to as *P600/SPS*.

Several studies have reported negativities that are different from the N400: these negativities show a more frontal maximum (but see Münte, Matzke, & Johannes, 1997), are sometimes larger over the left than the right hemisphere, hence *left* anterior negativity (but see for a bilateral distribution Hagoort, Wassenaar, & Brown, 2003a), and are often observed in the same latency range as the N400, that is between 300-500 ms post-stimulus (e.g. Friederici, Hahne, & Mecklinger, 1996; Kluender & Kutas, 1993; Münte, Heinze, & Mangun, 1993; Osterhout & Holcomb, 1992; Rösler, Friederici, Pütz, & Hahne, 1993)**.** In some cases the latency of a left-anterior negative effect is reported in a much earlier time window between 100-300 ms (e.g. Friederici, Pfeifer, & Hahne, 1993; Hahne & Friederici, 1999; Neville, Nicol, Barss, Forster, & Garrett, 1991). Friederici (2002) has proposed that the timing of these negativities differ as a function of the type of syntactic violation: she attributes LAN effects between 300-500 ms to morphosyntactic errors and early LAN effects (ELAN) that occur between 100 and 300 ms to violations of word-category. However, in other studies, LAN effects (and not ELAN effects) have been reported for word category violations (Hagoort et al., 2003a; Van den Brink & Hagoort, 2004).

The functional significance of LAN effects is not yet agreed upon. It has been proposed that these LAN effects are, in the context of language processing, specifically syntactic in nature. In a different account, LAN effects are viewed as a general index of verbal working memory load (Coulson, King, & Kutas, 1998; Kluender & Kutas, 1993). However, not all LAN effects seem to be related to verbal working memory. In conclusion, the anterior negativities seem to be much more variable in their latency and topography than for instance classical N400 effects. Presumably, under the heading of LAN effects more than one type of effect is subsumed with subtle distinctions in timing, topography and function (cf. Hagoort et al., 2003a).

A second ERP effect that has been related to syntactic processing is a late positivity, here termed P600/SPS, that occurs between 500-1000 ms. This effect has been observed in response to a variety of syntactic violations (e.g. of phrase structure, verb subcategorization, number and gender agreement) (e.g. Ainsworth-Darnell, Shulman, & Boland, 1998; Coulson et al., 1998; Friederici et al., 1996; Hagoort, Brown, & Groothusen, 1993; Münte et al., 1997; Neville et al., 1991; Osterhout & Holcomb, 1992; Osterhout, Holcomb, & Swinney, 1994; Osterhout & Mobley, 1995). However, an outright syntactic violation is not required to elicit a

P600/SPS effect. The effect has also been observed in sentences when a preferred syntactic analysis can no longer be maintained (e.g. Osterhout et al., 1994; Van Berkum, Brown, & Hagoort, 1999) or when syntactic complexity is increased (Kaan, Harris, Gibson, & Holcomb, 2000). It has been observed that the scalp distribution of the P600/SPS is different for ungrammatical and syntactic ambiguous sentence continuations. The P600/SPS to outright syntactic violations has a more posterior distribution, whereas P600/SPS effects in relation to syntactic ambiguity and syntactic complexity are more equally or more frontally distributed (Hagoort, Brown, & Osterhout, 1999; Kaan & Swaab, 2003).

To summarize, two classes of syntax-related ERP effects have been reported: (E)LAN and P600/SPS. (E)LAN effects have been seen only in response to syntactic violations and are normally followed by a P600/SPS. The P600/SPS is seen not only to syntactic violations but also to syntactically less preferred structures and to syntactically more complex sentences and shows up, in many cases, without a preceding negativity.

The precise functional interpretation of these syntax-related effects is still a matter of debate. Friederici (2002) relates ELAN, LAN, and P600/SPS to a three-phase neurocognitive model. The early negativity would reflect a first-pass parsing stage responsible for forming an initial syntactic structure based on word category information. The LAN is viewed to reflect a stage during which thematic role assignment takes place based on lexical-semantic and morphosyntactic processes. And finally, the P600/SPS is assumed here to mirror syntactic integration processes including processes of syntactic reanalysis and repair. A different functional specification for the P600/SPS effect is given in Kaan et al. (2000). They propose that the P600/SPS reflects difficulties with syntactic integration processes in general. In a more recent view, the P600/SPS with a posterior distribution is seen as an index of syntactic processing difficulty including repair and revision operations, whereas the more frontally distributed P600/SPS indexes ambiguity resolution and/or an increase in discourse level complexity (Kaan & Swaab, 2003). Hagoort (2003a) has described an explicit account of syntax-related ERP effects based on a lexicalist parsing model by Vosse and Kempen (2000). In this account, which does *not* assume a syntax-first architecture, it is explained why the P600/SPS has been observed in relation to syntactic violations, syntactic ambiguities, and syntactic complexity, whereas the anterior negativity has been observed only in response to syntactic violations (see for details Hagoort, 2003a; Hagoort et al., 2003a). Finally, Kolk, Chwilla, Van Herten, & Oor (2003) take the view that the P600/SPS is related to language monitoring: in case of an unexpected linguistic event, participants will reattend the input to check whether the unexpected linguistic event indeed occurred or that it stemmed from some kind of processing error.

Although it is next to impossible to imagine psycholinguistic experimentation today without the ERP method, studies using ERPs to investigate syntactic processes in agrammatic comprehenders, are still rare (Kotz & Friederici, 2003). This is surprising, since, essentially, deviant patterns of syntax-related ERP effects in patients with Broca's aphasia can be informative about possible changes in their syntactic processing (Friederici, 2001). For instance, if comprehension deficits in aphasia affect the rate at which syntactic information is processed, a delay of a syntax-related ERP might be expected. If the efficiency of syntactic processing is suboptimal, an amplitude reduction of the effect could result. In addition, the severity of the syntactic comprehension deficit can be of interest yielding for instance the largest deviation from the normal syntax-related ERP effect for patients with the most severe comprehension deficits.

Despite this potential of the ERP method, up to now, not many researchers were motivated to use it to study syntactic processing in agrammatic comprehenders[2]. However, Ter Keurs and colleagues (Ter Keurs, Brown, Hagoort, & Stegeman (1999); Ter Keurs, Brown, & Hagoort (2002)) used the ERP method to investigate the processing of lexical-syntactic information in patients with agrammatic comprehension. In these studies it was found that the agrammatic comprehenders were impaired in the on-line processing of word-class information: word-class information seemed incompletely and/or delayed available to them. The Leipzig group (Friederici and co-workers) however used ERPs to study syntactic processes beyond the lexical-syntactic level. Their experimental work has revealed the following. Friederici, Hahne, & von Cramon (1998) presented sentences containing phrase structure violations (viz. a word category violation), among other violations, to a Broca patient with an extended lesion restricted to the anterior part of the left hemisphere. The sentences were auditorily presented and the violations always showed up at sentence-final position. Whereas normal controls showed an early left anterior negativity followed by a P600/SPS for the syntactic violation condition, for the Broca patient no early left anterior

[2] For ERP studies that focus on integration of lexical-semantic information in agrammatic comprehenders, see Hagoort, Brown, & Swaab (1996); Swaab, Brown, & Hagoort, (1997); Swaab, Brown, & Hagoort (1998).

negativity was found. However, a P600/SPS was observed. According to their syntactic parsing model, the authors interpreted the results for this Broca patient as follows. The absence of the early left anterior negativity indicated a loss of the fast and automatic initial structure building processes. The presence of the P600/SPS suggested that secondary syntactic processes were still available to this patient, which was, according to the authors, in line with the finding that this patient had a relatively good grammaticality judgement task performance. In a follow-up study (Friederici, von Cramon & Kotz, 1999) patients with residual aphasia due to either cortical or subcortical lesions were tested with the same materials. The cortical group included one Broca patient and this patient showed the same ERP response to the word category violations as in the previous study: a P600/SPS but no early anterior negativity.

AIMS AND STRUCTURE OF THE DISSERTATION

The central objective of this dissertation is, *to further explore what syntax-related ERP effects can reveal about the nature of the deficit that underlies syntactic comprehension problems in patients with Broca's aphasia.* The general theme of the studies is to present electrophysiological data on on-line syntactic processing in agrammatic patients. The studies in this dissertation differ in a number of aspects from previous ERP studies that investigated syntactic processing beyond the lexical level in agrammatic comprehenders (Friederici et al., 1998, 1999). I used (i) a greater variety of syntactic violations, (ii) a larger group of Broca patients, (iii) the impact of severity of the syntactic comprehension on ERP effects was addressed, and (iv), ERPs were not only recorded during presentation of syntactic violations but also during a sentence-picture matching paradigm.

The dissertation is organized as follows. The next four chapters contain descriptions and discussions of experimental work. Each chapter is written in such a way that it can be read independently from the other chapters. This will sometimes lead to some overlap in the introduction of relevant issues.

Chapter two to four describe experiments in which event-related brain potentials were recorded while subjects (Broca patients, non-aphasic patients with a right-hemisphere lesion, and healthy elderly controls) were presented with sentences that contained either violations of syntactic constraints or were syntactically correct.

Chapter two investigates ERP effects of *subject-verb agreement violations* in the different subject groups, and seeks to answer the following questions: Do agrammatic comprehenders show sensitivity to subject-verb agreement violations as indicated by a syntax-related ERP effect? In addition, does the severity of the syntactic comprehension impairment in the Broca patients affect the ERP responses? This chapter was published in *Journal of Cognitive Neuroscience* (Wassenaar, Brown, & Hagoort, 2004).

Chapter three focuses on ERP effects of *violations of word order*. Word order violations differ at least in two aspects from subject-verb agreement violations. The word order violation as used in this dissertation is a violation in the relation between the head of a phrase and its arguments, whereas the subject-verb agreement violation is a violation across a major phrasal boundary. The two types of violations also differ with respect to their consequences for semantic interpretation of the sentence. Word order violations are less easily reinterpreted semantically in comparison to subject-verb agreement violations. Chapter three describes an investigation of whether Broca patients show sensitivity to these word order violations as indicated by a syntax-related ERP effect, and whether the ERP responses in the Broca patients are affected by the severity of their syntactic comprehension impairment. A shortened version of this chapter was published in *PNAS* (Hagoort, Wassenaar, & Brown, 2003b).

Chapter four reports on ERP effects of *violations of word-category.* Word category violations are interesting from the perspective that they have been reported to elicit in healthy subjects *two* syntax-related ERP-effects. In addition, also a semantic violation condition was added to track possible dissociations in the sensitivity to semantic and syntactic information in the Broca patients. This chapter was published in *Brain and Language* (Wassenaar & Hagoort, 2005).

Chapter five describes the development of a paradigm in which the electrophysiological approach and the classical sentence-picture matching approach are combined. In this chapter, the ERP method is applied to study *on-line thematic role assignment* in Broca patients during sentence-picture matching. Also the relation between ERP effects and behavioral responses will be pursued. This chapter has been submitted for publication.

Finally, Chapter 6 provides a summary of the main findings of the experiments and a general discussion.

ERP EFFECTS OF SUBJECT-VERB AGREEMENT VIOLATIONS IN PATIENTS WITH BROCA'S APHASIA

CHAPTER 2

Marlies Wassenaar, Colin M. Brown, and Peter Hagoort[1]

ABSTRACT

This paper presents electrophysiological data on on-line syntactic processing during auditory sentence comprehension in patients with Broca's aphasia. Event-related brain potentials (ERPs) were recorded from the scalp while subjects listened to sentences that were either syntactically correct or contained violations of subject-verb agreement. Three groups of subjects were tested: Broca patients (N=10), non-aphasic patients with a right hemisphere (RH) lesion (N=5), and healthy aged-matched controls (N=12). The healthy control subjects showed a P600/SPS effect as response to the agreement violations. The non-aphasic patients with a RH lesion showed essentially the same pattern. The overall group of Broca patients did not show this sensitivity. However, the sensitivity was modulated by the severity of the syntactic comprehension impairment. The largest deviation from the standard P600/SPS effect was found in the patients with the relatively more severe syntactic comprehension impairment. In addition, also ERPs to tones in a classical tone oddball paradigm were recorded. Like the normal control subjects and RH patients, also the group of Broca patients showed a P300 effect in the tone oddball condition. This indicates that aphasia in itself does not lead to a general reduction in all cognitive ERP effects. It was concluded that deviations from the standard P600/SPS effect in the Broca patients reflected difficulties with *on-line* maintaining of number information across clausal boundaries for establishing subject-verb agreement.

[1] A slightly adapted version of this chapter has been published in *Journal of Cognitive Neuroscience, 16: 4* (2004), pp. 553-576.

INTRODUCTION

Disorders of syntax resulting from brain damage have most often been studied in patients with Broca's aphasia. To explain syntactic comprehension problems in these patients, several accounts have been given (see for a review Kolk, 1998). In accounts that view the syntactic impairment as a processing deficiency, emphasis has been put either on limitations in processing capacity (e.g. Haarmann, Just, & Carpenter, 1997; Miyake, Carpenter, & Just, 1994, 1995) or on changes in the temporal organization of the parsing process (Hagoort, 1990): it has been suggested that the activation of grammatical information is slowed down (e.g. Friederici, 1988; Friederici & Kilborn, 1989; Haarmann & Kolk, 1991a, 1991b) or that syntactic information is subjected to a pathologically fast decay (e.g. Haarmann & Kolk, 1994). These studies on slow activation or fast decay have in common that syntactic processing was studied *on-line*; that is, with the help of tasks (viz. lexical decision and word monitoring) that tap the syntactic comprehension process as it unfolds in real time. However, these tasks require subjects to make fast and accurate responses. For instance, in a lexical decision task, subjects are asked to decide as fast and accurately as possible whether a presented string of letters or sequence of sounds is a word or not. In testing aphasic patients, such tasks have the following disadvantages: (i) patients with severe comprehension deficits might not understand the task; (ii) performing the task might interfere with the real-time language processing operations under study. An on-line method that can be applied without any additional task, over and above the natural one of listening to speech, is the event-related brain potential (ERP) method.

ERPs are small voltage changes in the EEG, recorded at the scalp and time-locked to the onset of a particular event (e.g. the onset of words in sentences). In relation to the processing of syntax, two ERP effects are especially relevant: the *LAN* and the *P600/SPS* (see for a review Hagoort, Brown, & Osterhout, 1999). In a number of studies negative-going ERP effects have been reported that seem to be related to syntactic processing. These effects differ from the N400 effect (Kutas & Hillyard, 1980) in that they have a more anterior distribution. These so-called LAN (Left Anterior Negativity) effects occur with a latency between 300 and 500 ms post-stimulus onset (Friederici, Hahne, & Mecklinger, 1996; Kluender & Kutas, 1993; Münte, Heinze, & Mangun, 1993; Rösler, Friederici, Pütz, & Hahne, 1993) or, sometimes, in an earlier latency range between 125 and 180 ms (Friederici, Pfeifer, & Hahne, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991). LAN-effects have been elicited by violations of word-category constraints (i.e. when a word of a certain syntactic class is replaced by a word of a different syntactic class) (e.g. Friederici et al., 1996; Münte et al., 1993; Rösler et al., 1993), but also by violations of number, gender, and tense agreement (e.g. Münte & Heinze, 1994; Münte et al., 1993). The distribution of these effects is usually more bilateral than left-lateralized. A more strictly left-lateralized LAN effect has been related to verbal working memory (Coulson, King, & Kutas, 1998b; Kluender & Kutas, 1993).

Another ERP effect that has been related to syntactic processing is the P600/SPS. The P600/SPS effect is characterized by a positive deflection, starting at about 500 ms post-stimulus onset and elicited by a word that creates a syntactic processing problem. This effect has been observed in response to a variety of syntactic violations (e.g. of phrase structure, verb subcategorization, number and gender agreement) (e.g. Ainsworth-Darnell, Shulman, & Boland, 1998; Coulson et al., 1998b; Friederici et al., 1996; Hagoort, Brown, & Groothusen, 1993; Münte, Matzke, & Johannes, 1997; Neville et al., 1991; Osterhout & Holcomb, 1992; Osterhout, Holcomb, & Swinney, 1994; Osterhout & Mobley, 1995). However, an outright syntactic violation is not required to elicit a P600/SPS effect. The effect has also been observed in sentences when a preferred syntactic analysis can no longer be maintained (e.g. Osterhout et al., 1994; Van Berkum, Brown, & Hagoort, 1999) or when syntactic complexity is increased (Kaan, Harris, Gibson, & Holcomb, 2000).

The purpose of this present study is to investigate agrammatic comprehension in patients with Broca's aphasia by exploiting the sensitivity of the P600/SPS effect to syntactic processing. One of the antecedent conditions of a P600/SPS effect is a violation of a syntactic constraint. In this study, *violations of subject-verb agreement* are used. Haarmann and Kolk (1994) found in a word monitoring study that patients with Broca's aphasia were sensitive to subject-verb agreement violations when these violations were couched in *conjoined* sentences (e.g., "*the *baker* greets the customers and *ask* the boy to not make so much noise"). The effect was, however, not obtained with *embedded* sentences (e.g., "*the *baker* that greets the customers *ask* the boy to not make so much noise"), unlike normal control subjects who showed this effect for both conditions. Following Haarmann and Kolk (1994), for our present study the on-line sensitivity to subject-verb agreement violations is tested for both *conjoined* and *embedded* sentences. Conjoined and embedded sentences differ in phrase structure complexity (see Materials section).

For the neurologically unimpaired subjects we expect, based on earlier experiments with Dutch agreement violations (Hagoort & Brown, 2000a), a P600/SPS effect in response to the agreement violations. Deviant patterns of ERP effects in Broca patients can reflect changes in their syntactic processing (Friederici, 2001): If comprehension deficits in aphasia affect the rate at which syntactic information is processed, a delay of the P600/SPS effect might be expected. If the efficiency of syntactic processing is suboptimal, an amplitude reduction of the P600/SPS effect could result. In addition, the severity of the syntactic comprehension deficit is of interest: the largest deviation from the normal P600/SPS effect is expected for those patients with the most severe comprehension deficits.

The results of the patients with Broca's aphasia will be compared to a group of normal age-matched controls and to a group of non-aphasic patients with a lesion in the right hemisphere, to control for non-specific effects of aging and brain damage on the P600/SPS effect. To check whether possible changes in the P600/SPS effect in the aphasic patients could be dissociated from general effects of brain damage on cognitive ERP-components, we included a non-linguistic control experiment: subjects were also tested with a classical tone oddball paradigm. Normally, this paradigm elicits a P300. Comparing the pattern of P300 results to the P600/SPS results of the language task will help to determine whether changes in the P600/SPS effect are related to altered syntactic processing rather than to an a-specific consequence of brain damage.

METHOD

Subjects

Ten patients with aphasia secondary to a single CVA in the left hemisphere participated in this study. A group of 12 healthy normal subjects, who were approximately matched in age and education level to the aphasic patients, were tested to control for age and education effects. To account for non-specific effects of brain damage on cognitive ERP components, a group of 5 non-aphasic patients with a single CVA in the right hemisphere (RH patients) was tested. All subjects gave informed consent, according to the declaration of Helsinki. The mean age of the aphasic patients was 59.8 years (range 42-74 years), the RH patients were on average 61.8 years (range 47-70 years) and the normal controls had a mean age of 58.9 years (range 49-72 years). All elderly control subjects were right-handed according to an abridged version of the Oldfield Handedness Inventory (Oldfield, 1971). Five of the elderly control subjects reported familial left-handedness. The aphasic patients and the RH patients were premorbidly, all right-handed. None of the elderly control subjects had any known neurological impairment or used neuroleptics. None of the control subjects reported hearing loss or memory problems.

All neurological patients were tested at least 9 months post-onset of their CVA. All neurological patients were tested with the Dutch version of the Aachen Aphasia Test (AAT) (Graetz, De Bleser, & Willmes, 1992). Both presence and type of aphasia were diagnosed on the basis of the test results and on the basis of a transcribed sample of their spontaneous speech. All RH patients were diagnosed as non-aphasic and all left-hemisphere patients were diagnosed as patients with Broca's aphasia. According to their scores on the comprehension subtest of the AAT, the aphasic patients had moderate to mild comprehension deficits. The presence of syntactic comprehension problems was determined by an off-line test that assesses the influence of syntactic complexity on sentence comprehension (Huber et al., 1993). The Dutch version (see for a detailed description Ter Keurs, Brown, Hagoort, & Stegeman, 1999) contains 5 levels of syntactic complexity, ranging from active, semantically irreversible sentences, to sentences containing an embedded subject-relative clause in the passive voice (see for examples Table 2-1). Patient's age, gender, results on the Token Test, scores on the AAT subtest on comprehension, overall scores on the syntactic off-line test and lesion site information are summarized in Table 2-2.

Materials

The materials for this experiment consisted of a list of 120 spoken sentence pairs. Half of each sentence pair was syntactically correct, half contained a *violation of subject-verb number agreement*. These number violations between nouns and verbs were couched in either relatively simple (60 sentence pairs) or relatively complex syntactic frames (60 sentence pairs), without changing word length or lexical content. An example is given in Table 2-3.

Table 2-1. Five types of sentences of the Dutch syntactic off-line test and their distracters.

Degree of syntactic complexity	Sentence
I	Active, semantically irreversible sentences e.g. “Het meisje met de strik draagt de bal”. (*The girl with the ribbon carries the ball.*)
II	Active, semantically reversible sentences e.g. “De man met de bal zoekt het kind”. (*The man with the ball is looking for the child.*)
III	Simple passive sentences e.g. “De man met de bal wordt door het kind gezocht”. (*The man with the ball is being looked for by the child.*)
IV	Sentences with an active subject relative clause e.g. “Het kind dat naar de man zoekt, heeft een bal”. (*The child that is looking for the man has a ball.*)
V	Sentences with a passive subject relative clause e.g. “Het kind dat door de man gezocht wordt heeft een bal”. (*The child that is being looked for by the man has a ball.*)

Type of distracter	Sentence
For I	Example: *The girl with the ribbon carries the ball.*
(i) incorrect lexical modifier	*The girl with the glasses carries the ball.*
(ii) lexically incorrect direct object	*The girl with the ribbon carries the basket.*
(iii) combination of (i) and (ii)	*The girl with the glasses carries the basket.*
For II – V	Example: *The man with the ball is looking for the child.*
(i) incorrect assignment of attribute	*The man is looking for the child with the ball.*
(ii) reversed agent-patient role	*The child is looking for the man with the ball.*
(iii) combination of (i) and (ii)	*The child with the ball is looking for the man.*

Table 2-2. Individual patient information for the patients with Broca's aphasia and the non-aphasic RH patients.

Patient	*Age*	*Sex*	*Token Test*[a]	*Overall Compreh. score AAT*[b]	*Audit. Compreh. score AAT*	*Syntactic off-line score*[c]	*Lesion*
1 Broca	68	M	24	105/120	54/60	88/144	Left fronto-temporal
2 Broca	50	F	10	97/120	48/60	95/144	L. fronto-temporo-parietal incl. insula
3 Broca	74	F	7	108/120	52/60	115/144	L. frontal including insula
4 Broca	65	F	18	91/120	45/60	111/144	L. fronto-temporal including insula
5 Broca	51	M	20	109/120	54/60	113/144	L. fronto-temporo-parietal incl. insula
6 Broca	63	M	38	67/120	39/60	52/144	L. frontal including insula
7 Broca	42	M	17	94/120	45/60	74/144	L. temporo-parietal
8 Broca	67	M	18	103/120	54/60	47/144	L. fronto-temporo-parietal incl. insula
9 Broca	70	M	50	90/120	46/60	59/144	L. fronto-temporal including insula
10 Broca	48	M	42	89/120	45/60	51/144	No adequate CT information available
1 RH	66	F	2	102/120	48/60	118/144	Right parietal
2 RH	58	M	1	117/120	57/60	134/144	R. fronto-temporo-parietal incl. insula
3 RH	47	M	0	113/120	58/60	134/144	No adequate CT information available
4 RH	68	F	2	106/120	53/60	89/144	R. temporo-parietal
5 RH	70	F	0	105/120	50/60	92/144	R. fronto-temporo-parietal

[a] Severity of the aphasic disorder as indicated by the Token Test: no/very mild disorder (0-6); light (7-23); middle (24-40); severe (41-50).

[b] Severity of the comprehension disorder as indicated by the Aachen Aphasia Test subtest on comprehension (includes word and sentence comprehension in both the auditory and visual modality): no/very mild disorder (107-120); light (90-106); middle (67-89); severe (1-66). compreh.= comprehension; AAT= Aachen Aphasia Test.

[c] Range of performance in healthy control subjects is 119-143. Two RH patients had a relatively low score on the off-line test, but were, on the basis of their spontaneous speech and the AAT results, clearly non-aphasic. Their score on more complex sentences was not very different from the more simple ones. This implies that their relatively poor performance is not so much due to a syntactic problem, but rather due to a different one, for instance a problem of visual attention.

In the conjoined condition (see Table 2-3), the two verb phrases were expressed by a conjunction. In the embedded condition, one of the verb phrases was embedded in the subject noun phrase. The embedded sentence is more complex than its conjoined counterpart. The linguistic argumentation for the complexity difference relates to the depth of the phrasal configuration (Frazier, 1985), with the embedded sentence having a phrase structure that is one level deeper than the conjoined sentence (see Figure 2-1).

Following Haarmann and Kolk (1994), the sentences were constructed in such a way that non-syntactic strategies to detect the subject-verb agreement violations would fail (see for details Haarmann et al., 1994).The violation always showed up at a mid-sentence position. The reason for this is twofold. We wanted the subjects to be fully engaged in the process of parsing before being confronted with a syntactic violation, and we wanted to avoid contamination of closure-effects at sentence-final position (cf. Hagoort et al., 1993).

Table 2-3. Example of the stimulus materials belonging to the conjoined (1a and 1b) and the embedded (2a and 2b) condition (critical words in italics; * marks violated sentence).

Relatively simple constituent structure (conjoined)[a]

(1a)	De vrouwen betalen de bakker en *nemen* het brood mee naar huis.
	(The women pay the baker and *take* the bread home.)
(1b)*	De vrouwen betalen de bakker en *neemt* het brood mee naar huis.
	(The women pay the baker and *takes* the bread home.)

Relatively complex constituent structure (embedded)[b]

(2a)	De vrouwen die de bakker betalen, *nemen* het brood mee naar huis.
	(The women who pay the baker, *take* the bread home.)
(2b)*	De vrouwen die de bakker betalen, *neemt* het brood mee naar huis.
	(The women who pay the baker, *takes* the bread home.)

[a] Conjoined: the two verb phrases are expressed by a conjunction.
[b] Embedded: one of the verb phrases is embedded in the subject noun phrase.

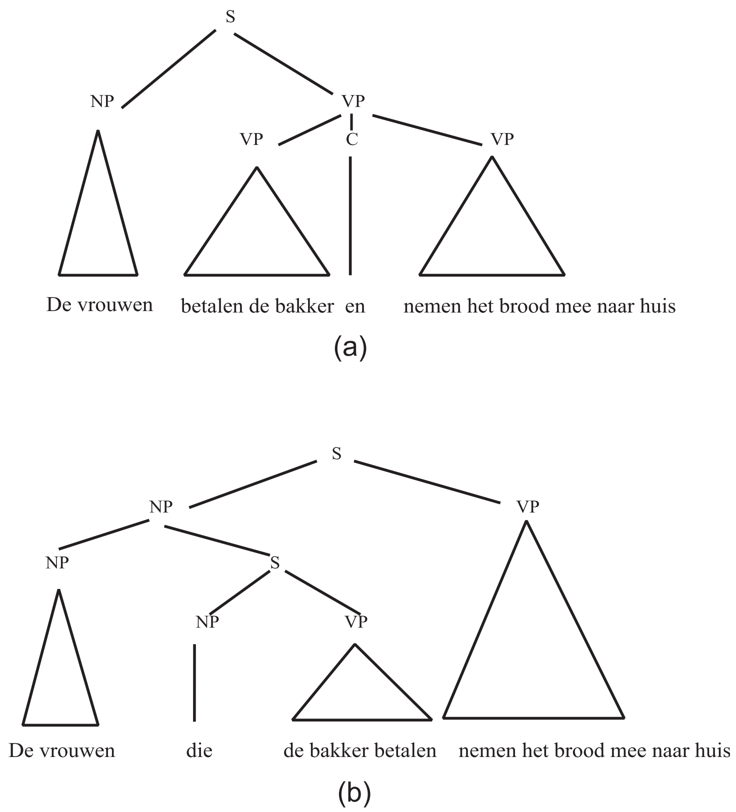

Figure 2-1. *Syntactic trees for (a) a conjoined and (b) an embedded sentence. Note the additional S node for the embedded sentence. This extra level makes the embedded sentence syntactically more complex than the conjoined sentence. S = Sentence; NP = Noun Phrase; VP = Verb Phrase; C = Conjunction. Translation conjoined sentence: The women pay the baker and take the bread home; translation embedded sentence: The women who pay the baker, take the bread home.*

An additional set of 260 sentences was used as practice and filler items. These contained semantic and syntactic violations (different from the present study) at varying positions in the sentence to prevent subjects from developing a strategy of predicting the position of an incorrect word.

A female speaker spoke all experimental sentences, fillers and practice sentences at a normal speaking rate. Special care was taken to produce the ungrammatical sentences with a natural sentence melody. Sentences were spoken in a sound attenuating booth, recorded on a digital audiotape, and stored on computer disk. A speech waveform editing system was used to mark the critical words and the onset and offset of each sentence.

The list of 240 experimental sentences was divided over two lists of 120 sentences each. Each list consisted of 60 correct and 60 incorrect experimental sentences. The 60 incorrect and the 60 correct sentences were made up of 30 sentences from the conjoined and

30 from the embedded condition. The members of a pair of incorrect and correct companion sentences were assigned to the different lists. Each list of 120 sentences was divided into three blocks of 40 sentences. A pseudo-randomised sequence of sentences was used for each list. The sequence was such that in immediate succession no more than two incorrect sentences from the same violation type occurred. Incorrect and correct sentences never occurred more than three times in a row. Each list was presented to all subjects in two different sessions separated by at least four weeks. The presentation order of the two lists was counterbalanced. The experimental list was preceded by a practice list of 20 items to familiarise the subjects with the experimental situation and to train them to fixate their eyes during sentence presentation and to blink only between trials. In order to induce the subjects to listen attentively to the sentences, a questionnaire was constructed with 4 questions per block about the content of a sentence.

A pulse for triggering the EEG acquisition program was placed 150 ms before onset of each experimental sentence. Each 8 seconds a sentence was presented. Three tapes were constructed: a practice tape containing 20 practice items and two tapes for the two experimental lists.

In addition to the test tapes with the sentence stimuli, a digital audiotape was constructed with tones. This tape contained 300 tones, 60 tones of 1 kHz and 240 tones of 2 kHz. The tones were presented in a random order with 20 ms duration and a frequency of one per second. A trigger pulse was placed before the onset of each 1 kHz tone, and before the onset of 60 randomly chosen 2 kHz tones. The experimental tones were preceded by 50 practice tones in order to familiarise the subjects with the stimuli and the task.

Procedure

Subjects were tested individually in a dimly illuminated sound-attenuating booth. They were instructed to keep their eyes fixated on a point at eye-level. Subjects were told that they would hear sentences, some of which had language errors in them, but they were given no information concerning the kind of errors that would occur. Subjects were asked to listen attentively to the sentences. They were told that the experimenter would sometimes stop the tape to ask them a question about a sentence they had just heard. No additional task demands were imposed. All stimuli were presented via a DAT recorder. Subjects listened to the stimuli via closed-ear headphones.

The ERPs to the tones in the oddball paradigm were recorded in a separate session. Subjects were asked to silently count the low tones, and to give a running total at the end of the session. The practice session of the tone oddball task was used to establish whether patients were able to silently count the low tones. Three patients were unable to count. For these subjects it was established that they could discriminate between the 1 kHz and 2 kHz tones (by raising a hand upon the occurrence of a low tone) and they were instructed to listen attentively, without an additional task.

EEG-recording

EEG activity was recorded by using an Electrocap with 13 scalp tin electrodes, each referred to the left mastoid. Nine electrodes (Fz, Cz, Pz, F7, F8, FT7, FT8, PO7, PO8) were placed according to the standards of the American Electroencephalographic Society. Four electrodes were placed over non-standard intermediate locations: a temporal pair (LT and RT) placed 33% of the interaural distance lateral to Cz, and a temporo-parietal pair (LTP and RTP) placed 30% of the interaural distance lateral to Cz and 13% of the inion-nasion distance posterior to Cz). The ERPs to the tones in the oddball paradigm were recorded with a subset of these 13 electrodes, viz. Fz, Cz, Pz, FT7, FT8, LTP and RTP (7 electrodes). Vertical eye movements and blinks were monitored via a supra- to sub-orbital bipolar montage. A right to left canthal bipolar montage was used to monitor for horizontal eye movements. Activity over the right mastoid bone was recorded on an additional channel to determine whether experimental variables had any effect on the mastoid recordings. No such effects were observed. The ground electrode was placed on the forehead.

The EEG and EOG recordings were amplified with Nihon Kohden AB-601G bioelectric amplifiers, using a Hi-Cut of 30 Hz and a time constant of 8 seconds. Impedances were kept below 5 kOhm. The EEG and EOG were digitised on-line with a sampling frequency of 200 Hz. A trigger pulse started sampling 150 ms before the presentation of the sentences and tones. The total sampling epoch for the sentence stimuli was 6315 ms (150 ms pre-sentence baseline + duration of longest sentence + 1000 ms). For the tone stimuli the total sampling epoch was 850 ms. Data were stored along with condition codes for subsequent off-line averaging and data analysis.

In the next section we will first present behavioral data (scores on a syntactic comprehension test), then the ERP data for listening to the *conjoined* (e.g. The women pay the baker and take/takes the bread home) and the *embedded sentences* (e.g. The women who pay the baker, take/takes the bread home), and, finally, the ERP data from the tone oddball paradigm.

RESULTS

Off-line Test for Syntactic Comprehension

Figure 2-2 shows the comprehension scores (in percentage correct) on the off-line test for syntactic sentence comprehension (see Method section) of the normal control subjects, the RH patients, and the patients with Broca's aphasia. Analyses were performed on the percentage-correct scores for the five sentence types of the syntactic off-line test. The data were entered into repeated measures analyses of variance with group (normal controls, RH patients, and Broca patients) as a between-subjects factor and sentence type (I-V) as a within-subjects factor. A Huynh-Feldt correction was applied when necessary, and Kramer's modification of Tukey's HSD test ($\alpha = 0.05$) was used for post-hoc analysis. The adjusted degrees of freedom and p-values are reported. Analyses with group as factor revealed that syntactic complexity had a differential effect on the comprehension scores of the different subject groups [Sentence Type: $F(3.38, 81.12) = 27.02$, $MSe = 110.70$, $p = 0.000$; Group: $F(2, 24) = 21.29$, $MSe = 937.73$, $p = 0.000$; Sentence Type x Group: $F(6.76, 81.12) = 6.92$, $MSe = 110.70$, $p = 0.000$]. Post hoc analyses ($\alpha = 0.05$) revealed that the Broca patients performed significantly worse than the normal controls on all sentence types except type I and significantly worse than the RH patients on sentence types III-V. In contrast, the normal controls and the RH patients did not differ significantly from each other, except on sentence type V. The size of the difference in comprehension scores between the Broca patients and the two control groups increased with increasing syntactic complexity. For the most complex sentence type the performance of the Broca patients approached chance level (25% on this test). This pattern of results substantiates the syntactic comprehension problems of the Broca patients in this study.

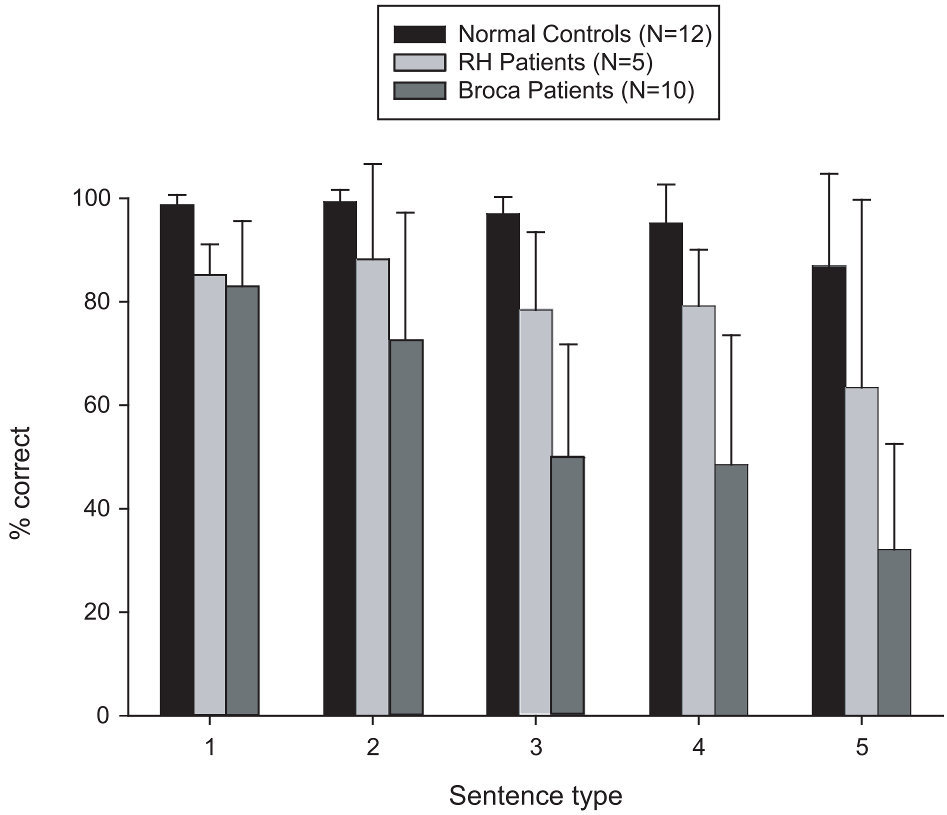

Figure 2-2. *Scores of the group of Normal Controls (N=12), the RH Patients (N=5), and the group of Broca Patients (N=10) for the off-line test for syntactic comprehension; for the five types of syntactic complexity: I = active, semantically irreversible; II = active, semantically reversible; III = simple passive; IV = sentences with an active subject relative clause; V = sentences with a passive subject relative clause.*

ERP experiment

The ERP data for the 12 normal control subjects, the 5 RH patients and the 10 Broca patients are presented in separate sections. In addition, also the ERP results for the non-linguistic control experiment (viz. tone oddball task) will be described. Prior to off-line averaging, all single trial waveforms were screened for electrode drifting, amplifier blocking, muscle artefacts, eye movements and blinks in a critical window that ranged from 600 ms before to 1500 ms after onset of the critical word (CW). The CW in this experiment is the incorrectly inflected verb form and its correct counterpart. Trials containing artefacts were rejected. However, for subjects with a substantial number of blinks, single trials were corrected via a procedure described by Gratton, Coles, & Donchin (1983). After artefact rejection, the overall rejection rate was 21.7 % for the normal elderly control subjects, 25.2 % for the RH patients, and 21.8 % for the patients with Broca's aphasia. For all groups, rejected trials were evenly distributed among conditions. For each subject, average waveforms were computed across all remaining trials per condition after normalizing the waveforms of the individual trials on the basis of a 150 ms pre-CW baseline. Mean amplitude values for each subject were computed in the following latency windows: 400-600 ms, and 600-1200 ms after onset of CW. These latency ranges were determined on the basis of a visual inspection of the waveforms and on the basis of earlier studies. The mean amplitude values were entered into repeated measures analyses of variance for each subject group respectively with Complexity (two levels: Conjoined, Embedded), Agreement (two levels: Correct, Incorrect) and Electrode Site (13 levels) as within-subjects factors. The Huynh-Feldt correction was applied when necessary. The adjusted degrees of freedom and p-values will be presented. The results of the ANOVAs are listed in Tables 2-4 to 2-12. To test for differences between the results for the normal controls and the patient groups, also group analyses are performed in the specified time-windows, with Group of Subjects as the additional between-subjects factor.

Normal Control Subjects

Figure 2-3 displays the grand average waveforms elicited by the critical word (CW) in the subject-verb agreement *conjoined* condition for the normal elderly control subjects. The incorrect critical words elicit a clear positive deflection in comparison to the correct words. This positive shift starts at around 500 ms after the acoustic onset of the word that renders the sentence ungrammatical. This grammaticality effect is strongest over posterior sites and has the characteristic morphology, time course and distribution of a P600/SPS effect (Hagoort et al., 1999; Osterhout & Holcomb, 1992, 1993). In addition, an early negativity (400-600 ms) was visible that preceded the P600/SPS effect in latency and this negativity was most prominent at the F8 and FT8 site.

Figure 2-4 shows the grand average waveforms elicited by the critical word (CW) in the *embedded* condition. The incorrect critical words elicit a clear positive deflection in comparison to the correct words, with the same characteristics as for the agreement violation in the conjoined condition. In addition, the frontal left and right electrode site showed a sustained negative deflection for the violation condition.

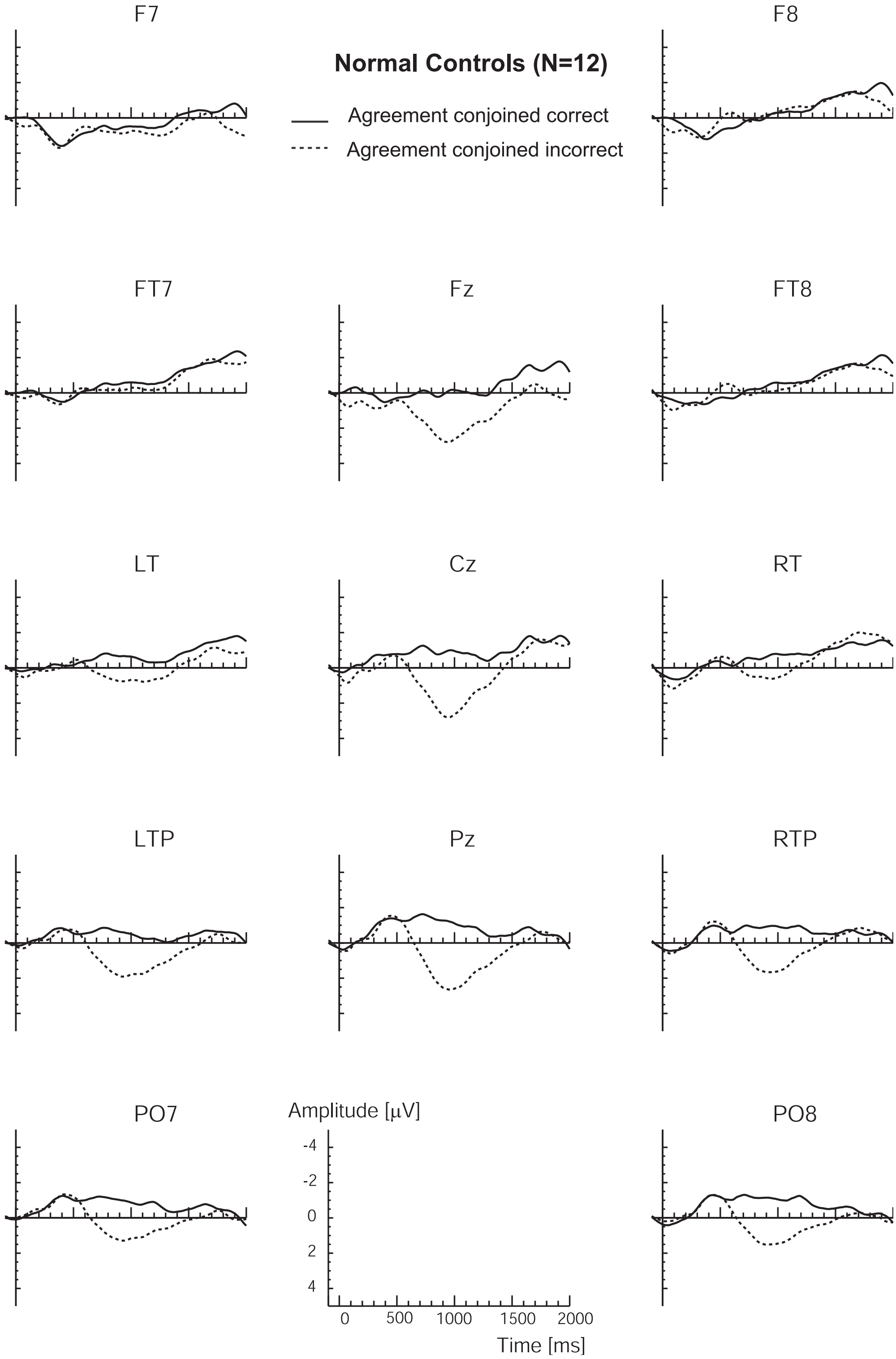

Figure 2-3. *Grand average ERP waveforms for the group of Normal Control Subjects (N=12) elicited by critical correct words (solid line) or incorrect words (dotted line) in the subject-verb agreement (conjoined) condition. In this and all following figures, negativity is plotted upwards. The onset of the critical word (CW) is at 0 ms.*

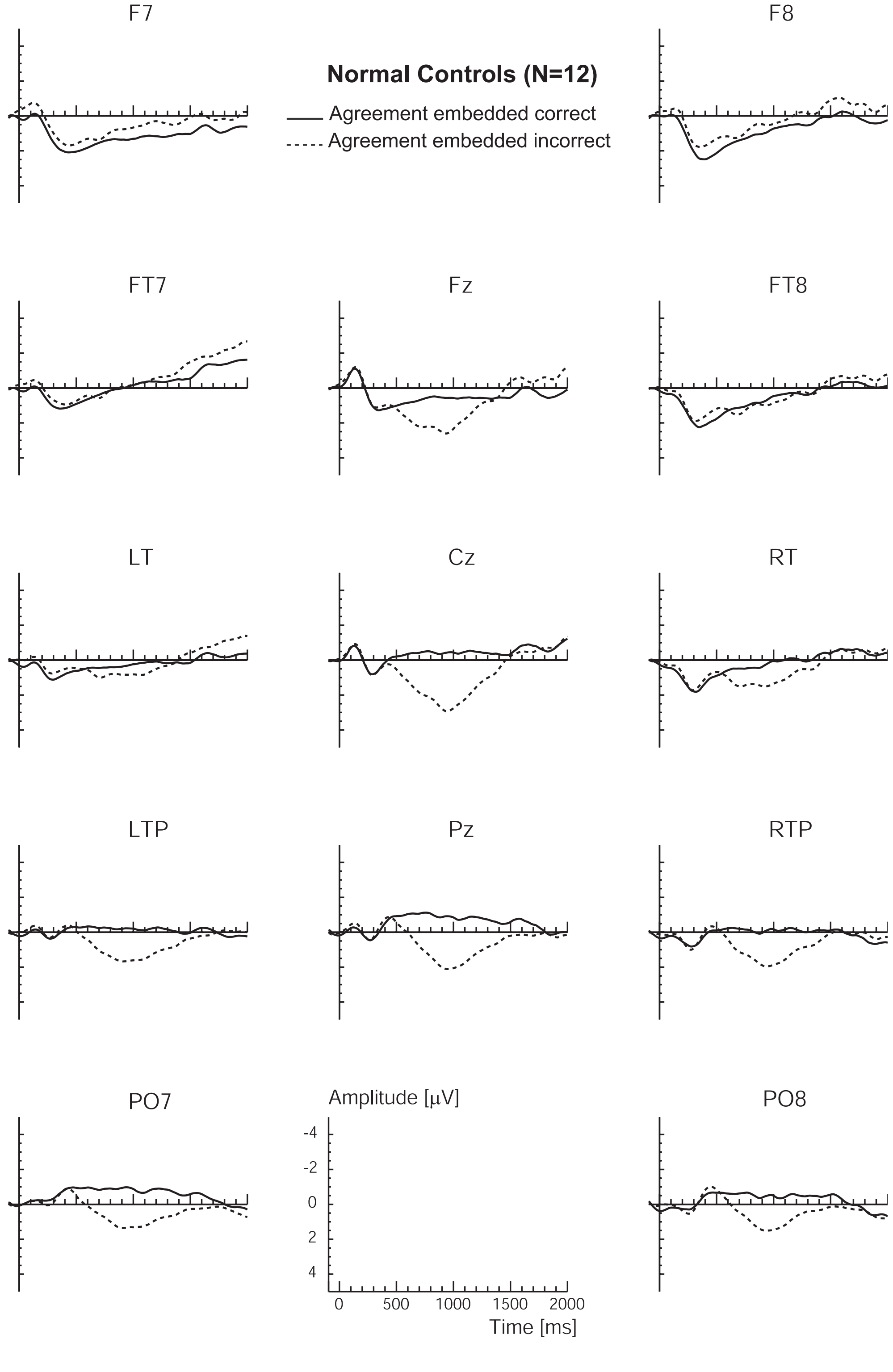

Figure 2-4. *Grand average ERP waveforms for the group of Normal Control Subjects (N=12) elicited by critical correct words (solid line) or incorrect words (dotted line) in the subject-verb agreement (embedded) condition. The onset of the critical word (CW) is at 0 ms.*

An ANOVA with all electrode sites (see Table 2-4) showed that the violation of subject-verb agreement had a significant main effect on mean amplitude in the 600-1200 ms latency window, with an effect size of 1.43 μV and 1.15 μV for the conjoined and embedded condition respectively. In the 600-1200 ms window, neither the Complexity effect nor the Complexity by Agreement interaction became significant in the omnibus ANOVA, showing that these control subjects showed sensitivity to subject-verb agreement violations irrespective of whether the sentences were conjoined or embedded. The Agreement effect interacted significantly with electrode site, due to its posterior distribution. The Agreement effect was largely symmetrical as indicated by the absence of an Agreement by Hemisphere interaction.

The negative effect that preceded the P600/SPS effect was mainly visible for the anterior sites and was tested in the 400-600 ms window (see Table 2-5). The analysis for anterior electrodes (F7, F8, FT7, FT8) failed to show a significant effect of Agreement. In addition, interactions with Complexity failed to reach significance

In sum, the normal elderly controls showed the expected P600/SPS effect to the violations of subject-verb agreement. They were sensitive to these violations irrespective of phrase structure complexity.

RH Patients

Figures 2-5 and 2-6 present the grand average waveforms for the RH patients. In the *conjoined* condition, the incorrect critical words elicited a positive deflection in comparison to the correct words mainly over centro-posterior electrode sites. This positive shift started at around 600 ms following the onset of the critical word and has the characteristics of a P600/SPS effect. In addition, the P600/SPS effect was preceded by a negative effect (latency range: 400-800 ms), which is mainly present at anterior and centro-temporal electrode sites.

The agreement violation in the *embedded* condition elicited an effect that is strongest over posterior sites and is characterized by a positive shift. For the posterior electrode sites, this P600/SPS effect started at around 600 ms following the onset of the critical word.

An ANOVA with all electrode sites (see Table 2-6) showed that the violation of subject-verb agreement had a marginally significant effect in the 600-1200 ms latency window, with an effect size of 0.50 μV and 0.58 μV for the conjoined and embedded condition respectively. The Agreement by Electrode interaction was significant, due to the

Table 2-4. Subject-verb agreement violations for Normal Control Subjects: Mean ERP amplitude ANOVAs in the 600- to 1200-ms latency range following the onset of the Critical Word.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Complexity	1, 11	3.04	11.61	0.109
Agreement	1, 11	21.17	11.65	0.001***
Compl x Agree	1, 11	2.14	2.14	0.171
Compl x El	4.09, 44.94	1.98	0.68	0.113
Agree x El	4.19, 46.13	17.25	0.75	0.000***
Compl x Agree x El	5.80, 63.80	0.80	0.33	0.568
		Midline ANOVA (3 electrodes)		
Complexity	1, 11	0.36	6.98	0.559
Agreement	1, 11	37.24	5.66	0.000***
Compl x Agree	1, 11	1.71	0.95	0.218
Compl x El	1.60, 17.60	1.55	0.40	0.239
Agree x El	1.34, 14.71	6.71	0.50	0.015*
Compl x Agree x El	2, 22	0.55	0.43	0.586
		Posterior ANOVA (5 electrodes)		
Complexity	1, 11	0.38	7.41	0.548
Agreement	1, 11	27.26	8.94	0.000***
Compl x Agree	1, 11	1.91	1.43	0.195
Compl x El	3.46, 38.01	1.25	0.39	0.306
Agree x El	2.79, 30.73	4.54	0.40	0.011*
Compl x Agree x El	2.97, 32.71	0.78	0.26	0.513
		Lateral ANOVA (2 x 5 electrodes)		
Complexity	1, 11	5.21	6.67	0.043*
Agreement	1, 11	13.28	7.46	0.004**
Compl x Agree	1, 11	1.90	1.59	0.195
Compl x El	1.61, 17.73	1.79	0.85	0.199
Agree x El	1.52, 16.67	22.06	0.97	0.000***
Compl x Hemi	1, 11	4.17	1.34	0.066
Agree x Hemi	1, 11	0.04	1.33	0.853
Compl x Agree x Hemi	1, 11	0.57	0.54	0.465

Note. Compl = Complexity (conjoined versus embedded); Agree = Subject verb agreement (correct versus incorrect); El = Electrode; Hemi = Hemisphere. * $p < 0.05$; ** $p < 0.01$; *** $p \leq 0.001$.

Table 2-5. Subject-verb agreement violations for Normal Control Subjects: Mean ERP amplitude ANOVAs in the 400- to 600-ms latency range following the onset of the Critical Word.

Source	*df*	*F*	*MSe*	*p*
	Anterior ANOVA (2 x 2 electrodes)			
Complexity	1, 11	10.24	5.07	0.008**
Agreement	1, 11	3.38	2.82	0.093
Compl x Agree	1, 11	0.03	1.38	0.861
Compl x El	1, 11	0.27	0.22	0.612
Agree x El	1, 11	0.78	0.39	0.396
Compl x Hemi	1, 11	14.53	0.42	0.003**
Agree x Hemi	1, 11	0.71	2.39	0.417
Compl x Agree x Hemi	1, 11	0.11	0.49	0.748

Note. Compl = Complexity (conjoined versus embedded); Agree = Subject verb agreement (correct versus incorrect); El = Electrode; Hemi = Hemisphere. ** $p < 0.01$.

posterior topography of the effect. We therefore performed an additional ANOVA in which only the posterior sites (Pz, LTP, RTP, PO7, PO8) were included. This analysis for the 600-1200 ms window resulted in a significant effect of Agreement. Neither the Complexity effect nor the Complexity by Agreement interaction became significant for the posterior sites.

The negative effect that preceded the P600/SPS effect in the conjoined sentences was tested in the 400-600 ms window (see Table 2-7). The analysis for anterior electrodes (F7, F8, FT7, FT8) did not yield a significant effect of Agreement, and the interaction between Complexity and Agreement was only marginally significant.

An omnibus ANOVA (see Table 2-9) in the 600-1200 ms latency range with Group of Subjects (Normal Controls, RH patients) as between-subjects factor revealed neither a main effect of Group of Subjects nor significant interactions. For the 400-600 ms latency range (see Table 2-9), an ANOVA for anterior electrodes showed a significant Group of Subjects by Complexity interaction, and a significant three-way interaction between Group of Subjects, Complexity, and Agreement. This was mainly due to the differential effects in the early latency window for the two sentence types in the RH patients. In sum, the RH patients showed a P600/SPS, which was statistically indistinguishable from that of the normal controls.

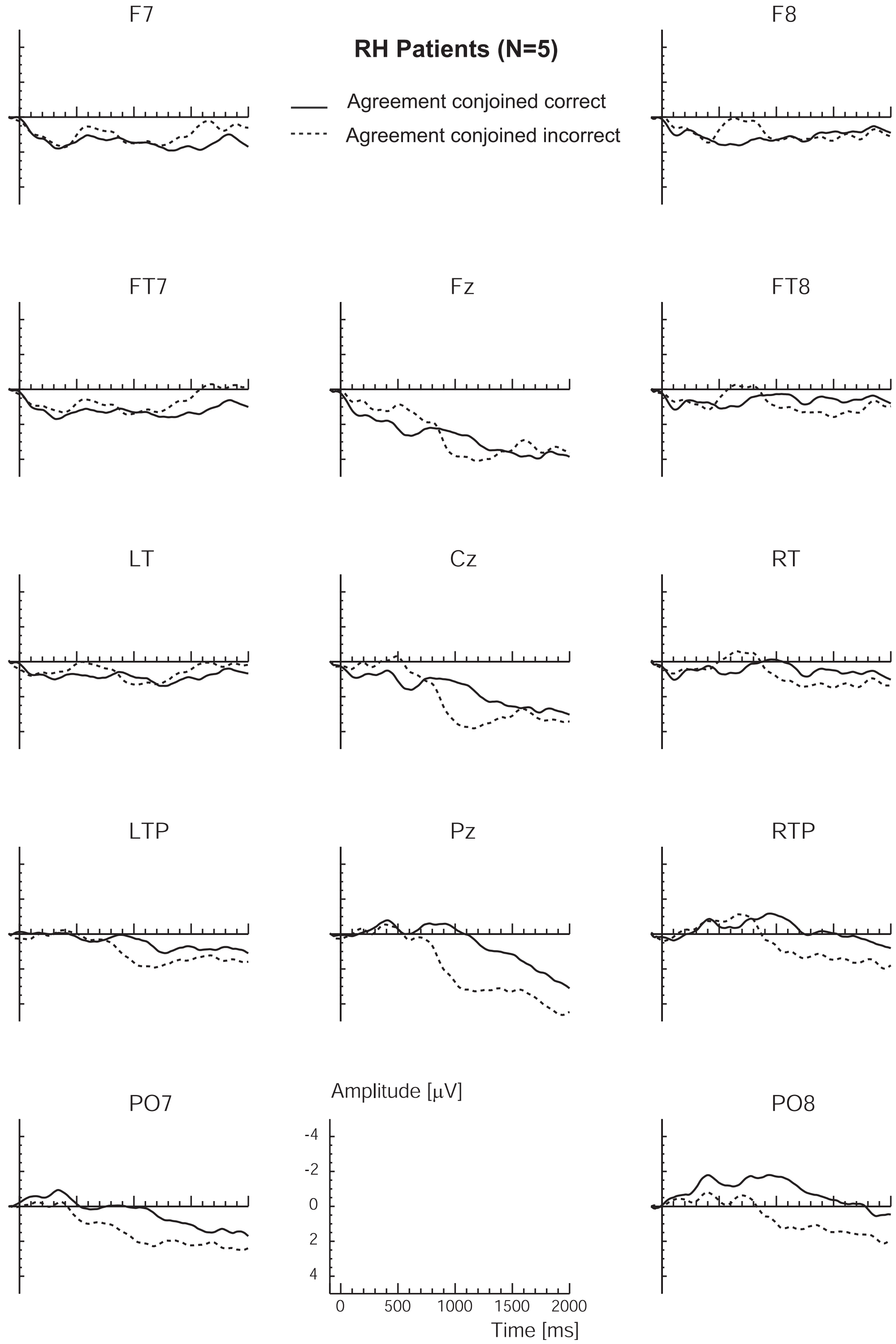

Figure 2-5. *Grand average ERP waveforms for the group of RH Patients (N=5) elicited by critical correct words (solid line) or incorrect words (dotted line) in the subject-verb agreement (conjoined) condition. The onset of the critical word (CW) is at 0 ms.*

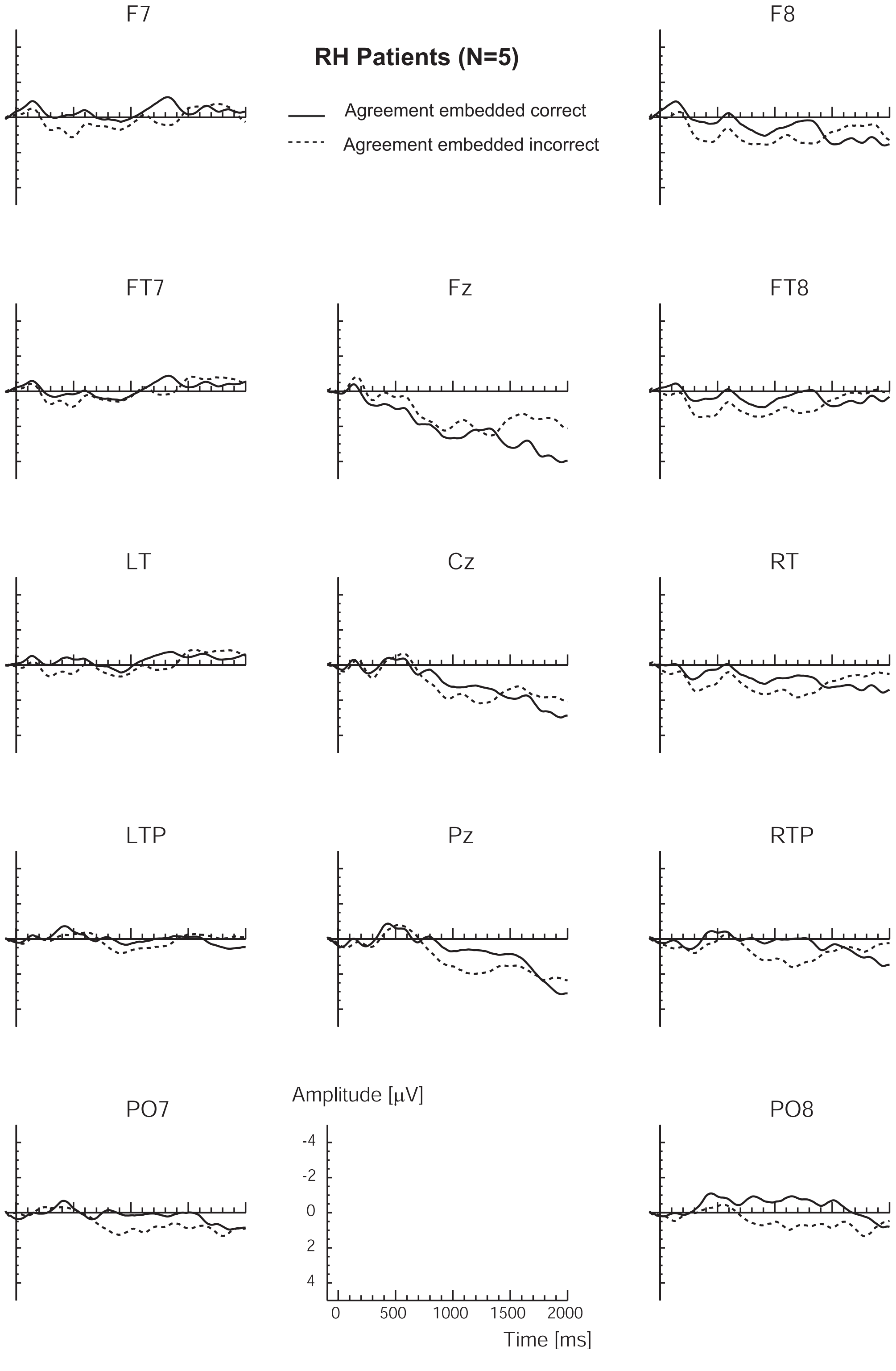

Figure 2-6. *Grand average ERP waveforms for the group of RH Patients (N=5) elicited by critical correct words (solid line) or incorrect words (dotted line) in the subject-verb agreement (embedded) condition. The onset of the critical word (CW) is at 0 ms.*

Table 2-6. Subject-verb agreement violations for RH Patients: Mean ERP amplitude ANOVAs in the 600- to 1200-ms latency range following the onset of the Critical Word.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Complexity	1, 4	0.12	11.71	0.743
Agreement	1, 4	6.20	2.84	0.067
Compl x Agree	1, 4	0.01	2.33	0.921
Compl x El	3.20, 12.82	1.78	1.27	0.199
Agree x El	12, 48	2.71	0.62	0.007**
Compl x Agree x El	4.12, 16.50	1.46	0.56	0.258
		Midline ANOVA (3 electrodes)		
Complexity	1, 4	1.24	2.32	0.328
Agreement	1, 4	1.92	3.27	0.238
Compl x Agree	1, 4	4.30	0.65	0.107
Compl x El	1.20, 4.82	0.71	1.06	0.465
Agree x El	2, 8	7.66	0.37	0.014*
Compl x Agree x El	1.94, 7.76	0.36	0.49	0.705
		Posterior ANOVA (5 electrodes)		
Complexity	1, 4	0.04	12.49	0.848
Agreement	1, 4	13.64	2.23	0.021*
Compl x Agree	1, 4	0.46	4.38	0.535
Compl x El	1.31, 5.22	2.79	0.54	0.153
Agree x El	4, 16	2.00	0.46	0.143
Compl x Agree x El	4, 16	0.90	0.35	0.489
		Lateral ANOVA (2 x 5 electrodes)		
Complexity	1, 4	0.02	9.69	0.893
Agreement	1, 4	12.54	0.93	0.024*
Compl x Agree	1, 4	0.54	2.25	0.504
Compl x El	2.28, 9.13	0.54	1.97	0.621
Agree x El	2.03, 8.13	7.47	0.44	0.014*
Compl x Hemi	1, 4	5.05	3.71	0.088
Agree x Hemi	1, 4	0.39	2.47	0.565
Compl x Agree x Hemi	1, 4	0.23	1.71	0.658

Note. Compl = Complexity (conjoined versus embedded); Agree = Subject verb agreement (correct versus incorrect); El = Electrode; Hemi = Hemisphere. * p < 0.05; ** p < 0.01.

Table 2-7. Subject-verb agreement violations for RH Patients: Mean ERP amplitude ANOVAs in the 400- to 600-ms latency range following the onset of the Critical Word.

Source	*df*	*F*	*MSe*	*p*
		Anterior ANOVA (2 x 2 electrodes)		
Complexity	1, 4	0.86	6.08	0.406
Agreement	1, 4	0.41	2.05	0.559
Compl x Agree	1, 4	5.09	1.92	0.087
Compl x El	1, 4	0.61	0.86	0.480
Agree x El	1, 4	0.39	0.06	0.565
Compl x Hemi	1, 4	1.13	0.82	0.348
Agree x Hemi	1, 4	0.02	1.56	0.892
Compl x Agree x Hemi	1, 4	0.81	0.14	0.418

Note. Compl = Complexity (conjoined versus embedded); Agree = Subject verb agreement (correct versus incorrect); El = Electrode; Hemi = Hemisphere.

Broca Patients

Figure 2-7 shows the grand average waveforms elicited by the critical word (CW) in the *conjoined* condition for the ten patients with Broca's aphasia. Unlike the normal elderly controls and the RH patients, a clear positive deflection for the incorrect critical words was absent. Only the midline sites Cz and Pz showed a small positive shift starting at around 600 ms. Between 200-500 ms, a negative deflection was present for almost all electrode sites, with a slight right hemisphere preponderance.

Figure 2-8 displays the grand average waveforms for the *embedded* condition. For the posterior electrode sites, the waveforms are characterized by a (small) positive shift, starting at around 750 ms. In addition, anterior right electrode sites (F8, FT8) showed a broad negative deflection for the violation condition.

An ANOVA with all electrode sites (see Table 2-8) did not reveal a significant effect of Agreement in the 600-1200 ms latency window. When only the posterior electrodes were included, the ANOVA also failed to show a significant agreement effect. No significant interactions were obtained.

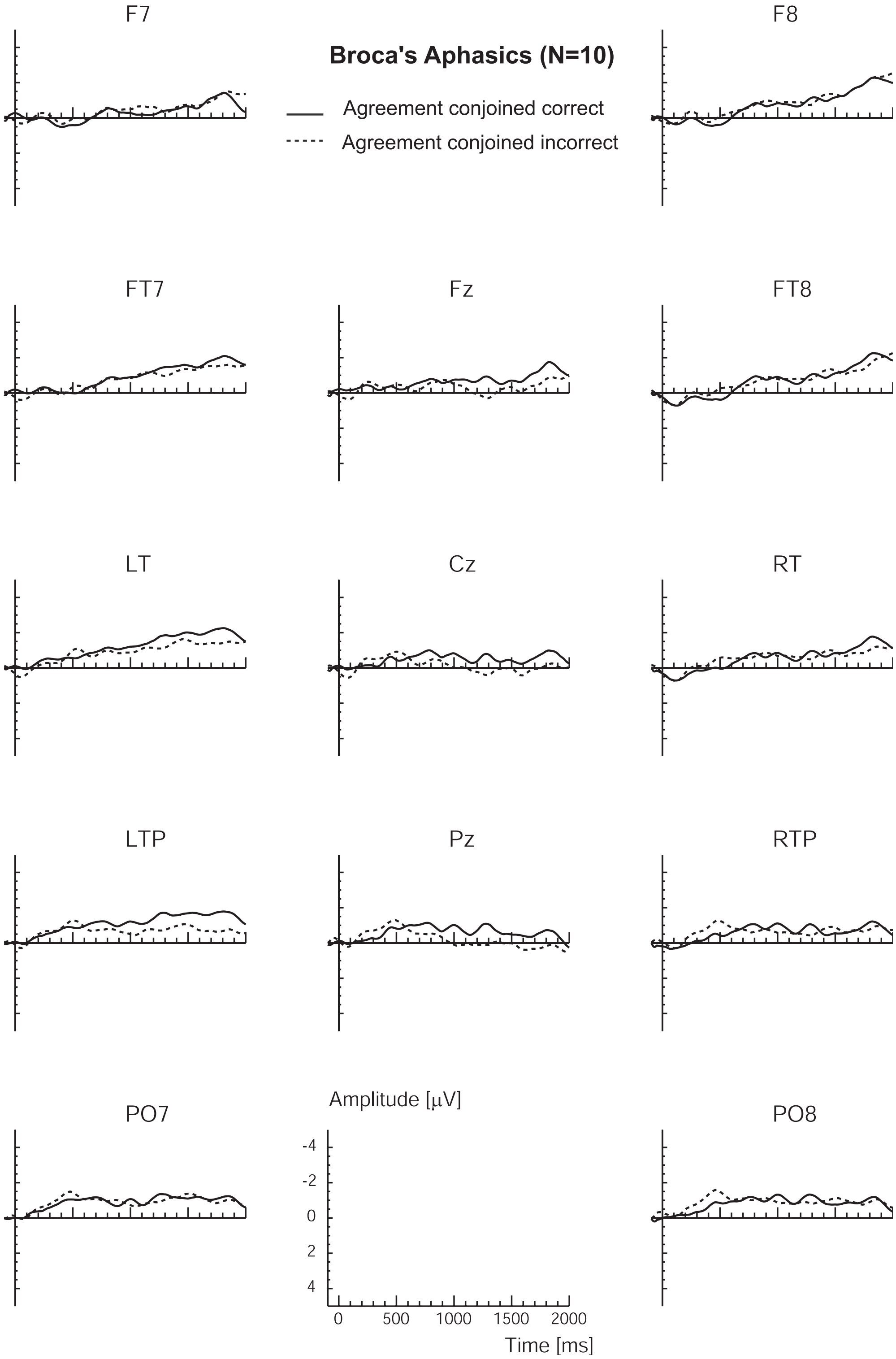

Figure 2-7. *Grand average ERP waveforms for the group of Broca Patients (N=10) elicited by critical correct words (solid line) or incorrect words (dotted line) in the subject-verb agreement (conjoined) condition. The onset of the critical word (CW) is at 0 ms.*

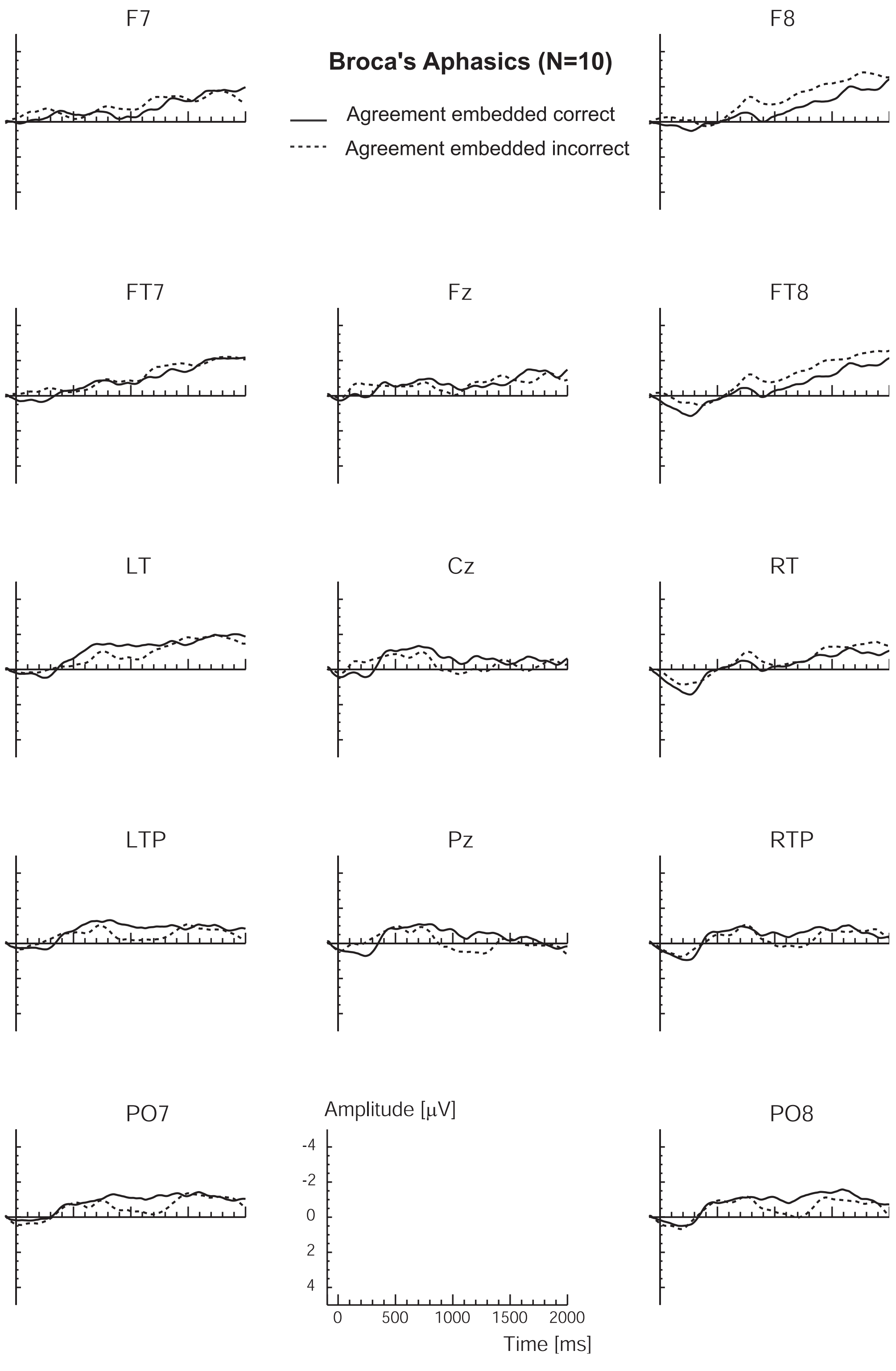

Figure 2-8. *Grand average ERP waveforms for the group of Broca Patients (N=10) elicited by critical correct words (solid line) or incorrect words (dotted line) in the subject-verb agreement (embedded) condition. The onset of the critical word (CW) is at 0 ms.*

Table 2-8. Subject-verb agreement violations for Broca Patients: Mean ERP amplitude ANOVAs in the 600- to 1200-ms latency range following the onset of the Critical Word.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Complexity	1, 9	0.03	14.09	0.873
Agreement	1, 9	0.70	7.14	0.423
Compl x Agree	1, 9	0.01	15.05	0.920
Compl x El	6.65, 59.84	0.44	0.51	0.863
Agree x El	3.07, 27.60	1.60	0.87	0.212
Compl x Agree x El	3.99, 35.93	0.59	0.68	0.669
		Midline ANOVA (3 electrodes)		
Complexity	1, 9	0.00	7.07	0.981
Agreement	1, 9	1.30	5.63	0.284
Compl x Agree	1, 9	0.00	5.10	0.949
Compl x El	2, 18	0.37	0.17	0.694
Agree x El	1.35, 12.19	0.96	0.47	0.374
Compl x Agree x El	1.22, 10.99	0.25	0.70	0.677
		Posterior ANOVA (5 electrodes)		
Complexity	1, 9	0.12	8.23	0.734
Agreement	1, 9	0.94	8.25	0.358
Compl x Agree	1, 9	0.06	5.20	0.815
Compl x El	3.14, 28.28	0.13	0.50	0.947
Agree x El	3.08, 27.73	1.55	0.25	0.222
Compl x Agree x El	2.61, 23.51	0.44	0.58	0.704
		Lateral ANOVA (2 x 5 electrodes)		
Complexity	1, 9	0.05	8.53	0.825
Agreement	1, 9	0.34	3.46	0.576
Compl x Agree	1, 9	0.03	10.26	0.870
Compl x El	1.75, 15.73	0.87	0.52	0.411
Agree x El	1.33, 11.97	1.11	1.24	0.335
Compl x Hemi	1, 9	0.86	0.64	0.377
Agree x Hemi	1, 9	3.01	1.82	0.117
Compl x Agree x Hemi	1, 9	0.75	2.73	0.409

Note. Compl = Complexity (conjoined versus embedded); Agree = Subject verb agreement (correct versus incorrect); El = Electrode; Hemi = Hemisphere.

The negative going effect was tested for each Agreement condition separately. For the conjoined condition the negative effect was tested in the 300-500 ms latency range. Neither the overall ANOVA, nor any site analysis yielded any significant effect of Agreement. The negative effect in the embedded condition was primarily visible over F8 and FT8 and was tested in the 600-1200 ms latency range. The ANOVA for these right anterior sites revealed a significant Agreement effect ($F(1, 9) = 5.99$; $MSe = 0.83$; $p = 0.037$).

An omnibus ANOVA (see Table 2-9) in the 600-1200 ms latency range with Group of Subjects (Normal Controls, Broca patients) as additional between-subjects factor showed a significant main effect of Group of Subjects, but more importantly also a significant Group of Subjects by Agreement interaction.

In sum, whereas the normal controls showed a P600/SPS for both types of sentences (conjoined versus embedded), the Broca's aphasics did not show this effect for either of these.

It is not inconceivable, however, that the absence of P600/SPS effects in the group of Broca patients is partly due to individual patient variability. It was therefore decided to group these Broca patients in a way that was related to the *severity* of their individual syntactic comprehension impairment. On the basis of their performance on the syntactic offline test (see Methods section), the ten Broca patients were divided into two subgroups.

Five Broca patients (subject numbers 1-5 from Table 2-2) showed an above-chance level of performance, even for the most complex sentence structures. These subjects were classified as "High Comprehenders". The other five Broca patients (subject numbers 6-10 from Table 2-2) showed a level of performance that was just above chance or not different from chance (25% on this offline test) for sentence structures that were more complex than simple passive sentences. These subjects were classified as "Low Comprehenders". An ANOVA (see Table 2-9) in the 600-1200 ms latency range on the mean amplitudes of the 10 Broca patients with Group of Patients (High Comprehenders, Low Comprehenders) as additional between-subjects factor, yielded a significant Group of Patients by Agreement interaction for the midline electrode sites (High Comprehenders: conjoined: 1.70 μV; embedded: 1.02 μV; Low Comprehenders: conjoined: -0.66 μV; embedded: -0.09 μV). Because of this Group by Agreement interaction, ANOVAs were done on the data of the two groups of Broca patients separately.

Table 2-9. Between-subjects ANOVAs for subject-verb agreement violations on mean ERP amplitude in specified latency ranges following the onset of the Critical Word.

Source	*df*	*F*	*MSe*	*p*
		Normal Controls versus RH Patients 600-1200 ms *Omnibus ANOVA (13 electrodes)*		
Group	1, 15	0.40	46.73	0.537
Complexity	1, 15	0.42	11.64	0.527
Group x Complexity	1, 15	1.54	11.64	0.234
Agreement	1, 15	15.60	9.30	0.001***
Group x Agreement	1, 15	2.68	9.30	0.123
Group x Compl x Agree	1, 15	0.77	2.19	0.395
		Normal Controls versus RH Patients 400-600 ms *Anterior ANOVA (4 electrodes)*		
Group	1, 15	0.10	13.69	0.756
Complexity	1, 15	0.74	5.34	0.404
Group x Complexity	1, 15	6.36	5.34	0.023*
Agreement	1, 15	0.31	2.61	0.584
Group x Agreement	1, 15	2.28	2.61	0.152
Group x Compl x Agree	1, 15	4.94	1.52	0.042*
		Normal Controls versus Broca Patients 600-1200 ms *Omnibus ANOVA (13 electrodes)*		
Group	1, 20	7.72	36.24	0.012*
Complexity	1, 20	1.56	12.73	0.226
Group x Complexity	1, 20	0.99	12.73	0.332
Agreement	1, 20	15.58	9.62	0.001***
Group x Agreement	1, 20	8.29	9.62	0.009**
Group x Compl x Agree	1, 20	0.38	7.95	0.544
		High Comprehenders versus Low Comprehenders 600-1200 ms *Midline ANOVA (3 electrodes)*		
Group	1, 8	0.56	13.58	0.474
Complexity	1, 8	0.00	6.10	0.979
Group x Complexity	1, 8	2.43	6.10	0.158
Agreement	1, 8	2.08	3.51	0.188
Group x Agreement	1, 8	6.43	3.51	0.035*
Group x Compl x Agree	1, 8	0.55	5.38	0.481

Note. Compl = Complexity (conjoined versus embedded); Agree = Subject verb agreement (correct versus incorrect); El = Electrode. * $p < 0.05$; ** $p < 0.01$; *** $p \leq 0.001$.

An ANOVA (see Table 2-10) for the High Comprehending Broca patients in the 600-1200 ms latency range revealed a significant main effect of Agreement for the midline electrode sites. The ANOVA for the Low Comprehending Broca patients (see Table 2-11) did not lead to any significant effect of Agreement.

Figure 2-9 presents data of individual subjects. This figure shows per subject the effect size in the 600-1200 ms epoch, collapsed over the conjoined and embedded sentences, and averaged over five posterior electrode sites (Pz, LTP, RTP, PO7, PO8), where P600/SPS effects are maximal. As is clear from this figure, there is considerable variation in the size of the agreement effect within all of the subject groups. However, all normal control subjects except one showed a P600/SPS effect. A P600/SPS effect was present in all RH patients. Thus, the overall pattern of results that was observed in the averaged data was present in most control and RH subjects. The Broca patients showed a less consistent pattern. Only six of the ten patients showed a P600/SPS effect. For the other patients, the effect size rendered either a negative value or was near zero. This variable performance is compatible with the overall absence of a significant effect of Agreement. Four High Comprehending Broca patients showed a P600/SPS effect. This in contrast to the subgroup with a relatively more severe syntactic comprehension impairment in which only two patients showed a P600/SPS effect of some size.

Tone Oddball Task

Artefact rejection and correction procedures were identical to the ones used for the sentence ERPs, in a critical window that ranged from 150 ms before onset of the tone to 850 ms after tone onset. The overall rejection rate was 19.9 % for the normal control subjects, 19.2 % for the RH patients, 11.8 % for the aphasic patients. For each subject, average waveforms were computed across all remaining trials per condition (rare versus frequent tones), after normalizing the individual trial ERPs on the basis of a 150 ms pre-stimulus baseline. Statistical analyses on P300 effects were performed on the mean amplitudes in the latency range of 250-500 ms.

Table 2-10. Subject-verb agreement violations for High Comprehending Broca Patients: Mean ERP amplitude ANOVAs in the 600- to 1200-ms latency range following the onset of the Critical Word.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Complexity	1, 4	1.88	3.91	0.242
Agreement	1, 4	3.53	5.65	0.133
Compl x Agree	1, 4	1.36	3.07	0.308
Compl x El	9.27, 37.06	0.77	0.54	0.650
Agree x El	2.04, 8.15	4.93	0.59	0.039*
Compl x Agree x El	5.20, 20.79	0.80	0.19	0.568
		Midline ANOVA (3 electrodes)		
Complexity	1, 4	2.84	2.52	0.167
Agreement	1, 4	12.85	2.16	0.023*
Compl x Agree	1, 4	1.51	1.15	0.287
Compl x El	2, 18	0.37	0.17	0.694
Agree x El	2, 8	3.33	0.08	0.089
Compl x Agree x El	2, 8	1.37	0.16	0.308
		Posterior ANOVA (5 electrodes)		
Complexity	1, 4	0.65	3.22	0.466
Agreement	1, 4	3.58	8.26	0.131
Compl x Agree	1, 4	0.06	2.11	0.812
Compl x El	4, 16	1.38	0.40	0.286
Agree x El	2.32, 9.26	2.93	0.17	0.098
Compl x Agree x El	2.17, 8.68	0.13	0.19	0.894
		Lateral ANOVA (2 x 5 electrodes)		
Complexity	1, 4	1.34	1.96	0.311
Agreement	1, 4	1.27	3.83	0.322
Compl x Agree	1, 4	1.22	2.13	0.332
Compl x El	1.63, 6.53	0.46	0.79	0.612
Agree x El	1.09, 4.35	3.65	1.22	0.123
Compl x Hemi	1, 4	0.55	0.57	0.498
Agree x Hemi	1, 4	2.11	0.75	0.220
Compl x Agree x Hemi	1, 4	0.36	0.55	0.581

Note. Compl = Complexity (conjoined versus embedded); Agree = Subject verb agreement (correct versus incorrect); El = Electrode; Hemi = Hemisphere. * $p < 0.05$.

Table 2-11. Subject-verb agreement violations for Low Comprehending Broca Patients: Mean ERP amplitude ANOVAs in the 600- to 1200-ms latency range following the onset of the Critical Word.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Complexity	1, 4	0.56	22.85	0.496
Agreement	1, 4	0.27	6.26	0.632
Compl x Agree	1, 4	0.24	28.09	0.648
Compl x El	5.14, 20.54	1.17	0.44	0.359
Agree x El	4.97, 19.86	0.92	0.81	0.488
Compl x Agree x El	5.57, 22.26	0.50	1.25	0.790
		Midline ANOVA (3 electrodes)		
Complexity	1, 4	0.79	9.69	0.424
Agreement	1, 4	0.43	4.86	0.547
Compl x Agree	1, 4	0.13	9.60	0.739
Compl x El	1.98, 7.94	1.55	0.18	0.269
Agree x El	1.39, 5.54	0.04	0.60	0.912
Compl x Agree x El	1.32, 5.30	0.99	1.13	0.392
		Posterior ANOVA (5 electrodes)		
Complexity	1, 4	0.63	12.99	0.471
Agreement	1, 4	0.53	4.27	0.507
Compl x Agree	1, 4	0.14	9.30	0.727
Compl x El	4, 16	1.11	0.48	0.384
Agree x El	4, 16	0.67	0.31	0.691
Compl x Agree x El	3.70, 14.80	0.38	1.06	0.807
		Lateral ANOVA (2 x 5 electrodes)		
Complexity	1, 4	0.44	15.02	0.544
Agreement	1, 4	0.16	2.91	0.710
Compl x Agree	1, 4	0.30	18.98	0.615
Compl x El	2.69, 10.77	0.66	0.35	0.578
Agree x El	3.15, 12.62	1.32	0.60	0.313
Compl x Hemi	1, 4	9.24	0.28	0.038*
Agree x Hemi	1, 4	1.28	3.26	0.321
Compl x Agree x Hemi	1, 4	0.46	5.44	0.536

Note. Compl = Complexity (conjoined versus embedded); Agree = Subject verb agreement (correct versus incorrect); El = Electrode; Hemi = Hemisphere. * $p < 0.05$.

Individual Subject Data Subject-Verb Agreement Violations

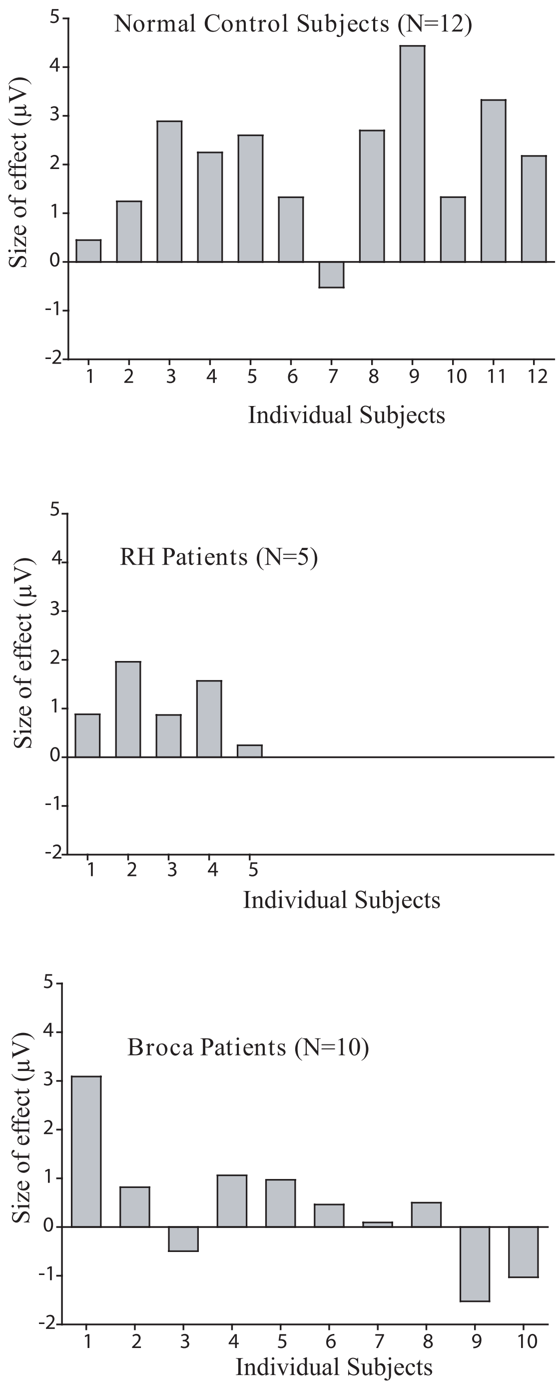

Figure 2-9. *Mean amplitude of the grammaticality effect in μV (collapsed over conjoined and embedded sentences) over five posterior electrode sites (latency: 600-1200 ms), for each individual subject. High Comprehending Broca Patients correspond with Broca patients 1–5 in Table 2-2, Low Comprehending Patients with subject numbers 6–10 in the same table.*

Figure 2-10 summarizes the P300 effects by means of the difference waveforms. Table 2-12 summarizes the statistical analyses. For the *normal control subjects* a significant P300 effect (4.20 µV) was obtained, with a characteristic centro-parietal distribution. Also the P300 effect (3.13 µV) for the *RH patients* was significant and did not differ from the normal controls, as indicated by the absence of a significant Group by Tones interaction. Likewise, the overall P300 effect in the *Broca patients* was significant and corresponded to a 2.55 µV amplitude difference. Although the size of the effect in the Broca patients was somewhat reduced relative to the normal controls, the Group by Tones interaction was not significant. When testing High Comprehenders against Low Comprehenders no significant Group of Patients by Tones interaction was obtained.

Figure 2-11 shows tone oddball data of individual subjects. All normal control subjects, all RH patients, and eight of the ten Broca patients showed P300 effects, which varied in size. Two Broca patients showed more negative waveforms to the rare tones than to the frequent tones. Such opposite P300 effects have been reported before (Hagoort, Brown, & Swaab, 1996; Swaab, Brown, & Hagoort, 1997). It has been suggested that such an abnormal P300 effect might be related to the inability to count. One of the patients who showed this abnormal P300 effect (subject 10) was indeed unable to count.

Questionnaire

The normal controls answered of 98% of the questions correctly (range: 91-100%). For the other groups the scores were 96% for the RH patients (range: 92-100%), and 89% for the Broca patients (range: 63-100%). These results indicate that the subjects were engaged in attentive listening to the sentences.

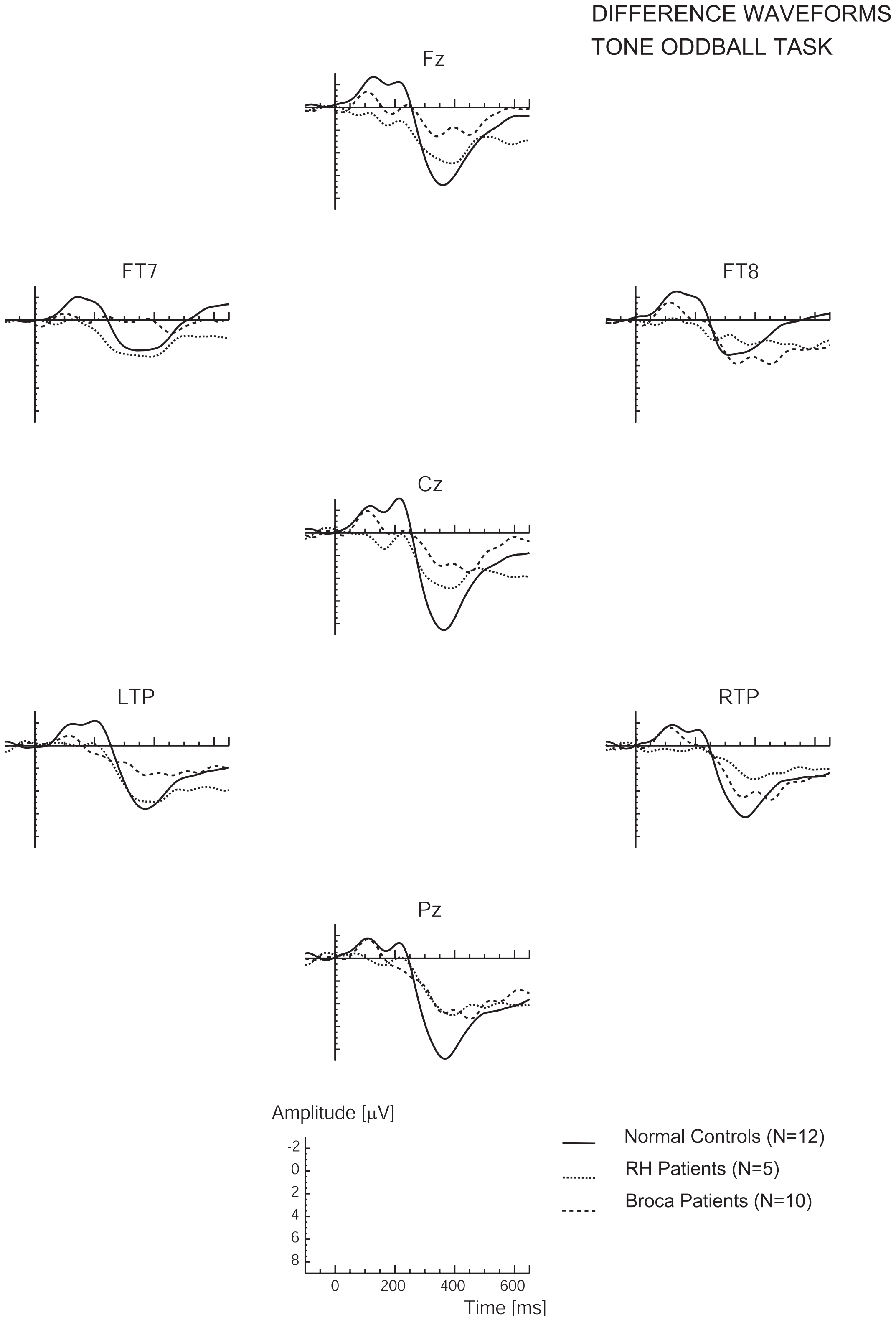

Figure 2-10. *Grand average difference waveforms (oddballs minus standards) for Normal Control Subjects (solid line), RH Patients (dotted line), and Broca Patients (dashed line).*

Table 2-12. ANOVAs for Tone Oddball task: mean ERP amplitude in the 250-500 ms latency range.

Source	*df*	*F*	*MSe*	*p*
		Normal Controls *Omnibus ANOVA (7 electrodes)*		
Tones	1, 11	41.38	17.87	0.000***
Tones x El	3.50, 38.51	11.46	1.46	0.000***
		RH Patients *Omnibus ANOVA (7 electrodes)*		
Tones	1, 4	7.96	21.50	0.048*
Tones x El	3.16, 12.65	2.35	0.87	0.119
		Broca Patients *Omnibus ANOVA (7 electrodes)*		
Tones	1, 9	5.54	40.94	0.043*
Tones x El	3.41, 30.70	2.54	3.11	0.068
		Normal Controls versus RH Patients *Omnibus ANOVA (7 electrodes)*		
Group	1, 15	1.39	56.23	0.257
Tones	1, 15	35.17	18.84	0.000***
Group x Tones	1, 15	0.75	18.84	0.401
		Normal Controls versus Broca Patients *Omnibus ANOVA (7 electrodes)*		
Group	1, 20	4.54	37.58	0.046*
Tones	1, 20	30.70	28.25	0.000***
Group x Tones	1, 20	1.84	28.25	0.190
		High Comprehenders versus Low Comprehenders *Omnibus ANOVA (7 electrodes)*		
Group	1, 8	4.55	12.64	0.065
Tones	1, 8	5.43	41.72	0.048*
Group x Tones	1, 8	0.83	41.72	0.388

Note. Tones = Tone oddball condition; El = Electrode. * $p < 0.05$; *** $p \leq 0.001$.

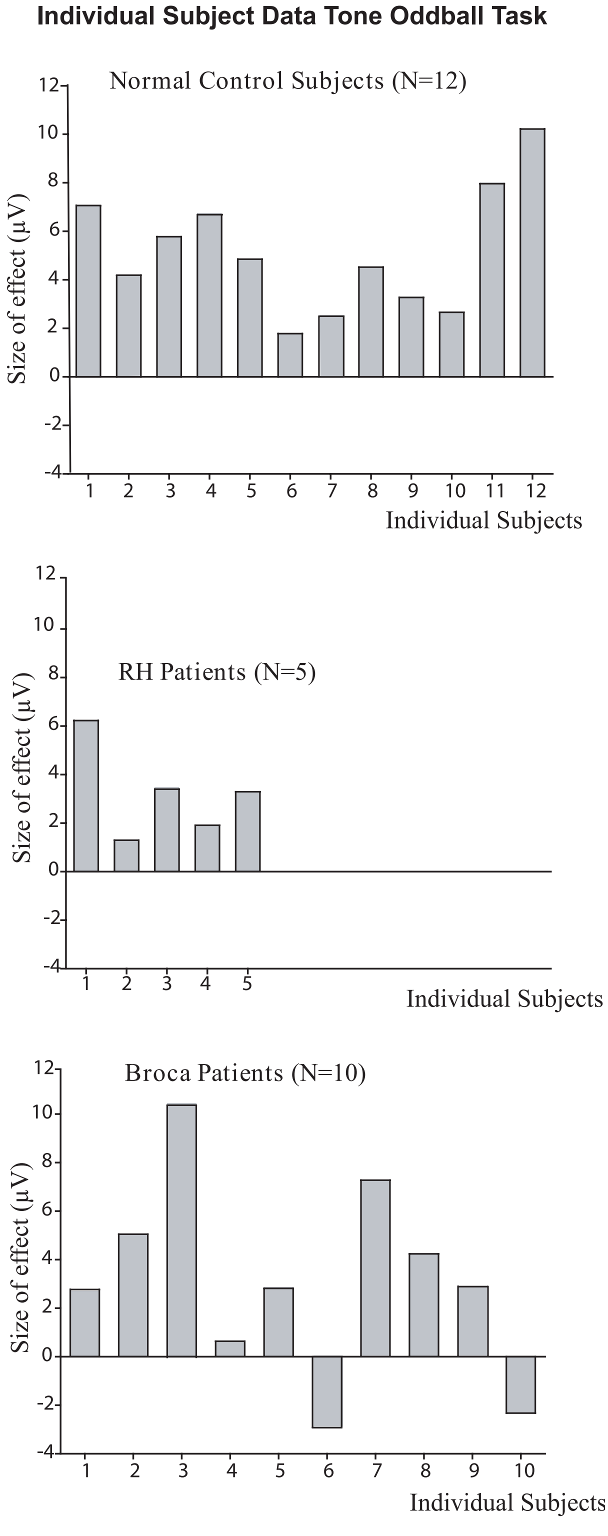

Figure 2-11. *Mean amplitude of tone oddball effects in μV over four centro-posterior electrodes (latency: 250-500 ms), for each individual subject. High Comprehending Broca patients correspond with Broca patients 1–5 in Table 2-2, Low Comprehending patients with subject numbers 6–10 in the same table.*

DISCUSSION

The aim of the present study was to investigate syntactic information processing during auditory sentence comprehension in patients with Broca's aphasia. For that purpose ERPs were recorded while subjects listened to sentences that were either syntactically correct or contained violations of subject-verb agreement. The central questions were: First, do the Broca patients show sensitivity to subject-verb agreement violations as indicated by a P600/SPS effect? Second, does the severity of the syntactic comprehension impairment in the Broca patients affect the ERP responses?

To summarize the results, figure 2-12 presents for the three different subject groups an overlay of the difference waveforms for the conjoined and embedded sentences. Difference waveforms reflect the size of an effect and are obtained by subtracting the correct condition from the violated one.

The age-matched normal controls showed the expected P600/SPS effect to the agreement violations for both the conjoined and embedded sentences. Although the P600/SPS effect in the embedded condition was somewhat smaller in amplitude, the effect for the embedded condition was statistically indistinguishable from the conjoined condition. So, the normal controls were sensitive to these violations, irrespective of syntactic complexity.

The non-aphasic patients with a lesion in the right hemisphere showed essentially the same pattern of P600/SPS effects to these syntactic violations. Although the size of the effect in the embedded condition seemed reduced when compared to the conjoined condition, this difference did not turn out to be significant. Even though the size P600/SPS was reduced relative to the normal controls, averaged over electrodes this difference was not statistically significant. These results indicate that there were no qualitative differences in the pattern of results for the normal controls and the RH patients. Thus, relatively normal P600/SPS effects can be obtained in brain-damaged patients without aphasia. This is not to say that a lesion in the right hemisphere will never have its impact on syntactic sentence understanding. A study of Caplan, Hildebrandt, and Makris (1996), for instance, showed significantly lower performance for syntactically complex sentences in right-hemisphere patients than in normal control subjects. In a meta-analysis of neuro-imaging studies on syntactic processing (in healthy subjects), *right* hemisphere activation was found on repeated occasions (Indefrey, 2001). The right posterior inferior frontal gyrus became active during the processing of

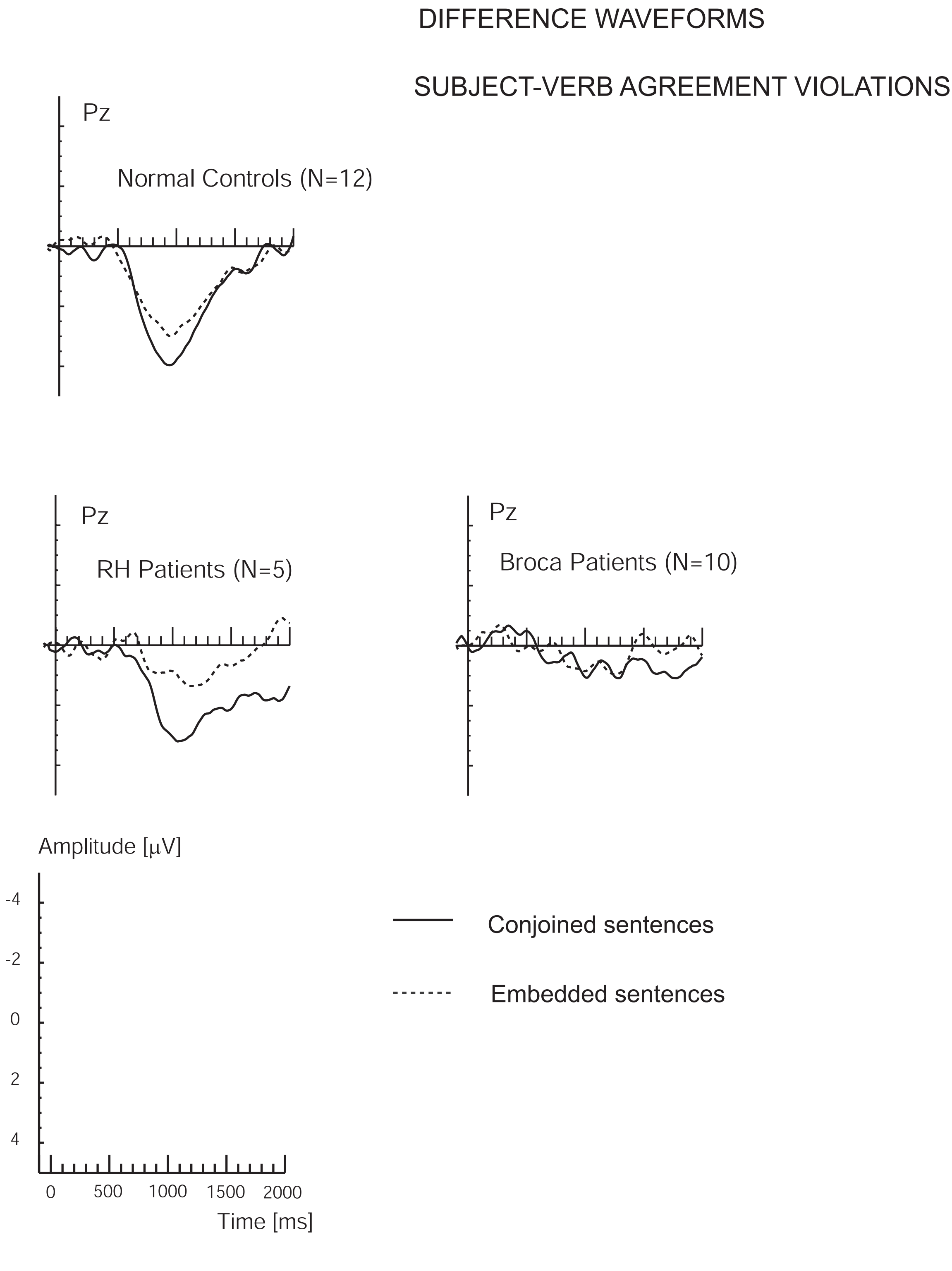

Figure 2-12. *Grand average difference waveforms for Pz (grammatically incorrect minus grammatically correct) for Normal Control Subjects, RH Patients, and Broca Patients. Solid line for conjoined sentences, dashed line for embedded sentences.*

syntactically more complex sentences. These studies indicate that there might be some right hemisphere involvement in auditory syntactic processing. However, the presence of P600/SPS effects in the RH patients of our study seems to suggest that the processing of subject-verb agreement relations is relatively undisrupted in these patients.

In contrast to the control groups, the overall group of Broca patients did not show clear P600/SPS effects in response to the subject-verb agreement violations. The effects were absent for both the conjoined and the embedded sentences. These findings suggest thus that these Broca patients, unlike the normal control subjects and the RH patients, did not show the same on-line sensitivity as their controls to these types of violations. The absence of P600/SPS effects might be indicative of the difficulties that these patients experience with the processing of this type of *syntactic* dependency. To determine whether the absence of a P600/SPS effect can correctly be ascribed to an alteration in syntactic processing, rather than to a general effect of brain damage on cognitive ERP components, we need to discuss the P300 results of the control experiment.

Like the normal control subjects and RH patients, also the group of Broca patients showed a significant P300 effect in the tone oddball condition. Furthermore, the size of the P300 effect was statistically indistinguishable from the effect of the controls. Since, the Broca patients had a relatively normal P300 effect, it can be concluded that aphasia in itself does not lead to a general reduction in all cognitive ERP effects. Therefore, the absence of P600/SPS effects cannot be interpreted in terms of a general a-specific lesion effect, equally affecting different endogenous ERP components. Overall then, it most likely reflects aspects of the underlying language processing deficit in the patients studied and not an a-specific effect of their brain damage.

The observed dissociation between the P300 and P600/SPS effect in these Broca patients is also interesting from the perspective of the P600/SPS-P300 debate. Some studies (e.g. Coulson, King, & Kutas, 1998a; Gunter, Stowe, & Mulder, 1997) have claimed that the P600/SPS belongs to the family of classical P300 effects. The P600 component is viewed then as being identical to the P3b, a broadly distributed positive-going component with a centro-parietal maximum whose amplitude is sensitive to aspects of stimuli such as task relevance, salience, and probability. Osterhout and Hagoort (1999) have criticized this view. The fact that a P600/SPS effect and a P300 effect can summate (Osterhout, McKinnon, Bersick, &

Corey, 1996), has been put forward as an argument for the belief that the ERP response to syntactic anomalies is at least partially distinct from the ERP response to unexpected anomalies that do not involve a grammatical violation. The finding of our study that a P600/SPS effect can be absent in the presence of a sound P300 effect, favours the interpretation that the triggering conditions for the P600/SPS are more specific than a general surprise response (cf. Donchin, 1981), context updating or other explanations in terms of task relevance, salience, and probability.

The overall group of Broca patients did not show on-line sensitivity to the subject-verb agreement violations. However, this sensitivity appeared to be modulated by the *severity* of the syntactic comprehension impairment. When the Broca patients were divided into two subgroups based on their performance on the syntactic off-line test, the group of Low Comprehenders did not show an Agreement effect at all. These patients seemed to experience difficulties with maintaining or exploiting the morphosyntactic number marking for establishing agreement. On the other hand, the group of High Comprehenders showed an Agreement effect, albeit reduced in comparison to the control subjects. This might suggest that the on-line sensitivity to this type of syntactic information as displayed by these patients was at least weakened. Thus, the severity of the syntactic comprehension impairment seemed to be reflected in the ERP response with the largest deviation from the normal P600/SPS effect for those patients with the most severe syntactic comprehension deficit.

Of special interest for our discussion, is a study of Haarmann and Kolk (1994). They explored in Broca's aphasics the on-line sensitivity to almost the same type of subject-verb agreement violations as we used, by means of a word-monitoring paradigm. Our results for the elderly control subjects are consistent with the data of Haarmann and Kolk who also found an Agreement effect in elderly controls (namely significantly faster monitoring latencies for a target word in agreeing than in non-agreeing sentences) irrespective of syntactic complexity. The Broca patients in their study showed an effect of Agreement, which was mostly due to the simple sentences. This pattern of results contrasts with the absence of Agreement effects in the data of our overall group of Broca patients. But, it clearly bears resemblance to our data of patients that suffered from a relative less severe syntactic comprehension impairment. The authors describe the comprehension deficit of their Broca patients as mild, but no specific information is given about the level of severity of the syntactic comprehension impairment.

Before further discussing our results, it should be pointed out that we tried to tap the syntactic comprehension process as it unfolds in real time: the brain potentials were recorded while subjects listened to sentences without any additional task. There were no task demands like for instance explicit error detection or word monitoring, except the very natural one of listening to speech. This situation approximates sentence processing under natural circumstances. Furthermore, the sentence materials were constructed in such a manner that non-syntactic strategies to detect the subject-verb agreement violations would not be effective. Therefore, deviations from the standard P600/SPS effect as response to subject-verb agreement violations are most likely indicative of changes in *on-line syntactic processing*. Given the results of the questionnaire, it is very unlikely that deviations from the standard P600/SPS effect are due to a lack of attention to the auditory stimuli. On the contrary, the aphasic patients were well able to answer the questions as far as *semantic* aspects of the sentences were concerned.

What do our data imply for accounts of syntactic comprehension deficits in aphasia? It has been suggested that syntactic comprehension deficits in Broca's aphasics are due to changes in the temporal organization of the parsing process. Two kinds of temporal disturbance have been proposed: 1) the activation of syntactic information is slowed down (Friederici & Kilborn, 1989; Haarmann & Kolk, 1991b); 2) syntactic information is subjected to a pathologically fast decay (Haarmann & Kolk, 1994). Both disturbances can have a disruptive effect on the ability to co-activate sentence-representational elements. For instance, in the case of the sentences that we presented, number information not only needs to be extracted from the subject noun and the verb forms, but it has to be maintained long enough in verbal working memory to establish agreement between them. This requirement of computational simultaneity taxes verbal working memory both in terms of time and structure. In the auditory sentences of our study the subject noun and the critical verb form were non-adjacent. The number information of the subject noun had to be available for some time before the relevant verb form information came in. If number information decays too fast, agreement cannot be established. At the same time it is the phrasal configuration of the sentence that determines which elements should agree in number. More complex structures will tax memory stronger than simple structures. In this study we did not find a complexity effect, presumably because the difference in complexity was not substantially enough to result in observable effects. Nevertheless, the data obtained allow some relevant conclusions about the nature of the syntactic comprehension problems in Broca's aphasics, especially in relation to the effect of severity of the impairment. Assuming that the degree of severity affects the processing problems in a quantitative (e.g. rate of decay) rather than a qualitative way a few relevant conclusions can be drawn.

First, the data of the patients with the less severe syntactic comprehension impairment showed an Agreement effect that was reduced in size, but nevertheless showed the same time course as the effects of the other subject groups. If it were a matter of too slow activation of number information, one should actually expect a shift in the onset latency of the effect. This was not the case for these patients. Second, the presence of an agreement effect in the High Comprehenders suggests that morphosyntactic information is not lost, but can be extracted from the input. Third, the reduction of the Agreement effect suggests that in these patients the on-line sensitivity to this type of structural information was weakened. Presumably this is due to a too fast decay of the morphosyntactic number information. When arriving at the inflected verb, the subject noun phrase is checked for number (cf. Nicol, Forster, & Veres, 1997), but due to decay, the mismatch between the number information will be no longer detected. This could then show up as a reduction in the ERP effect, or in the case of the more severely impaired patients even as an absence of the effect.

A too fast decay can result from reduced initial levels of activation, a faster-than-normal decay rate, or some combination of these two. Within the computational parsing model of Vosse and Kempen (2000) simulation of agrammatic parsing required that next to a faster decay rate, additional parameters had to be changed as well. These included the initial amount of activation and strength of inhibition (cf. Hagoort, 1993). Haarmann et al. (1997) assume in their computational account of aphasic sentence comprehension that Broca's aphasics have insufficient verbal working memory capacity to sustain normal comprehension performance. In this model, the degree of severity of the syntactic comprehension impairment varies with the amount of reduction in verbal working memory capacity. Results from simulation studies showed that the activation of elements at the beginning of a sentence rapidly decays over time, especially under the situation of low verbal working memory capacity (cf. Saffran, Dell, & Schwartz, 2000). The data obtained in this study are compatible with both computational models of syntactic deficits in Broca's aphasia.

An alternative explanation for the absence of the effect in the Low Comprehenders, could be that these severely impaired patients have lost access to syntactic information. This interpretation cannot be excluded. However, differences in degree of severity are one of the key features of any group of aphasic patients. Therefore, we give preference to the account provided here because it explains these differences in degree of severity quite naturally and parsimoniously. Finally, when the same severely impaired patients were confronted with syntactic violations of word order, they did show an effect: their waveforms were dominated by a meaning-related ERP effect (Hagoort, Wassenaar, & Brown, 2003b). The N400 effect for the word order violation suggests that these sentences were processed through a semantic compensatory processing route that was not available for the agreement violation.

WORD ORDER VIOLATIONS IN PATIENTS WITH BROCA'S APHASIA: AN ERP STUDY[1]

CHAPTER 3

ABSTRACT

This paper presents electrophysiological data on on-line syntactic processing during auditory sentence comprehension in patients with Broca's aphasia. Event-related brain potentials were recorded from the scalp while subjects listened to sentences that were either syntactically correct or contained violations of word order. Three groups of subjects were tested: Broca patients (N=10), non-aphasic patients with a right hemisphere (RH) lesion (N=5), and healthy aged-matched controls (N=12). The results for the aphasic patients were analyzed according to the severity of their syntactic comprehension deficit. When listening to the sentences with grammatical violations, the non-aphasic brain damaged patients and the Broca patients with a light syntactic comprehension deficit (High Comprehenders, N=5) showed a P600/SPS effect that was comparable to that of the neurologically unimpaired subjects. The Broca patients with a relatively more severe syntactic comprehension impairment (Low Comprehenders, N=5), did not show a syntax-related ERP effect. Instead, they showed a meaning-related ERP effect, possibly reflecting their attempts to achieve understanding by the use of a semantic processing route. These data demonstrate that although agrammatic comprehenders are impaired in their ability to exploit syntactic information in real time, they can reduce the consequences of a syntactic deficit by relying on processing options that are still available to the impaired language comprehension system.

[1] A shortened version of this chapter has been published as Hagoort, P., Wassenaar, M. & Brown, C.M. (2003b). Real-time semantic compensation in patients with agrammatic comprehension: Electrophysiological evidence for multiple-route plasticity. *PNAS*, 100, 4340-4345.

INTRODUCTION

Spoken language comprehension is essential to human communication and involves the complex process of deriving a message from acoustic input. To accomplish this, the brain combines in essence, very rapidly, all different kinds of linguistic information, including sounds, semantics and syntax. Whereas *semantics* concerns particularly the meaning of words, *syntax* specifies constraints on combining words in a grammatically well-formed manner. The qualitative distinction between semantics and syntax can also be observed in electrophysiological recordings of brain activity (Hagoort & Brown, 2000a). Qualitatively different event-related brain potentials (ERPs) have been reported that are differentially sensitive to semantic and syntactic aspects of language processing. ERPs reflect the sum of simultaneous post-synaptic activity of a large number of neurons, recorded at the scalp as small voltage fluctuations in the electroencephalogram. An ERP component that is especially sensitive to semantic aspects of language stimuli is the *N400*. Kutas and Hillyard (1980) were the first to report that semantically anomalous words appearing at the end of a sentence (e.g. “He spread the warm bread with butter and *socks*”) elicited a large-amplitude negative peak in the ERP signal that reaches its maximum value around 400 ms after the onset of the anomalous word. Semantically congruous words elicited the same ERP profile, but the amplitude of the negative peak was much smaller compared to the anomalous endings. This ERP component was labeled the N400, and the modulation of its amplitude by semantic context is known as the N400 effect. A widely held view is that in sentence contexts, the N400 amplitude indexes the relative ease of semantic integration (e.g. Brown & Hagoort, 1993; Hagoort & Brown, 2000b): words that are incongruent or less fitting given the preceding sentence frame typically elicit a much larger N400 than words that fit well within the context (see for reviews Kutas & Van Petten, 1994; Osterhout & Holcomb, 1995).

Other brain responses have been observed in relation to syntactic processing. These include the *LAN* (Left Anterior Negativity) and the *P600/*SPS (see for a review Hagoort, Brown, & Osterhout, 1999). LAN effects are usually largest over anterior sites and occur between 300-500 ms (e.g. Coulson, King, & Kutas, 1998; Gunter, Stowe, & Mulder, 1997; Osterhout & Mobley, 1995) or in an earlier time window of 100-300 ms (e.g. Friederici, Pfeifer, & Hahne, 1993; Hahne & Kiefer, 1999; Neville, Nicol, Barss, Forster, & Garrett, 1991). Friederici (2002) has attributed the Early LAN effects (ELAN) that occur between 100 and 300 ms to violations of word-category, and the LAN effects between 300-500 ms to morphosyntactic violations. A qualitatively different ERP effect that has been related to syntactic processing is the P600/SPS. When subjects are presented with sentences containing a syntactic violation (e.g. "The husband is startled by the emotional rather response of his wife"), a positive shift can be observed in the ERP waveform that starts at about 500 ms after the onset of the word that creates a syntactic processing problem. This ERP effect is known as the *P600/SPS* (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992). Whereas LAN effects only occur for words that are ungrammatical given the preceding sentence context, the P600/SPS has not only been found to a large number of different syntactic violations (e.g. Coulson et al., 1998; Hagoort et al., 1993; Osterhout & Holcomb, 1992), but also to syntactic ambiguities (e.g. Osterhout, Holcomb, & Swinney, 1994; Van Berkum, Brown, & Hagoort, 1999), and to increases in syntactic complexity (e.g. Kaan, Harris, Gibson, & Holcomb, 2000).

ERPs have certain characteristics that make them suitable to study not only language comprehension in the normal language system, but also to investigate language under impairment as in aphasia. First, ERPs can be recorded without imposing additional, potentially interfering task demands on aphasic patients, other than the natural one of listening to spoken language for instance. Second, ERPs provide a high temporal resolution of neural activity underlying language processing. This allows inferences about the time course of language processing in aphasic patients. Third, in the context of language processing, ERPs are differentially affected by distinct types of linguistic information (viz. semantics versus syntax). Therefore, ERPs can be informative about the types of linguistic information that patients are (in)sensitive to.

In aphasia research, the *N400* component has been used to study real-time comprehension deficits in brain-damaged patients, where it has revealed processing deficiencies in the time course of meaning activation and integration (Hagoort, Brown, & Swaab, 1996; Swaab, Brown, & Hagoort, 1997, 1998). Aphasic patients with moderate to severe comprehension deficits showed a delay and reduction of the N400 effect compared to control subjects. The authors concluded that comprehension impairments in the aphasic patients can result from a delay in lexical integration: the patients have problems in rapidly merging the lexical-semantic and lexical-syntactic information into an overall message interpretation. In aphasic patients, the onset latency of the N400 can be delayed by about 150 ms relative to control subjects. The distribution of the component over the scalp can deviate somewhat from that found in normal controls (possibly associated with changes in volume conduction due to the brain lesion). Nevertheless, the overall electrophysiological pattern is consistent with that of the standard N400 effect.

The ERP technique has also been applied to study *syntactic* processing. In a case report by Friederici et al. (1998), a Broca patient, when listening to sentences with syntactic violations, did not show an early LAN effect in response to the violations but a P600/SPS effect was present. This pattern of results was replicated for a different Broca patient in Friederici et al. (1999). Under the assumption that the early anterior negativity and the P600/SPS reflect initial syntactic structure building and more controlled second-pass parsing processes respectively, the authors concluded that patients with Broca's aphasia have particular difficulties with initial syntactic structure building.

To see whether the ERP response to syntactic violations in Broca patients was influenced by the severity of the syntactic comprehension impairment, Wassenaar et al. (2004) presented sentences with subject-verb agreement violations to a group of ten Broca patients. Healthy control subjects showed a P600/SPS effect as response to the agreement violations. The overall group of Broca patients did not show this sensitivity. However, the sensitivity was modulated by the severity of the syntactic comprehension impairment. The largest deviation from the standard P600/SPS effect was found in the patients with the relatively more severe syntactic comprehension impairment. Deviations from the standard P600/SPS seemed to reflect aspects of the underlying processing deficit. From the ERP data it was concluded that deviations from the standard P600/SPS effect in the Broca patients reflected difficulties with on-line maintaining of number information across clausal boundaries for establishing subject-verb agreement.

Broca patients' sensitivity to agreement violations has been investigated before (e.g. Grossman & Haberman, 1982; Haarmann & Kolk, 1994; Wulfeck & Bates, 1991). Wulfeck and Bates found in an on-line error detection task that Broca patients were less sensitive to violations of agreement than to violations of word order. Subject-verb agreement violations and violations of word order differ in several aspects. Their distinction can be viewed as a contrast between long-distance (agreement) and local (word order) syntactic dependencies.

They differ also with respect to syntactic structure. Both distance and structural differences can be responsible for the fact that the detection of word order violations can be easier than the detection of agreement violations. An alternative explanation why word order violations can be detected more easily is the following. As a consequence of aphasia, agrammatic comprehenders can be limited in their ability to use grammatical information such as morphosyntactic features and word-order constraints during on-line sentence interpretation. There might be a possibility that the severily impaired patients, by necessity, try to understand sentences in a way that is less dependent on grammatical processing, but on semantic processing instead (Caplan, 1987; Caplan & Hildebrandt, 1988): a (partly) adequate sentence interpretation can be derived by recognizing and combining the individual word meanings in their linear order. In this case, the adequacy of the interpretation is determined by the semantic coherence of the individual words in their left-to-right order. Here then, the linear order of the input string, rather than the hierarchical phrase structure, determines the ease of interpretation. Whereas a violation of subject-verb agreement leaves the semantic coherence of the individual words undisturbed, a violation of word order constraints can affect this semantic coherence seriously. This would lead then to the following prediction. If patients for sentence understanding rely primarily on the linear order of individual word meanings, the violation of word order constraints will not elicit a syntax-related ERP effect but a semantic related ERP effect instead. This prediction will be tested in our present study.

Present study

The aim of this present study is to investigate the real-time consequences of brain damage in patients with Broca's aphasia for their on-line processing of syntactic information. In this study, subjects listened to sentences containing a *violation of word order constraints* (e.g. "The thief steals the *expensive very clock* from the living room"). In intact language listeners, this violation will elicit a P600/SPS effect. But what will this violation bring about in patients with Broca's aphasia? First, do these patients show sensitivity to the word order violations? Second, does the severity of the syntactic comprehension impairment in the Broca patients affect the ERP response?

If Broca patients are still able to use grammatical information such as word order constraints during on-line sentence interpretation, then we expect a P600/SPS effect that bears similarity to that of the healthy control subjects. However, it is possible that Broca patients are limited in their ability to use grammatical information such as word-order constraints during on-line sentence interpretation (Linebarger, Schwartz, & Saffran, 1983), and by consequence, rely primarily on the linear order of individual word meanings for sentence interpretation. The syntactic violation of word order constraints can disturb the semantic coherence of these individual words. An ERP component that is especially sensitive to semantic coherence is the N400. We expect that, if patients for sentence understanding rely primarily on the linear order of individual word meanings, the violation of word order constraints will not lead to a syntax-related ERP effect, but to a meaning-related ERP effect instead.

In order to be able to reliably interpret possible changes in the ERP-effects of the Broca's aphasics as reflecting changes in their syntactic processing, it is important to identify factors that could contaminate the results of the experiment. To control for the non-specific effect of aging, the results of the patients with Broca's aphasia will be compared to a group of normal age-matched controls. A group of non-aphasic patients with a lesion in the right hemisphere will be tested to control for non-specific effects of brain damage.

METHOD

Subjects

Ten patients with aphasia secondary to a single cerebral vascular accident (CVA) in the left hemisphere participated in this study. A group of twelve healthy normal subjects, who were approximately matched in age and education level to the aphasic patients, were tested to control for age and education effects. To account for non-specific effects of brain damage on cognitive ERP components, a group of five non-aphasic patients with a single cerebral vascular accident in the right hemisphere (RH patients) was tested. All subjects gave informed consent, according to the declaration of Helsinki. The elderly control subjects and the RH patients were paid for their participation. The mean age of the aphasic patients was 59.8 years (range 42-74 years), the RH patients were on average 61.8 years (range 47-70 years) and the normal controls had a mean age of 58.9 years (range 49-72 years). All elderly control subjects were right-handed according to an abridged version of the Oldfield Handedness Inventory (Oldfield, 1971). Five of the elderly control subjects reported familial left-handedness. The aphasic patients and the RH patients were premorbidly, all right-handed. None of the elderly control subjects had any known neurological impairment or used neuroleptics. None of the control subjects reported hearing loss or memory problems.

All neurological patients were tested at least 9 months post-cerebro-vascular accident. Median post-onset time for the patients with Broca's aphasia was 4.3 years (range 1.5–13.7 years) and for the RH patients 2.4 years (range 2.3–9.9 years). All neurological patients were administered the standardised Dutch version of the Aachen Aphasia Test (Graetz, De Bleser, & Willmes, 1992). Both presence and type of aphasia were diagnosed on the basis of the test results and on the basis of a transcribed sample of their spontaneous speech. Three experts evaluated this spontaneous speech. All RH patients were diagnosed as non-aphasic and all left-hemisphere patients were classified as patients with Broca's aphasia (see Table 3-1). All Broca patients showed slow, effortful speech and omissions and/or reductions of morphosyntactic elements in their speech output. According to their scores on the comprehension subtest of the Aachen Aphasia Test, the aphasic patients had moderate to mild comprehension deficits. To select the aphasic patients who were severely agrammatic in their comprehension, we administered a Dutch version of a sentence-picture matching test (Huber, Klingenberg, Poeck, & Willmes, 1993). The participants listened to a total of 72 spoken sentences and selected one out of four pictures that matched each sentence. The test contained fives levels of syntactic complexity, ranging from active, semantically irreversible sentences (e.g., “The man with the tie carries the ball”) to sentences containing an embedded subject-relative clause in the passive voice (“The child that is sought by the man carries a ball”). For complexity levels 2-5, correct matching could only be based on syntactic information. Five patients showed a level of performance that was just above or not different from chance (25% on this test) for sentence structures that were more complex than simple active sentences (see Figure 3-1). These patients were classified as Low Comprehenders. The remaining five aphasic subjects also showed a complexity effect. However, even for the most complex structures their performance level was still above chance, demonstrating some remaining sensitivity to syntactic cues. These patients were classified as High Comprehenders on the basis of their remaining capacity for processing syntax.

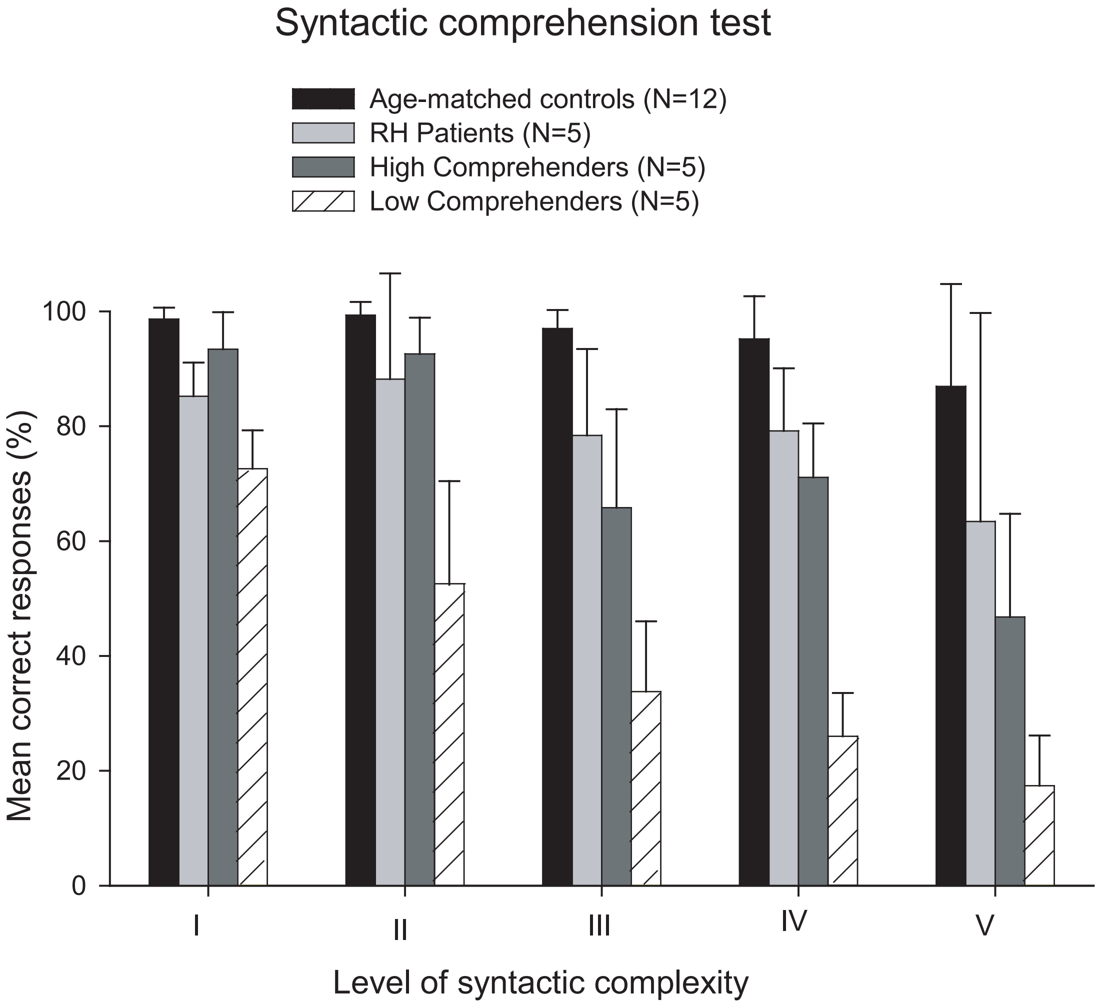

Figure 3-1. *Syntactic comprehension test. Mean percentage correct responses for the age-matched controls, the RH Patients, the High Comprehenders, and the Low Comprehenders, for five different sentence types: (I) active, semantically irreversible sentences; (II) active, semantically reversible sentences; (III) simple passive sentences; (IV) sentences with an active subject-relative clause; and (V) sentences with a passive subject-relative clause. Syntactic complexity increases from II to V.*

Table 3-1. Individual patient information for the patients with Broca's aphasia and the non-aphasic RH patients.

Patient [a]	*Age, years*	*Sex*	*Token Test* [b]	*Compreh. score AAT* [c]	*Syntactic compreh. score* [d]	*Lesion*
1 Broca HC	68	M	24	105/120	88/144	Left fronto-temporal
2 Broca HC	50	F	10	97/120	95/144	L. fronto-temporo-parietal including insula
3 Broca HC	74	F	7	108/120	115/144	Left frontal including insula
4 Broca HC	65	F	18	91/120	111/144	Left fronto-temporal including insula
5 Broca HC	51	M	20	109/120	113/144	L. fronto-temporo-parietal including insula
6 Broca LC	63	M	38	67/120	52/144	Left frontal including insula
7 Broca LC	42	M	17	94/120	74/144	Left temporo-parietal
8 Broca LC	67	M	18	103/120	47/144	L. fronto-temporo-parietal including insula
9 Broca LC	70	M	50	90/120	59/144	Left fronto-temporal including insula
10 Broca LC	48	M	42	89/120	51/144	No adequate CT information available
1 RH	66	F	2	102/120	118/144	Right parietal
2 RH	58	M	1	117/120	134/144	R. fronto-temporo-parietal including insula
3 RH	47	M	0	113/120	134/144	No adequate CT information available
4 RH	68	F	2	106/120	89/144	Right temporo-parietal
5 RH	70	F	0	105/120	92/144	Right fronto-temporo-parietal

[a] Broca patients were classified as High Comprehender (HC) or Low Comprehender (LC) on the basis of their scores on a specific syntactic comprehension test. Scores were computed on a 3-point system: 2 points for a correct response, 1 point for a correct response after repetition or self-correction, and 0 points for an incorrect response. Maximum score is 144 (72 x 2 points). Range of performance in healthy control subjects is 119-143. High Comprehending Broca's aphasics had a score of above 85. Low Comprehending Broca's aphasics had a score of below 75. The Low Comprehending Broca's aphasics showed chance-level performance on the most complex structures (see Figure 3-1).

[b] Severity of the aphasic disorder as indicated by the Token Test: no/very mild disorder (0-6); light (7-23); middle (24-40); severe (41-50).

[c] Severity of the comprehension disorder as indicated by the Aachen Aphasia Test (AAT) subtest on comprehension (includes word and sentence comprehension in both the auditory and visual modality): no/very mild disorder (107-120); light (90-106); middle (67-89); severe (1-66). compreh.= comprehension.

[d] Two RH patients had a relatively low syntactic comprehension score, but were, on the basis of their spontaneous speech and the AAT results, clearly non-aphasic. Their score on more complex sentences was not very different from the more simple ones. This implies that their relatively poor performance is not due to a syntactic problem, but most likely to problems of visual attention. ANOVA's on the percentage-correct scores of the sentences with increasing syntactic complexity of the off-line test showed that syntactic complexity had a differential effect on the comprehension scores of the different subject groups (normals, RH patients, High Comprehenders, Low Comprehenders): [Complexity: $F(3.06, 70.27) = 40.29$, $MSe = 105.80$, p = 0.000; Group: $F(3, 23) = 48.68$, $MSe = 369.31$, p = 0.000; Complexity x Group: $F(9.17, 70.27) = 5.53$, $MSe = 105.80$, p = 0.000]. Post hoc analyses ($\alpha = 0.05$) revealed that the Low Comprehending Broca's aphasics performed significantly worse than the normal controls on all five sentence types and significantly worse than the High Comprehending Broca patients on sentence types II, III, IV and V. The High Comprehending Broca patients performed significantly worse than the normal controls on sentence types III, IV, and V. In contrast, the normal controls and the RH patients did not differ significantly from each other except on sentence type V. The pattern of results substantiates the syntactic comprehension problems of the Broca patients in this study.

Materials

The materials for this experiment consisted of a list of 60 spoken sentence pairs. The full set of sentence materials is listed in the Appendix. Half of each sentence pair was syntactically correct, half contained a violation of word order constraints. Each sentence in a violated set was derived from a sentence in the correct set, such that the words preceding and following the word string that made the sentence ungrammatical were the same as in the correct version. An additional set of 380 sentences was used as practice and filler sentences.

The w*ord order violations* all consisted of nouns preceded by transpositions of adverbs and adjectives. In Dutch, it is a violation of word order constraints to have an Adjective-Adverb-Noun sequence. For example (the adjective and adverb are in italics):

(1a) De dief steelt de *erg dure klok* uit de woonkamer.
(The thief steals the *very expensive clock* from the living room.)

(1b)* De dief steelt de *dure erg klok* uit de woonkamer.
(The thief steals the *expensive very clock* from the living room.)

In this example, as in all of the word order violation sentences, the actual violation occurs on the noun following the adverb (i.e., on '*klok*'). It is only at this point that the sentence can no longer be continued in a grammatically correct manner. This is because in Dutch, the adjective-adverb combination could be part of a more complex adjective-adverb-adjective-noun sequence (e.g., '*the expensive very antique clock*'). However, previous studies with these types of word order violations (Hagoort & Brown, 2000a; Hagoort et al., 1993) have shown that a P600/SPS was elicited already by the adverb. This finding has been interpreted as indicating that with these word order violations, parsing difficulties already arise at the adverb: the adverb signals that a more complex, less frequent structure has to be assigned than the preferred adjective-noun sequence (i.e. '*expensive* clock'). Since, in terms of syntactic properties of Dutch, it is only at the presentation of the noun that the parser is confronted with a real syntactic violation, we will refer throughout this study to the noun as the Critical Word (CW), and to the adverb as the word that violates word-order preferences.

The violations always showed up at a mid-sentence position. The reason for this is twofold. We wanted the subjects to be fully engaged in the process of parsing before being confronted with a syntactic violation, and we wanted to avoid contamination of closure-effects at sentence-final position (cf. Hagoort et al., 1993).

Mean sentence length for the word order violation condition was 10.7 words (range: 9 – 13 words). Mean sentence duration for the well-formed sentences was 3769.4 ms (s.d.: 443.3 ms) and 3841.5 ms (s.d.: 425.7 ms) for the violated companion sentences. An additional set of 380 sentences was used as practice and filler sentences.

All sentence materials were spoken at a normal rate by an experienced female speaker. Special care was taken to ensure that the correct and incorrect versions were matched on prosody and rhythm. In Dutch, the critical regions of the experimental sentences (i.e., *very expensive clock* and *expensive very clock)* can be realized with a natural neutral prosodic contour, without intonational breaks or differential stress patterns. This is the contour that we used. Sentences were spoken in a sound attenuating booth and recorded on a digital audiotape. The stimuli were stored on a hard disk. A speech waveform editing system (Xwaves/ESPS package) was used to mark the onset and offset of each sentence. The onset of the critical words and the word preceding it were marked.

The list of 120 experimental sentences was divided over two lists of 60 sentences each. Each list consisted of 30 correct and 30 incorrect experimental sentences. The members of a pair of incorrect and correct companion sentences were assigned to the different lists. Each list of 60 sentences was divided into three blocks of 20 sentences. A pseudo-randomised sequence of sentences was used for each list. The sequence was such that in immediate succession no more than two incorrect sentences from the same violation type occurred. Each list was presented to all subjects in two different sessions separated by at least four weeks. The presentation order of the two lists was counterbalanced.

A pulse for triggering the EEG acquisition program was placed 150 ms before onset of each experimental sentence. Each 8 seconds a sentence was presented. The silent interval between two sentences varied in duration depending on the length of the preceding sentence. Three tapes were constructed: a practice tape containing 20 practice items containing correct and incorrect sentences (but with different violation types than used in the experimental lists) and two tapes for the two experimental lists.

The same set of practice sentences was used in the two testing sessions. The practice list was used to familiarise the subjects with the experimental set-up. In order to induce the subjects to listen attentively to the sentences during the experiment, a questionnaire was constructed with four questions per block about a grammatically well-formed experimental sentence.

Procedure

Participants were tested individually in a dimly illuminated sound-attenuating booth, seated in a comfortable reclining chair (apart from two patients who had to be tested in their wheelchair). Sentences were presented via a digital audio tape (DAT) recorder (300ES; Sony, Tokyo). The participants listened to the stimuli via closed-ear headphones (HD-224; Sennheiser, Wedemark, Germany) while fixating their eyes on a fixation cross in front of them. Participants were told that they would hear sentences, some of which had language errors in them, but they were given no information concerning the kind of errors that would occur. Participants were informed that they would occasionally be asked a question about the last presented sentence. All questions were related to the content of the correct sentences. For example, after the presentation of the sentence, “The thief steals the very expensive clock from the living room”, the question asked was, “What did the thief steal?” The total number of questions was 24, four per block. The answers to these questions should certify that the participants were actively engaged in processing the sentences. The participants were tested in two sessions separated by at least four weeks. Correct and incorrect versions of a particular item were tested in different sessions, with each session containing the same number of correct and incorrect trials. Each session started with a practice list. The total duration of stimulus presentation was 40 min per session.

EEG-recording

EEG activity was recorded by using an Electrocap with 13 scalp tin electrodes, each referred to the left mastoid. Nine electrodes (Fz, Cz, Pz, F7, F8, FT7, FT8, PO7, PO8) were placed according to the standard convention of the American Electroencephalographic Society. Four electrodes were placed over non-standard intermediate locations: a temporal pair (LT and RT) placed 33% of the interaural distance lateral to Cz, and a temporo-parietal pair (LTP and RTP) placed 30% of the interaural distance lateral to Cz and 13% of the inion-nasion distance posterior to Cz. Vertical eye movements and blinks were monitored via a supra- to sub-orbital bipolar montage. A right to left canthal bipolar montage was used to monitor for horizontal eye movements. Activity over the right mastoid bone was recorded on an additional channel to determine whether there were differential contributions of the experimental variables to the presumably neutral mastoid site. No such differential effects were observed. The ground electrode was placed on the forehead, 10% of the nasion-inion distance above the nasion.

The electroencephalogram EEG and electro-oculogram (EOG) recordings were amplified with Nihon Kohden AB-601G bioelectric amplifiers, using a Hi-Cut of 30 Hz and a time constant of 8 seconds. Impedances were kept below 5 kOhm. The EEG and EOG signals were digitised on-line with a sampling frequency of 200 Hz. A trigger pulse started sampling 150 ms before the presentation of the sentence. The total sampling epoch for the sentence stimuli was 6315 ms (150 ms pre-sentence baseline + duration of longest sentence + 1000 ms). Data were stored along with condition codes for subsequent off-line averaging and data analysis. Prior to off-line averaging, all single trial waveforms were screened for electrode drifting, amplifier blocking, muscle artefacts, and eye movements in a critical window that ranged from 600 ms before the word that violated word order preferences to 1500 after onset of this word. Trials containing these artefacts were rejected. Datasets with a substantial number of eye blinks were corrected for blink artifacts (Gratton, Coles, & Donchin, 1983). The overall rejection rate was 21.7 % for the age-matched controls, 25.2 % for the RH patients, and 21.8 % for the Broca patients. For all groups, rejected trials were evenly distributed among conditions. For each subject, average waveforms were computed across all remaining trials per condition after normalizing the waveforms of the individual trials on the basis of the EEG activity 150 ms before the onset of the word that violates word order preferences. Mean amplitude values for each subject were computed in the latency window of 600 to 1500 ms after the onset of the word that has been shown to elicit the P600/SPS to word order violations in normal populations (Hagoort et al., 1993), viz. the word that violates word order preferences. The latency range was determined on the basis of a visual inspection of the waveforms. The mean amplitude values were entered into repeated measures analyses of variance for each subject group respectively with Grammaticality (two levels: Correct, Incorrect) and Electrode Site (13 levels) as within-subjects factors. The Huynh-Feldt correction was applied when evaluating effects with more than 1 degree of freedom in the numerator, to compensate for inhomogeneous variances and co-variances across treatment levels. The adjusted degree of freedom and p-values will be presented. The results of the ANOVAs are listed in Table 3-2 up to Table 3-7. If necessary, also mean amplitude values for additional latency windows were computed and analysed (see below). To test for differences between the results for the normal controls and the patient groups, also group analyses were performed in the specified time-window, with Group of Subjects as the additional between-subjects factor.

RESULTS

Behavioral data

The mean average of the correct responses to the content questions was 98% for the elderly control subjects (range 91-100%), 96% for the RH patients (range 92-100%), and 89% for the Broca patients (range 63-100%; High Comprehenders: 97% (range 96-100%); Low Comprehenders: 81% (range 63-92%). Although the Low Comprehenders had a lower score than the High Comprehenders and control groups, their level of performance indicates that they actively processed the sentences. Answering the questions did not require a syntactic analysis of the sentence and was therefore unrelated to the scores on the syntactic comprehension test.

ERP experiment

Normal Control Subjects

Figure 3-2 displays the grand average waveforms for the normal control subjects, aligned at the onset of the word that violates word order preferences. Due to the fact that the critical words were embedded in the continuous speech stream with no clear physical separation between the words, N1 and P2 components are not visible in the waveforms. The waveforms are characterized by a positive deflection for the words with wrong word order in comparison to the correct words. As can be seen in Figure 3-3 where the topographic distribution of the word-order violations is shown, the effect for the normal controls is strongest over posterior

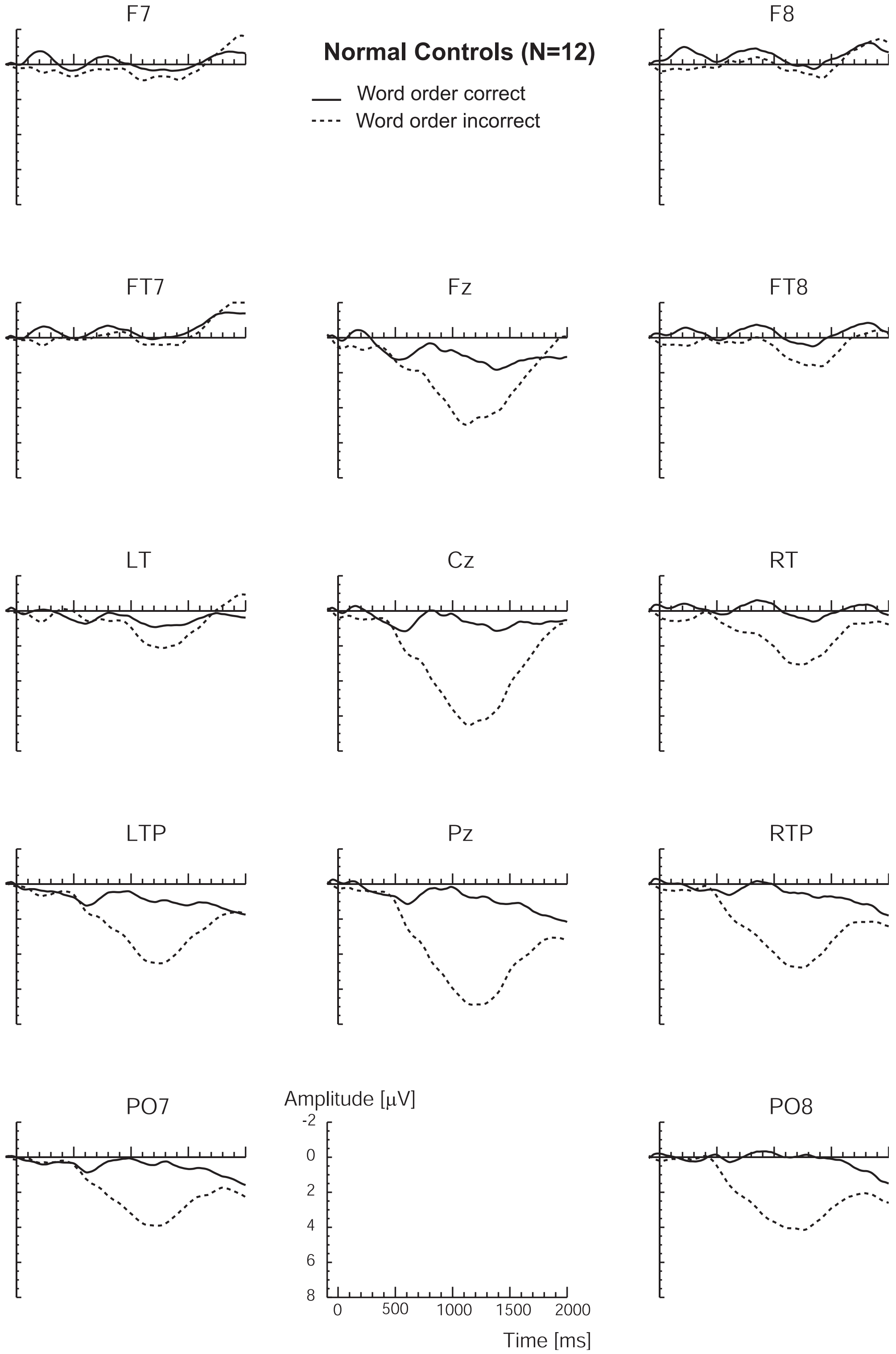

Figure 3-2. *Grand average ERP waveforms for the group of Normal Control Subjects (N=12) elicited by correct words (solid line) or incorrect words (dotted line) in the word order violation condition. At 0 ms is the onset of the word that violates word order preferences. In this and all following figures, negativity is plotted upwards.*

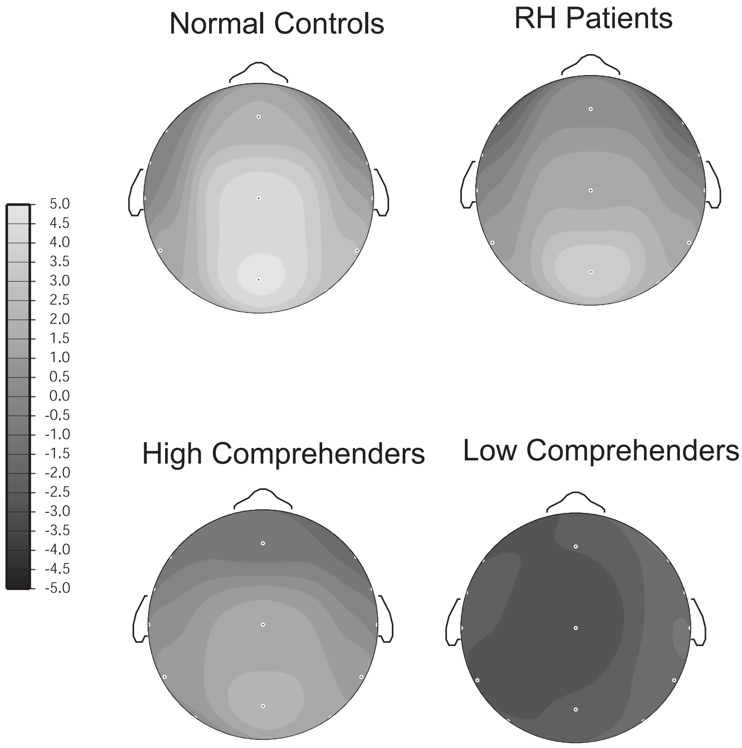

Figure 3-3. *Scalp distribution of the ERP effects that were obtained for the Word order violations in the Normal Controls, the RH Patients, the High Comprehenders, and the Low Comprehenders. Effects were based on mean amplitudes in the 600- to 1500 ms latency window. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in µV.*

electrode sites. The effect starts at around 500 ms following the onset of the word that violates word order preferences, and has the characteristic morphology, time course and distribution of a P600/SPS effect (Hagoort et al., 1999; Osterhout & Holcomb, 1992, 1993).

An ANOVA with all electrode sites (see Table 3-2) showed that the violation of word order had a significant main effect on mean amplitude in the 600-1500 ms latency window (corresponding to a 2.13 µV average amplitude difference). The Word Order effect interacted significantly with Electrode. Separate analyses for individual electrodes showed significant Word Order effects for all electrodes with the exception of F7, FT7, LT, and F8. The Word Order effect interacted significantly with Hemisphere due to the right hemisphere preponderance of the effect.

In sum, the normal elderly controls were sensitive to the word order violations and showed the expected P600/SPS effect.

Table 3-2. Word order violations for Normal Control Subjects: Mean ERP amplitude ANOVAs in the 600- to 1500-ms latency range following the onset of the word that violates word order preferences.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Word order	1, 11	29.74	11.85	0.000***
Word order x El	4.89, 53.81	19.45	0.71	0.000***
		Midline ANOVA (3 electrodes)		
Word order	1, 11	29.61	8.99	0.000***
Word order x El	2, 22	20.23	0.39	0.000***
		Posterior ANOVA (5 electrodes)		
Word order	1, 11	39.30	8.05	0.000***
Word order x El	3.02, 33.17	10.47	0.46	0.000***
		Lateral ANOVA (2 x 5 electrodes)		
Word order	1, 11	26.18	5.94	0.000***
Word order x He	1, 11	8.30	0.89	0.015*
Word order x El	2.43, 26.74	26.93	0.66	0.000***
Word order x He x El	2.54, 27.94	2.72	0.30	0.072

Note. Word order = Word order condition; El = electrode; He = Hemisphere. * $p < 0.05$; *** $p \leq 0.001$.

RH Patients

Figure 3-4 shows the grand average waveforms for the RH patients, aligned at the onset of the word that violates word order preferences. Mainly over centro-posterior electrode sites, the ungrammatical condition elicits a positive deflection in comparison to the correct condition. This positive shift for the ungrammatical condition starts at around 500 ms following the onset of the word that violates word order preferences, and resembles the characteristics of a P600/SPS effect. As can be seen in Figure 3-3, also for the RH patients, the effect was strongest over posterior electrode sites.

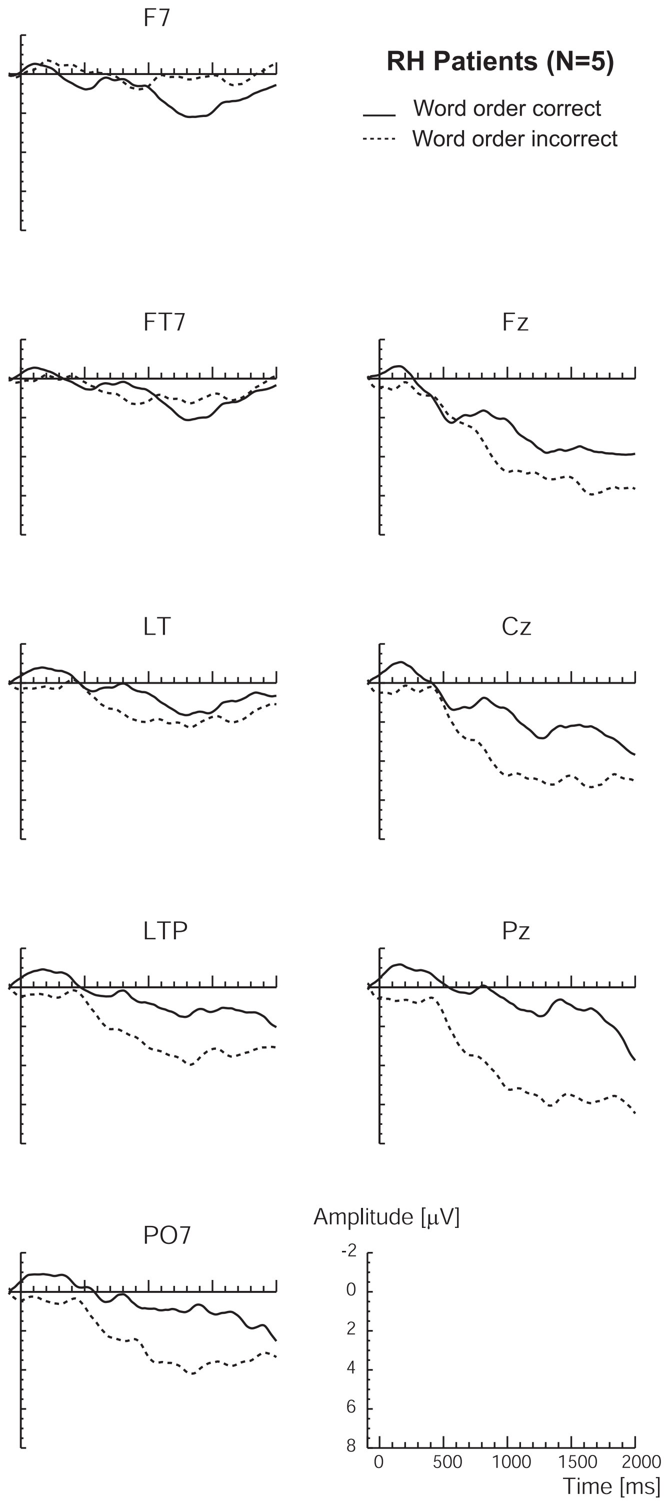

Figure 3-4. *Grand average ERP waveforms for the group of RH Patients (N=5) elicited by critical correct words (solid line) or incorrect words (dotted line) in the word order violation condition. At 0 ms is the onset of the word that violates word order preferences.*

Table 3-3. Word order violations for RH Patients: Mean ERP amplitude ANOVAs in the 600- to 1500-ms latency range following the onset of the word that violates word order preferences.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Word order	1, 4	16.22	3.37	0.016*
Word order x El	6.46, 25.86	6.98	0.82	0.000***
		Midline ANOVA (3 electrodes)		
Word order	1, 4	28.69	1.75	0.006**
Word order x El	1.66, 6.62	8.34	0.52	0.018*
		Posterior ANOVA (5 electrodes)		
Word order	1, 4	16.60	5.38	0.015*
Word order x El	2.57, 10.29	3.29	0.47	0.070
		Lateral ANOVA (2 x 5 electrodes)		
Word order	1, 4	9.12	2.27	0.039*
Word order x He	1, 4	0.07	2.46	0.802
Word order x El	1.33, 5.33	10.42	1.03	0.018*
Word order x He x El	1.69, 6.77	0.26	0.38	0.745

Note. Word order = Word order condition; El = electrode; He = Hemisphere. * $p < 0.05$; ** $p < 0.01$; *** $p \leq 0.001$.

An ANOVA with all electrode sites (see Table 3-3) yielded a significant effect (1.30 µV) of grammaticality in the 600-1500 ms latency window. The Word Order by Electrode interaction was significant. Separate analyses for individual electrodes showed significant grammaticality effects for Fz, Cz, Pz, PO7, RTP, and PO8. The absence of a Word Order by Hemisphere interaction showed that the Word Order effect was evenly distributed over right and left electrodes.

An omnibus ANOVA with Group of Subjects (Normal Controls, RH patients) as between-subjects factor (see Table 3-5) resulted neither in a main effect of Group nor in a significant Group by Word order interaction.

In sum, the RH patients, like the normal controls, showed a P600/SPS effect as response to the violations of word order. Although smaller, the overall P600/SPS effect was statistically indistinguishable from the normal elderly controls.

Broca Patients

Figure 3-5 shows the grand average waveforms for the ten patients with Broca's aphasia, aligned at the onset of the word that violates word order preferences. As can be seen, an effect of grammaticality is visible in the waveforms, but this effect is clearly reduced when compared to the elderly control subjects and the RH patients. For the centro-posterior electrodes the waveforms are characterized by a small positive deflection for the ungrammatical condition. For the right electrode sites the effect starts at around 500 ms following the onset of CW-1, but the onset for the left electrodes is much later (1000 ms).

An overall ANOVA (see Table 3-4) failed to show a significant effect of Word Order. Also the interaction between Word Order and Electrode failed to reach significance. Separate analyses for individual electrodes yielded only a significant effect of grammaticality for the right temporal electrode, RT, ($p < 0.05$), and marginally significant effects for RTP ($p = 0.059$) and PO8 ($p = 0.072$). The interaction between Word Order and Hemisphere did not turn out to be significant.

An omnibus ANOVA with Group of Subjects (Normal Controls, Broca patients) as additional between-subjects factor (see Table 3-5) showed a significant main effect of Group of Subjects, but more importantly also a significant Group of Subjects by Word Order interaction.

In sum, whereas both the normal controls and the RH patients showed a P600/SPS effect to the word order violations, the group Broca patients showed no overall significant P600/SPS effect as response to the word order violations. So the results of this group clearly deviated from both control groups.

It is not inconceivable, however, that the absence of an overall P600/SPS effect in the group of Broca patients is partly due to individual patient variability. It was therefore decided to group these Broca patients in a way that was related to the *severity* of their individual syntactic comprehension impairment. On the basis of their performance on the syntactic off-line test (see Method section), the ten Broca patients were divided into two subgroups.

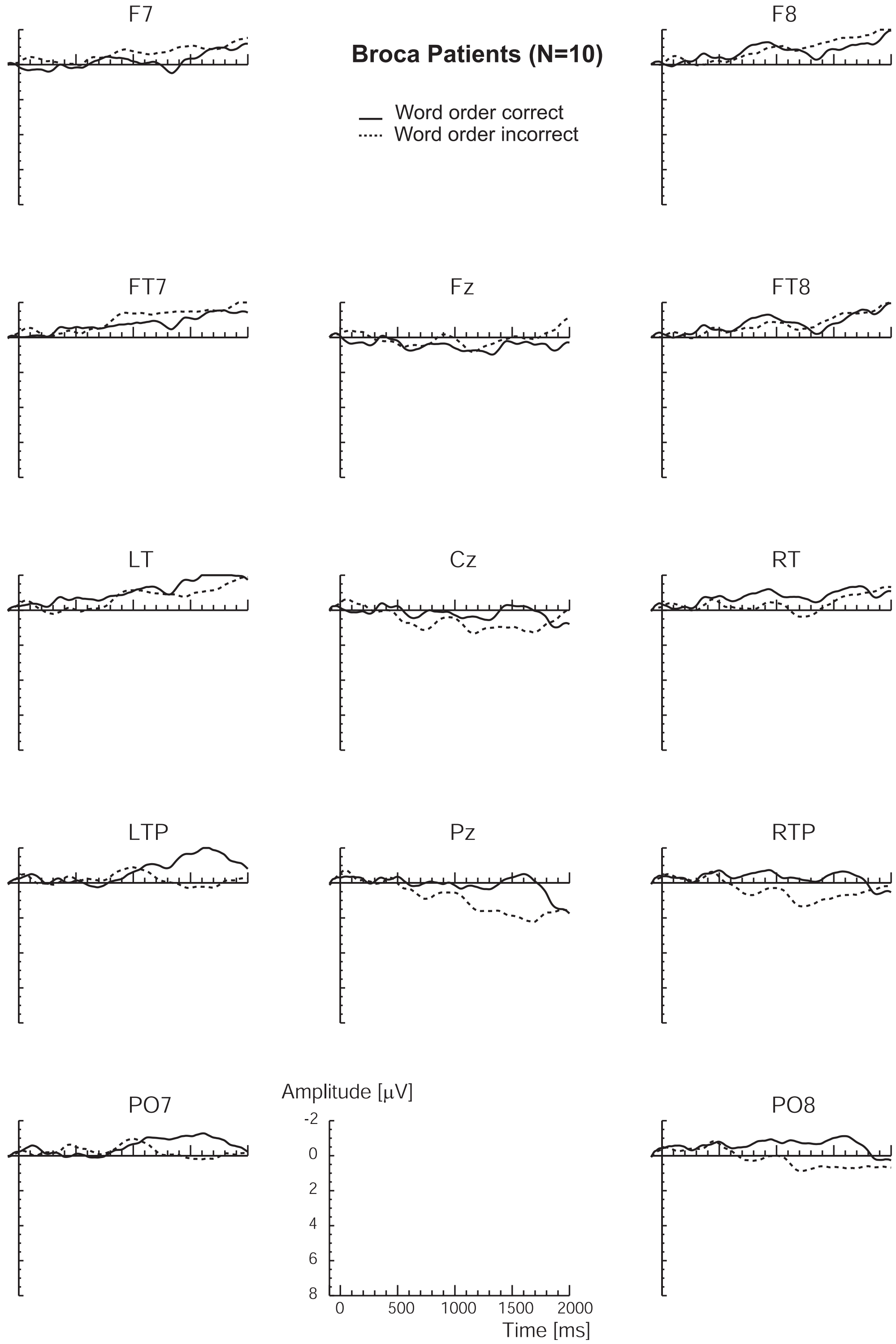

Figure 3-5. *Grand average ERP waveforms for the group of Broca Patients (N=10) elicited by critical correct words (solid line) or incorrect words (dotted line) in the word order violation condition. At 0 ms is the onset of the word that violates word order preferences.*

Table 3-4. Word order violations for Broca Patients: Mean ERP amplitude ANOVAs in the 600- to 1500-ms latency range following the onset of the word that violates word order preferences.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Word order	1, 9	0.50	6.28	0.497
Word order x El	4.43, 39.88	1.71	0.92	0.162
		Midline ANOVA (3 electrodes)		
Word order	1, 9	0.37	4.47	0.557
Word order x El	1.30, 11.69	2.63	0.83	0.126
		Posterior ANOVA (5 electrodes)		
Word order	1, 9	1.60	6.76	0.238
Word order x El	3.05, 27.46	1.88	0.48	0.155
		Lateral ANOVA (2 x 5 electrodes)		
Word order	1, 9	0.44	3.97	0.525
Word order x He	1, 9	2.37	1.86	0.158
Word order x El	2.22, 19.94	2.26	1.02	0.126
Word order x He x El	2, 17.99	0.40	0.31	0.678

Note. Word order = Word order condition; El = electrode; He = Hemisphere.

Five Broca patients (subject numbers 1-5 from Table 3-1) showed an above chance level of performance, even for the most complex sentence structures. These subjects were classified as "High Comprehenders". The other five Broca patients (subject numbers 6-10 from Table 3-1) showed a level of performance that was just above chance or not different from chance for sentence structures that were more complex than simple passive sentences. These subjects were classified as "Low Comprehenders". An omnibus ANOVA (see Table 3-5) in the 600-1500 ms latency range with Group of Patients (High Comprehenders, Low Comprehenders) as additional between-subjects factor, yielded a significant Group of Patients by Word order interaction. Because of this highly significant interaction we present here also the grand average waveforms for the two subgroups of Broca patients separately.

Table 3-5. Between-subjects ANOVAs for word order violations on mean ERP amplitude in specified latency ranges following the onset of the word that violates word order preferences.

Source	*df*	*F*	*MSe*	*p*
Normal Controls versus RH Patients 600-1500 ms				
Omnibus ANOVA (13 electrodes)				
Group	1, 15	0.01	28.03	0.932
Word order	1, 15	28.01	9.59	0.000***
Group x Word order	1, 15	1.65	9.59	0.219
Normal Controls versus Broca Patients 600-1500 ms				
Omnibus ANOVA (13 electrodes)				
Group	1, 20	10.81	36.51	0.004**
Word order	1, 20	20.88	9.34	0.000***
Group x Word order	1, 20	13.78	9.34	0.001***
High Comprehenders versus Low Comprehenders 600-1500 ms				
Omnibus ANOVA (13 electrodes)				
Group	1, 8	0.95	55.83	0.359
Word order	1, 8	2.53	1.24	0.150
Group x Word order	1, 8	37.47	1.24	0.000***
Normal Controls versus High Comprehenders 600-1500 ms				
Omnibus ANOVA (13 electrodes)				
Group	1, 15	3.30	41.27	0.089
Word order	1, 15	25.81	9.06	0.000***
Group x Word order	1, 15	2.84	9.06	0.112
Normal Controls versus Low Comprehenders 600-1500 ms				
Omnibus ANOVA (13 electrodes)				
Group	1, 15	21.37	19.29	0.000***
Word order	1, 15	5.74	8.99	0.030*
Group x Word order	1, 15	19.32	8.99	0.001***

Note. Word order = Word order condition; * $p < 0.05$; ** $p < 0.01$; *** $p \leq 0.001$.

High Comprehending Broca Patients

Figure 3-6 displays the grand average waveforms for the High Comprehending Broca patients. The word order violations elicited an effect of grammaticality that is strongest over centro-posterior electrode sites. The effect is characterized by a positive shift. The effect starts at around 500 ms and resembles the characteristics of a P600/SPS effect.

An omnibus ANOVA (see Table 3-6) showed that the violation of word order had a significant main effect on mean amplitude in the 600-1500 ms latency window (corresponding to a 1.07 μV average amplitude difference). The interaction between Word Order and Electrode was marginally significant. Separate analyses for individual electrodes showed significant Word Order effects for Cz, Pz, PO7, RTP, and PO8. The effect was largely symmetrical over both hemispheres as indicated by the absence of a significant Word Order by Hemisphere interaction.

An omnibus ANOVA with Group of Subjects (Normal Controls, High Comprehending Broca patients) as between-subjects factor (see Table 3-5) resulted neither in a significant effect of Group nor in a significant Group by Word Order interaction.

In sum, the High Comprehending Broca patients, like the normal controls, showed a P600/SPS effect as a response to the violations of word order. Although the amplitude of the syntactic violation effect was smaller in the High Comprehending Broca patients than in the normal control subjects, both subject groups showed the same onset latency of the effect.

Low Comprehending Broca Patients

Figure 3-7 depicts the grand average waveforms for the Low Comprehending Broca patients. Unlike the other groups (normal controls, RH patients and High comprehending Broca patients), the grammaticality effect in these patients is not characterized by a P600/SPS effect. Instead, the early part of the waveforms is dominated by a negative-going shift. The scalp distribution of this negative shift has a posterior maximum with a left-scalp preponderance (see Figure 3-3). This distribution is quite standard for auditory N400 effects and compares well with normal subject populations (Hagoort & Brown, 2000b). No N400 effect is seen over right-scalp electrodes. Although deviant form normal populations in this latter topographical aspect, the overall pattern is consistent with the N400 literature on aphasic patients, where N400 effects tend to have a left-scalp preponderance (Swaab et al., 1997). Over electrode site

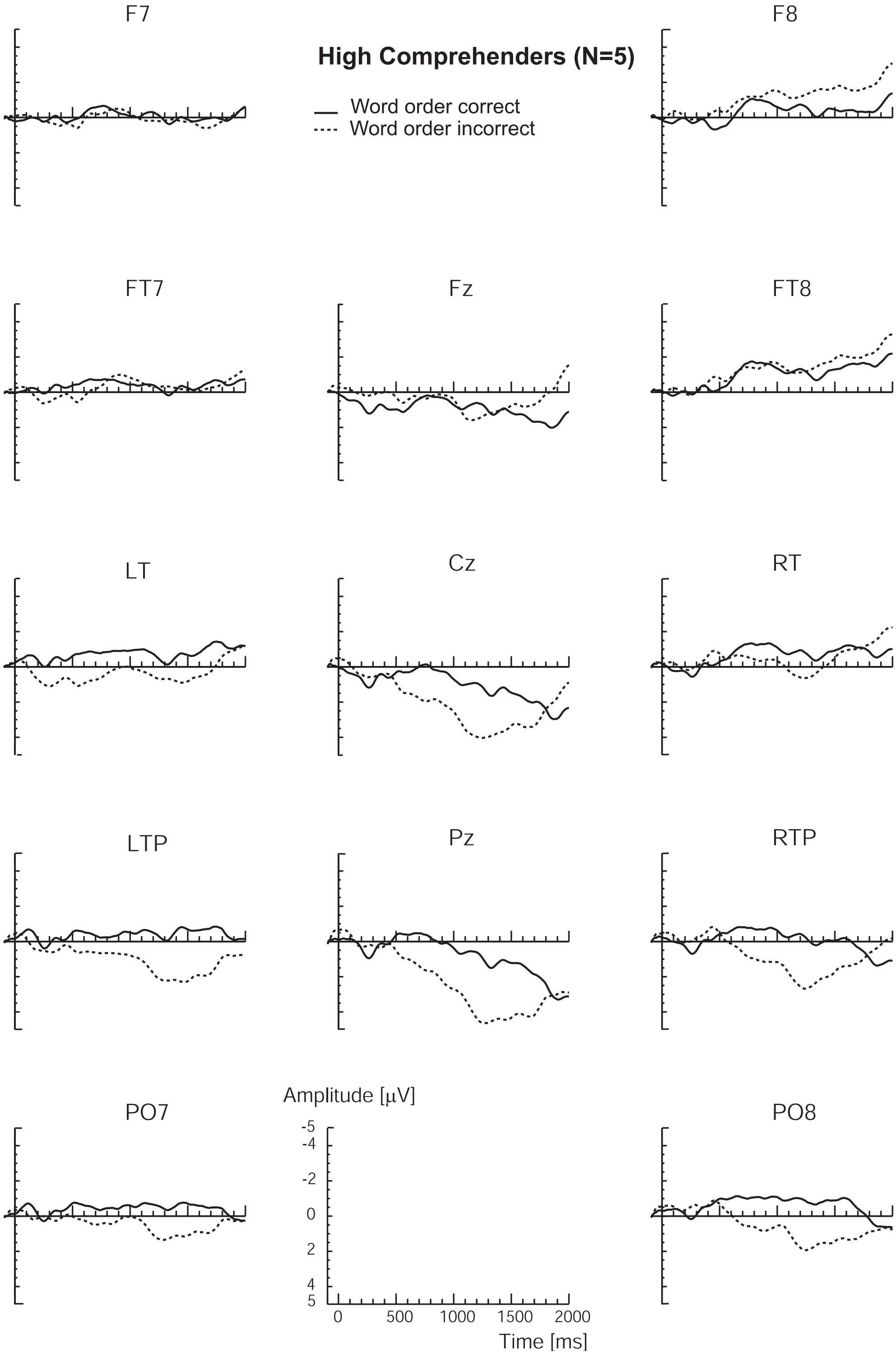

Figure 3-6. *Grand average ERP waveforms for the group of High Comprehending Broca Patients (N=5) elicited by critical correct words (solid line) or incorrect words (dotted line) in the word order violation condition. At 0 ms is the onset of the word that violates word order preferences.*

Table 3-6. Word order violations for High Comprehending Broca Patients: Mean ERP amplitude ANOVAs in the 600- to 1500-ms latency range following the onset of the word that violates word order preferences.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Word order	1, 4	27.05	1.37	0.007**
Word order x El	4.04, 16.15	2.87	1.02	0.056
		Midline ANOVA (3 electrodes)		
Word order	1, 4	9.26	2.47	0.038*
Word order x El	1.33, 5.30	5.69	0.81	0.055
		Posterior ANOVA (5 electrodes)		
Word order	1, 4	16.27	2.98	0.016*
Word order x El	2.33, 9.33	1.10	0.74	0.382
		Lateral ANOVA (2 x 5 electrodes)		
Word order	1, 4	9.37	1.99	0.038*
Word order x He	1, 4	0.00	2.01	0.954
Word order x El	4, 16	4.31	1.11	0.015*
Word order x He x El	1.60, 6.41	2.15	0.26	0.193

Note. Word order = Word order condition; El = electrode; He = Hemisphere. $p < 0.05$; ** $p < 0.01$.

LTP, where the N400 effect was maximal (see Figure 3-7), the onset of the N400 effect is at about 300 ms. As has been previously observed in agrammatic patients (Swaab et al., 1997), the onset of the N400 effect was (slightly) later than usually found in normal populations. In addition, the N400 effect lasted for a relatively long period, until around 1500 ms. As can be seen in Figure 3-7, the N400 effect was followed by a late positivity that started at around 1400 ms. This positivity was seen only over posterior electrode sites.

An omnibus ANOVA (see Table 3-7) showed that the violation of word order resulted in a significant main effect on the mean amplitude in the 600-1500 latency range (corresponding to a -0.63 µV average amplitude difference). Separate analyses for individual electrodes showed significant Word Order effects for Cz, Pz, LT, and LTP. The significant

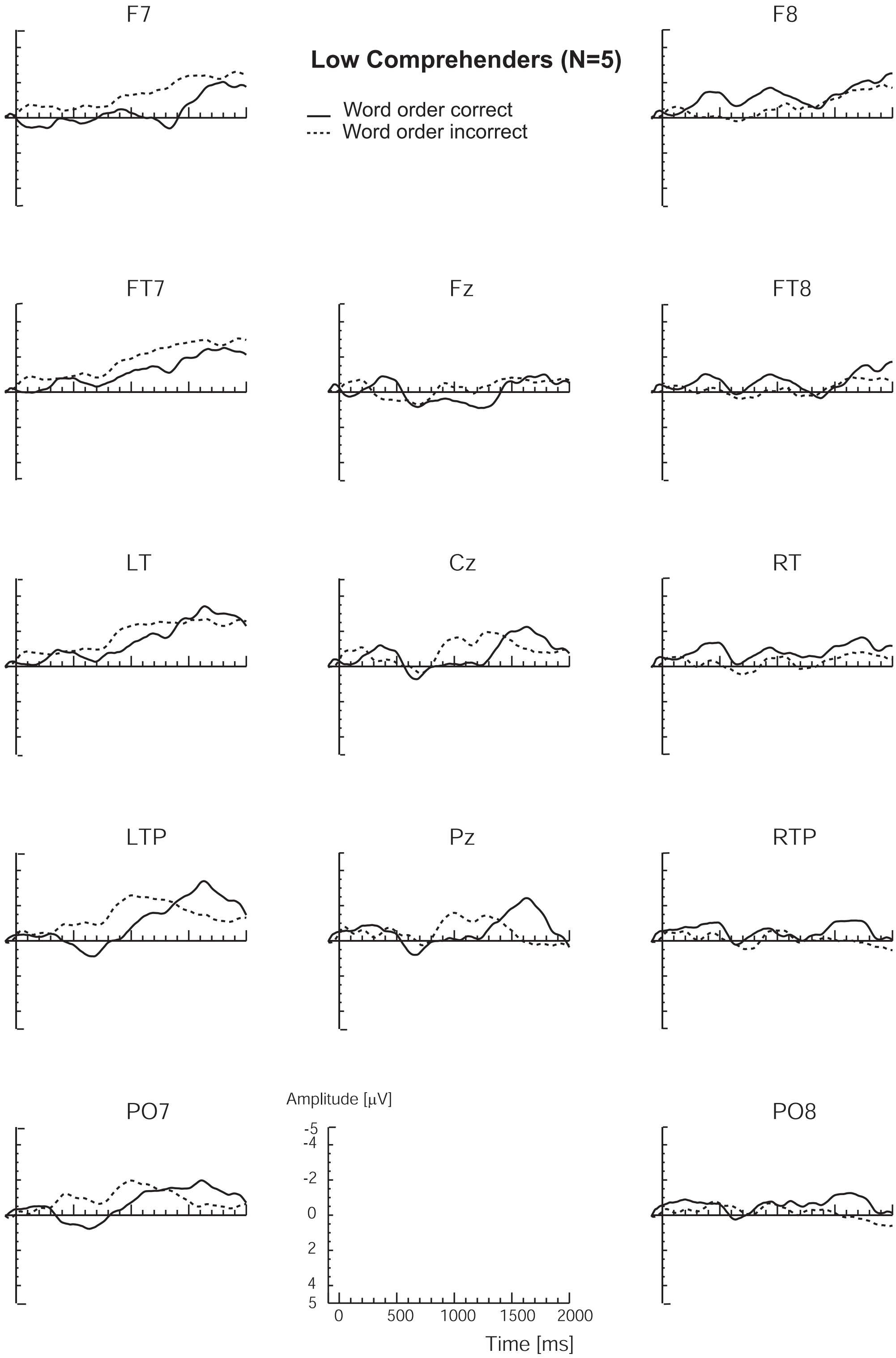

Figure 3-7. *Grand average ERP waveforms for the group of Low Comprehending Broca Patients (N=5) elicited by critical correct words (solid line) or incorrect words (dotted line) in the word order violation condition. At 0 ms is the onset of the word that violates word order preferences.*

Table 3-7. Word order violations for Low Comprehending Broca Patients: Mean ERP amplitude ANOVAs in the 600- to 1500-ms latency range following the onset of the word that violates word order preferences.

Source	*df*	*F*	*MSe*	*p*
		Omnibus ANOVA (13 electrodes)		
Word order	1, 4	11.40	1.12	0.038*
Word order x El	4.44, 17.78	2.39	0.44	0.085
		Midline ANOVA (3 electrodes)		
Word order	1, 4	82.93	0.11	0.001***
Word order x El	1.49, 5.97	0.13	0.42	0.822
		Posterior ANOVA (5 electrodes)		
Word order	1, 4	3.69	1.45	0.127
Word order x El	2.86, 11.43	4.87	0.17	0.021*
		Lateral ANOVA (2 x 5 electrodes)		
Word order	1, 4	4.91	1.22	0.091
Word order x He	1, 4	10.02	0.93	0.034*
Word order x El	1.39, 5.57	0.19	0.56	0.754
Word order x He x El	1.85, 7.41	0.67	0.27	0.531

Note. Word order = Word order condition; El = electrode; He = Hemisphere. * $p < 0.05$; *** $p \leq 0.001$.

Word Order by Hemisphere interaction affirmed that the effect was restricted to the left side of the scalp.

An omnibus ANOVA with Group of Subjects (Normal Controls, Low Comprehending Broca patients) as between-subjects factor (see Table 3-5) resulted both in a significant effect of Group and, more importantly, in a significant Group by Word Order interaction.

An omnibus ANOVA on the mean amplitudes in the 1500 – 1800 ms latency range, to test the late positivity, failed to reach significance ($F < 1$). However the positivity became significant in an analysis over five posterior electrode sites ($F(1, 4) = 16.79$; $MSe = 1.05$; $p = 0.015$).

In sum, the ERP response of the Low Comprehending Broca patients to the word order violations was qualitatively different in comparison to all other subject groups.

To see to what extent the pattern of results in the group averages is also noticeable in the individual subjects, the individual subject data will be presented here below.

Individual subject data

Figure 3-8 presents data of individual subjects. This figure shows for the three different groups (normal controls, RH patients, and Broca patients) per subject the effect size in the 600-1500 ms epoch, averaged over five posterior electrode sites (Pz, LTP, RTP, PO7, PO8). Posterior sites were chosen because of the posterior distribution of P600/SPS effects.

As is evident from this figure, there is considerable variation in size of the grammaticality effect within all of the subject groups. However, all normal control subjects, all five RH patients, and all the High Comprehending Broca patients (patients 1-5) showed a P600/SPS effect. In contrast, at least four of the five Low Comprehenders (patients 6-10) showed that their waveforms for the word order violations were dominated by the N400 effect. The overall pattern of results that was observed in the averaged data was present in nearly all individual subjects.

As can be seen in Table 3-1, the Low Comprehending Broca patients had a lower score than the High Comprehending Broca patients on not only the syntactic off-line test, but also on the Token Test and the AAT comprehension test. One can, therefore, ask whether the ERP results reflect a syntactic deficit or, more generally, the severity of the aphasia. Because syntactic cues contribute to the performance on both the Token Test and the AAT comprehension test, it is to be expected that these scores correlate with the performance on the syntactic off-line test. Thus, to address the issue of the specificity for syntax, we have to look at an aspect of comprehension that does not invoke sentential-syntactic cues. This aspect is provided by a part of the AAT comprehension test that measures single-word comprehension. In this part of the comprehension test, single words are presented either auditorily or visually. The patients have to select one picture (from an array of four pictures) that matches the presented word. The test results showed an average score for the Low Comprehending Broca patients of 50 (range 40-59) that is very similar to the average score of the High Comprehenders, which was 53 (range 50-57). A median split of the single-word

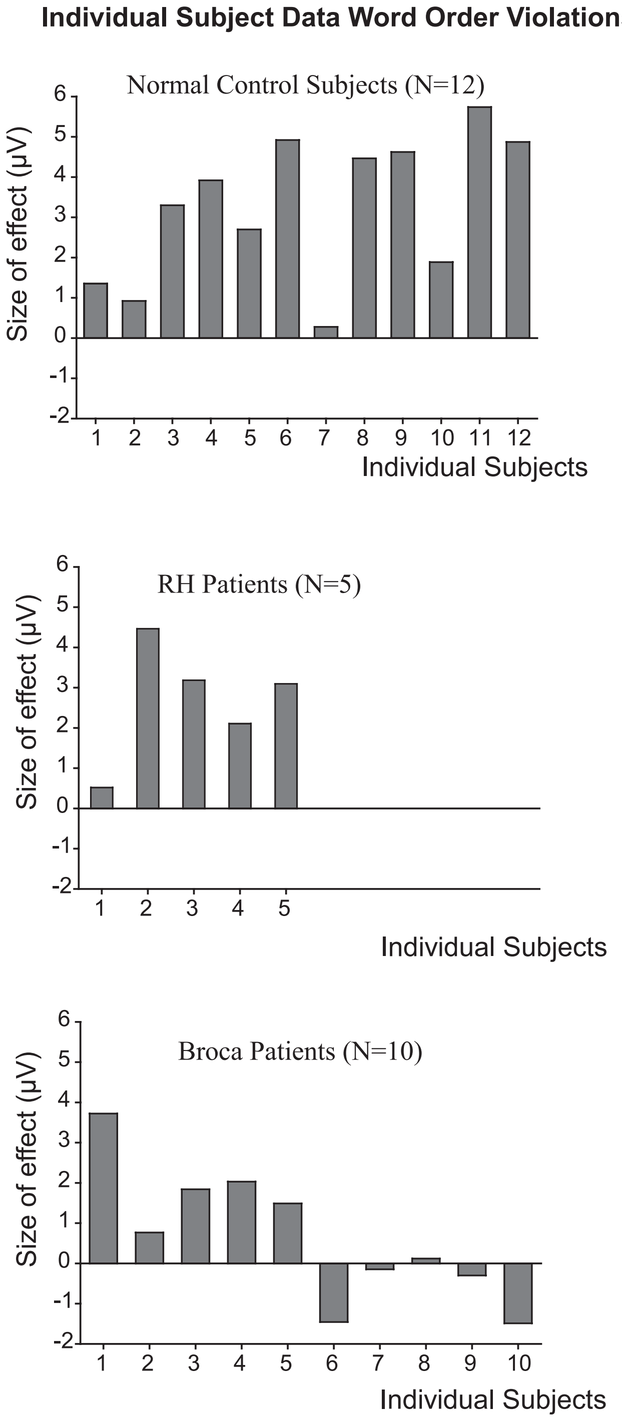

Figure 3-8. *Mean amplitude of the grammaticality effects in μV over five posterior electrode sites (latency: 600 - 1500 ms), for each individual subject elicited in the word order violation condition. High Comprehending Broca Patients correspond with Broca patients 1–5 in Table 3-1, Low Comprehending Patients with subject numbers 6–10 in the same table.*

comprehension scores resulted in a group of high single-word comprehenders consisting of two Low Comprehending Broca patients and three High Comprehending Broca patients (subjects 1, 3, 5, 7, and 8 in Figure 3-8) and a group of low single-word comprehenders consisting of three Low Comprehending Broca patients and two High Comprehending Broca patients (subjects 2, 4, 6, 9, and 10 in Figure 3-8). The ERP results for the individual patients indicate that the grouping of patients on the basis of single-word comprehension does not pattern with the N400 and P600/SPS effects that were obtained for the word-order violations in the Low Comprehending and High Comprehending Broca patients, respectively. It is therefore, more likely that the ERP results reflect impairments that are relatively specific for on-line syntactic processing than a relatively unspecific impairment in on-line processing of verbal material in general.

DISCUSSION

The aim of the present study was to investigate syntactic information processing during auditory sentence comprehension in patients with Broca's aphasia. For that purpose, ERPs were recorded while subjects listened to sentences that were either syntactically correct or contained violations of word order. The central questions were: First, do Broca patients show sensitivity to these word order violations as indicated by a P600/SPS effect? Second, does the severity of the syntactic comprehension impairment in the Broca patients affect the ERP responses?

To summarize the results, Figure 3-9 presents an overlay of the difference waveforms for all subject groups. Difference waveforms reflect the size of an effect and are obtained by subtracting the correct condition from the violated one.

In line with our expectations, the age-matched controls showed a P600/SPS effect to the word-order violations. This result for the *elderly* controls replicates the P600/SPS effect to Dutch word-order violations in connected speech in *young* (adult) subjects (Hagoort & Brown, 2000a).

The non-aphasic patients with a lesion in the right hemisphere also showed a clear P600/SPS effect. Although somewhat smaller, the overall effect was statistically indistinguishable from the normal elderly controls. So, a relatively normal P600/SPS effect

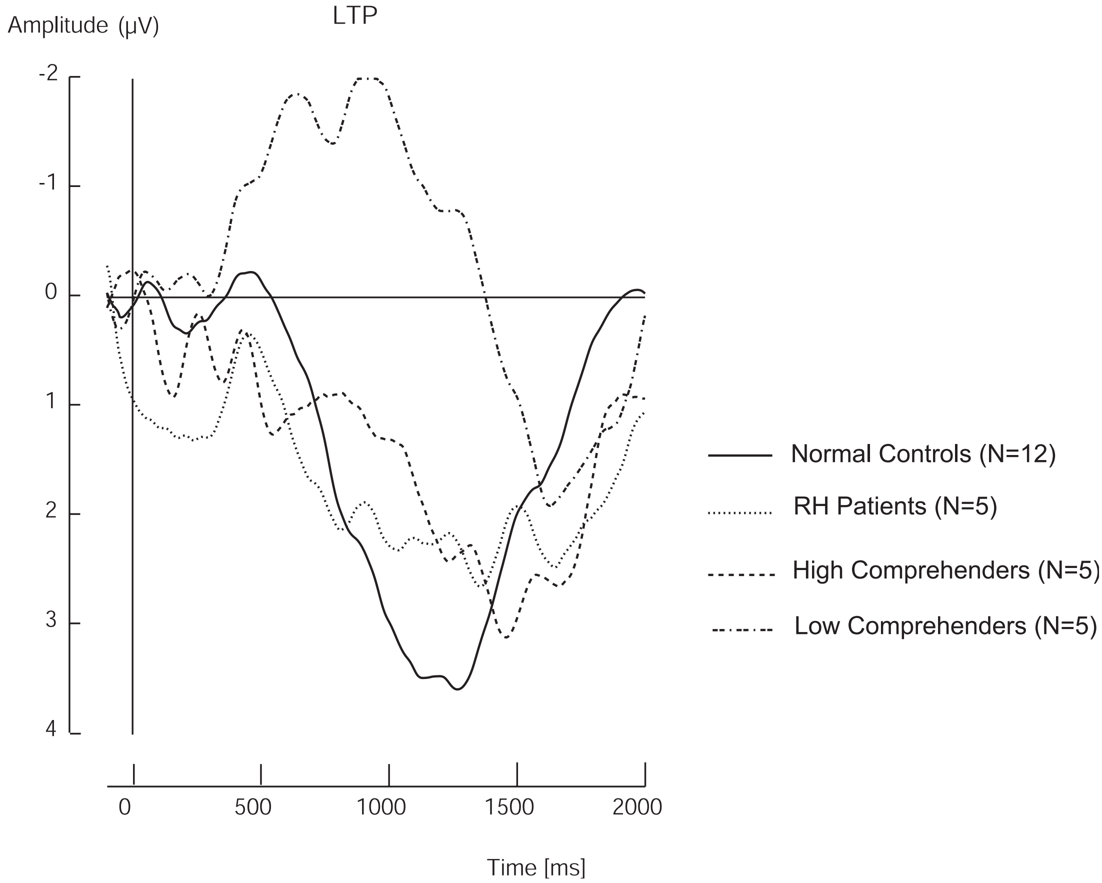

Figure 3-9. *Grand average difference waveforms (obtained by subtracting the waveforms for the correct from the incorrect condition) at a left temporo-parietal electrode site (LTP). Waveforms are averaged over participants for the group of Normal Controls (N=12, solid line), RH Patients (N=5, dotted line), High Comprehenders (N=5, dashed line), and Low Comprehenders (N=5, dashed-dotted line). The waveforms are aligned at 0 ms on the onset of the word that violates word order preferences.*

can be obtained in brain-damaged patients without aphasia.

The data for the Broca patients were analyzed according to the relative severity of their syntactic comprehension deficit. The group of Broca patients with a mild syntactic comprehension deficit (High Comprehenders) showed essentially the same pattern of results as both control groups. Even though the size of the P600/SPS effect was reduced relative to the normal controls, averaged over electrodes this difference was not statistically significant. Furthermore, the onset latency of the effect in the High Comprehending Broca patients was not different from that of the normal control subjects. So, there was no qualitative difference in the on-line processing of the word-order violations between the normal controls and the

High Comprehending Broca patients. Thus, these High Comprehenders were able to exploit this type of syntactic information in real-time spoken language understanding.

In contrast, the ERP response of the Low Comprehending Broca patients was dominated by an N400 effect that usually is observed to semantic binding operations during on-line language processing. Although the late positivity after the N400 effect might indicate some remaining capacity for syntactic processing, it more likely reflects a general taxing of processing resources after a semantic binding problem. A similar positivity after the N400 effect has been observed for aphasic patients in a study with semantic violations only (Swaab et al., 1997). In summary, although word order violations triggered a syntax-related ERP response in normal controls, RH patients, and Broca patients with a mild syntactic comprehension deficit, the same violations triggered an ERP response related to semantic binding in Broca patients with a relatively severe syntactic comprehension deficit.

We offer the following explanation for this semantic ERP response in the Broca patients with a severe syntactic comprehension deficit. The absence of a P600/SPS effect in combination with chance performance in an off-line syntactic comprehension task for sentences that were more complex than simple actives suggests that these patients were very limited in their ability to exploit syntactic information during on-line sentence comprehension. The N400 effect for the word order violations suggests that these sentences were processed through another (*compensatory*) processing route. The lack of a syntax-related ERP effect suggests that the Broca patients with a severe syntactic comprehension deficit did not interpret these sentences through a hierarchically organized phrase-structure representation. Instead, they seemed to focus on *semantic* information. Caplan (1987; 1988) has suggested that agrammatic comprehenders can resort to a semantically based processing route by recognizing and combining individual word meanings in their linear order. Suppose that the Low Comprehenders in our study relied on such a semantic processing route and integrated word meanings incrementally into the semantic representation of the linear string of preceding words. The ease of interpretation will be determined by the semantic coherence of the individual words in their left-to-right order. The violation of word order constraints (viz. the transpositions of adverbs and adjectives), which we used in our ERP-experiment, can disturb the semantic coherence of the individual words. Remember that in the incorrect condition the adjective preceded the adverb (*thief steal expensive very …*), whereas in the correct condition the adjective followed the adverb (*thief steal very expensive* …). For the incorrect word order, the internal event structure is less coherent than for the correct word order, due to the reversal of the semantic arguments of the denoted event (Sirigu et al., 1998). That is, in the semantic context of *thief steal expensive*, the canonical structure of events is better matched by mentioning what is being stolen, than by further expanding the meaning of *expensive* (as in *thief steal expensive very*). The results indicate that these patients still have access to this level of semantic information and are able to use this during real-time processing. This is not to say that their usage of semantic information is optimal, but it is certainly less affected than syntactic processing operations. As such, the relative preservation of a semantic processing route presumably results in the N400-effect.

N400-effects for auditorily presented phrase structure violations have also been reported for cochlear-implant (CI) users with post-lingually acquired deafness (Hahne & Kiefer, 1999; Wolf & Hahne, 2001). The perceived auditory input with a cochlear-implant deviates substantially from normal hearing. The authors suggested that impoverished auditory input could lead to compensatory comprehension strategies relying on semantics rather than on syntax, as reflected by the N400-effects in the CI users.

In another study (Wassenaar et al., 2004), we presented the same group of Broca patients with sentences containing subject-verb agreement violations (e.g., "The women pay the baker and *takes* the bread home"). Whereas this violation elicited a P600/SPS effect in the control subjects and the group of Broca patients with a mild syntactic comprehension deficit, the Broca patients with a severe syntactic comprehension impairment did not show an Agreement effect at all. In contrast to the word order violation, in the agreement violation the event structure of sentence violating the subject-verb agreement remains the same as in the correct counterpart. In the absence of the capacity to process the morphosyntactic number marker in establishing agreement between the subject and the finite verb, the two sentence versions are identical. This might explain why an N400 effect is observed for word order violations but no such effect is seen for the agreement violations. The latter type of sentence did not offer the possibility for a compensatory processing route.

The data of our present study speak to the real-time functioning of the language system under impairment: the way in which different sources of linguistic information are combined to derive an interpretation seems to be tailored to the processing options that are still available to the impaired language comprehension system. The results that we obtained suggest that a semantic processing stream provides an optimization of language comprehension within the limitations imposed by a syntactic deficit resulting from brain damage. Although this finding does not imply that semantic processing is fully optimal in Broca patients with severe syntactic comprehension problems, it is relatively more preserved than syntactic processing. Under impairment, the comprehension system seems to weigh the remaining information differently or more strongly. The data of this study point to *multiple-route plasticity* (cf. Kolk, 2000): a semantic route is favored to compensate for a syntactic deficit. This multiple-route plasticity instantiates the potential for on-line adaptation to impairments in the language comprehension system.

WORD-CATEGORY VIOLATIONS IN PATIENTS WITH BROCA'S APHASIA: AN ERP STUDY

CHAPTER 4

Marlies Wassenaar and Peter Hagoort[1]

ABSTRACT

An event-related brain potential experiment was carried out to investigate on-line syntactic processing in patients with Broca's aphasia. Subjects were visually presented with sentences that were either syntactically correct or contained violations of word-category. Three groups of subjects were tested: Broca patients (N=11), non-aphasic patients with a right hemisphere (RH) lesion (N=9), and healthy aged-matched controls (N=15). Both control groups appeared sensitive to the violations of word category as shown by clear P600/SPS effects. The Broca patients displayed only a very reduced and delayed P600/SPS effect. The results are discussed in the context of a lexicalist parsing model. It is concluded that Broca patients are hindered to detect on-line violations of word-category, if word class information is incomplete or delayed available.

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INTRODUCTION

Language comprehension is crucial for everyday communication. The relative ease by which humans understand language is amazing given all the different types of information that have to be dealt with in a very short time. However, in patients with aphasia, language processing occurs less straightforwardly. Patients with Broca's aphasia for instance can experience serious difficulties with sentences that require a full analysis of the syntactic structure for correct sentence interpretation (Caplan & Hildebrandt, 1988). These syntactic comprehension problems in aphasic patients do not seem to originate from a complete loss of linguistic knowledge, but are rather caused by impairments in exploiting this knowledge in real-time during the construction of a syntactic representation. With respect to the underlying deficit in Broca's aphasia different positions can be distinguished (see for a review Kolk, 1998). One of the hypotheses, among others, is that syntactic comprehension deficits in Broca patients would reflect a change in the temporal organization of the parsing process. Two kinds of temporal disturbance have been suggested: (1) the activity level of syntactic information is liable to pathologically fast decay (e.g. Haarmann & Kolk, 1994) or (2) the activation rate of structural information is slowed down (Friederici, 1988; Friederici & Kilborn, 1989; Haarmann & Kolk, 1991a, 1991b). Friederici (1988; 1995; 1998) has considered the effects of a slow down in syntactic activation rate from the perspective of a structure-driven two stage parsing model (e.g. Ferreira & Clifton, 1986; Frazier, 1978; Frazier & Fodor, 1978). In this model[2], it is assumed that there is a first stage, that operates fast and with a high degree of automaticity, during which the parser assigns an initial syntactic structure primarily based on syntactic word category information. During a later stage, thematic role assignment takes place by mapping syntactic and lexical-semantic information onto each other. A delay in the initial stage of phrase structure building would form a serious hindrance for efficient parsing (Friederici, Hahne, & von Cramon, 1998). Findings from some behavioural studies (i.e. syntactic priming studies) (Haarmann & Kolk, 1991b; Kilborn & Friederici, 1994) fit well within a framework that assumes that syntactic activation in Broca patients, instead of being fast and automatic, occurs at a slower than normal rate (but see Haarmann & Kolk, 1994).

[2] An alternative view to *serial, syntax-first* models is represented by *interactive* models that emphasize parallel processing of information (e.g. MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell, Tanenhaus, & Garnsey, 1994).

A different methodology to investigate temporal aspects of language processing is to register event-related brain potentials (ERPs). ERP research focusing on language has identified a number of specific ERP patterns characterized by their polarity, peak latency, and topographical distribution. An important finding in language-related ERP research is a negative-going component, the N400, typically peaking at 400 ms after stimulus onset. The amplitude of this component increases when the semantics of the eliciting words do not match with the preceding sentence context, as in "He spread the warm bread with butter and *socks*" (cf. Kutas & Hillyard, 1980). The modulation of the N400 amplitude by semantic context is known as the N400 effect. Today, a widely held view is that in sentence contexts, the N400 amplitude indexes the relative ease of semantic integration (e.g. Brown & Hagoort, 1993; Hagoort & Brown, 2000b; see for reviews Kutas & Van Petten, 1994; Osterhout & Holcomb, 1995).

In recent years, a number of ERP studies have reported two *syntax*-related ERP effects: an anterior negativity also referred to as *LAN (Left Anterior Negativity*) and a more posterior positivity, here referred to as *P600/SPS*.

Several studies have reported negativities that are different from the N400: these negativities show a more anterior maximum, are sometimes larger over the left than the right hemisphere, and are often observed between 300-500 ms post-stimulus (e.g. Friederici, Hahne, & Mecklinger, 1996; Kluender & Kutas, 1993; Münte, Heinze, & Mangun, 1993; Osterhout & Holcomb, 1992; Rösler, Friederici, Pütz, & Hahne, 1993) or sometimes in an earlier window between 100-300 ms (e.g. Friederici, Pfeifer, & Hahne, 1993; Hahne & Friederici, 1999; Neville, Nicol, Barss, Forster, & Garrett, 1991). Friederici (2002) has recently attributed the early LAN effects (ELAN) that occur between 100 and 300 ms to violations of word-category, and the LAN effects beween 300-500 ms to morphosyntactic errors.

In an alternative account, LAN effects have been viewed as a general index of verbal working memory load (Coulson, King, & Kutas, 1998; Kluender & Kutas, 1993). However, not all LAN effects can be lumped under the verbal working memory account. Presumably, under the heading of LAN effects more than one type of effect is subsumed with subtle distinctions in timing, topography and function (cf. Hagoort, Wassenaar, & Brown, 2003a).

A second ERP effect that has been related to syntactic processing is a late positivity, here termed P600/SPS, that occurs between 500-1000 ms. P600/SPS effects have been reported for outright syntactic violations, but also in response to less preferred syntactic structures in so-called garden-path sentences, and with processing of syntactically complex sentences (e.g. Hagoort, Brown, & Groothusen, 1993; Kaan, Harris, Gibson, & Holcomb, 2000; Osterhout & Holcomb, 1992; Osterhout, Holcomb, & Swinney, 1994).

The precise functional interpretation of these syntax-related effects is still a matter of debate. Friederici (2002) describes a three-phase neurocognitive model in which ELAN, LAN, and P600/SPS are respectively related to initial syntactic structure building based on word-category information, to morphosyntactic processes, and to syntactic integration processes including processes of syntactic reanalysis and repair. Kaan & Swaab (2003) propose that the P600/SPS with a posterior distribution reflects syntactic processing difficulty including repair and revision operations, whereas the more frontally distributed P600/SPS indexes ambiguity resolution and/or an increase in discourse level complexity. Hagoort (2003a; 2003b) has attempted to relate syntax-related ERP-effects to a lexicalist parsing model (Unification Space model) by Vosse and Kempen (2000). According to this model (see for details Vosse and Kempen (2000), incoming words activate lexical frames that are stored in the mental lexicon. While a sentence unfolds, the nodes of these frames try to link up and form a network of possible attachments (‘unification links’). A successful parse consists of lexical frames that are connected by winning binding links. Hagoort (2003a) claims that an AN originates from a failure to bind. This can happen in case of a negative outcome of the agreement check of grammatical feature specifications or in case of a failure to find a matching category node. The P600/SPS is considered as being related to the time it takes to build up binding links of sufficient strength. This amount of time is affected by ongoing competition between alternative binding options (syntactic ambiguity), by syntactic complexity, and by semantic influences. Syntactic violations will result in a P600/SPS effect, as long as unification attempts are made.

The ERP components that we described above have also been used as a tool to study language processing in aphasic patients. So far, studies investigating syntactic processes in aphasic patients using ERPs are limited (Kotz & Friederici, 2003). Here, we will focus on studies that report on violations of word category constraints. That is, if the syntactic context requires a word of a certain syntactic class (e.g. a noun in the context of a preceding article and adjective), but in fact a word of a different syntactic class is presented (e.g. a verb). Word category violations are interesting from the perspective that they have been reported to elicit in healthy subjects *two* syntax-related ERP-effects: anterior negativities as well as a P600/SPS. Friederici et al. (1998) presented a Broca patient with sentences containing *word-category violations*, among other violations. The sentences were auditorily presented and the violations always showed up at sentence-final position. Whereas normal controls showed an early left anterior negativity followed by a P600/SPS for the syntactic violation condition, for the Broca patient no early left anterior negativity was found. However, a P600/SPS was observed. The authors interpreted the results for this Broca patient as follows. The absence of the early left anterior negativity would indicate a loss of the fast and automatic initial structure building processes. The presence of the P600/SPS suggested that secondary syntactic processes were still available to this patient. In an additional study (Friederici, von Cramon, & Kotz, 1999), patients with cortical and subcortical left hemisphere lesions were tested with the same stimulus materials. The cortical patient group consisted of only one Broca patient. The results for this patient were similar to the findings of the earlier case report (Friederici et al., 1998).

Present study

The purpose of this present study is to explore what syntax-related ERP effects to Dutch word category violations can reveal about syntactic processing in Broca patients. In a study of Hagoort (Hagoort et al., 2003a), young college-aged subjects were presented with Dutch word category violations. The stimulus presentation was visually and the violations were always at sentence-internal position[3]. The word category violations elicited in these young subjects an anterior negativity between 300-500 ms and a P600/SPS starting at about 600 ms. For our present study we will use the same stimulus materials (see materials section). We are interested to see what the ERP response will be to these word category violations in patients

[3] The violations were, in contrast to most word category violation studies (but see for an exception Friederici et al., 1996), on purpose, *not* presented at sentence-final position. The violations were placed at mid-sentence position to prevent a possible overlap of the specific effect of the word category violation and more general sentence-final effects like sentence wrap-up.

with Broca's aphasia. Does this ERP-reponse deviate from effects in normal control subjects? If so, in what respect? In addition, we added also a semantic violation condition to see whether, in the same subjects, semantic anomalies resulted in a classical N400-effect to track possible dissociations in the sensitivity to semantic and syntactic information in the Broca patients.

In order to be able to reliably interpret possible changes in the ERP-effects of the Broca's aphasics as reflecting changes in their syntactic processing, it is important to identify factors that could contaminate the results of the experiment. To control for the non-specific effect of aging, the results of the patients with Broca's aphasia will be compared to a group of normal age-matched controls. A group of non-aphasic patients with a lesion in the right hemisphere was tested to control for non-specific effects of brain damage. To determine whether possible changes in the syntax-related ERP-effects can be dissociated from general effects of brain damage on cognitive ERP components, the different subject groups were also tested with a non-linguistic cognitive task. For that purpose we used the classical auditory oddball paradigm, in which subjects were presented with a series of high and low tones. It is a standard observation in ERP research that in neurologically unimpaired subjects the infrequently presented tones in such a paradigm elicit a large positive deflection in the ERP waveform (cf. Fabiani, Gratton, Karis, & Donchin, 1987). Usually this positivity reaches its maximum amplitude at around 300 ms after stimulation, and is therefore known as the P300.

METHOD

Subjects

Eleven patients with aphasia secondary to a single cerebral vascular accident (CVA) in the left hemisphere participated in this study. In addition, a group of fifteen healthy normal subjects, who were approximately matched in age and education level to the aphasic patients, were tested. To account for non-specific effects of brain damage on cognitive ERP components, a group of nine non-aphasic patients with a single CVA in the right hemisphere (RH patients) was tested. All subjects gave informed consent, according to the declaration of Helsinki. The elderly control subjects and the RH patients were paid for their participation. The mean age of the aphasic patients was 58.9 years (range: 44-72 years), the RH patients were on average 59.5 years (range: 40-71 years) and the normal elderly controls had a mean age of 60.6 years (range: 53-73 years). All subjects had normal or corrected-to-normal vision without signs of hemianopia or spatial neglect. They were premorbidly right-handed according to an abridged Dutch version of the Oldfield Handedness Inventory (Oldfield, 1971). Four of the elderly control subjects reported familial left-handedness. None of the elderly control subjects had any known neurological impairment or used neuroleptics.

All neurological patients were tested at least nine month post-onset of their CVA. Median post-onset time for the patients with Broca's aphasia was 4;5 years (range: 1;2 – 9;4 years) and for the RH patients 3;0 years (range: 1;5 – 6;10 years).

All neurological patients were tested with the standardized Dutch version of the Aachen Aphasia Test (AAT) (Graetz, De Bleser, & Willmes, 1992). Both presence and type of aphasia were diagnosed on the basis of the AAT results and on the basis of a transcribed sample of the patient's spontaneous speech. Three experts evaluated this spontaneous speech. All RH patients were diagnosed as non-aphasic and all left-hemisphere patients were diagnosed as patients with Broca's aphasia on the basis of a procedure that matches the individual score profiles against a norm population of patients. According to their scores on the comprehension subtest of the AAT, the aphasic patients had moderate to mild comprehension deficits. All normal control subjects were tested with the language comprehension subtest of the AAT.

The presence of syntactic comprehension problems was determined by administering all subjects the Dutch version of an off-line test that assesses the influence of syntactic complexity on sentence comprehension (after Huber, Klingenberg, Poeck, & Willmes, 1993) (for a detailed description of the Dutch version see Ter Keurs, Brown, Hagoort, & Stegeman, 1999). Statistical evaluation of the syntactic off-line test results confirmed the syntactic comprehension problems of the Broca patients as compared to the normal controls and the RH control patients. ANOVA's on the percentage-correct scores of the sentences with increasing syntactic complexity showed that syntactic complexity had a differential effect on the comprehension scores of the different subject groups [Complexity: $F(4, 128) = 17.76$; $MSe = 152.53$; $p < 0.000$; Group: $F(2, 32) = 46.90$; $MSe = 364.69$; $p < 0.000$; Complexity x Group: $F(8, 128) = 4.35$; $MSe = 152.53$; $p < 0.000$]. Post hoc analyses ($\alpha = 0.05$) revealed that the Broca patients performed significantly worse than both the normal controls and the RH controls. The two control groups did not differ significantly from each other. This pattern of results substantiates the syntactic comprehensions problems of the Broca patients in this study. Participant's age, gender, results on the Token Test, scores on the Aachen Aphasia Test subtest on comprehension (overall and visually), overall scores on the syntactic off-line test and lesion site information are summarised in Table 4-1. The Token Test is a valid measure of the general severity of the aphasia, independent of syndrome type (Orgass, 1986). The general severity of the aphasia ranged from light to severe.

Materials

The stimuli were identical to the stimuli of Experiment 1 from Hagoort et al. (2003a) and consisted of a list of 308 visually presented Dutch sentences. Of these sentences, 272 were the critical sentences for the experiment. The critical sentences belonged either to the *syntactic violation* condition or to the *semantic violation condition.* The remaining sentences were used as practice trials (16) and warm-up trials (5 at the start of each of the four blocks).

The syntactic violation condition consisted of 96 sentence pairs. Next to the correct version of each sentence, a version was created that contained a *word category violation.* In this version a verb was placed at a position where this was grammatically incorrect given the syntactic context. To guarantee that the observed ERP effects could be ascribed to the syntactic violation alone, two additional constraints were used during the construction of the materials. The first one was that apart from word category (noun versus verb) the critical words (CWs) in the correct and incorrect version of the sentences were maximally alike. This was done by using noun-verb pairs that are semantically strongly related (*the cook* vs. *to cook*). Secondly, to prevent differences in transition probabilities from context to CW, this probability was made zero in both correct and incorrect versions. In the correct version this was done by adding an adjective before the noun that made the sentence pragmatically very unlikely. An example is given in Table 4-2. The zero cloze probability was verified in a pretest. In this pretest subjects were given the sentence context up to, but not including the Critical Word. Subjects were instructed to continue the sentence with one or more words. Twelve subjects participated in this pretest. All subjects filled in a noun at the Critical Word position. However, this was never the actual noun used in the experimental materials.

Table 4-1. Individual information for the patients with Broca's aphasia, the non-aphasic RH Patients, and the Normal Control Subjects (NC).

Subject	Age	Sex	Token Test [a]	Overall comp. score AAT [b]	Visual comp. score AAT	Syntactic off-line score	Lesion site
1 Broca	55	F	10	97/120	49/60	95/144	Left fronto-temporo-parietal incl. insula
2 Broca	69	F	18	91/120	46/60	111/144	Left fronto-temporal including insula
3 Broca	69	F	11	103/120	50/60	90/144	No adequate CT information available
4 Broca	71	M	34	83/120	34/60	93/144	Left fronto-temporal including insula
5 Broca	59	M	9	111/120	55/60	104/144	Left capsula interna
6 Broca	47	M	17	94/120	49/60	74/144	Left temporo-parietal
7 Broca	52	M	42	89/120	44/60	51/144	No adequate CT information available
8 Broca	44	M	29	67/120	28/60	60/144	Left fronto-temporo-parietal incl. insula
9 Broca	72	M	18	89/120	46/60	106/144	Left temporal
10 Broca	50	F	21	84/120	43/60	88/144	Left parieto-occipital
11 Broca	60	M	14	95/120	47/60	126/144	Left temporo-parietal
1 RH	52	M	0	113/120	55/60	134/144	No adequate CT information available
2 RH	55	M	9	106/120	55/60	128/144	Right insular
3 RH	71	F	0	117/120	60/60	138/144	Right capsula interna
4 RH	68	F	2	108/120	56/60	135/144	Right basal ganglia
5 RH	58	F	1	103/120	48/60	125/144	Right basal ganglia
6 RH	66	M	2	116/120	56/60	137/144	Right parietal
7 RH	40	M	0	102/120	52/60	127/144	Right temporo-parietal
8 RH	51	M	3	103/120	55/60	120/144	Right fronto-parietal
9 RH	66	F	1	120/120	60/60	143/144	Right temporo-parietal
1 NC	66	F		116/120	58/60	140/144	
2 NC	59	F		120/120	60/60	143/144	
3 NC	67	M		116/120	56/60	134/144	
4 NC	73	M		115/120	57/60	133/144	
5 NC	53	M		114/120	54/60	132/144	
6 NC	61	M		118/120	60/60	142/144	
7 NC	54	F		118/120	58/60	143/144	
8 NC	64	M		106/120	54/60	132/144	
9 NC	54	M		117/120	58/60	142/144	
10 NC	62	F		117/120	60/60	136/144	
11 NC	55	F		112/120	55/60	139/144	
12 NC	53	F		107/120	54/60	131/144	
13 NC	68	M		114/120	57/60	133/144	
14 NC	53	F		111/120	56/60	132/144	
15 NC	67	F		112/120	57/60	116/144	

[a] Severity of the aphasic disorder as indicated by the Token Test: no/very mild disorder (0-6); light (7-23); middle (24-40); severe (41-50). RH patient 2 had a Token Test score of 9, but was, on the basis of his spontaneous speech and ALLOC classification (a procedure that matches individual score profiles against a norm population of patients) non-aphasic. For the normal controls there were no Token Test data available.

[b] Severity of the comprehension disorder as indicated by the Aachen Aphasia Test subtest on comprehension (includes word and sentence comprehension in both the auditory and visual modality): no/very mild disorder (107-120); light (90-106); middle (67-89); severe (1-66). Comp.= comprehension; AAT= Aachen Aphasia Test.

The mean length for the syntactic violation condition was 8.8 words (range: 7 - 11 words). The mean lemma frequencies of the CWs were 908 (nouns) and 922 (verbs). The frequency counts were based on the Dutch Celex corpus (cf. Baayen, Piepenbrock, & Van Rijn, 1993), which contains over 42 million tokens.

For the semantic violation condition we selected 40 sentence pairs from the materials of a study by Swaab, Brown and Hagoort (1997). One member of each pair consisted of a sentence that ended with a critical word that matched the sentential-semantic constraints. The other sentence of these pairs ended with a word that violated the sentential-semantic constraints. An example is given in Table 4-2. The full set of sentence materials is listed in the Appendix. The 40 semantically congruent and semantically anomalous critical words (CWs) were matched for lemma frequency (with an average of 1872 for congruent CWs, and an average of 1873 for anomalous CWs). Congruent and anomalous items were matched for syntactic structure. The mean sentence length for both the congruent and the anomalous items was 7.5 words (range: 5 - 10 words).

Table 4-2. Example of stimulus materials.

Syntactic condition:	
Correct:	*De houthakker ontweek de ijdele* ***schroef*** *op dinsdag.* *(The lumberjack dodged the vain* ***propeller*** *on Tuesday.)*
Violation:	*De houthakker ontweek de ijdele* ***schroeft*** *op dinsdag.* *(The lumberjack dodged the vain* ***propelled*** *on Tuesday.)*
Semantic condition:	
Correct:	*De timmerman kreeg een compliment van zijn* ***baas***. (*The carpenter got a compliment of his* ***boss***.)
Violation:	*Het meisje stopte een snoepje in haar* ***bloem***. *(The girl put a sweet in her* ***flower***.*)*

On the basis of these materials two experimental lists were created. Subjects were equally distributed over the two lists. For the first list, all the semantically congruent and semantically anomalous sentences, and all sentences with and without a word-category violation were distributed over 4 blocks, such that the congruent / correct items and their anomalous / incorrect counterparts were separated by one intervening block. The critical sentences were pseudo-randomized with the constraint that a particular trial type never occurred more than four times in a row. The second list was derived from the first by changing the presentation order of the blocks: (list 1: block 1,2,3,4; list 2: block 3,4,1,2). Each experimental list was preceded by a practice list of 16 sentences.

In addition to the sentence stimuli, a digital audiotape was constructed with tones. This tape contained 300 tones: 60 tones of 1 kHz and 240 tones of 2 kHz. The tones were presented in a random order with 20 ms duration and a frequency of one per second. The experimental tones were preceded by 50 practice tones (10 tones of 1 kHz, and 40 tones of 2 kHz) in order to familiarise the subjects with the stimuli and the task.

Procedure

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

At the beginning of each trial a horizontal rectangle was displayed for 3 seconds, to inform the subjects that they were allowed to blink and move their eyes. After its offset, an asterisk was displayed for 400 ms, to warn the subjects that they had to fixate their eyes on the centre of the screen. The asterisk was followed by the visual presentation of the sentence. Sentences were presented on the centre of a computer screen, word-by-word in white lowercase letters (font: Arial; font size: 21) against a dark background. Viewing distance was approximately 100 cm and the stimuli subtended a visual angle of about 3° horizontally and 0.5° vertically. Each word was presented for 400 ms, followed by a blank screen for another 400 ms (i.e. the stimulus-onset asynchrony was 800 ms[4]). The final word was presented

[4] An SOA of 800 ms was also used in previous ERP investigations on visual language comprehension in Dutch Broca patients (Ter Keurs, Brown, & Hagoort, 2002; Ter Keurs et al., 1999), and turned out to be a good presentation rate for elderly subjects.

together with a period, followed by a blank screen for 1 second before the next trial began.

The testing session began with a short practice block. The experimental trials were presented in four blocks of approximately 10 minutes each. Subjects were given short breaks between the blocks. To stimulate the subjects to read each sentence attentively, at the end of some randomly determined trials the experimenter asked the subjects a question about the content of the sentence that was just presented. The experimenter wrote down the answers to get an informed understanding of how well each subject performed the reading task. Subjects knew that questions would be asked, but not when. Each time a question was asked, the subjects were again motivated to read the sentences carefully. Subjects were asked whether a particular noun had occurred in the sentence or not (e.g., “Did the word ‘piano’ occur in the last sentence?”). Half of the nouns that were presented to the subjects had been presented in the preceding sentence, half were nouns that had not been presented. The total number of questions was 16, equally distributed over four blocks. At the end of the session, subjects were interviewed with a list of questions to recover the subjects’ ideas about what kind of experiment they had been involved in and to see whether they had noticed the language errors they had been presented with. No further additional task demands were imposed.

The ERPs to the tones in the oddball paradigm were recorded in a separate session. Subjects were asked to press a button upon the occurrence of a low tone. The practice session was used to establish whether subjects could discriminate between the high and low tones. Throughout the presentation of the tones an asterisk was displayed on the centre of a screen to keep the eyes of the subjects fixated on a point at eye-level 1.5 m in front of them.

EEG-recording

Continuous EEG was recorded from 29 Ag/AgCl-sintered electrodes mounted in an elastic cap, each referred to the left mastoid. Figure 4-1 shows the electrode montage that was used. Twenty three electrodes (Fz, FCz, Cz, Pz, Oz, AF3, AF4, F7, F8, F3, F4, FT7, FT8, FC3, FC4, C3, C4, CP3, CP4, P3, P4, PO7, PO8) were placed according to the standard system of the American Electroencephalographic Society (1994). Six electrodes were placed over non-standard intermediate locations: (a) a temporal pair (LT and RT) placed laterally to Cz, at 33% of the interaural distance, (b) a temporo-parietal pair (LTP and RTP) placed 30% of the interaural distance lateral and 13% of the nasion-inion distance posterior to Cz, and (c) a parietal pair midway between LTP/RTP and PO7/PO8 (LP and RP). Vertical eye movements were monitored via a supra- to suborbital bipolar montage. A right to left canthal bipolar montage was used to monitor for horizontal eye movements. Activity over the right mastoid bone was recorded on an additional channel to determine if there were differential contributions of the experimental variables to the presumably neutral mastoid site. No such differential effects were observed. The EEG and EOG recordings were amplified by a SynAmp™ Model 5083 EEG amplifier system (Neuroscan) using a band-pass filter of 0.05 to 30 Hz. Impedances were kept below 3 kΩ. The EEG and EOG signals were digitized on-line with a sampling frequency of 200 Hz.

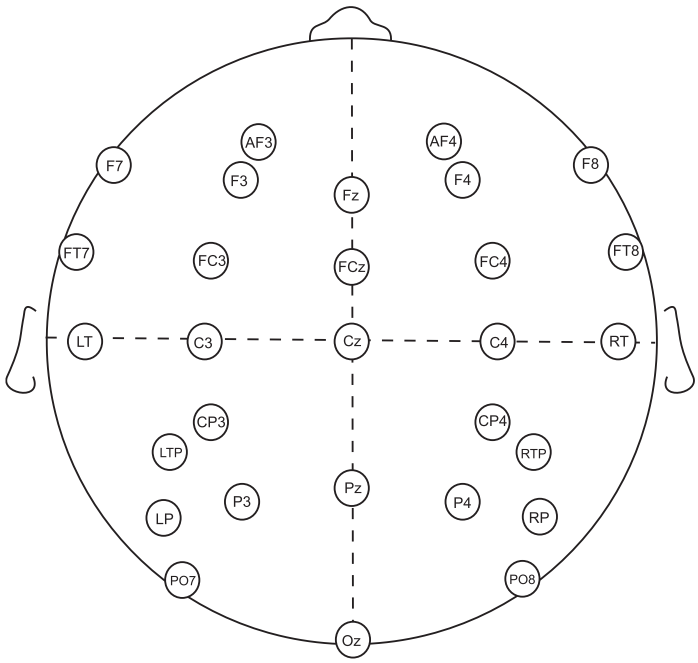

Figure 4-1. *Distribution of the 29 electrodes across the scalp.*

EEG-analysis

Prior to off-line averaging, all single trials waveforms were screened for electrode drifting, amplifier blocking, muscle artefacts, eye movements and blinks. This was done over an epoch that ranged from 150 ms before onset of the word immediately preceding the CW to 1200 ms and 1400 ms after CW, for the semantic and word-category violation respectively. Trials containing artefacts were rejected. However, for subjects with a substantial number of blinks, single trials were corrected via a procedure described by Gratton, Coles, & Donchin (1983). This correction procedure removes the contribution of eye blinks from the ERP recorded at each electrode site. After artefact rejection, the overall rejection rate was 6.2 % for the normal elderly control subjects, 16.4 % for the RH patients, and 14 % for the patients with Broca's aphasia. For all groups, rejected trials were evenly distributed among conditions.

For each subject, average waveforms were computed across all remaining trials per condition. This was done after normalizing the waveforms of the individual trials on the basis of the averaged activity of 150 ms before onset of the critical word. Several latency windows were selected for statistical analysis. These included for the word-category violation condition 400-500 ms and 600-900 ms after critical word onset. These time-epochs roughly correspond, respectively, to the latency ranges of a LAN-effect and the P600/SPS effect. For the semantic violation condition the following latency windows were selected: 300-500 ms and 700-900 ms after critical word onset. These time-epochs correspond to the N400 effect and a late positive effect. The latency windows were determined after careful visual inspection of the waveforms. If necessary, also additional latency ranges were analysed (see below). Subsequent ANOVAs used mean amplitude values computed for each subject, condition and electrode site in the selected latency window. In the analyses reported below different subsets of electrodes were taken together to investigate the ERP-effects. For purposes of brevity we use the following labels: Anterior Left (AL: AF3, F3, F7, FC3, FT7), Anterior Right (AR: AF4, F4, F8, FC4, FT8), Posterior Left (PL: CP3, LTP, P3, LP, PO7), Posterior Right (PR: CP4, RTP, P4, RP, PO8). For each subject group, omnibus ANOVAs with Condition, Site (4 quadrants: AL, AR, PL, PR) and Hemisphere (Left, Right) as within subject factors were performed, followed by ANOVAs on more specific regions of interest. The Huynh-Feldt correction was applied when evaluating effects with more than one degree of freedom in the numerator, to compensate for inhomogeneous variances and co-variances across treatment levels. The adjusted degrees of freedom and p-values will be presented. To test for differences between the results for the normal elderly control subjects and the patient groups, also group analyses are performed in the specified time-windows, with Condition as a within-subjects factor and Group of Subjects as a between-subjects factor. In addition, also individual subject data will be presented.

RESULTS

Word category violation condition

Normal Control Subjects

Figure 4-2 shows the results for the word category violation in the normal elderly control subjects. The word category violation results in a clear positive shift with a centro-posterior maximum. The onset of this positivity is at about 550 ms, and lasts until approximately 1000 ms. This effect resembles the characteristics of a P600/SPS effect that has been reported before in response to syntactic violations. In addition, for some left fronto-central electrode sites (F3, FC3, C3) this P600/SPS effect seems to be preceded by a small negative effect in the latency range of 380–500 ms. Such negative effects have been reported before and have been referred to as LAN (*Left Anterior Negativity*) (Friederici & Mecklinger, 1996) or AN (*Anterior Negativity*) (Hagoort et al., 2003a).

The omnibus ANOVA for the 400-500 ms window did not result in a significant effect of Grammaticality ($F < 1$). Also the Grammaticality by Site interaction failed to reach significance ($F < 1$). Analyses on individual electrode sites revealed also no significant effects. Thus, no AN effects were obtained.

In the 600-900 ms latency window, the omnibus ANOVA resulted in a significant main effect of Grammaticality ($F(1, 14) = 20.74$; $MSe = 27.68$; $p = 0.000$), and a significant Grammaticality by Site interaction ($F(1.95, 27.29) = 6.57$; $MSe = 1.75$; $p = 0.005$). Additional analyses showed that this interaction was due to a hemispheric difference: the P600/SPS effect was significantly larger over right hemisphere (AR and PR) than left hemisphere (AL and PL) areas ($F(1, 14) = 9.75$; $MSe = 1.59$; $p = 0.007$). In addition, the P600/SPS effect was significantly larger over posterior (PL and PR) than over anterior (AL and AR) scalp regions ($F(1, 14) = 4.96$; $MSe = 3.99$; $p = 0.043$).

In sum, the normal controls showed a P600/SPS effect to the violations of word category. An Anterior Negativity, however, was not present.

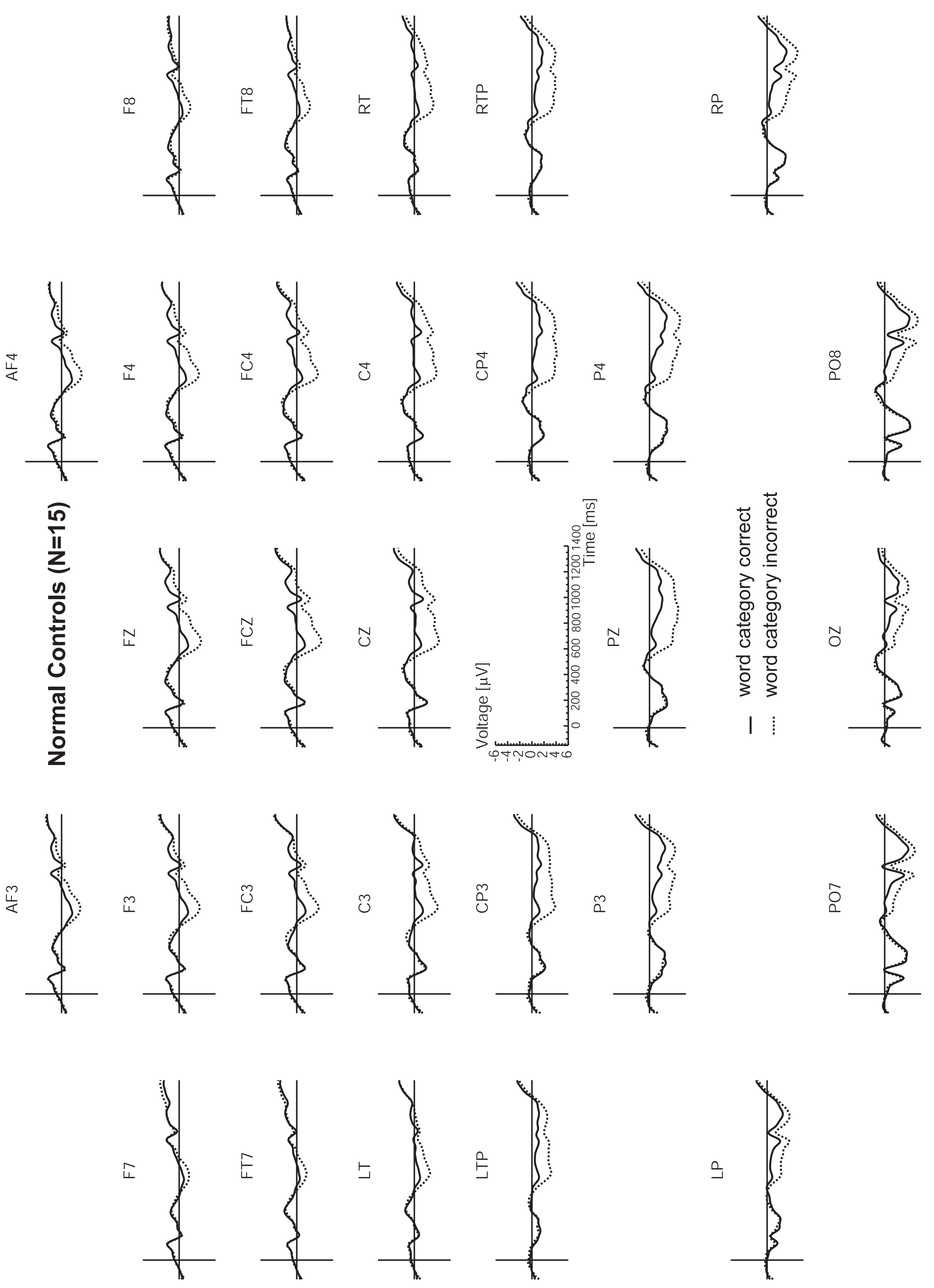

Figure 4-2. *Grand average ERP waveforms for the group of Normal Control Subjects (N=15) for the word category violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the syntactic violation.*

RH Patients

Figure 4-3 shows the results for the word category violation in the group of RH patients. A positive shift is visible in the latency range of 600-1000 ms and this effect is maximal over centro-posterior electrode sites. Prior to this P600/SPS effect, a negative shift is present in the latency range of 350–550 ms, but also in an earlier time-window of 100-300 ms. The negative effects in the RH patients are widely distributed over the scalp, but are maximal over fronto-central electrode sites.

The early negative effect was tested in an additional ANOVA on the mean amplitudes in the 100-300 ms latency range. This ANOVA did not result in a significant effect of Grammaticality ($F(1, 8) = 2.48$; $MSe = 13.55$; $p = 0.154$). Also the Grammaticality by Site interaction failed to reach significance ($F < 1$). Analyses on individual electrode sites revealed also no significant effects.

In the 400-500 ms latency window, the omnibus ANOVA resulted in a significant main effect of Grammaticality ($F(1, 8) = 5.97$; $MSe = 9.18$; $p = 0.040$). The Grammaticality by Site interaction was not significant ($F < 1$).

For the 600-900 ms latency window, the omnibus ANOVA failed to show a significant effect of Grammaticality ($F(1, 8) = 3.12$; $MSe = 19.07$; $p = 0.115$). The Grammaticality by Site interaction was not significant ($F(1.81, 14.47) = 2.12$; $MSe = 1.61$; $p = 0.159$). However, the interaction between Grammaticality and Hemisphere was significant ($F(1, 8) = 5.99$; $MSe = 2.34$; $p = 0.040$), due to the slight right hemisphere preponderance of the P600/SPS-effect. An additional ANOVA with the inclusion of only the electrodes over the right hemisphere resulted in a marginally significant main effect of Grammaticality ($F(1, 8) = 4.67$; $MSe = 15.88$; $p = 0.063$).

An omnibus ANOVA in the 400-500 ms latency range with Group of Subjects (Normal Controls, RH patients) as additional between-subjects factor revealed no significant interaction between Group of Subjects and Grammaticality ($F(1, 22) = 2.02$; $MSe = 25.83$; $p = 0.170$). Also in the 600-900 ms latency range, an omnibus ANOVA comparing the normal controls with the RH patients did not yield a significant Group of Subjects by Grammaticality interaction ($F(1, 22) = 2.99$; $MSe = 41.53$; $p = 0.098$).

In sum, the RH patients showed as response to word category violations a negative effect followed by a P600/SPS effect that was most clear over right hemisphere electrodes.

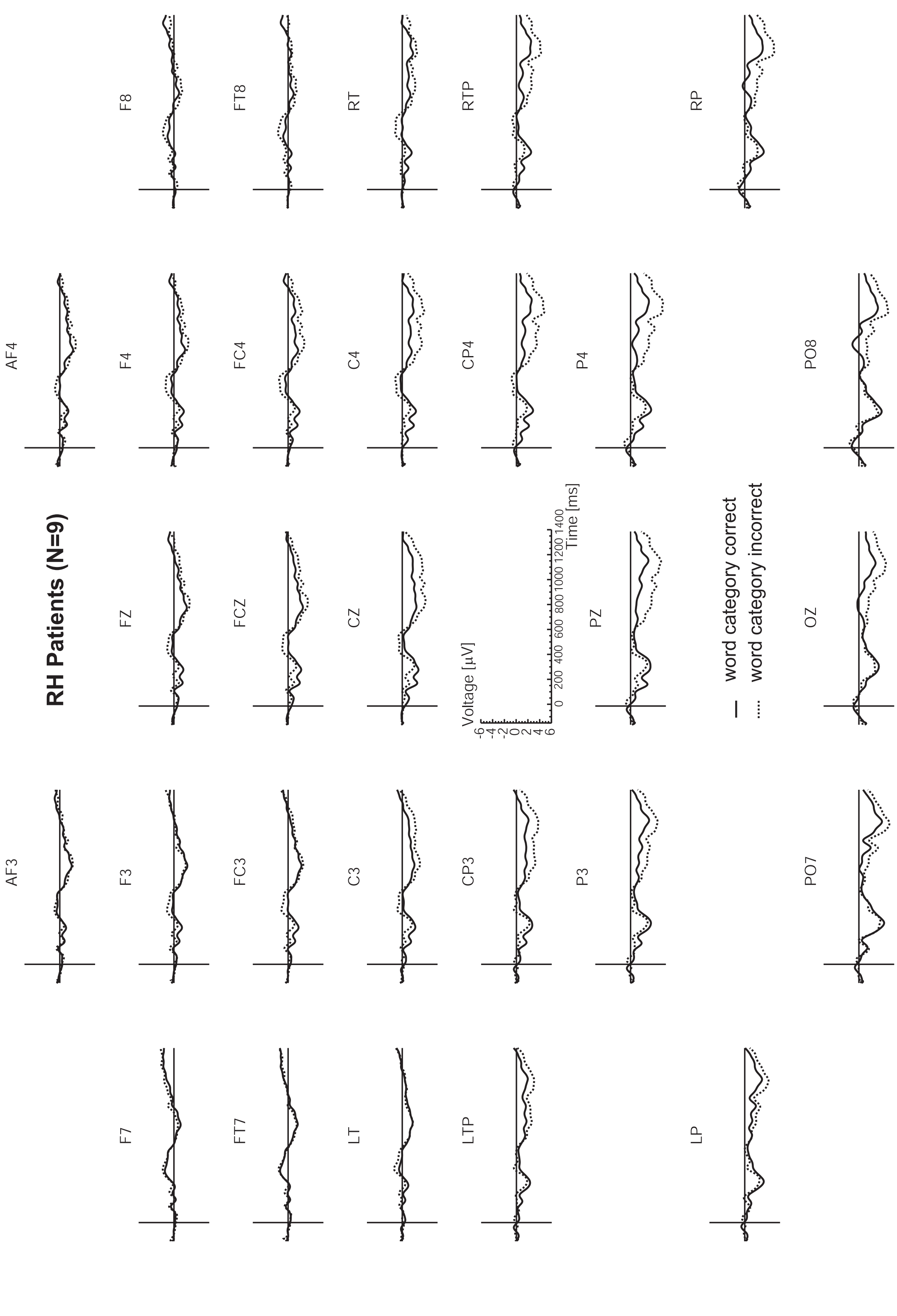

Figure 4-3. *Grand average ERP waveforms for the group of RH Patients (N=9) for the word category violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the syntactic violation.*

The overall effects were, however, not significantly different from the Normal Control subjects.

Broca Patients

In Figure 4-4 the results of the Broca patients for the Word Category Violation are presented. Unlike the normal controls and RH patients, in the 600-1000 ms latency range a clear P600/SPS effect as response to the word category violation is absent. Instead, mainly over frontal, right fronto-temporal and right parietal electrode sites a small negative effect is visible in this time window. Only in a later time window (800-1100 ms), a small positive shift is visible, mainly over left electrode sites.

ANOVAs performed in latency ranges that we also used for the normal elderly controls and the RH patients (400-500 ms and 600-900 ms) revealed the following: An omnibus ANOVA in the 400-500 ms latency range did not reveal a significant main effect of Grammaticality ($F(1, 10) = 1.30$; $MSe = 8.88$; $p = 0.281$). The Grammaticality by Site interaction also failed to reach significance ($F < 1$), just as the analyses on individual electrodes failed to show any significant effects.

In the 600-900 ms latency window, no significant main effect of Grammaticality was present ($F < 1$). Also the Grammaticality by Site interaction was not significant ($F(1.49, 14.90) = 2.72$; $MSe = 1.38$; $p = 0.109$).

In addition, to test for a possible late positive effect an ANOVA in the 800-1100 ms latency range was performed. This yielded no significant main effect of Grammaticality ($F < 1$). The Grammaticality by Site interaction also failed to reach significance ($F(1.62, 16.25) = 2.20$; $MSe = 2.23$; $p = 0.149$). However, the Grammaticality by Hemisphere interaction reached significance ($F(1, 10) = 5.08$; $MSe = 4.07$; $p = 0.048$), due to the left hemisphere preponderance of the positive effect. An ANOVA with inclusion of only the electrodes over the left hemisphere resulted in a significant main effect of Grammaticality ($F(1, 10) = 5.27$; $MSe = 4.86$; $p = 0.045$). This suggests that the word category violations elicited in the Broca patients only a small, and considerably delayed P600/SPS effect, which was less wide-spread over the scalp in comparison to the control groups.

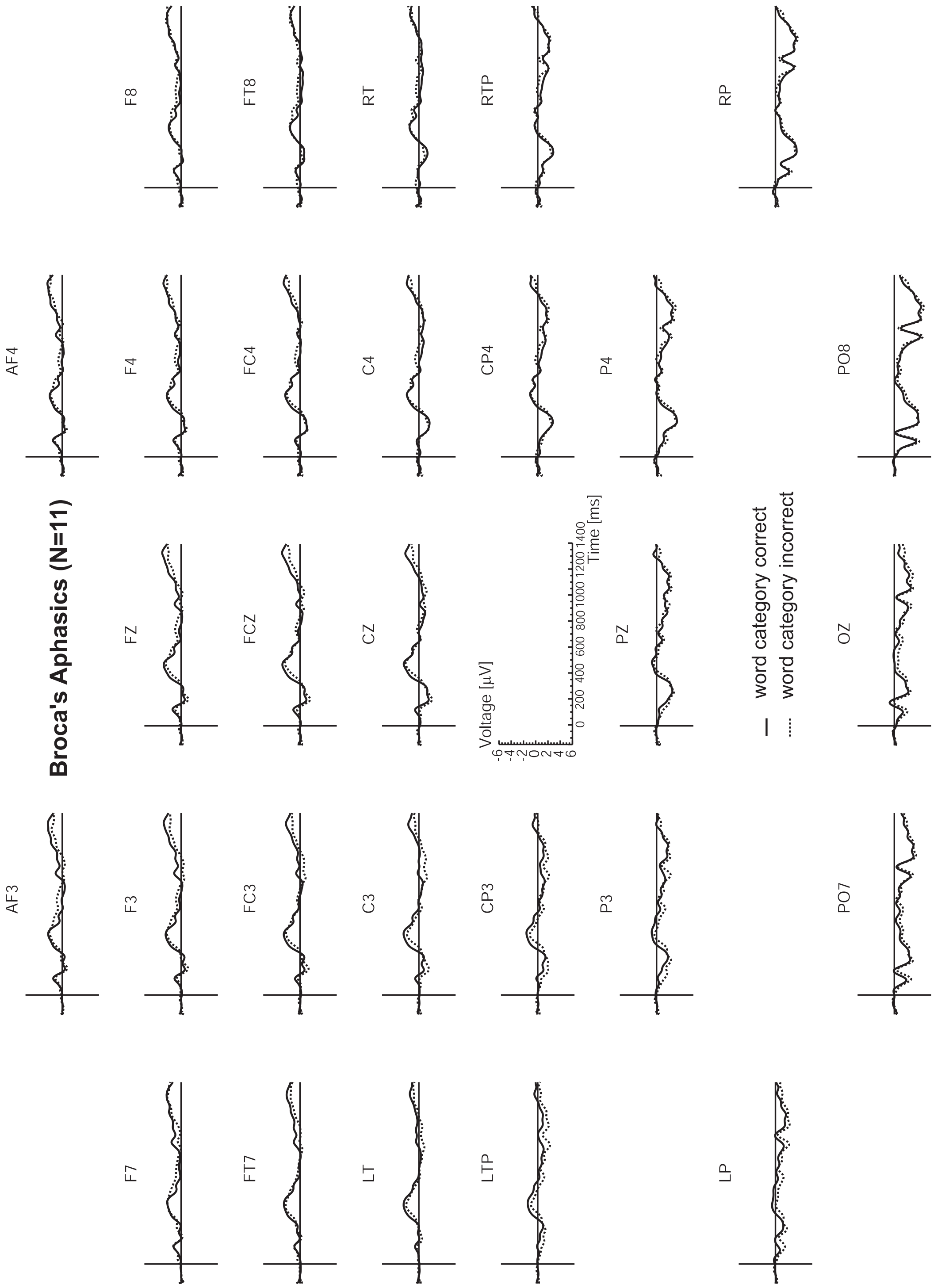

Figure 4-4. *Grand average ERP waveforms for the group of Broca Patients (N=11) for the word category violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the syntactic violation.*

In the latency range of 400-500 ms, an omnibus ANOVA with Group of Subjects (Normal Controls, Broca patients) as additional between-subjects factor showed no significant interaction between Group of Subjects and Grammaticality ($F < 1$). However, comparing the P600/SPS effect in the 600-900 ms latency window in the normal controls with the Broca patients resulted in a significant interaction between Group of Subjects and Grammaticality ($F(1, 24) = 15.10$; $MSe = 31.45$; $p = 0.001$).

In sum, the Broca patients showed as response to the word category violations a small P600/SPS effect that was present for left scalp electrode sites. However, with respect to the size and latency of this effect, the results of the Broca patients clearly deviated from the normal control subjects.

To see to what extent the pattern of results in the group averages is also noticeable in the individual subjects, the individual subject data will be presented here below.

Individual subject data for the word category violation condition

Figure 4-5 displays data of individual subjects. This figure shows for the three different groups (normal controls, RH patients, and Broca patients) per subject the effect size in the 400-500 ms epoch (averaged over 8 anterior electrodes: Fz, FCz, AF3, F3, F7, AF4, F4, F8). Averaged over 8 posterior electrodes (Pz, Oz, P3, LP, PO7, P4, RP, PO8), the figure shows the effect size in the 600-900 ms latency range for the normal controls and the RH patients. For the Broca patients the latency window of 800-1100 ms is used.

As is clear from this figure, there is considerable variation in the size of the effects within all subject groups. With respect to the normal controls, only six of the fifteen subjects showed a negative effect in the 400-500 ms window, which is compatible with the absence of a significant effect of the word category violation for this epoch. However, all normal control subjects except one showed a P600/SPS effect. Thus, the overall pattern of P600/SPS results that was observed in the averaged data was present in most normal control subjects. Seven of the nine RH patients showed a negative effect in the 400-500 latency range, and six showed a P600/SPS effect. The Broca patients showed the following pattern. Only three of the eleven patients showed a negative effect in the 400-500 ms latency range, and six showed a delayed and for most of them small P600/SPS effect in the 800-1100 ms latency window.

Individual Subject Data Word Category Violation Condition

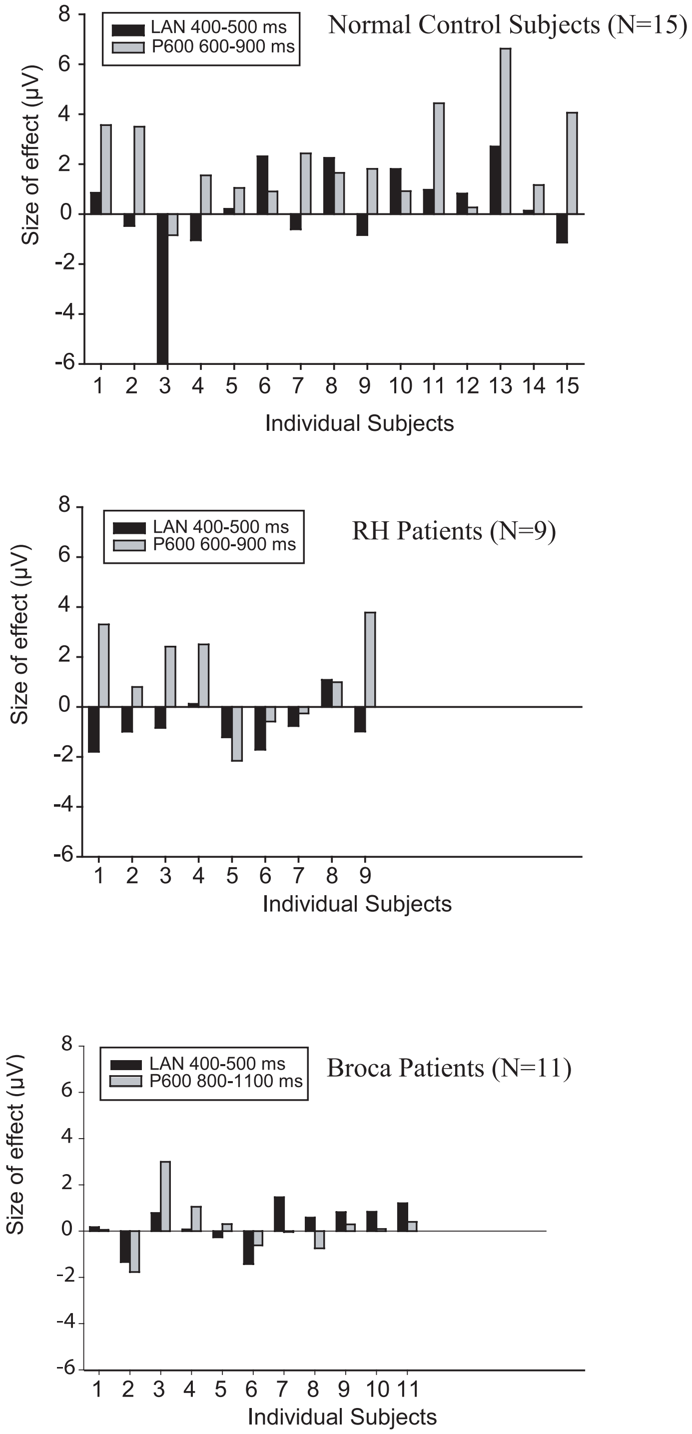

Figure 4-5. *Mean amplitude of word category violation effects in µV over 8 anterior electrodes (400-500 ms) and 8 posterior electrodes (Normal Controls and RH Patients: 600-900 ms; Broca Patients: 800-1100 ms), for each individual subject.*

Semantic violation condition

Normal Control Subjects

Figure 4-6 shows the results for the semantic condition in the normal elderly control subjects. As can be seen, the sentence-final semantic violation resulted in a clear N400-effect. This effect shows the standard characteristics; that is, it starts at about 250 ms after the onset of CW, and has its maximal amplitude at around 400 ms. The effect is clearly visible over both hemispheres, with the slight right-hemisphere preponderance that is regularly reported for visual N400 effects (Kutas & Van Petten, 1994). Except for some fronto-temporal electrodes (F7, F8, FT7, and FT8), the N400 effect is followed by a late positivity between 600 and 1000 ms. This late positivity reaches a maximal amplitude at around 700 ms and is maximal over posterior sites.

In the 300-500 ms latency window, the omnibus ANOVA resulted in a significant main effect of Semantic Violation ($F(1, 14) = 19.55$; $MSe = 16.93$; $p = 0.001$), and a significant Semantic Violation by Site interaction ($F(1.91, 26.71) = 3.52$; $MSe = 4.57$; $p = 0.046$). This interaction was due to a hemispheric difference: the Semantic Violation by Hemisphere interaction was almost significant ($F(1, 14) = 4.27$; $MSe = 3.86$; $p = 0.058$). The difference in N400 amplitude tended to be larger over right than left areas.

For the 700-900 ms latency window, the omnibus ANOVA resulted in a significant main effect of Semantic Violation ($F(1, 14) = 10.23$; $MSe = 36.74$; $p = 0.006$). However, the Semantic Violation by Site interaction was not significant ($F(1.51, 21.21) = 1.07$; $MSe = 5.73$; $p = 0.344$).

In sum, the normal control subjects showed both an N400 effect and a late positive effect to the semantic anomalies.

RH Patients

Figure 4-7 shows the results for the semantic condition in the RH patients. First, a small negative effect at approximately 200 ms is visible in the waveforms. Secondly, the semantic violation results in an N400 effect with a clear centro-posterior maximum. The onset of the effect is at around 300 ms and its maximal amplitude is reached at around 450 ms. This N400

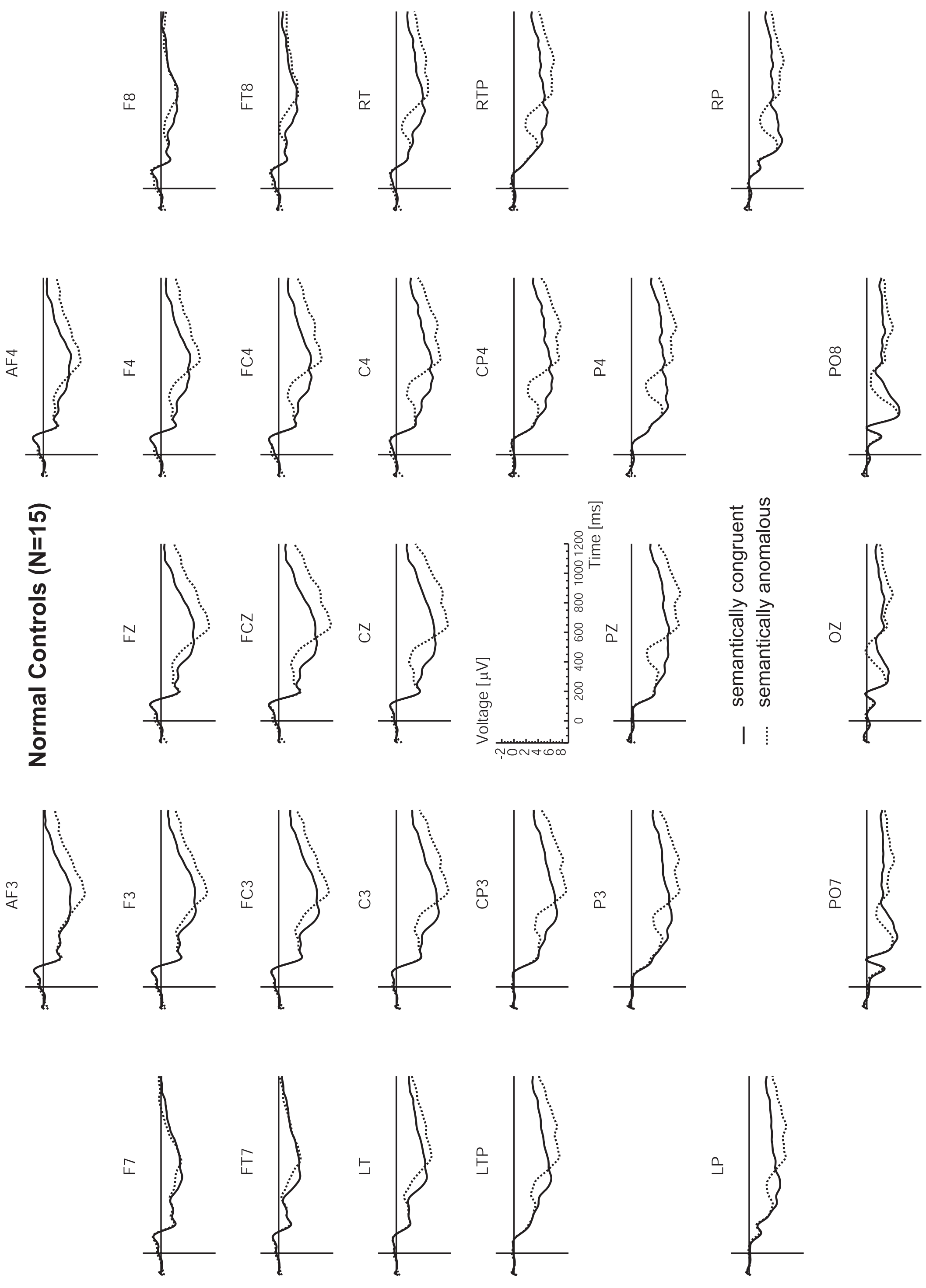

Figure 4-6. *Grand average ERP waveforms for the group of Normal Control Subjects (N=15) for the semantic violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the semantic violation.*

effect is followed by a late positivity between 600 and 1000 ms. This late positivity reaches maximal amplitude at around 700 ms and is maximal over posterior sites.

The small negative effect at approximately 200 ms was tested in an omnibus ANOVA on mean amplitudes in the 200-300 ms latency range. Neither a significant effect of Semantic Violation ($F(1, 8) = 2.59$; $MSe = 17.84$; $p = 0.146$), nor a significant Semantic Violation by Site interaction ($F < 1$) was obtained.

For the 300-500 ms latency window, the omnibus ANOVA revealed a marginally significant effect of Semantic Violation ($F(1, 8) = 4.38$; $MSe = 29.04$; $p = 0.07$) and a significant Semantic Violation by Site interaction ($F(1.94, 15.52) = 3.74$; $MSe = 5.98$; $p = 0.048$). This interaction was related to the posterior topography of the N400-effect in these patients. An ANOVA that focused on the posterior electrode sites (quadrants PL and PR) resulted in a significant Semantic Violation effect ($F(1, 8) = 8.51$; $MSe = 20.58$; $p = 0.019$). No significant Semantic Violation by Hemisphere interaction was obtained ($F(1, 8) = 2.52$; $MSe = 4.95$; $p = 0.151$).

In the 700-900 ms latency window, an omnibus ANOVA resulted in a significant main effect of Semantic Violation ($F(1, 8) = 7.00$; $MSe = 24.06$; $p = 0.029$). In addition, also the Semantic Violation by Site interaction was significant ($F(2.94, 23.55) = 4.22$; $MSe = 2.96$; $p = 0.016$). This interaction was related to the left posterior topography of the effect.

Omnibus ANOVAs in the 300-500 ms and 700–900 ms latency ranges with Group of Subjects (Normal Controls, RH patients) as additional between-subjects factor did not yield significant Group of Subjects by Semantic Violation interactions (both $F's < 1$).

In sum, like the normal controls, the RH patients showed both an N400 effect and a late positive effect as response to the semantic anomalies. Although the effects were somewhat smaller for the RH patients, the overall pattern of results was statistically not different between the groups.

Broca Patients

Figure 4-8 presents the data for the semantic condition for the Broca patients. As can be seen in this figure, the semantic violation resulted in an N400 effect. However, compared to the normal controls, the effect is clearly reduced. Furthermore, the effect is not widely distributed over the scalp but is mainly restricted to midline and right electrode sites. The onset-latency

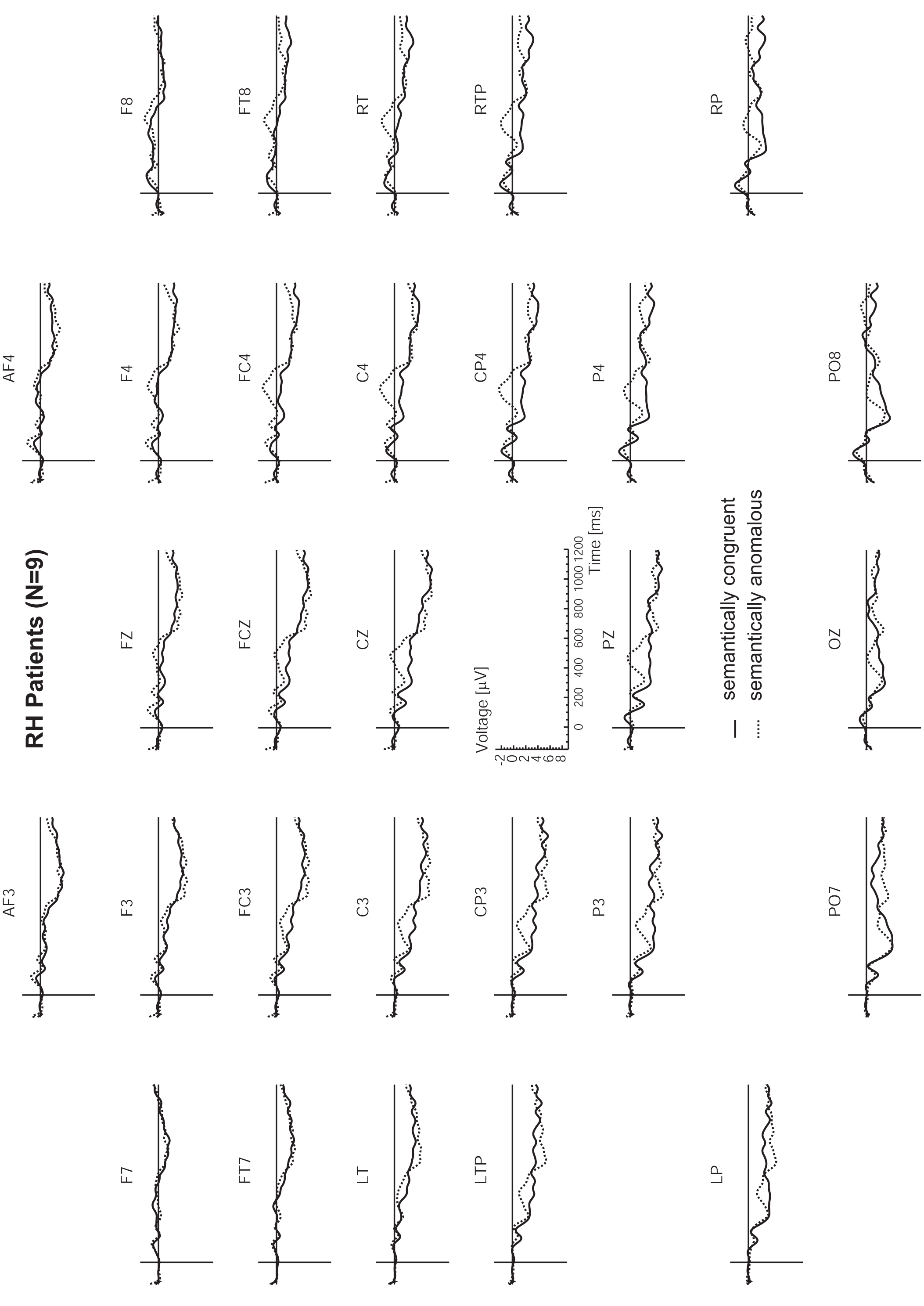

Figure 4-7. *Grand average ERP waveforms for the group of RH Patients (N=9) for the semantic violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the semantic violation.*

of the N400 effect in these Broca patients seems to be shifted in time: the onset of the effect is at around 375 ms and maximal amplitude is reached at around 450 ms. A late positive effect was only visible for electrode sites over the left hemisphere.

Due to the later onset of the N400 effect in the Broca patients, the statistical analysis was performed in the 400-600 ms latency window. The omnibus ANOVA for the 400-600 window did not result in a significant effect of Semantic Violation ($F(1, 10) = 1.53$; $MSe = 31.27$; $p = 0.245$). However, the Semantic Violation by Site interaction was significant ($F(2.59, 25.86) = 3.54$; $MSe = 4.76$; $p = 0.034$). This was due to the fact that the semantic violation effect was significantly larger over the right than over the left hemisphere ($F(1, 10) = 7.93$; $MSe = 7.19$; $p = 0.018$). An additional ANOVA in which only the electrodes over the right hemisphere were included resulted in a marginally significant effect of Semantic Violation ($F(1, 10) = 3.78$; $MSe = 30.35$; $p = 0.080$).

For the 700-900 ms latency window, the omnibus ANOVA only showed a marginally significant main effect of Semantic Violation ($F(1, 10) = 3.35$; $MSe = 25.48$; $p = 0.097$). The Semantic Violation by Site interaction did not result in a significant interaction ($F(3, 30) = 1.40$; $MSe = 5.67$; $p = 0.262$). However, the Semantic Violation by Hemisphere interaction was marginally significant ($F(1, 10) = 3.72$; $MSe = 8.37$; $p = 0.083$). This was due to the fact that the positive effect was larger over the left than the right hemisphere. An additional ANOVA in which only the electrodes over the left hemisphere were included resulted in a significant effect of Semantic Violation ($F(1, 10) = 6.16$; $MSe = 19.63$; $p = 0.0032$).

An omnibus ANOVA in the 300-500 ms latency range with Group of Subjects (Normal Controls, Broca patients) as additional between-subjects factor showed a significant main effect of Group of Subjects ($F(1, 24) = 8.59$; $MSe = 335.88$; $p = 0.007$). This main effect was qualified by a significant Group of Subjects by Semantic Violation interaction ($F(1, 24) = 7.90$; $MSe = 29.54$; $p = 0.010$), due to a reduction of the N400 effect in the Broca patients for electrodes over the left hemisphere. Also for the 700-900 ms latency range, an omnibus ANOVA comparing the normal controls with the Broca patients resulted in a significant main effect of Group of Subjects ($F(1, 24) = 10.24$; $MSe = 274.07$; $p = 0.004$). However, the Group of Subjects by Semantic Violation interaction was not significant ($F(1, 24) = 1.43$; $MSe = 52.69$; $p = 0.243$).

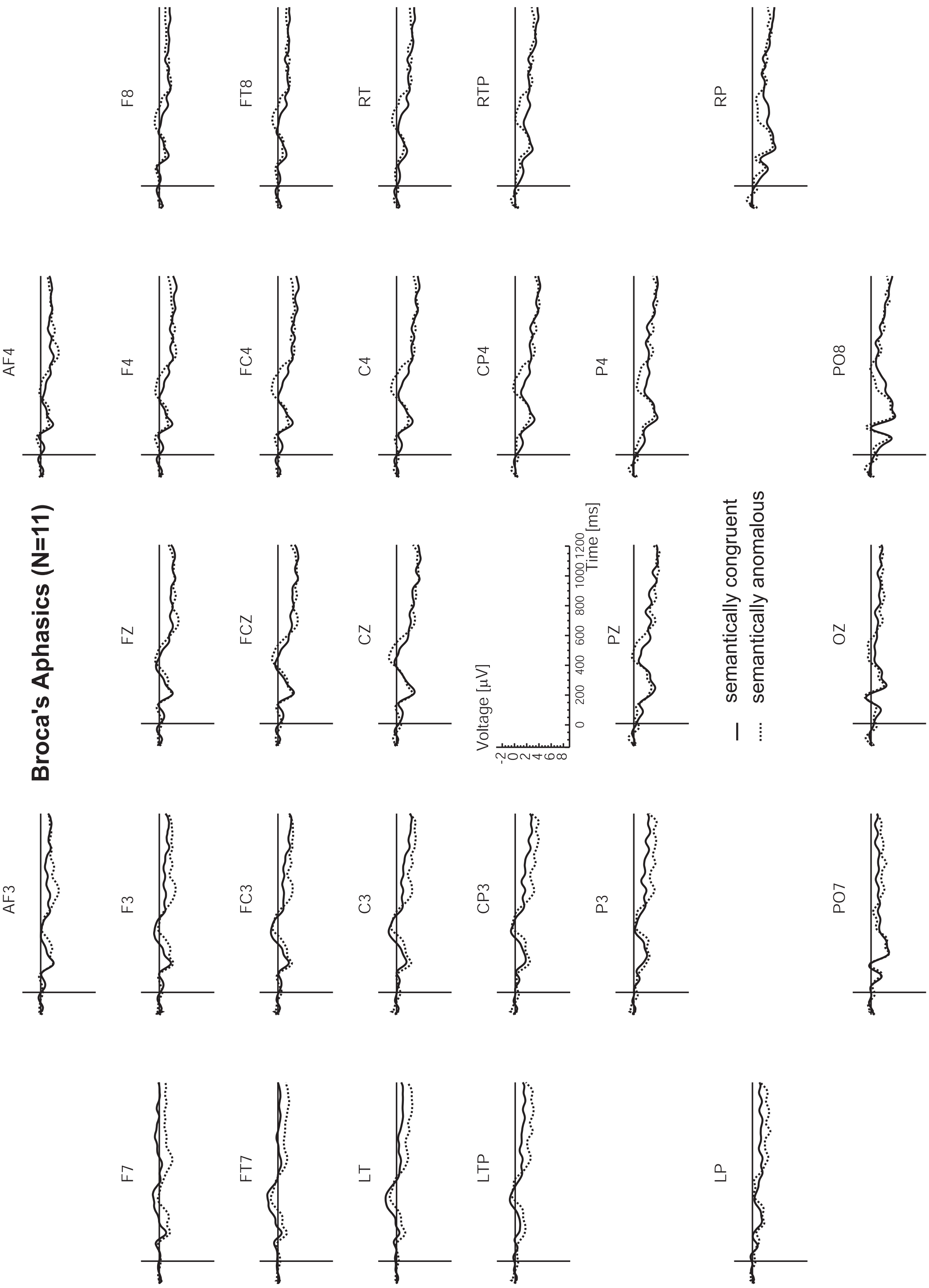

Figure 4-8. *Grand average ERP waveforms for the group of Broca Patients (N=11) for the semantic violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the semantic violation.*

In sum, the Broca patients showed in response to the semantic anomalies over right posterior electrodes a marginally significant N400 effect. The onset of this effect was later than in the normal controls and RH patients. The late positive effect was present over left electrode sites.

To see to what extent the pattern of results in the group averages is also noticeable in the individual subjects, the individual subject data will be presented here below.

Individual subject data for the semantic violation condition

Figure 4-9 presents data of individual subjects. It shows for the normal controls subjects and RH patients per subject the effect size in the 300-500 and 700-900 ms latency range, averaged over 8 posterior sites: Pz, Oz, P3, LP, PO7, P4, RP, PO8. Also for the Broca patients the effect size in the latency range of 700-900 ms is displayed, but instead of 300-500 ms, the window of 400-600 ms is used.

As is clear from this figure, there is considerable variation in the size of the effects within all of the subject groups. However, an N400-effect was present in twelve of the fifteen normal controls, and in seven of the nine RH patients. Thus, the overall pattern of results that was observed in the averaged data in the 300-500 ms latency range was present in most control and RH subjects. Seven of the eleven Broca patients showed an N400 effect.

The late positive effect was present in twelve of the fifteen normal control subjects, in all RH patients, and in eight of the eleven Broca patients. Thus, the pattern of results in the group averages was noticeable in most individual subjects.

Tone oddball task

The Normal Control subjects detected the rare tones with an accuracy of 99 %. The RH patients, and Broca patients had an accuracy of 94 % and 91 %, respectively. Artefact rejection and correction procedures were identical to the ones used for the sentence ERPs, in a critical window that ranged from 150 ms before onset of the tone to 850 ms after tone onset. The overall rejection rate was 9.3 % for the normal control subjects, 14.2 % for the RH patients, and 14.8 % for the patients with Broca's aphasia. Due to a technical failure, the data

Individual Subject Data Semantic Violation Condition

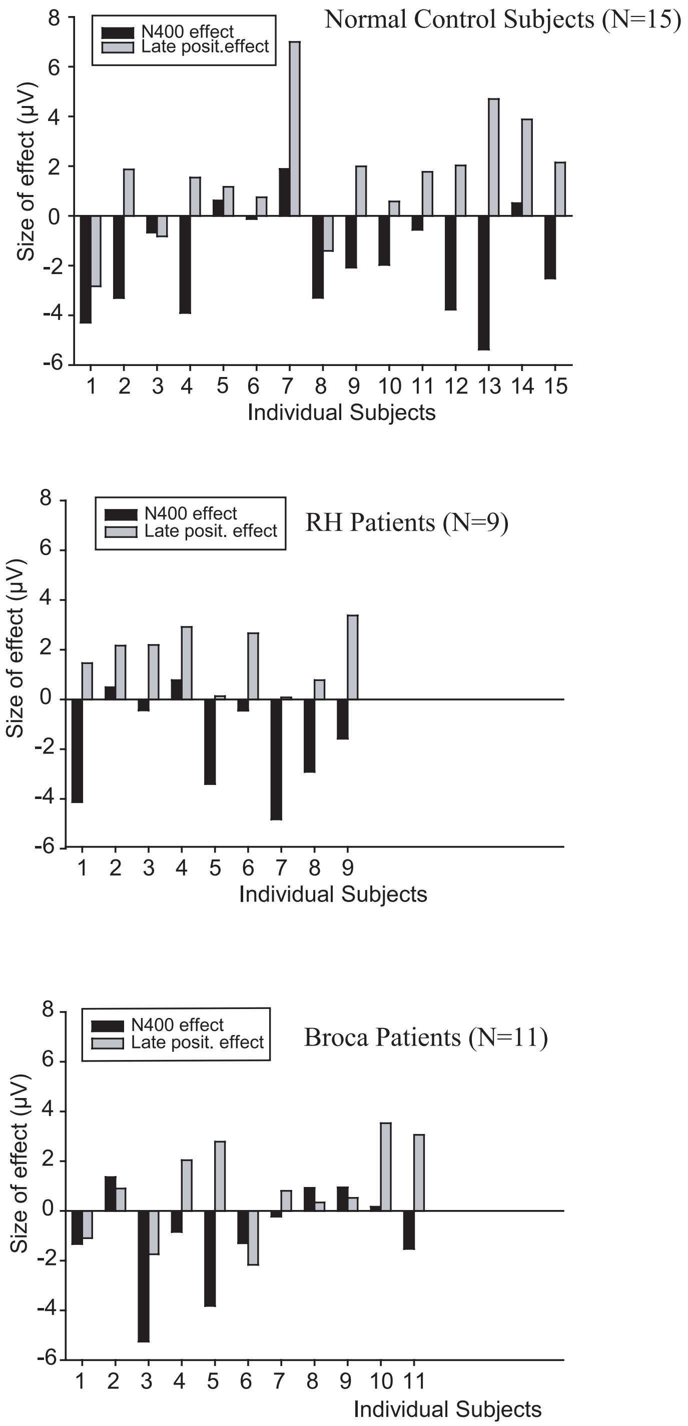

Figure 4-9. *Mean amplitude of semantic violation effects in µV over 8 posterior electrodes (Normal Controls and RH Patients: 300-500 ms; Broca Patients: 400-600 ms) and 700-900 ms, for each individual subject.*

of one Broca patient was not available. For each subject, average waveforms were computed across all remaining trials per condition (rare versus frequent tones), after normalizing the waveforms of the individual trials on the basis of a 150 ms pre-stimulus baseline. Statistical analyses on P300 effects were performed on the mean amplitudes in the latency range of 250-500 ms after tone onset. Mean amplitudes were entered into a repeated measurement analysis of variance for each subject group separately, with Tones (two levels: Standards, Oddballs) and Electrode (29 levels) as within-subjects factors. To test for differences between the results for the normal controls and the patient groups, also group analyses were performed in the specified time window, with Group of Subjects as the additional between-subjects factor.

Figure 4-10 presents for the three different subject groups an overlay of the difference waveforms for one representative electrode.

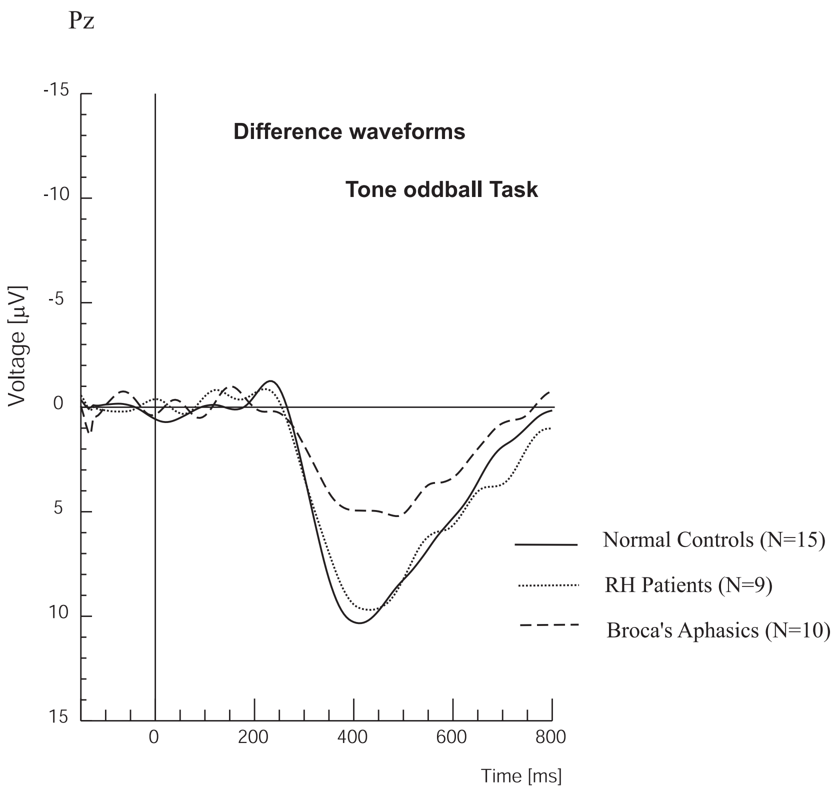

Figure 4-10. *Grand average difference waveforms tone oddball condition at Pz for Normal Control Subjects, RH Patients and Broca Patients.*

For the *normal control subjects*, a significant P300 oddball-effect (4.71 µV) was obtained, with a characteristic centro-parietal distribution ($F(1, 14) = 39.03$; $MSe = 123.73$; $p = 0.000$). Also the P300 effect (4.33 µV) for the *RH patients* was significant ($F(1, 8) = 29.89$; $MSe = 82.29$; $p = 0.001$) and did not differ from the normal controls, given the absence of a significant Group by Tones interaction ($F < 1$). The overall P300 effect in the *Broca patients* was significant ($F(1, 9) = 16.09$; $MSe = 38.13$; $p = 0.003$) and corresponded to a 2.06 µV amplitude difference. An omnibus ANOVA comparing the normal controls with the Broca patients revealed a significant interaction between Group of Subjects and Tones ($F(1, 23) = 6.80$; $MSe = 90.23$; $p = 0.016$). This interaction was due to a reduction of the P300 effect in the Broca patients relative to the normal controls, with the largest reduction at left electrode sites.

Questionnaire

The questionnaire was designed to induce the subjects to read the sentences attentively. Subjects knew that questions would be asked, but not when. In order to be able to answer the questions it was therefore important for them to read each sentence attentively. The mean average of the correct responses was 92% for the normal controls (range: 81 – 100%, sd: 9.93), 89% for the RH patients (range: 75 – 100%, sd: 8.72), and 78% for the patients with Broca's aphasia (range 63 – 100%, sd: 13.22). An ANOVA on the correct responses with Group of Subjects (Normals, RH patients, Broca patients) as between-subjects factor revealed a significant Group of Subjects effect ($F(2, 32) = 5.457$; $MSe = 116.7$; $p = 0.009$). Post-hoc Tukey HSD comparisons showed the following. Only the difference between the normal controls and the Broca patients was significant. Thus, the RH patients did not differ significantly from the normal controls, and also the difference between the RH patients and the Broca patients was not significant. These results show that the Broca patients performed more poorly than the control subjects. This result, however, necessarily reflects their aphasic impairment as well. Overall, the results of this questionnaire seem to provide evidence that the subjects were attending to the sentences.

DISCUSSION

The present study was designed to explore what syntax-related ERP effects to Dutch word category violations can reveal about syntactic processing in Broca patients. For that purpose, ERPs were recorded while subjects read sentences that were either syntactically correct or contained violations of word category. In Table 4-3, the results of the experiment are summarized for the three different subject groups.

The age-matched *normal controls* were sensitive to the violations of word category and showed to these violations a clear P600/SPS effect. But, rather unexpectedly, the manipulation of word category did not result in an anterior negativity. This result differs from data with *young* college-aged subjects as reported in Hagoort et al. (2003a). In these young subjects, Dutch word-category violations elicited not only a P600/SPS but also an Anterior Negativity (from now on referred to as AN) between 300-500 ms. Since in our current study exactly the same experimental materials have been used under the same presentation circumstances (visual, word-by-word, SOA 800 ms), it is not immediately clear why this AN effect is not present in the normal elderly controls. Certainly their language comprehension was within normal limits (see Table 1). Moreover, there was no significant difference between their auditory and visual language comprehension on the AAT, indicating that for reasons of visual acuity or otherwise a possible specific impairment in reading can be excluded.

When comparing the data of the young subjects (Hagoort et al., 2003a) and the present data of the elderly controls more carefully, it strikes that in the data of the elderly controls the P600/SPS effect is also present over anterior electrode sites. This was however not the case for the young subjects. The effects of aging on AN effects have not been systematically investigated. This in contrast to the N400 effect, which gets smaller, slower and more variable with age (Kutas & Iragui, 1998). If such a scenario would apply to the AN as well**,** it might not be unconceivable that with age the AN effect can be overshadowed by a widely distributed P600/SPS. It is unclear whether this situation could have been enhanced by the use of the rather long SOA (800 ms): some studies report that AN effects to word category violations seem to appear later with longer SOAs (e.g. Münte et al., 1993). However, Hagoort et al. (2003a) did not find an effect of SOA on ERP effects to word-category violations.

Table 4-3. Summary of results[a]

	Normal Controls (N=15)	RH patients (N=9)	Broca patients (N=11)
Word Category Violation	***P600/SPS effect*** 600-900 ms: 2.20 μV	***Negative effect*** 400-500 ms: -0.79 μV ***P600/SPS effect*** 600-900 ms: 1.20 μV	***Very delayed and reduced P600/SPS effect*** 800-1100 ms: 0.18 μV
Semantic Violation	***N400 effect*** 300-500 ms: -1.89 μV ***Late positive effect*** 700-900 ms: 1.67 μV	***N400 effect*** 300-500 ms: -1.83 μV ***Late positive effect*** 700-900 ms: 1.75 μV	***Delayed/reduced N400 effect*** 400-600 ms: -0.99 μV ***Late positive effect*** 700-900 ms: 0.81 μV
Tone oddball	***P300 effect*** 250-500 ms: 4.71 μV	***P300 effect*** 250-500 ms: 4.33 μV	***Reduced P300 effect*** 250-500 ms: 2.06 μV

[a] Effect sizes (in μV) were based upon mean amplitude values for 8 posterior electrodes (P600/SPS, N400, late positive effect), 8 anterior electrodes (negative effect), and all electrodes (P300).

It should be emphasized here that previous studies with elderly control subjects that did report AN effects to word-category violations, were all carried out in the auditory modality (Friederici et al. 1998, 1999). How with aging, the overall pattern of syntax-related anterior negativities and the posterior P600/SPS observed in young college students, changes, is not yet known. Since we were not able to demonstrate a clear AN effect in the normal elderly subjects, we will confine our conclusions with respect to the data of the Broca patients to their P600/SPS effect.

The *non-aphasic patients* with a lesion in the right hemisphere showed two ERP effects to the violations of word-category. Unlike the normal elderly controls, the RH patients did display a negative effect in the 350-550 ms latency range. They showed also a P600/SPS effect, which, however, was somewhat reduced in size compared to the elderly controls. The negative ERP effect bears some resemblance to the N400 effect of the RH patients that was elicited in the semantic condition. However, it is much less posteriorly distributed than the N400 effect that the RH patients displayed to the semantic condition. One could argue that this is to be expected when there is an overlap between an N400 and a subsequent positivity. However, a study in which semantic and syntactic violations were combined, showed that an N400 with a classical posterior distribution can be obtained together with a P600/SPS effect (Hagoort, 2003b). In addition, the onset of the negative effect for the RH patients in the syntactic condition seems to be earlier than for the semantic condition. The negative effect in these RH patients, which is maximal over fronto-central sites, shows also resemblance to the AN effect in the Hagoort et al. (2003a) study in which college-aged subjects were presented with the same word category violations. Upon the assumption that the negative effect reflects such an AN effect, the question could be raised why the effect is present in RH patients and not in elderly controls. Although a definitive answer cannot be given, it is not unlikely that the lesion in the RH-patients has consequences for the volume conduction of the different ERP effects, such that the relative sizes of overlapping effects with opposing polarity varies. Whatever causes the difference between elderly controls and RH-patients, the pattern of effects in the RH patients is comparable to ERP effects in young neurologically unimpaired subjects.

In conclusion, the data provide no evidence that the on-line processing of word category information in the elderly controls and the RH patients is disrupted.

The major finding of this study is that the word category violations in the *Broca patients* elicited a considerably reduced and delayed P600/SPS effect. Before further interpreting these findings, we first need to take the results of the other conditions (semantic violations and tone oddball task) into consideration.

The semantic violations elicited in the Broca patients a delayed and reduced N400 effect followed by a late positive effect. The reduced and delayed visual N400 effect is consistent with earlier studies on semantic violations in Broca patients with an auditory stimulus presentation (Swaab, 1996; Swaab et al., 1997). Given the functional interpretation of the N400 effect (Brown & Hagoort, 1993; Hagoort & Brown, 2000b; Holcomb, 1993; but see Kutas & Federmeier, 2000), the present data suggest that these Broca patients were somewhat slower and less efficient than normal in the process of integrating lexical information into the overall message representation of the whole utterance.

A tone-oddball paradigm was added to test whether a possible abnormal word category violation effect in the aphasic patients could be attributed to general processing problems resulting from brain lesion. We found that the Broca patients were able to detect the rare tones in the tone oddball paradigm with a 91% accuracy. The Broca patients showed a significant P300 oddball effect, which, however, was reduced in amplitude. A possible source of concern ensuing from this reduction of the P300 effect is that patients with lesions in the temporo-parietal junction can show such a reduction in correlation with attentional deficits (cf. Knight, Scabini, Woods, & Clayworth, 1989). But, importantly, the size of the P300 oddball effect did not correlate with the syntax-related P600/SPS effect, as the Pearson product-moment correlation between the P300 and P600/SPS effect in the Broca's aphasics was low and not significant ($r = -0.11$, $p = 0.37$). In addition, the P300 effect in the Broca patients was not delayed in time compared to the non-aphasic subjects. Although overall processing problems are likely in these patients, it is unlikely that changes in the syntax-related ERP effects can be *completely* attributed to attentional impairments.

Taken together, the following picture emerges from the present data. The Broca patients demonstrated a reduced and delayed N400 effect to the semantic condition, and a reduced and considerably delayed P600/SPS effect to the syntactic condition. Although the results of the Broca patients showed some impairment in semantic integration, syntactic processing in these patients seemed more affected. The relative reduction in size and the delay were more substantial for the P600/SPS than for the N400-effect (8% and 52% of the normal effect sizes, respectively, see Table 4-3).

The relative dissociation in semantic versus syntactic processing can also be seen in Figure 4-11 where topographic distributions of the semantic and word-category violations are shown. The topographic distribution of the ERP effect of the Broca patients in the semantic violation condition bears a reasonable resemblance to that of the normal controls. However,

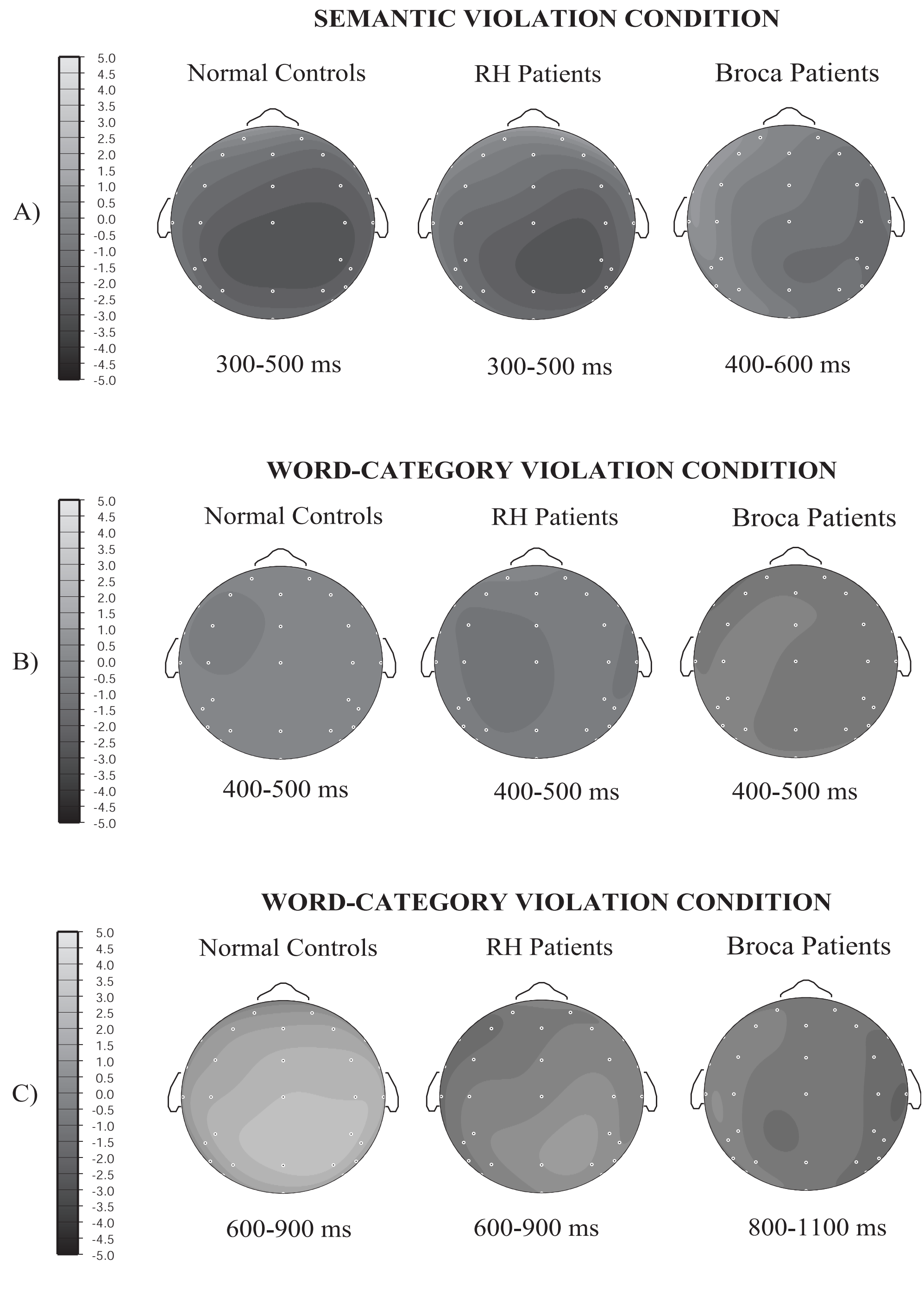

Figure 4-11. *Scalp distribution of the ERP effects that were obtained for A) the semantic violations (latency window: for Normal Controls and RH Patients 300-500 ms and for Broca Patients 400-600 ms; B) word category violations (latency window: 400-500 ms) and C) word category violations (latency window: for Normal Controls and RH Patients 600-900 ms and for Broca Patients 800-1100 ms). Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in µV.*

the topographic distributions of the word category violation effects of the Broca patients deviate clearly from the normal controls.

What can we conclude from the electrophysiological response of the Broca patients to word category violations as obtained in this study? Detecting a violation of word category, requires that the syntactic word category of an incoming word is identified correctly and that this information is used in building up the phrasal configuration. The ERP response of the Broca patients suggests that in these patients this process is disturbed.

According to Hagoort's account of the P600/SPS, this effect is related to the time it takes to build-up binding links of sufficient strength between lexically specified syntactic frames (Hagoort, 2003a). For this binding process to occur smoothly, word category information is necessary. The finding that the Broca patients showed only a very limited P600/SPS effect suggests that word category information might not be available with the right level of activation, to enable binding operations to occur with the required speed. Given the speed at which language processing normally occurs, the observed delay of 250 ms is quite substantial. This impairment of the P600/SPS effect thus suggests that the build-up of binding strength was changed in the Broca patients.

This interpretation is supported by ERP studies on the processing of word class information in Broca's aphasics (Ter Keurs, Brown, & Hagoort, 2002; Ter Keurs et al., 1999) In these studies it was found that Broca patients were impaired in the on-line processing of word-class information. Word-class information was incompletely and/or delayed available. For constructing a phrasal configuration of a sentence, it is essential a word's lemma information, including word category, is available at the right moment in time. It is not unlikely that if word class information is incomplete or delayed, this will hinder Broca patients to detect on-line violations of word-category as in the present study; and by consequence they will be impaired in constructing a phrasal configuration of a sentence.

THEMATIC ROLE ASSIGNMENT IN PATIENTS WITH BROCA'S APHASIA: SENTENCE-PICTURE MATCHING ELECTRIFIED

CHAPTER 5

Marlies Wassenaar and Peter Hagoort[1]

ABSTRACT

An event-related brain potential experiment was carried out to investigate on-line thematic role assignment during sentence-picture matching in patients with Broca's aphasia. Subjects were presented with a picture that was followed by an auditory sentence. The sentence either matched the picture or mismatched the visual information depicted. Sentences differed in complexity, and ranged from simple active semantically irreversible sentences to passive semantically reversible sentences. ERPs were recorded while subjects were engaged in sentence-picture matching. In addition, reaction time and accuracy were measured. Three groups of subjects were tested: Broca patients (N=10), non-aphasic patients with a right hemisphere (RH) lesion (N=8), and healthy aged-matched controls (N=15). The results of this study showed that, in neurologically unimpaired individuals, thematic role assignment in the context of visual information was an immediate process. This in contrast to patients with Broca's aphasia who demonstrated no signs of *on-line* sensitivity to the picture-sentence mismatches. The syntactic contribution to the thematic role assignment process seemed to be diminished given the reduction and even absence of P600/SPS effects. Nevertheless, Broca patients showed some off-line behavioral sensitivity to the sentence-picture mismatches. The long response latencies of Broca's aphasics make it likely that off-line response strategies were used.

[1] This chapter has been submitted for publication.

INTRODUCTION

In patients with Broca's aphasia, the ability to understand what is spoken to them is relatively spared when compared to their sentence production. However, comprehension problems can typically emerge when the understanding of sentences hinges exclusively upon the correct analysis of syntactic structure (Caplan & Hildebrandt, 1988). These comprehension difficulties especially arise when sentences are *semantically reversible* (Caramazza & Zurif, 1976). A sentence is semantically reversible if, after major noun phrases have exchanged position, the sentence still makes sense.

[1] The lion is chasing the tiger.

[2] The lion is eating the bone.

For instance, sentence [1] is semantically reversible, because either of the two nouns is an equally probable candidate for the thematic role of agent. This in contrast to sentence [2] that is semantically nonreversible, since bones cannot eat lions. While Broca patients have usually little difficulty with interpreting semantically nonreversible sentences, they often perform relatively poorly on reversible sentences (Berndt, Mitchum, & Haendiges, 1996): whereas assignment of thematic roles (*who was doing what to whom*) seems to be constrained by real world knowledge in nonreversible sentences, these constraints are absent in the semantically reversible sentences.

The most prevalent means of testing the comprehension of semantically (non)reversible sentences has been the use of *sentence-picture matching tasks*. In this task, patients usually see a set of pictures. After some inspection time, a spoken sentence is presented. One of the pictures depicts the sentence content; the others are distracters. The patient's task is then to select from this set of pictures the one that best portrays the meaning of the presented sentence. By manipulating the kind of disagreement between the sentence and the distracter pictures, information can be obtained as to which aspects of the language system are affected in the patient. For instance, distracter pictures for semantically reversible sentences usually portray a reversal of thematic roles of the sentence noun phrases (cf. Berndt et al., 1996).

During the last decades, the sentence-picture matching task has been applied to a variety of sentences of different structural types to probe Broca patients' ability to understand these types of sentences (Berndt, Mitchum, & Wayland, 1997). This approach has revealed relative good comprehension for canonical structures like actives and subject-relatives and poor comprehension for non-canonical structures like passives and object-relatives (Grodzinsky, Piñango, Zurif, & Drai, 1999). Although there has been a lively debate regarding the proportion of Broca patients that actually manifest chance-level comprehension for non-canonical sentences (Berndt & Caramazza, 1999; Berndt et al., 1996; Caramazza, Capitani, Rey, & Berndt, 2001; Zurif & Piñango, 1999), the tendency of Broca patients with agrammatic comprehension toward thematic reversals in the comprehension of semantically reversible passive sentences has been frequently observed.

A number of hypotheses have been offered to account for Broca patients' difficulty with knowing 'who is doing what to whom' in semantically reversible sentences. Some proposals approach the comprehension problems from a linguistic perspective; other accounts highlight processing limitations (Burkhardt, Piñango, & Wong, 2003; Kolk, 1998).

Grodzinsky's *Trace Deletion Hypothesis* (TDH) (Grodzinsky, 1986, 1995, 2000) locates the comprehension problems in Broca patients at the syntactic level: syntactic traces (i.e. markers of syntactic movement) are deleted. Absence of such traces leaves the agrammatic patient with an incomplete syntactic representation and this activates a default strategy that assigns the role of Agent to the first NP. Thus, in a passive sentence, as in [3], the NP in sentence initial position is assigned the Agent role by default. The NP argument of the by-phrase is given the Agent role directly: it is assumed here that normal thematic role assignment takes place in the by-phrase. As a result, the agrammatic representation has two NPs with the same thematic role. Confronted with a sentence-picture matching task, the agrammatic patient is faced with two possible Agents and is forced to guess which NP should be assigned the Agent role. This guessing will result in chance-level performance.

[3] [The girl] is kissed by [the boy]
Default Agent Syntactic Agent (agrammatic representation)

One of the criticisms that have been raised against the TDH is its empiral evidence. In a meta-analysis of published sentence-picture matching data from patients with agrammatic comprehension (Berndt et al., 1996), only one-third of the agrammatic patients showed chance-level performance for passive sentences. The TDH also fails to account for severity variation (Kolk & Hartsuiker, 2000). In addition, the TDH does not explain high performance in grammaticality judgement tasks (Linebarger, Schwartz, & Saffran, 1983). Another objection that has been put forward relates to the patients' default strategy. This strategy is not linguistically motivated (e.g. Beretta, 2001; Beretta & Munn, 1998).

The *Mapping Hypothesis* (Linebarger et al., 1983; Linebarger, 1990, 1995; Schwartz, Linebarger, Saffran, & Pate, 1987; Schwartz, Linebarger, & Saffran, 1985) assumes that the agrammatic comprehenders' problem does not lie in extracting structural information from linguistic input but rather in the ability to use this information in the assignment of thematic roles, i.e. in *mapping* from a syntactically structured representation to a semantic representation. This would account for the observed discrepancy between performance on grammaticality judgement tasks and sentence-picture matching tasks (Linebarger et al., 1983). Sentence-picture matching requires such mapping, but grammaticality judgement does not. The mapping process is facilitated when sentences have canonical order. But, in the case of non-canonicity as in passive sentences for example, the mapping process is rendered more complicated. A problem for the mapping hypothesis is that it does not explain why detection of ungrammaticalities is affected by phrase structure complexity (Kolk & Weijts, 1996).

A third approach is the *Capacity Constraint Hypothesis* (Haarmann, Just, & Carpenter, 1997; Just & Carpenter, 1992; Miyake, Carpenter, & Just, 1994, 1995). Here it is hypothesized that comprehension performance is undermined by pathological limitation of working memory capacity. One way to characterize this limitation in processing resources is as an inability to have syntactic representational elements simultaneously co-active (e.g. Haarmann & Kolk, 1991). It is assumed that syntactic analysis and thematic role assignment share resources. The more resources are required for syntactic analysis, the less will be available for thematic role assignment. The capacity limitation approach offers two accounts for the negative effect of non-canonical word order on comprehension (Kolk & Weijts, 1996). One is that the underlying representations of these sentences contain traces and coindexations and these are assumed to cause additional computational load. Second, if patients lose track of a syntactic representation, they could compensate for this by choosing thematic roles directly on the basis of word order: this strategy will be beneficial for canonical sentences but works out unfavourably for noncanonical sentences. In this view, a linear order strategy is *not* invariably applied: it is applied only whenever there is a situation of computational overload that depends upon sentence complexity and the severity of the capacity limitation.

Most hypotheses that we described above have in common that they account for comprehension data that have been gathered almost exclusively from off-line tasks, especially the sentence-picture matching task. Such a task is off-line in the sense that patients are requested to operate on a final product of the language comprehension process (Hagoort & Kutas, 1995). Usually, in sentence-picture matching tasks, subjects are asked to give their responses well after the sentence has been fully presented. The sentence-picture matching task in its classical form thus does not give any information on temporal aspects of the process of thematic role assignment that results in the overt performance on the task. In contrast to off-line tasks, on-line measures tap into the language comprehension process as it unfolds in real time. A measure that provides an on-line *and* continuous record of language related processing events is the registration of event-related brain potentials (ERPs). The present study will use ERPs to gain an insight into on-line thematic role assignment in patients with Broca's aphasia during sentence-picture matching.

Present study

The present study aimed to study *on-line thematic role assignment* in patients with Broca's aphasia during sentence-picture matching. ERPs were recorded while subjects were engaged in sentence-picture matching. They were presented with a picture on a computer screen. After some inspection time, the picture disappeared and a spoken sentence was presented over headphones. After hearing the sentence, subjects pressed a button to indicate whether the sentence corresponded to the picture or not.

It is assumed here, that healthy subjects, when they are faced with a picture (e.g. a picture which portrays an action with the involvement of an agent and a recipient of the action) will form some kind of mental representation of the depicted event (Chatterjee, Maher, & Heilman, 1995; Chatterjee, Southwood, & Basilico, 1999). While the subjects hear the sentence, a linguistic representation of the sentence will be incrementally constructed as words come in. The match/non-match decision requires that this sentence representation is compared to the representation of the depicted event. In order to establish whether the sentences in our study correspond to the pictures or not, thematic role information is needed. As soon as this thematic role information is available, subjects can compare the roles described in the sentence to the roles depicted in the picture. The sentence will correspond to the picture if the thematic roles as expressed in the sentence are in agreement with the ones being portrayed. The sentence does not match the picture if thematic roles have been reversed.

The exact moments at which syntactic information in the context of visual information is used for thematic role assignment is still largely unknown. However, there are strong indications that, in real-time sentence comprehension, relevant visual context is immediately taken into account (Spivey, Tanenhaus, Eberhard, & Sedivy, 2002; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995). With the on-line sentence picture matching paradigm the immediacy of thematic role assignment can be investigated. Consider the following example of a picture paired with a spoken sentence.

[4]  *The tall man on this picture pushes the young woman*

After presentation of a picture in which a woman pushes a man in a wheelchair, the sentence “The tall man on this picture pushes the young woman” is presented. The sentence part “The tall man pushes” allows the assignment of grammatical subject to *man* and, in combination with the active voice of the sentence, the mapping onto the thematic role of agent. However, there are two options for the moment at which the thematic role of patient can be assigned. One possibility is that, given the presence of a man and a woman on the picture, the thematic role of patient can already be assigned by inference to the *woman*, before the actual lexical item *woman* is heard. This *immediacy option* would imply that the mismatch between the event structure of the picture and the event structure of the sentence can already be detected upon hearing the verb form ‘pushes’, thus as soon as the argument structure belonging to the verb ‘to push’ is available and one of the thematic roles (i.c. the role of agent) has been assigned. An alternative option is that the assignment of the thematic role of patient waits for the actual lexical information that is to be associated with the thematic grid. This *completeness option* assumes that in the example above mismatch detection will emerge not until the word form *woman* is heard. Thus, if healthy control subjects assign thematic roles immediately, then the mismatch can be detected early in the sentence (i.e. at the verb); if subjects wait for full lexical information when assigning thematic roles, then the mismatch between the sentence and picture can only be detected after this information has been presented.

It is assumed that the detection of the mismatch between the sentence and the picture will be reflected in the electrophysiological signal (cf. Connolly & D´Arcy, 2000; Connolly, D´Arcy, Newman, & Kemps, 2000). For this purpose, the ERP profiles for matching versus non-matching sentences will be compared. This can indicate whether, and on the basis of which information the mismatch has been detected.

This study focuses on possible impairments in the on-line thematic role assignment in aphasia. We will compare the ERP signature of Broca's aphasics to the ERP signature observed in healthy controls for on-line thematic role assignment. Beforehand we do not make strong claims about which kind of ERP componentry will be involved. However, there are several possible candidates. For instance, as the detection of the (mis)match between the sentence and the picture requires some kind of semantic analysis, it is possible that an N400 effect may appear. Further, a P600/SPS effect may be involved since, recently, Kuperberg et al. (2003) found such an effect when subjects were presented with sentences containing thematic role animacy violations. They interpreted this P600/SPS as a result of a discrepancy between the probable thematic role and the actual assigned thematic role. In their view (but see also Kolk, Chwilla, van Herten & Oor, 2003), this P600/SPS could reflect an online attempt to structurally repair a sentence by reassigning thematic roles.

In order to be able to reliably interpret possible changes in the ERP effects of the Broca's aphasics as reflecting changes in their on-line language processing, it is important to identify factors that could contaminate the results of the experiment. To control for the non-specific effect of aging, the results of the Broca patients will be compared to a group of healthy age-matched controls. A group of non-aphasic patients with a lesion in the right hemisphere will be tested to control for non-specific effects of brain damage on the ERP effects (cf. Hagoort & Kutas, 1995).

METHOD

Subjects

Ten patients with aphasia secondary to a single cerebral vascular accident (CVA) in the left hemisphere participated in this study. A group of fifteen healthy normal subjects, who were approximately matched in age and education level to the aphasic patients were tested to control for age and education effects. To account for non-specific effects of brain damage on cognitive ERP components, a group of eight non-aphasic patients with a single CVA in the right hemisphere (RH patients) was tested. All subjects gave informed consent, according to the declaration of Helsinki. The elderly control subjects and the RH patients were paid for their participation. The mean age of the aphasic patients was: 58.6 years (range: 44-73 years), the RH patients were on average 61.6 years (range: 47-76 years) and the normal elderly controls had a mean age of 60.0 years (range: 52-74 years). All elderly control subjects were right-handed according to an abridged Dutch version of the Oldfield Handedness Inventory (Oldfield, 1971). Five of the elderly control subjects reported familial left-handedness. None of the elderly control subjects had any known neurological impairment or used neuroleptics, according to their responses on a questionnaire. The aphasic patients and the RH patients were premorbidly, all right-handed. All subjects had normal or corrected-to-normal vision. None of the subjects reported hearing loss.

All neurological patients were tested at least 9 months post-onset of their cerebral vascular accident. Median post-onset time for the patients with Broca's aphasia was 6;1 years (range: 1;9 – 11;1 years) and for the RH patients 3;3 years (range 2;2 – 7;3 years). All neurological patients were tested with the standardised Dutch version of the Aachen Aphasia Test (AAT) (Graetz, De Bleser, & Willmes, 1992). Both presence and type of aphasia were diagnosed on the basis of the AAT results and on the basis of a transcribed sample of the patient's spontaneous speech. Three experts evaluated this spontaneous speech. All RH patients were diagnosed as non-aphasic and all left-hemisphere patients were diagnosed as patients with Broca's aphasia on the basis of a procedure that matches the individual score profiles against a norm population of patients. According to their scores on the comprehension subtest of the AAT, the aphasic patients had mild to moderate comprehension deficits. The presence of syntactic comprehension problems was determined by administering all subjects the Dutch version of an off-line test that assesses the influence of syntactic complexity on sentence comprehension (after Huber, Klingenberg, Poeck, & Willmes, 1993). For a detailed description of the Dutch version, see Ter Keurs et al. (1999). Statistical evaluation of the syntactic off-line test results (see Table 5-1) confirms the syntactic comprehension problems of the Broca patients as compared to the normal controls and the RH control patients. The pattern of results substantiates the syntactic comprehensions problems of the Broca patients in this study. All patients were also tested with the subtest Sentence Comprehension of the WEZT (Werkwoorden- en Zinnen Test) (Bastiaanse, Maas, & Rispens, 2000). This subtest assesses whether a patient is able to attribute correct thematic roles to different sentence constituents. Broca patients performed relatively poorly when compared to the RH patients. Based on the patients' scores on the Token Test, which is a valid measure of the general severity of the aphasia (Orgass, 1986), the general severity of the aphasia ranged from light to severe. For further patient information, see Table 5-1.

Materials

The stimuli for this experiment consisted of a list of 316 pairs of a picture and a spoken sentence. Of these picture-sentence pairs, 288 were the critical pairs for the experiment. The remaining pairs were used as practice trials (12) and filler items (16). *Pictures* (96) came from a German syntax test (Huber et al., 1993) and consisted of simple black on white line drawings. Half of these pictures depicted semantically irreversible situations (e.g. a woman is reading a book), half depicted semantically reversible situations (e.g. a man is pushing a woman in a wheel chair). *Sentences* were taken from the Dutch adaptation of this German syntax test (Ter Keurs et al., 1999; Wassenaar & Hagoort, 1994). The sentences were slightly adapted for the purposes of this experiment and were paired with the pictures. Three different sentence types were combined with matching/non-matching pictures in a full factorial design (see Figure 5-1). The sentence types were (I): semantically *irreversible active* sentences; (II): semantically *reversible active* sentences; (III): semantically *reversible passive* sentences. With these sentences we could vary (1) semantic (ir)reversibility and (2) syntactic complexity. It has often been reported that Broca patients have typically more problems with reversible than irreversible sentences. Contrary to irreversible sentences, reversible sentences provide no lexical-semantic but only syntactic cues to assign thematic roles. In addition, passive reversible

Table 5-1. Individual information for the patients with Broca's aphasia and the non-aphasic RH patients.

Patient	Age	Sex	Token Test [a]	Overall compreh. score AAT [b]	Syntactic off-line score[c]	Sentence compreh. WEZT[d]	Lesion site
1 Broca	55	F	10	97/120	95/144	30/40	Left fronto-temporo-parietal incl. insula
2 Broca	70	F	11	103/120	111/144	31/40	No adequate CT information available
3 Broca	60	M	9	111/120	90/144	27/40	Left capsula interna
4 Broca	48	M	17	94/120	93/144	37/40	Left temporo-parietal
5 Broca	51	F	21	84/120	104/144	27/40	Left parieto-occipital
6 Broca	53	M	42	89/120	74/144	21/40	No adequate CT information available
7 Broca	69	F	18	91/120	51/144	34/40	Left fronto-temporal incl. insula
8 Broca	73	M	18	89/120	60/144	23/40	Left temporal
9 Broca	63	M	46	86/120	106/144	20/40	Left fronto-temporal
10 Broca	44	F	14	94/120	88/144	32/40	Left parieto-occipital
1 RH	52	M	0	113/120	134/144	40/40	No adequate CT information available
2 RH	56	M	9	106/120	128/144	38/40	Right insular
3 RH	67	M	2	116/120	137/144	40/40	Right parietal
4 RH	69	F	2	108/120	135/144	39/40	Right basal ganglia
5 RH	66	F	1	120/120	143/144	40/40	Right temporo-parietal
6 RH	76	M	0	102/120	139/144	40/40	Right parietal
7 RH	60	F	1	103/120	125/144	40/40	Right basal ganglia
8 RH	47	F	0	108/120	126/144	37/40	Right fronto-temporal

[a] Severity of the aphasic disorder as indicated by the Token Test: no/very mild disorder (0-6); light (7-23); middle (24-40); severe (41-50). RH patient 2 had a Token Test score of 9, but was, on the basis of his spontaneous speech and ALLOC classification (a procedure that matches individual score profiles against a norm population of patients) non-aphasic.

[b] Severity of the comprehension disorder as indicated by the Aachen Aphasia Test subtest on comprehension (includes word and sentence comprehension in both the auditory and visual modality): no/very mild disorder (107-120); light (90-106); middle (67-89); severe (1-66). compreh.= comprehension; AAT= Aachen Aphasia Test.

[c] Range of performance in healthy control subjects is 132-144. ANOVA's on the percentage-correct scores of the sentences with increasing syntactic complexity of the off-line test showed that syntactic complexity had a differential effect on the comprehension scores of the different subject groups [Complexity: F (3.83, 114.75) = 35.58, MSe = 79.77, p = 0.000; Group: F (2, 30) = 36.52, MSe = 514.24; Complexity x Group: F (7.65, 114.75) = 12.36, MSe = 79.77, p = 0.000]. Post hoc analyses (α = 0.05) revealed that the Broca patients performed significantly worse than both the normal controls and the RH controls. The two control groups did not differ significantly from each other.

[d]The subtest sentence comprehension of the WEZT assesses whether a patient is able to attribute the correct thematic roles to different sentence constituents. Range of performance in healthy subjects is 39-40 (Bastiaanse et al., 2000).

sentences are for Broca patients usually more difficult to understand than their active counterparts (but see Berndt et al., 1996). We therefore included these different sentence types to see whether the process of on-line thematic role assignment, as revealed in the electrophysiological profile, was differentially affected by semantic (ir)reversibility and syntactic complexity.

A sentence matched a picture if the sentence content was in agreement with the depicted event. Consequently, if the sentence content did not correspond to the depicted event, the sentence and the picture did not match.

For the semantically irreversible sentences (Sentence Type I), identical pictures (N=48) were used in the matching and non-matching condition, but the sentences were different (see Figure 5-1a). A sentence mismatched the picture when the patient role from the picture was placed into the grammatical subject position of the sentence. For the semantically reversible sentences (Sentence Type II and III) identical sentences were used in the matching and non-matching condition, but the pictures were different (see Figure 5-1b and 5-1c). A sentence did not match the picture when the thematic roles of agent and patient had been reversed.

For all Sentence Type conditions, each picture was presented twice and was paired with a matching sentence and a mismatching sentence respectively. This resulted for each Sentence Type in a total of 96 (48 x 2) experimental picture-sentence pairs.

It has been reported that perceptual characteristics of pictures (like relative position of agent/patient, the direction of an action) affect the ease of both production and comprehension of sentences (e.g. Chatterjee et al., 1999; Flores D'Arcais, 1973). Therefore, the factors of position of agent/patient and the direction of action have been carefully counterbalanced.

A female speaker spoke all the experimental sentences, the fillers and the practice sentences, at a normal speaking rate. Sentences were spoken in a sound attenuating booth and recorded on a digital audiotape. The stimuli were stored on a hard disk. A speech waveform editing system (Xwaves/ESPS package) was used to mark the onset and offset of each sentence, together with the onset of various words within the sentences. Sentence length for the active and passive sentences was 10 and 11 words respectively. Mean sentence duration was 2734 ms (s.d. 188.1 ms) for the active, semantically irreversible sentences, 2587 ms (s.d.

a)

Picture	Sentence type I: semantically irreversible active sentences
	Match: *De jonge vrouw op dit plaatje leest het spannende boek* *(The young woman on this picture reads the exciting book)*
	Mismatch: *Het spannende boek op dit plaatje leest de jonge vrouw* *(The exciting book on this picture reads the young woman)*

b)

Picture	Sentence type II: semantically reversible active sentences
	Match: *De lange man op dit plaatje duwt de jonge vrouw* *(The tall man on this picture pushes the young woman)*
	Mismatch: *De lange man op dit plaatje duwt de jonge vrouw* *(The tall man on this picture pushes the young woman)*

c)

Picture	Sentence type III: semantically reversible passive sentences
	Match: *De vrouw op dit plaatje wordt geduwd door de lange man* *(The woman on this picture is pushed by the tall man)*
	Mismatch: *De vrouw op dit plaatje wordt geduwd door de lange man* *(The woman on this picture is pushed by the tall man)*

Figure 5-1. *Examples of stimulus materials for the three sentence types (I: semantically irreversible active sentences; II: semantically reversible active sentences; III: semantically reversible passive sentences). A sentence either matched or mismatched the picture. For sentence type I a sentence mismatched the picture when the patient role from the picture was placed into the grammatical subject position of the sentence. For sentence types II and III a sentence mismatched the picture when the thematic roles of agent and patient had been reversed.*

217.4 ms) for the active, semantically reversible sentences, and 2712 ms (s.d. 206.1 ms) for the passive semantically reversible sentences.

On the basis of these materials two experimental lists were created. Approximately, an equal number of subjects was assigned to each list. For the first list, all the experimental picture-sentence pairs were distributed over four blocks such that a matching and a non-matching pair were never presented in the same block. Within each block the items were presented in a pseudo-randomised order with the constraint that there were never more than three successive trials with the same sentence type. Repeated pictures were always separated by at least 3 other items. Successive matching or non-matching trials never occurred more than three times in a row. The second list was derived from the first by reversing the presentation order of the blocks. Each experimental list was preceded by a practice list of 12 picture-sentence pairs. A number of 16 filler trials were added to each list (4 per block).

Procedure

Participants were tested individually in a dimly illuminated sound-attenuating booth. They were seated in a comfortable reclining chair (apart from five patients who had to be tested in their wheelchair), in front of a computer screen. Viewing distance was approximately 100 cm. A trial started with the presentation of a picture for 4 seconds. After picture offset, a fixation point (i.e. an asterisk) appeared, to warn the subjects that they had to fixate their eyes on the middle of the screen. At 1000 ms after the onset of the asterisk, a sentence was presented. Participants were asked not to blink or to move their eyes during the period in which the fixation point was on the screen. The fixation point remained on the screen until 1000 ms after sentence offset and was followed by a horizontal rectangle. The appearance of the rectangle signalled that a judgement task had to be carried out: if the sentence matched the picture, subjects were instructed to press the green button on a response button box which was placed in front of them. If the sentence did not match the picture, the red button had to be pressed. We used this delayed judgement task to eliminate effects of motor response preparation on the ERPs of interest. The position of the green and red button on the button box (i.e. left and right) was counterbalanced across subjects. Due to the occurrence of hemiparesis in a number of patients, Broca patients were required to respond with their left index finger, and the RH patients with their right index finger. Half of the normal control subjects had to press with their left index finger, half of them with their right index finger. Push button responses and latencies were measured from sentence offset. The horizontal rectangle disappeared as soon as the response button was pressed. The time-out period (the moment in time after which responses were registered as missing) was set at 4000 ms. Two seconds after either pressing the push button or passing the time-out period, a new trial started.

The pictures were presented on a computer screen, in black on a white background. The presentation of the pictures and the sentences, and the acquisition of the response button data were controlled by NESU, a stimulus presentation system developed at the Max Planck Institute for Psycholinguistics. The subjects listened to the stimuli via a closed-ear Sennheiser HMD-224 headphone.

At the beginning of a session, participants were given a booklet containing all experimental pictures. They were asked to carefully look at the pictures. When a participant indicated that he/she had looked at all the pictures, the practice block was presented to familiarize the subjects with the task. The actual experiment consisted of four experimental blocks of approximately 16 minutes each. Subjects were given short breaks between the blocks.

EEG-recording

Continuous EEG was recorded from 29 Ag/AgCl-sintered electrodes mounted in an elastic cap, each referred to the left mastoid. Twenty three electrodes (Fz, FCz, Cz, Pz, Oz, AF3, AF4, F7, F8, F3, F4, FT7, FT8, FC3, FC4, C3, C4, CP3, CP4, P3, P4, PO7, PO8) were placed according to the standard system of the American Electroencephalographic Society (1994). Six electrodes were placed over non-standard intermediate locations: (a) a temporal pair (LT and RT) placed laterally to Cz, at 33% of the interaural distance, (b) a temporo-parietal pair (LTP and RTP) placed 30% of the interaural distance lateral and 13% of the nasion-inion distance posterior to Cz, and (c) a parietal pair midway between LTP/RTP and PO7/PO8 (LP and RP). Vertical eye movements were monitored via a supra- to suborbital bipolar montage. A right to left canthal bipolar montage was used to monitor for horizontal eye movements. Activity over the right mastoid bone was recorded on an additional channel to determine if there were differential contributions of the experimental variables to the presumably neutral mastoid site. No such differential effects were observed. The EEG and EOG recordings were amplified by a SynAmp™ Model 5083 EEG amplifier system (Neuroscan) using a band-pass filter of 0.05 to 30 Hz. Impedances were kept below 3 kΩ. The EEG and EOG signals were digitised on-line with a sampling frequency of 200 Hz.

RESULTS

Behavioural results

Data analysis. The results for the normal control subjects and the neurological patients were analysed separately. Analyses were done on response latency data and on error data. Response latencies were measured from sentence offset to the onset of the reaction of the participant. Analyses of the latency data were based on the subjects' median response latency in each condition. Errors and missing values (due to time-outs) were replaced for every subject by his/her median per condition. Analyses of the error data were done on the number of errors per participant per condition. Repeated Measures Analyses of Variance were performed with *Sentence Type* (3 levels: semantically *irreversible active*, semantically *reversible active,* semantically *reversible passive*) and *Matching* (2 levels: matching, non-matching) as within-subjects factors. A Huynh-Feldt correction was applied to all repeated measures with more than one degree of freedom in the numerator. The Tukey-HSD multiple range test (alpha = 0.05) was used for post hoc analysis.

Latency analyses

The results for the normal control subjects and both patient groups are summarized in Figure 5-2. Inspection of this figure reveals that the quickest responses were given by the normal control subjects. The RH patients performed somewhat slower than the normal controls, whereas the by far longest decision times came from the Broca patients.

For the *normal control subjects,* in the overall ANOVA, there was a main effect of Sentence Type ($F(1.4, 19.2) = 17.9$; $MSe = 1291.27$; $p = 0.000$). There was no significant effect of Matching ($F(1, 14) = 1.71$; $MSe = 4631.51$; $p = 0.212$), nor a significant Sentence Type by Matching interaction ($F < 1$).

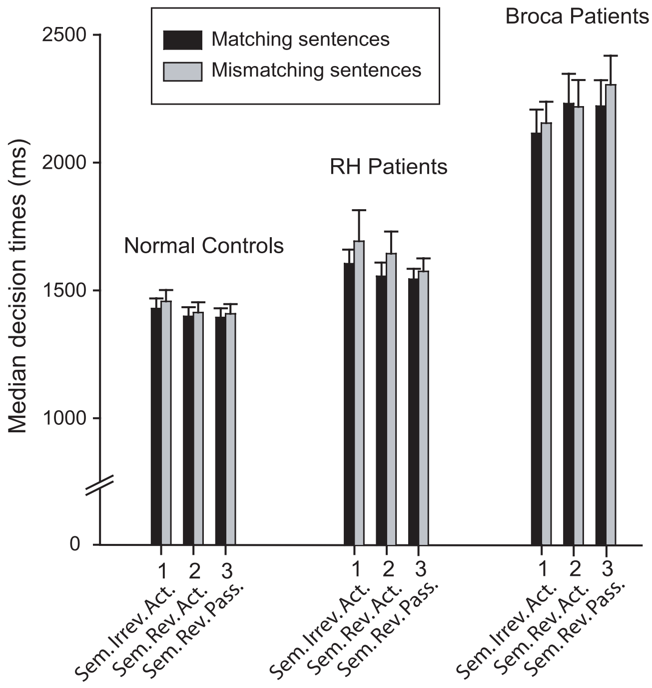

Figure 5-2. *Mean decision times (ms) as a function of Sentence and Matching Type for the group of Normal Controls (N=15), RH Patients (N=8), and Broca Patients (N=10). Average percentage of time-outs was 1.02 for Normal Controls, 1.3 for RH Patients, and 3.4 for Broca Patients.*

Post-hoc comparisons revealed that normal control subjects responded significantly more slowly to the irreversible active sentences ($RT_{irrev\ act}$ = 1443 ms) than to both types of reversible sentences ($RT_{rev\ act}$ = 1406 ms and $RT_{rev\ pass}$ = 1401 ms respectively).

For the *RH patients*, the overall ANOVA did not yield any significant effect [Sentence Type: $F(1.4, 9.5) = 2.38$; $MSe = 19960.18$; $p = 0.152$; Matching: $F(1, 7) = 2.00$; $MSe = 28535.9$; $p = 0.20$; Sentence Type x Matching: $F < 1$].

Whereas both normal control subjects and RH patients responded slowest to the irreversible active sentences, the overall data of the *Broca patients* showed just an increase in response latency from the irreversible active sentences to the reversible passive sentences. In the overall ANOVA, there was no main effect of Sentence Type, but a tendency for response latency to be longer in the reversible passive sentences ($F(1.34, 12.08) = 3.53$; $MSe = 37000.78$; $p = 0.076$). There was no significant effect of Matching ($F < 1$). Also the Sentence Type x Matching interaction did not reach significance level ($F(2, 18) = 2.36$; $MSe = 4809.58$; $p = 0.123$).

An analysis with Group of Subjects as additional between-subjects factor revealed a significant Group of Subjects effect ($F(2, 30) = 42.74$; $MSe = 269292.41$; $p = 0.000$). A post-hoc analysis showed that the Broca patients overall responded significantly slower than both the Normal Controls and the RH patients. The overall response latencies of the Normal Controls and RH patients did not differ significantly. In addition, there was a significant Group of Subjects by Sentence Type interaction ($F(3.01, 45.11) = 6.16$; $MSe = 14679.11$; $p = 0.001$), reflecting the increasing decision times over the three sentence types in the Broca patients, as visualized in Figure 5-2.

Error analyses

Figure 5-3 summarizes the error data for both normal control subjects and patient groups. As can be seen from this figure, the highest error percentages were found for the Broca patients, whereas RH patients and normal control subjects showed relatively low error percentages.

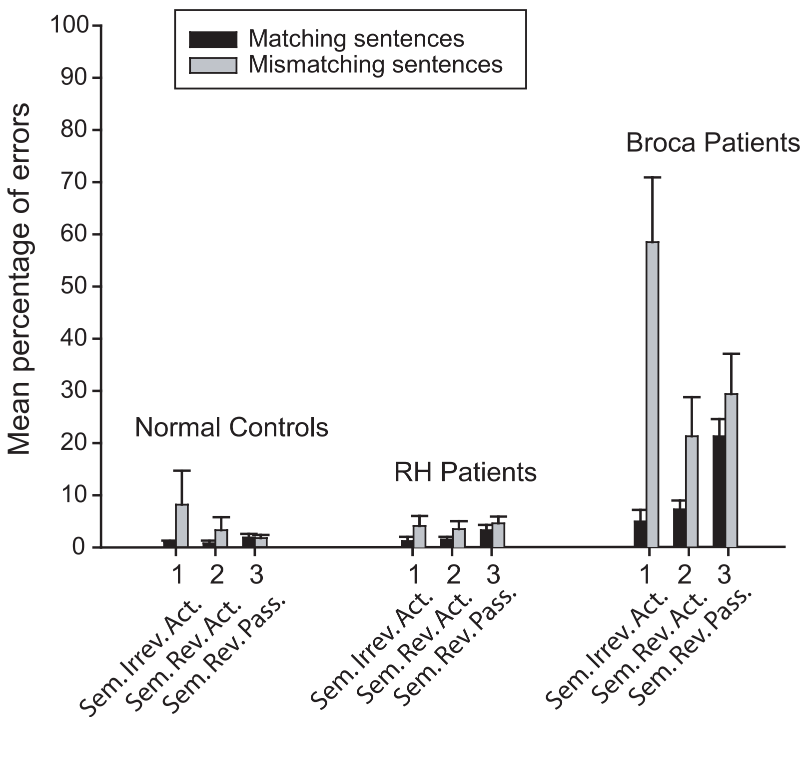

Figure 5-3. *Mean percentage of errors as a function of Sentence and Matching Type for the group of Normal Controls (N=15), RH Patients (N=8), and Broca Patients (N=10).*

The *normal control subjects* made errors on 2.8% of the critical sentences, without significant differences between conditions [Sentence Type: $F < 1$; Matching: $F(1, 14) = 1.09$; $MSe = 48.69$; $p = 0.315$; Sentence Type x Matching: $F(1.02, 14{,}21) = 1.29$; $MSe = 36.79$; $p = 0.276$].

The group of *RH patients* made errors on 3.1% of the sentences. No condition effects were obtained [Sentence Type: $F(1.75, 12.23) = 2.31$; $MSe = 1.15$; $p = 0.145$; Matching: $F(1, 7) = 3.04$; $MSe = 3.95$; $p = 0.125$; Sentence Type x Matching: $F < 1$].

The group of *Broca patients* had an overall error score of 23.8%. Although this error percentage is substantial, it should be pointed out that these patients still performed above chance, with the exception of the non-matching irreversible active sentences. The large number of errors for the matching passive sentences suggests a tendency in the patients to interpret the passives as active sentences. Statistical analysis showed the following. A significant main effect emerged for Sentence Type ($F(1.53, 13.80) = 5.43$; $MSe = 87.78$; $p = 0.024$) and also for Matching ($F(1, 9) = 15.37$; $MSe = 143.64$; $p = 0.004$). These main effects were qualified by a significant Sentence Type x Matching interaction ($F(1.08, 9.75) = 6.39$; $MSe = 202.42$; $p = 0.029$): as can be seen in Figure 5-3, the Matching effect was disproportionately large for sentence type 1 ($F(1, 9) = 14.81$; $MSe = 967.93$; $p = 0.004$). Furthermore, significantly more errors were made for the matching passive sentences than for the other matching sentences ($F(1.68, 15.15) = 12.14$; $MSe = 75.70$; $p = 0.001$).

An analysis with Group of Subjects as additional between-subjects factor revealed a significant Group of Subjects effect ($F(2, 30) = 28.13$; $MSe = 74.16$; $p = 0.000$). A post-hoc analysis showed that the Broca patients made overall significantly more errors than both the Normal Controls and the RH patients. The overall error rates of the Normal Controls and RH patients did not differ significantly from each other. In addition, there were significant interactions between Group of Subjects and Sentence Type ($F(2.90, 43.52) = 3.84$; $MSe = 39.87$; $p = 0.017$), Group of Subjects and Matching ($F(2, 30) = 9.13$; $MSe = 66.73$; $p = 0.001$) and there was a significant three-way interaction of Group of Subjects x Sentence Type x Matching ($F(2.32, 34.84) = 4.69$; $MSe = 72.74$; $p = 0.012$). All these interactions could be attributed to the response pattern of the Broca patients, since all interactions disappeared when a between-subjects analysis was carried out in which the Broca patients were left out.

In conclusion, the normal control subjects responded slower to the semantically irreversible sentences than to the other sentence conditions, but their error rates did not differ between conditions. For the RH patients the different sentence types had no differential influence on either response latency or error rates. The Broca patients showed, overall, much longer response latencies than both other subject groups. Also their overall error percentage was much higher, with the highest error rates for the non-matching irreversible active sentences.

ERP experiment

Prior to off-line averaging, all single trials waveforms were screened for electrode drifting, amplifier blocking, muscle artefacts, eye movements and blinks. This was done over an epoch that ranged from 150 ms before to 3770 ms (= longest sentence plus 500 ms). Trials containing artefacts were rejected. However, for subjects with a substantial number of blinks, single trials were corrected via a procedure described by Gratton et al. (1983). This correction procedure removes the contribution of eye blinks from the ERP recorded at each electrode site. After artefact rejection, the overall rejection rate was 8.8 % for the normal elderly controls, 15.4 % for the RH patients, and 13.2 % for the patients with Broca's aphasia. For all groups, rejected trials were evenly distributed among conditions. For each subject, average waveforms were computed across all remaining trials per condition after normalizing the waveforms of the individual trials on the basis of a 150 ms pre-stimulus baseline.

Several latency windows were selected for statistical analysis (see Table 5-2). These latency windows were determined after careful visual inspection of the waveforms and depended upon the time interval in which maximal differences between conditions were obtained. If necessary also additional latency ranges were analysed.

Subsequent ANOVAs used mean amplitude values computed for each subject, condition and electrode site in the selected latency windows. For each subject group, the results were first analysed in an omnibus ANOVA that crossed Matching with the 29-level electrode factor. Scalp distributions were subsequently explored in an ANOVA with Site (4 quadrants: Anterior Left (AL: AF3, F3, F7, FC3, FT7), Anterior Right (AR: AF4, F4, F8, FC4, FT8), Posterior Left (PL: CP3, LTP, P3, LP, PO7), and Posterior Right (PR: CP4, RTP, P4, RP, PO8) as within-subjects factor. The Huyhn-Feldt correction was applied when evaluating effects with more than one degree of freedom in the numerator, to compensate for inhomogeneous variances and co-variances across treatment-levels. The adjusted degrees of freedom and p-values will be presented. To test for differences between the results for the normal elderly control subjects and the patient groups, also group analyses are performed in the specified time-windows, with Matching as within-subject factor and Group of Subjects as between-subjects factor.

Table 5-2. Latency windows that were selected for statistical analysis.

Semantically irreversible active sentences	100-200 ms following acoustic onset verb 500-800 ms following acoustic onset verb 250-600 ms following acoustic onset sentence-final noun
Semantically reversible active sentences	150-300 ms following acoustic onset verb 500-700 ms following acoustic onset verb 250-600 ms following acoustic onset sentence-final noun
Semantically reversible passive sentences	250-350 ms following acoustic onset auxiliary verb 450-700 ms following acoustic onset auxiliary verb 400-700 ms following acoustic onset sentence-final noun

Semantically irreversible active sentences

Figures 5-4, 5-5, and 5-6 display grand average waveforms for two representative electrodes and isopotential voltage maps, time-locked to the acoustic onset of the critical verb (upper panel) and sentence-final noun (lower panel) for the normal control subjects, the RH patients and the Broca patients respectively. Waveforms were time-locked to the onset of the verb for the following reason. It is the verb that provides the argument structure of the sentence. This implies that the earliest possible moment in the sentence at which a mismatch between picture and sentence could be detected is at the verb's position. A different option is that listeners wait until all argument positions are filled with lexical information. In our materials it was always the sentence-final noun that provided the second argument. Therefore, waveforms were also time-locked to the sentence-final noun. Tables 5-3, 5-4, and 5-5 show the relevant statistical results for the different time epochs, belonging to this condition.

Normal Control Subjects

In an early time epoch, between approximately 50 and 250 ms, a small negativity is elicited by the critical *verb* in the mismatching condition (see Figure 5-4a). This negative effect is followed by a positive shift with a predominant centro-posterior distribution. The omnibus ANOVA for the 100-200 ms window focusing on the negative effect resulted in a significant effect of Matching (see Table 5-3). Also the positive shift tested in the 500-800 ms latency window was significant, and it was significantly larger over posterior than anterior regions (see Table 5-4).

The *sentence-final noun* (see Figure 5-4b) elicited a broad and sustained negative shift in the mismatching condition, starting at 200 ms post-onset and continuing throughout the remaining epoch. This effect was significant (see Table 5-5) and largest over posterior sites.

RH Patients

A positive effect is elicited by the critical *verb* in the mismatching condition between approximately 450 and 1000 ms (see Figure 5-5a). This positive-going waveform does not seem to be preceded by a clear negative effect. Statistical analysis corroborates this latter observation: in the 100-200 ms latency range there is no overall significant effect of Matching (see Table 5-3). The positive shift, tested in an omnibus ANOVA in the 500-800 ms latency window, failed to reach significance level. However, an ANOVA in which only the posterior sites were included showed a marginally significant effect of Matching ($p < 0.055$; see Table 5-4).

The *sentence-final noun* (see Figure 5-5b) elicited a broad and sustained negative shift in the mismatching condition, starting at 200 ms post-onset and continuing throughout the remaining epoch. This effect was significant (see Table 5-5).

Broca Patients

The negative effect in the early time window was not significant (see Figure 5-6a and Table 5-3). A positive-going waveform with a posterior distribution appears to be present in these Broca patients, but the onset of the effect (at around 700 ms) is considerably delayed with

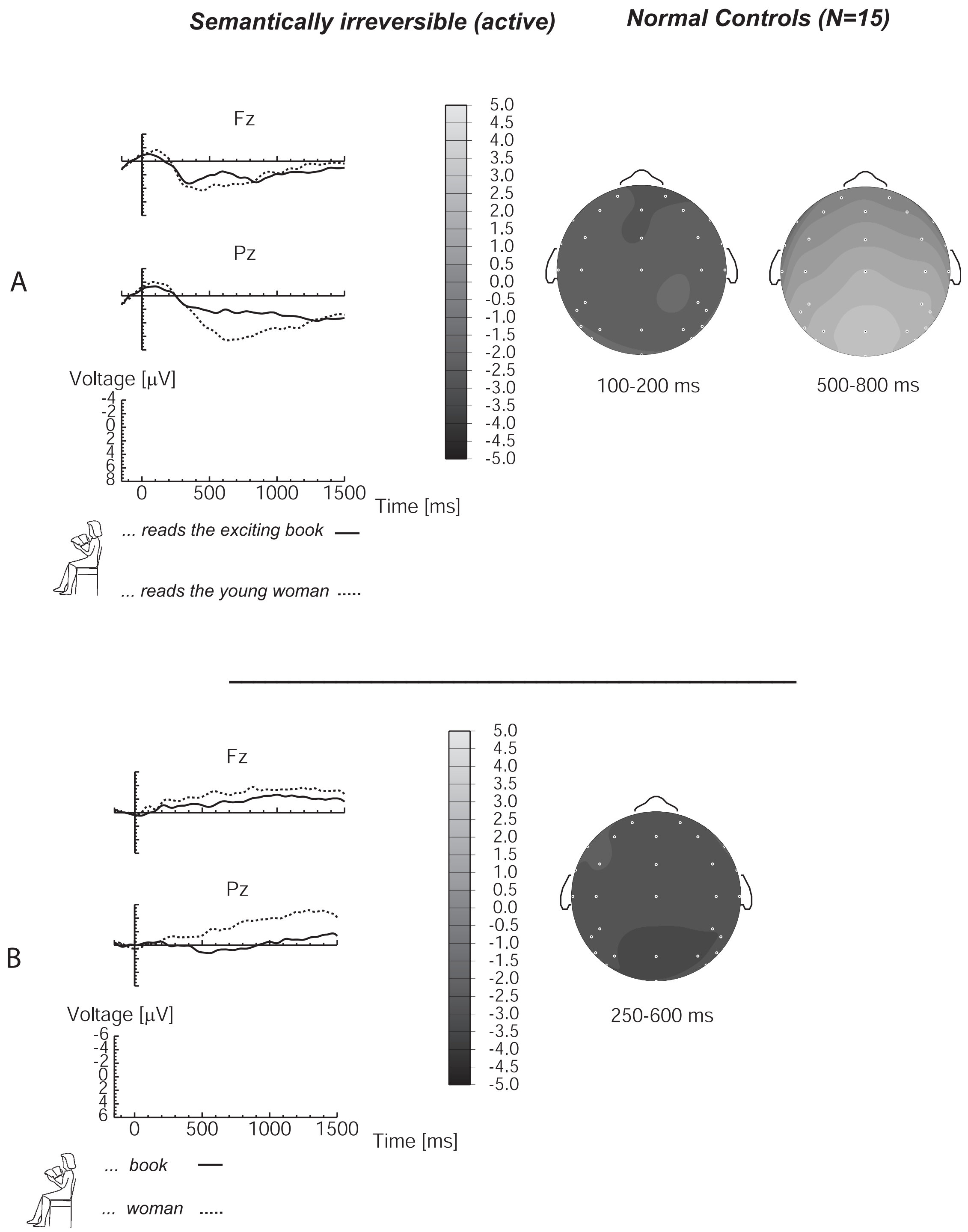

Figure 5-4. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the verb (A) and sentence-final noun (B) for the Normal Control Subjects (N=15) for the semantically irreversible active sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in µV.*

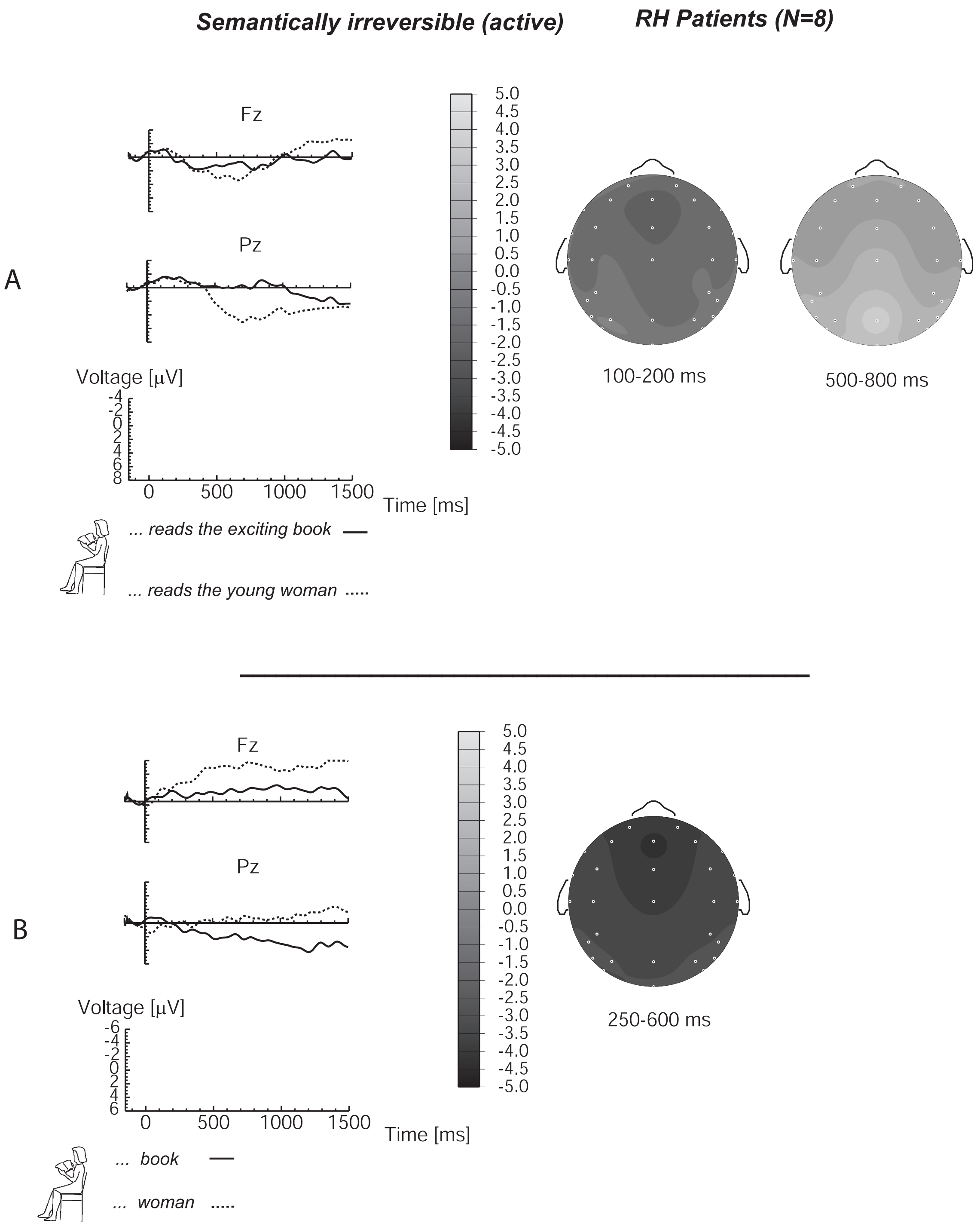

Figure 5-5. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the verb (A) and sentence-final noun (B) for the RH Patients (N=8) for the semantically irreversible active sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in μV.*

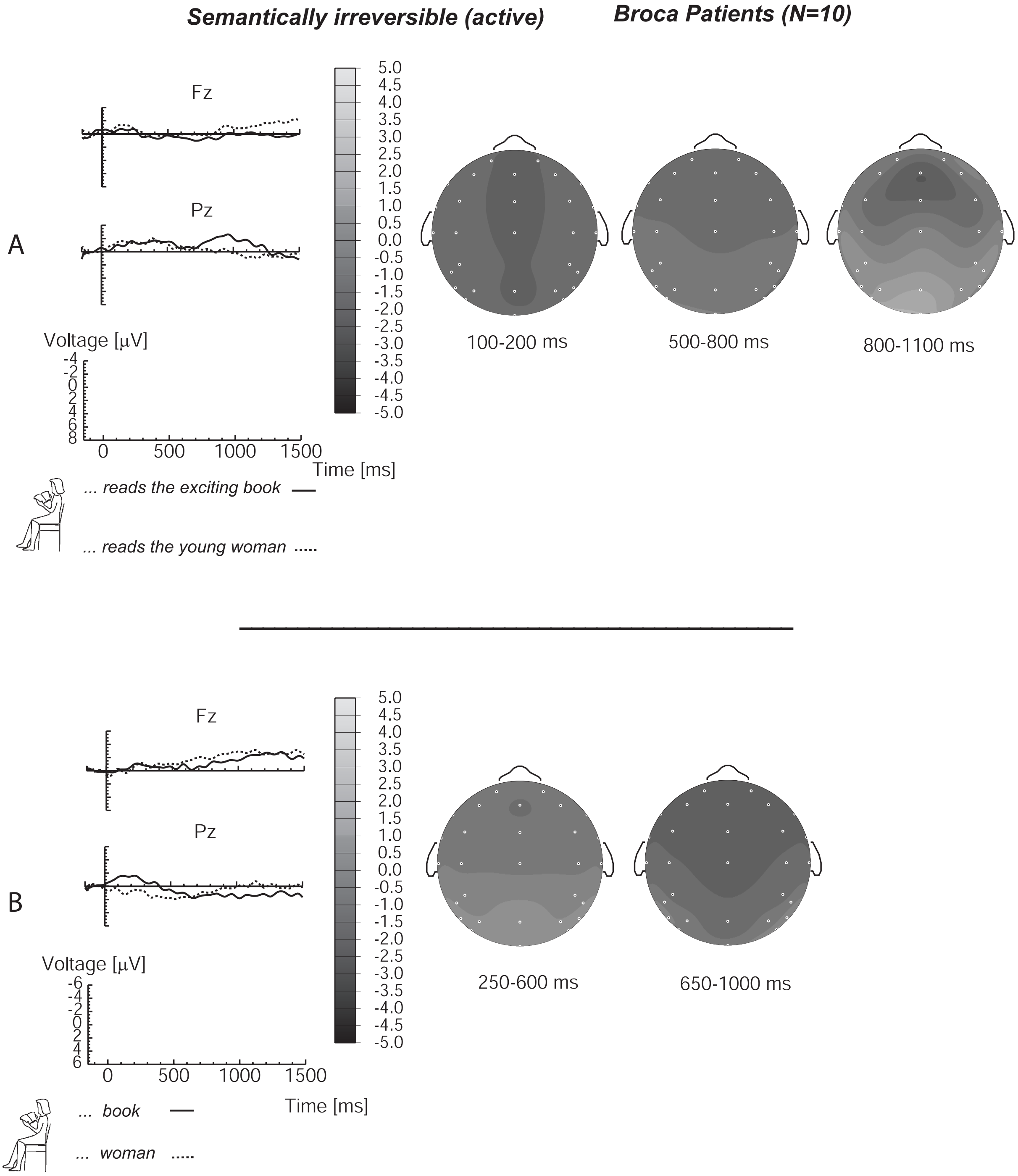

Figure 5-6. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the verb (A) and sentence-final noun (B) for the Broca Patients (N=10) for the semantically irreversible active sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in µV.*

Table 5-3. Mean ERP amplitude ANOVAs in the 100-200 ms latency range following the acoustic onset of the *verb* for the semantically irreversible active sentences.

Subject group	source	df	F	p
Normal Control Subjects	*Omnibus ANOVA*			
	Mat	1, 14	7.65	0.015*
	Quadrant ANOVA			
	Mat x Site	2.47, 34.59	0.61	0.585
Non-aphasic RH Controls	*Omnibus ANOVA*			
	Mat	1, 7	0.15	0.708
	Quadrant ANOVA			
	Mat x Site	3, 21	1.55	0.231
Broca Patients	*Omnibus ANOVA*			
	Mat	1, 9	2.49	0.149
	Quadrant ANOVA			
	Mat x Site	2.88, 25.92	0.23	0.866
Normal Controls vs. RH Controls	*Omnibus ANOVA*			
	Group	1, 21	0.00	0.979
	Mat	1, 21	3.82	0.064
	Group x Mat	1, 21	1.78	0.197
Normal Controls vs. Broca Patients	*Omnibus ANOVA*			
	Group	1, 23	0.00	0.979
	Mat	1, 23	8.82	0.007*
	Group x Mat	1, 23	0.31	0.584

Note. Mat= Matching type (matching versus mismatching).* $p < 0.05$. Omnibus ANOVA: 29 electrodes; Quadrant ANOVA: 4 x 5 electrodes.

respect to the control groups. The omnibus ANOVA in the 500-800 ms latency window did not reveal a significant effect of Matching (see Table 5-4). However, when the effect was tested in a later window (800-1100 ms), a significant effect was found for posterior electrode sites (see Table 5-4).

For the *sentence-final noun* (see Figure 5-6b), mainly at posterior sites, a positive shift in the 0-500 ms latency range is visible, which possibly reflects the delayed ERP response to the critical verb. It is only from 600 ms onwards that the waveforms show a negative shift for the mismatching condition. However, none of the main effects were significant (see Table 5-5).

Table 5-4. Mean ERP amplitude ANOVAs in the 500-800 ms latency range following the acoustic onset of the *verb* for the semantically irreversible active sentences.

Subject group		source	df	F	p
Normal Control Subjects		*Omnibus ANOVA*			
		Mat	1, 14	7.45	0.015*
		Quadrant ANOVA			
		Mat x Site	2.65, 37.04	24.48	0.000**
		Ant. vs. Post. ANOVA			
		Mat x A/P	1, 14	52.04	0.000**
		Posterior ANOVA			
		Mat	1, 14	15.92	0.001**
Non-aphasic RH Controls		*Omnibus ANOVA*			
		Mat	1, 7	3.92	0.088
		Quadrant ANOVA			
		Mat x Site	1.69, 11.84	4.49	0.040*
		Ant. vs. Post. ANOVA			
		Mat x A/P	1, 7	4.02	0.085
		Posterior ANOVA			
		Mat	1, 7	5.27	0.055
Broca Patients	500–800 ms	*Omnibus ANOVA*			
		Mat	1, 9	0.00	0.953
		Quadrant ANOVA			
		Mat x Site	1.45, 13.01	1.95	0.186
	800-1100 ms	*Omnibus ANOVA*			
		Mat	1, 9	0.50	0.499
		Quadrant ANOVA			
		Mat x Site	1.50, 13.50	10.29	0.003*
		Ant. vs. Post. ANOVA			
		Mat x A/P	1, 9	31.63	0.000**
		Posterior ANOVA			
		Mat	1, 9	5.23	0.048*
Normal Controls vs. RH Controls		*Omnibus ANOVA*			
		Group	1, 21	3.04	0.096
		Mat	1, 21	10.91	0.003*
		Group x Mat	1, 21	0.10	0.749
Normal Controls vs. Broca Patients		*Omnibus ANOVA*			
		Group	1, 23	15.27	0.001**
		Mat	1, 23	4.05	0.056
		Group x Mat	1, 23	4.28	0.050*

Note. Mat= Matching type (matching versus mismatching).* $p \leq 0.05$; ** $p \leq 0.001$. Omnibus ANOVA: 29 electrodes; Quadrant ANOVA: 4 x 5 electrodes; Anterior vs. Posterior ANOVA: 2 x 10 electrodes; Posterior ANOVA: 10 electrodes.

Table 5-5. Mean ERP amplitude ANOVAs in the 250-600 ms latency range following the acoustic onset of the *sentence-final noun* for the semantically irreversible sentences.

Subject group	source	df	F	p
Normal Control Subjects	*Omnibus ANOVA*			
	Mat	1, 14	8.51	0.011*
	Quadrant ANOVA			
	Mat x Site	1.85, 25.94	4.22	0.028*
	Ant. Left vs. Post. Left			
	Mat x AL/PL	1, 14	5.37	0.036*
Non-aphasic RH Controls	*Omnibus ANOVA*			
	Mat	1, 7	7.41	0.030*
	Quadrant ANOVA			
	Mat x Site	1.38, 9.64	0.62	0.501
Broca Patients 250-600 ms	*Omnibus ANOVA*			
	Mat	1, 9	0.95	0.354
	Quadrant ANOVA			
	Mat x Site	2.67, 24.04	3.08	0.051
Broca Patients 650-1000 ms	*Omnibus ANOVA*			
	Mat	1, 9	0.32	0.583
	Quadrant ANOVA			
	Mat x Site	2.64, 23.78	0.57	0.618
Normal Controls vs. RH Controls	*Omnibus ANOVA*			
	Group	1, 21	0.09	0.772
	Mat	1, 21	16.03	0.001**
	Group x Mat	1, 21	0.47	0.502
Normal Controls vs. Broca Patients	*Omnibus ANOVA*			
	Group	1, 23	3.54	0.073
	Mat	1, 23	1.59	0.219
	Group x Mat	1, 23	6.93	0.015*

Note. Mat= Matching type (matching versus mismatching).* $p < 0.05$; ** $p \leq 0.001$. Omnibus ANOVA: 29 electrodes; Quadrant ANOVA: 4 x 5 electrodes; Anterior Left vs. Posterior Left ANOVA: 2 x 5 electrodes.

Between-subjects analyses semantically irreversible active sentences

Results of the patient groups (RH patients, Broca patients) were statistically compared to the normal controls in analyses with Group of Subjects as additional factor. For the RH patients, no significant interactions between Group of Subjects and Matching were obtained (see

Tables 5-3, 5-4, and 5-5). Thus, the overall pattern of results was statistically not different between the normal controls and the RH patients.

In the analysis of the Broca patients, for the 500-800 ms epoch, the Group of Subjects by Matching interaction was significant (see Table 5-4). This interaction was due to the delay of the positive effect in the Broca patients relative to the normal controls. Also the omnibus ANOVA for the sentence-final latency window resulted in a significant Group of Subjects by Matching interaction (see Table 5-5). Thus, the pattern of ERP results of the Broca patients was clearly different from the normal controls.

Semantically reversible active sentences

Figures 5-7, 5-8, and 5-9 display grand average waveforms for two representative electrodes and isopotential voltage maps, time-locked to the acoustic onset of the *critical verb* (upper panel) and *sentence-final noun* (lower panel) for the normal control subjects, the RH patients and the Broca patients respectively. Tables 5-6, 5-7, and 5-8 show the relevant statistical results.

Normal Control Subjects

The critical *verb* in the mismatching condition elicited at centro-posterior sites a marked negative-going wave in the 50-450 ms epoch, for anterior sites between approximately 50 and 300 ms (see Figure 5-7a). The negativity was significant (see Table 5-6) and largest over posterior sites. The negative effect was followed by a positive shift. For the anterior sites the positivity started at about 300 ms extending up to 700 ms. At posterior sites this positive effect started somewhat later (at around 500 ms). However, the positivity failed to reach significance (see Table 5-7).

The *sentence-final noun* elicited in the mismatching condition a broad, widely distributed sustained negative shift (see Figure 5-7b). This effect was significant (see Table 5-8).

RH Patients

The critical *verb* in the mismatching condition elicited a negative-going wave that was present approximately between 50 and 300 ms for anterior sites (see Figure 5-8a). For posterior sites the negative effect lasted somewhat longer (until 450 ms). This negativity was marginally significant (see Table 5-6). The negative-going wave was followed by a positive shift starting at about 350 ms for anterior and at about 450 ms for posterior sites, and extending up to 900 ms for posterior sites. The positive shift was largest over posterior sites. However, an analysis in which only posterior electrodes were included failed to reach significance level (see Table 5-7).

The *sentence-final noun* in the mismatching condition elicited a broad, widely distributed sustained negative shift (see Figure 5-8b), which was largest over anterior sites. An ANOVA that included only the anterior electrode sites revealed a significant Matching effect (see Table 5-8).

Broca Patients

The critical *verb* in the mismatching condition (see Figure 5-9a) elicited no significant Matching effects (see Tables 5-6 and 5-7).

For the *sentence-final noun* (see Figure 5-9b) a significant interaction between Matching and Posterior Left/ Posterior Right regions was present. The negative shift was, in an ANOVA that included only right posterior electrode sites, significant (see Table 5-8).

Between-subjects analyses semantically reversible active sentences

Results of the patient groups (RH patients, Broca patients) were statistically compared to the normal controls in analyses with Group of Subjects as additional factor. For the RH patients, no significant interactions between Group of Subjects and Matching were obtained (see Tables 5-6, 5-7, and 5-8). Thus, the overall pattern of results was statistically not different between the normal controls and the RH patients.

For the Broca patients, highly significant Group of Subjects effects were obtained (see Table 5-6, 5-7, and 5-8). The interaction between Group of Subjects and Matching approached significance for posterior sites in the 500-700 ms window (see Table 5-7).

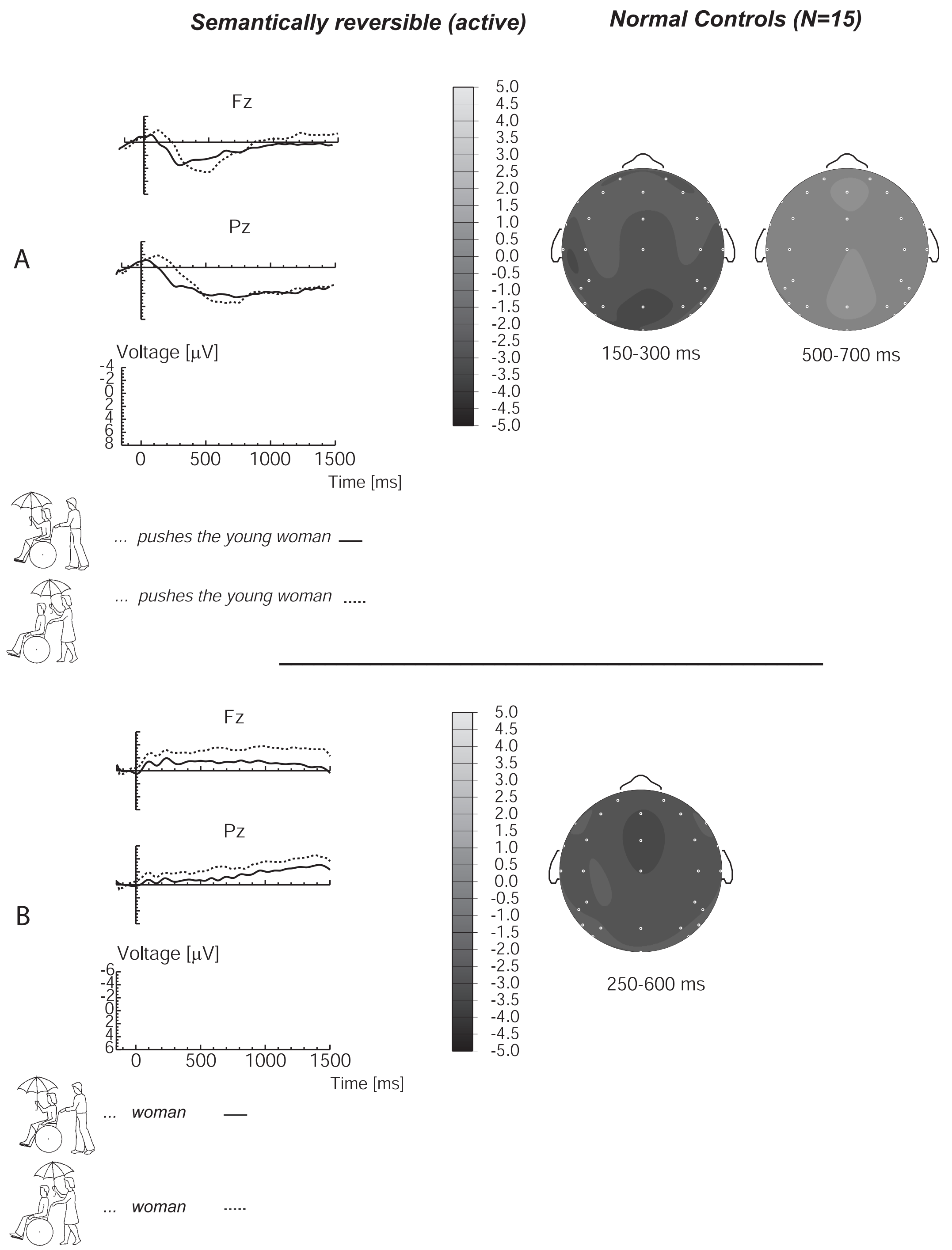

Figure 5-7. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the verb (A) and sentence-final noun (B) for the Normal Control Subjects (N=15) for the semantically reversible active sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in μV.*

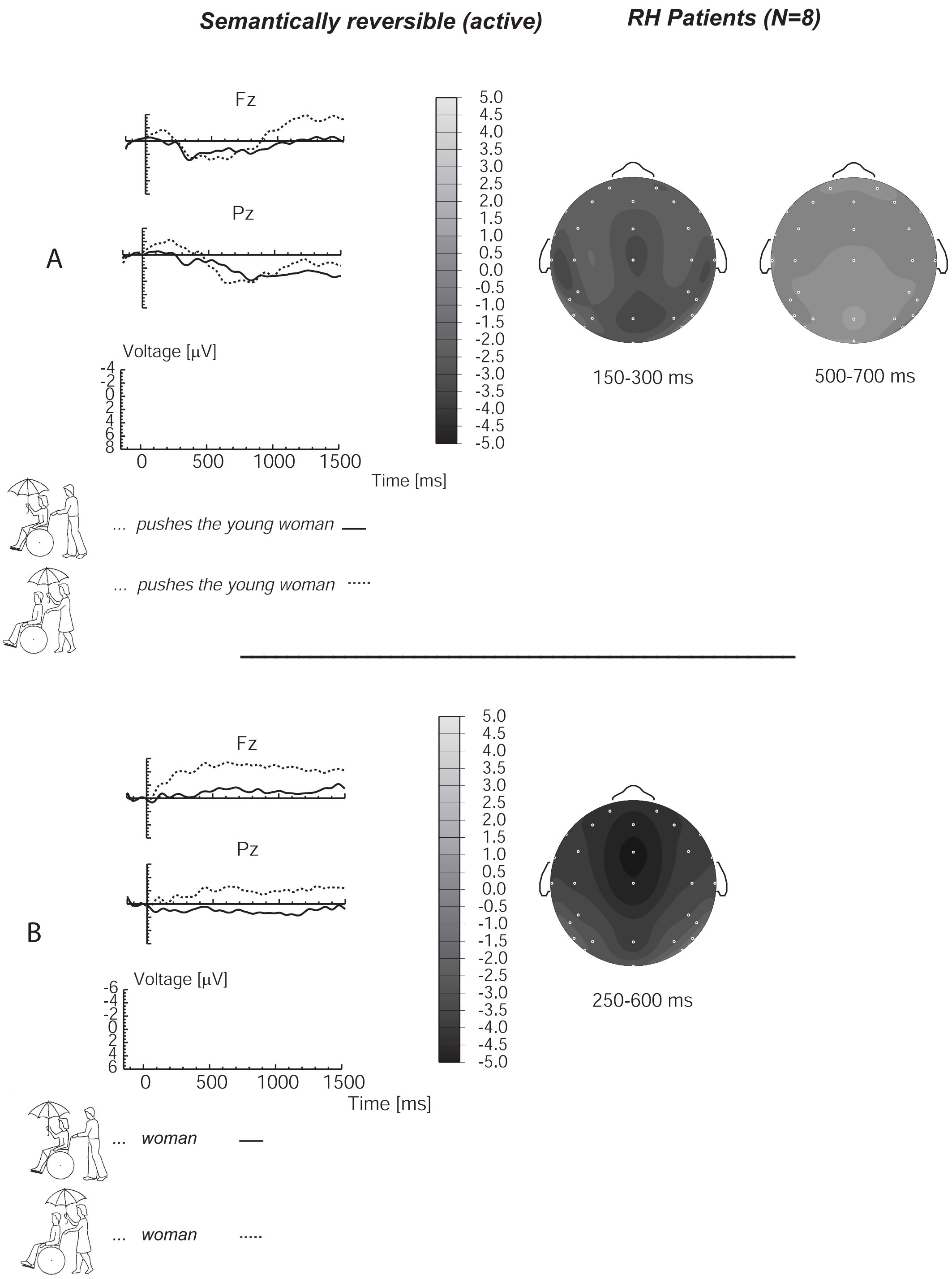

Figure 5-8. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the verb (A) and sentence-final noun (B) for the RH Patients (N=8) for the semantically reversible active sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in µV.*

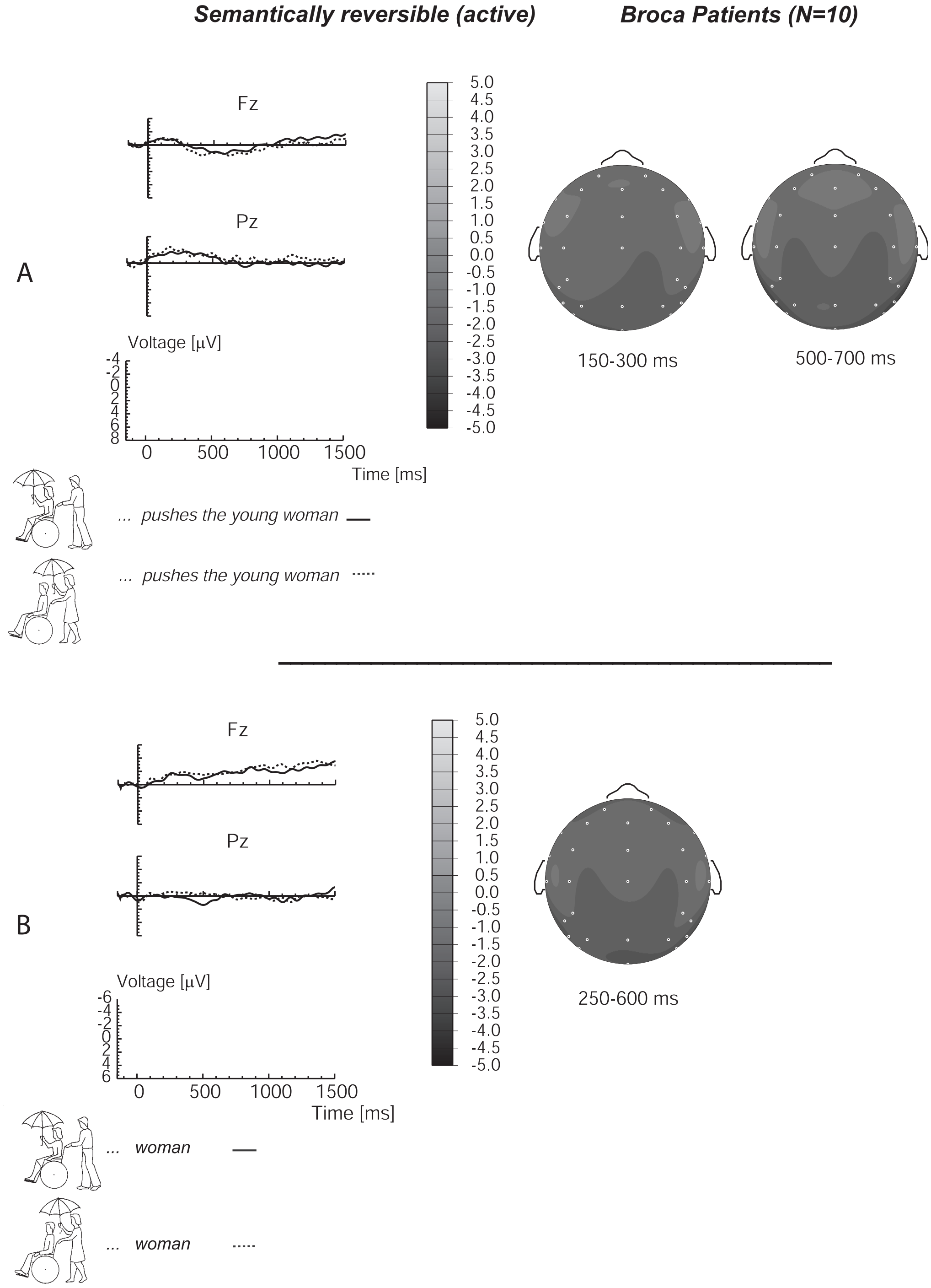

Figure 5-9. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the verb (A) and sentence-final noun (B) for the Broca Patients (N=10) for the semantically reversible active sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in μV.*

Table 5-6. Mean ERP amplitude ANOVAs in the 150-300 ms latency range following the acoustic onset of the v*erb* for the semantically reversible active sentences.

Subject group	source	df	F	p
Normal Control Subjects	*Omnibus ANOVA*			
	Mat	1,14	7.54	0.016*
	Quadrant ANOVA			
	Mat x Site	2.57, 35.94	7.27	0.001**
	Ant. vs. Post. ANOVA			
	Mat x A/P	1, 14	13.65	0.002*
	Posterior ANOVA			
	Mat	1, 14	12.79	0.003*
Non-aphasic RH Controls	*Omnibus ANOVA*			
	Mat	1, 7	4.77	0.065
	Quadrant ANOVA			
	Mat x Site	1.64, 11.46	2.11	0.169
Broca Patients	*Omnibus ANOVA*			
	Mat	1, 9	0.84	0.383
	Quadrant ANOVA			
	Mat x Site	1.97, 17.74	3.58	0.050*
	Ant. vs. Post. ANOVA			
	Mat x A/P	1, 9	4.17	0.071
	Posterior ANOVA			
	Mat	1, 9	2.57	0.143
Normal Controls vs. RH Controls	*Omnibus ANOVA*			
	Group	1, 21	1.00	0.330
	Mat	1, 21	10.78	0.004*
	Group x Mat	1, 21	0.01	0.915
Normal Controls vs. Broca Patients	*Omnibus ANOVA*			
	Group	1, 23	13.89	0.001**
	Mat	1, 23	6.24	0.020*
	Group x Mat	1, 23	2.14	0.157

Note. Mat= Matching type (matching versus mismatching).* $p < 0.05$; ** $p \leq 0.001$. Omnibus ANOVA: 29 electrodes; Quadrant ANOVA: 4 x 5 electrodes; Anterior vs. Posterior ANOVA: 2 x 10 electrodes; Posterior ANOVA: 10 electrodes.

Table 5-7. Mean ERP amplitude ANOVAs in the 500-700 ms latency range following the acoustic onset of the *verb* for the semantically reversible active sentences.

Subject group	source	df	F	p
Normal Control Subjects	*Omnibus ANOVA*			
	Mat	1, 14	2.21	0.159
	Quadrant ANOVA			
	Mat x Site	2.36, 33.09	0.58	0.591
Non-aphasic RH Controls	*Omnibus ANOVA*			
	Mat	1, 7	1.31	0.289
	Quadrant ANOVA			
	Mat x Site	2.05, 14.33	6.56	0.009*
	Ant. vs. Post. ANOVA			
	Mat x A/P	1, 7	13.27	0.008*
	Posterior ANOVA			
	Mat	1, 7	3.00	0.127
Broca Patients	*Omnibus ANOVA*			
	Mat	1, 9	0.39	0.547
	Quadrant			
	Mat x Site	3, 27	8.79	0.000**
	Ant. vs. Post. ANOVA			
	Mat x A/P	1, 9	9.39	0.013*
	Posterior ANOVA			
	Mat	1, 9	2.02	0.189
Normal Controls vs. RH Controls	*Omnibus ANOVA*			
	Group	1, 21	2.33	0.142
	Mat	1, 21	3.56	0.073
	Group x Mat	1, 21	0.12	0.735
Normal Controls vs. Broca Patients	*Omnibus ANOVA*			
	Group	1, 23	16.50	0.000**
	Mat	1, 23	0.42	0.522
	Group x Mat	1, 23	2.05	0.166
	Ant. vs. Post. ANOVA			
	Group	1, 23	16.74	0.000**
	Mat	1, 23	0.50	0.487
	Group x Mat	1, 23	2.22	0.150
	Gr. x Mat x A/P	1, 23	4.38	0.048*
	Posterior ANOVA			
	Group	1, 23	29.18	0.000**
	Mat	1, 23	0.06	0.803
	Group x Mat	1, 23	3.60	0.070

Note. Mat= Matching type (matching versus mismatching).* $p < 0.05$; ** $p \leq 0.001$. Omnibus ANOVA: 29 electrodes; Quadrant ANOVA: 4 x 5 electrodes; Anterior vs. Posterior ANOVA: 2 x 10 electrodes; Posterior ANOVA: 10 electrodes.

Table 5-8. Mean ERP amplitude ANOVAs in the 250-600 ms latency range following the acoustic onset of the *sentence-final noun* for the semantically reversible active sentences.

Subject group	source	df	F	p
Normal Control Subjects	*Omnibus ANOVA*			
	Mat	1,14	7.65	0.015*
	Quadrant ANOVA			
	Mat x Site	1.99, 27.81	0.31	0.732
Non-aphasic RH Controls	*Omnibus ANOVA*			
	Mat	1, 7	4.25	0.078
	Ant. vs. Post. ANOVA			
	Mat x A/P	1, 7	6.54	0.038*
	Anterior ANOVA			
	Mat	1, 7	6.76	0.035*
Broca Patients 250-600 ms	*Omnibus ANOVA*			
	Mat	1, 9	0.79	0.396
	Quadrant ANOVA			
	Mat x Site	3, 27	4.10	0.016*
	Post. L. vs Post. R. ANOVA			
	Mat x PL/PR	1, 9	8.67	0.016*
	Posterior Right ANOVA			
	Mat	1, 9	8.69	0.016*
Normal Controls vs. RH controls	*Omnibus ANOVA*			
	Group	1, 21	4.69	0.042*
	Mat	1, 21	7.57	0.012*
	Group x Mat	1, 21	0.22	0.645
Normal Controls vs. Broca Patients	*Omnibus ANOVA*			
	Group	1, 23	9.52	0.005*
	Mat	1, 23	6.22	0.020*
	Group x Mat	1, 23	1.95	0.176

Note. Mat= Matching type (matching versus mismatching).* $p < 0.05$. Omnibus ANOVA: 29 electrodes; Quadrant ANOVA: 4 x 5 electrodes; Anterior vs. Posterior ANOVA: 2 x 10 electrodes; Anterior ANOVA: 10 electrodes; Posterior Left vs. Posterior Right ANOVA: 2 x 5 electrodes; Posterior Right: 5 electrodes.

Semantically reversible passive sentences

Figures 5-10, 5-11, and 5-12 display grand average waveforms for two representative electrodes and isopotential voltage maps, time-locked to the acoustic onset of the *auxiliary verb* (upper panel) and *sentence-final noun* (lower panel) for the normal control subjects, the RH patients and the Broca patients respectively. For this condition, the auxiliary verb (instead of the verb) was used as critical time-locking point. Although it is the main verb that provides the argument structure, it is not unconceivable that, in the context of visual information as in this experiment, the information of the *auxiliary* verb already is used, to detect a (mis)match between a picture and a sentence as early as possible. Tables 5-9, 5-10, and 5-11 show the relevant statistical results.

Normal Control Subjects

The critical *auxiliary verb* in the mismatching condition (see Figure 5-10a) elicited mainly at centro-posterior sites a negative-going wave in the 200-400 ms epoch. The negativity was significant in an ANOVA that included only posterior electrodes (see Table 5-9). The negative effect was followed by a positive shift starting at about 400 ms and extending up to 900 ms. For anterior sites at which the negative-going wave was absent, this positive shift started earlier and was present in, approximately, the 300-750 ms latency range. The positivity was significant in an omnibus ANOVA in the 450-700 ms latency window (see Table 5-10).

The *sentence-final noun* (see Figure 5-10b) elicited mainly for frontal electrodes a small but sustained negative shift, starting at around 400 ms. However, this effect was not significant (see Table 5-11).

RH Patients

The critical *auxiliary verb* in the mismatching condition (see Figure 5-11a) elicited mainly for posterior electrode sites a negative-going wave in, approximately, the 200-400 ms epoch followed by a positive shift starting at about 400 ms and extending up to 1300 ms. The negative shift was not significant (see Table 5-9). The positive shift was marginally significant in an omnibus ANOVA for the 600-850 ms window (see Table 5-10).

The *sentence-final noun* (see Figure 5-11b) elicited in the mismatching condition a broad and sustained negative shift, clearly manifest at 100 ms post-onset and continuing throughout the remaining epoch. This effect was significant (see Table 5-11).

Broca Patients

As can be seen in Figure 5-12, the Broca's aphasics did not show reliable ERP effects for this sentence type. Both the critical auxiliary verb and the sentence-final noun in the mismatching condition elicited in the Broca patients no significant effects (see Tables 5-9, 5-10 and 5-11).

Between-subjects analyses semantically reversible passive sentences

Results of the patient groups (RH patients, Broca patients) were statistically compared to the normal controls in analyses with Group of Subjects as additional factor. For the RH patients, no significant interactions between Group of Subjects and Matching were obtained (see Tables 5-9 and 5-10) except for the sentence-final noun (see Table 5-11), due to the presence of the large sustained negative shift in the RH patients while this was not the case for the normal control subjects.

For the Broca patients, there was a (marginally) significant Group of Subjects by Matching interaction for the 250-350 ms latency window following the auxiliary verb over posterior electrodes (see Table 5-9).

Individual subject data

There was considerable individual variation in the size of the effects. However, the overall pattern of results that was observed in the averaged data was present in most control and RH subjects. Also, the pattern of the individual data of the Broca patients was largely compatible with the picture that emerged from the averaged data.

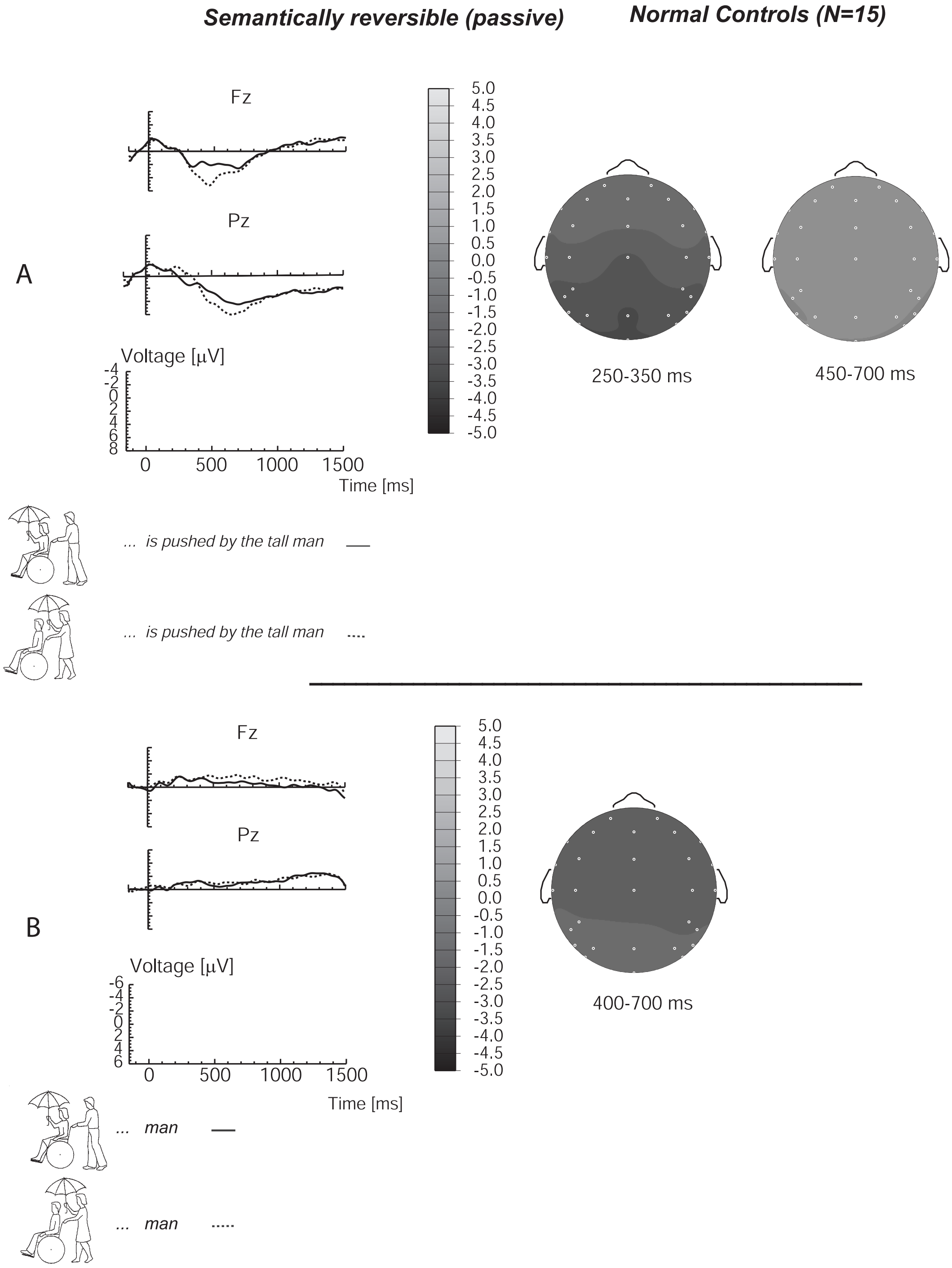

Figure 5-10. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the auxiliary verb (A) and sentence-final noun (B) for the Normal Control Subjects (N=15) for the semantically reversible passive sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in µV.*

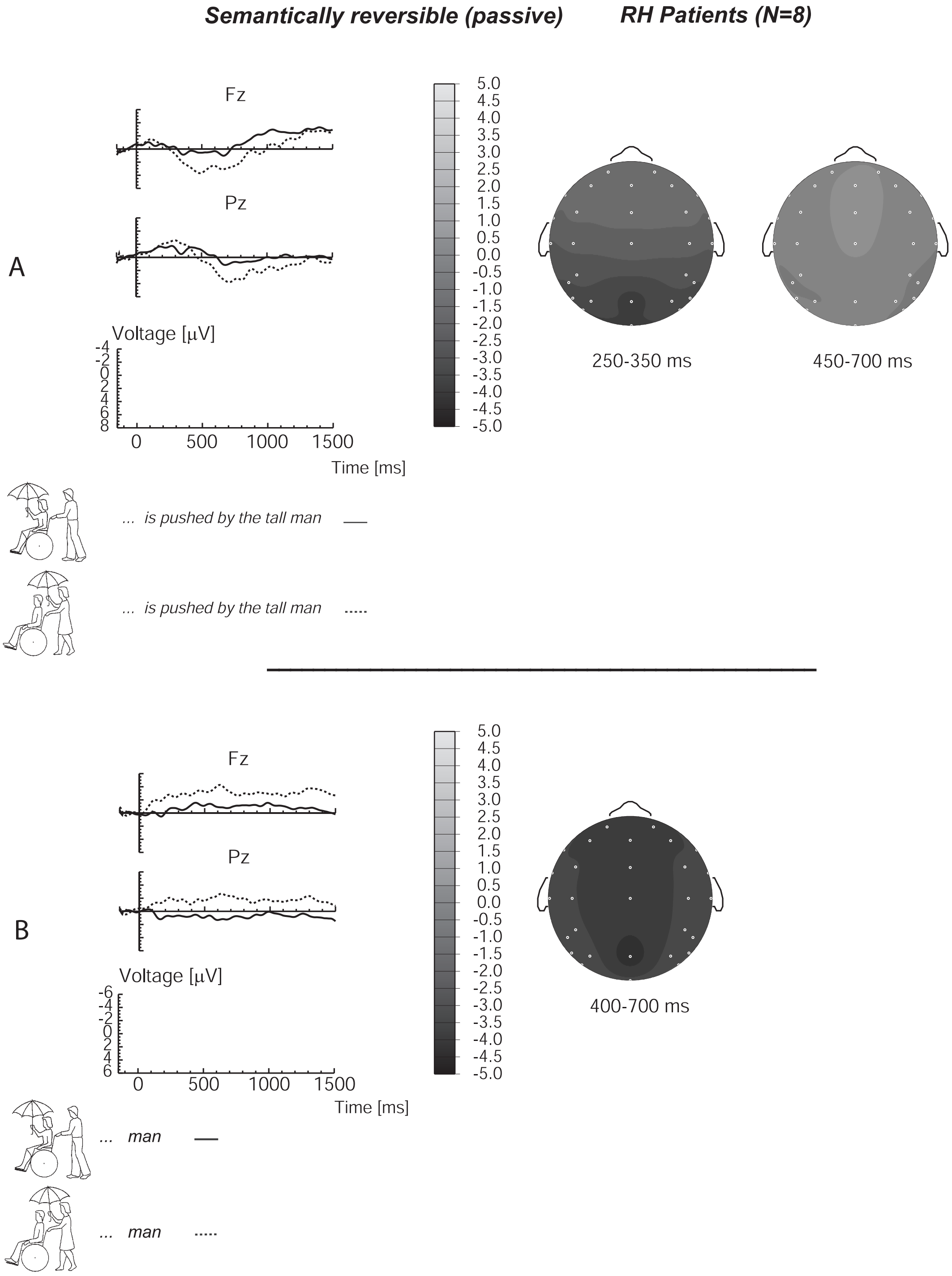

Figure 5-11. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the auxiliary verb (A) and sentence-final noun (B) for the RH Patients (N=8) for the semantically reversible passive sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in μV.*

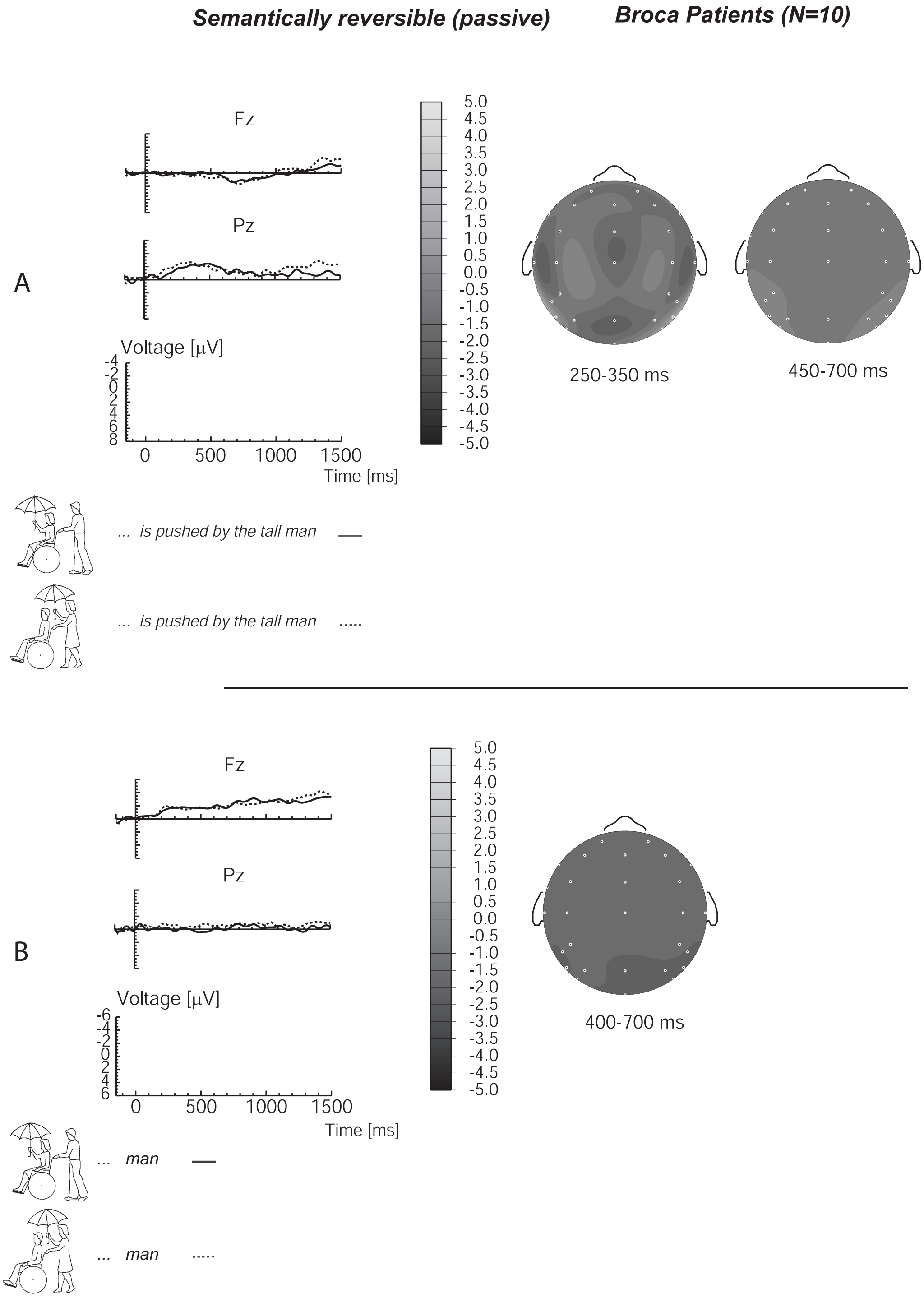

Figure 5-12. *Grand average waveforms for two representative electrodes (Fz, Pz) and isopotential voltage maps, time-locked to the acoustic onset of the auxiliary verb (A) and sentence-final noun (B) for the Broca Patients (N=10) for the semantically reversible passive sentences. Dotted line is used for the mismatching sentences, solid line for the matching counterparts. Isopotential voltage maps were based on mean amplitude differences in the specified latency windows. Darker colours indicate negative amplitudes, whereas the lighter colours correspond to more positive values. Scale values are in µV.*

Table 5-9. Mean ERP amplitude ANOVAs in the 250-350 ms latency range following the acoustic onset of the *auxiliary verb* for the semantically reversible passive sentences.

Subject group	source	df	F	p
Normal Control Subjects	*Omnibus ANOVA*			
	Mat	1, 14	2.46	0.139
	Ant. vs. Post. ANOVA			
	Mat	1, 14	2.24	0.157
	Mat x A/P	1, 14	14.81	0.002*
	Posterior ANOVA			
	Mat	1, 14	7.30	0.017*
Non-aphasic RH Controls	*Omnibus ANOVA*			
	Mat	1, 7	0.02	0.884
Broca Patients	*Omnibus ANOVA*			
	Mat	1, 9	0.01	0.932
Normal Controls vs. RH Controls	*Omnibus ANOVA*			
	Group	1, 21	8.47	0.008*
	Mat	1, 21	0.90	0.353
	Group x Mat	1, 21	0.42	0.523
	Posterior ANOVA			
	Group	1, 21	8.56	0.008*
	Mat	1, 21	5.48	0.029*
	Group x Mat	1, 21	0.26	0.618
Normal Controls vs. Broca Patients	*Omnibus ANOVA*			
	Group	1, 23	8.68	0.007*
	Mat	1, 23	1.32	0.262
	Group x Mat	1, 23	1.08	0.310
	Ant. vs. Post. ANOVA			
	Group	1, 23	8.73	0.007
	Mat	1, 23	1.21	0.282
	Group x Mat	1, 23	0.99	0.329
	Gr. x Mat x A/P	1, 23	4.28	0.050*
	Posterior ANOVA			
	Group	1, 23	10.77	0.003*
	Mat	1, 23	5.40	0.029*
	Group x Mat	1, 23	3.22	0.086

Note. Mat= Matching type (matching versus mismatching).* $p < 0.05$. Omnibus ANOVA: 29 electrodes; Anterior vs. Posterior ANOVA: 2 x 10 electrodes; Posterior ANOVA: 10 electrodes.

Table 5-10. Mean ERP amplitude ANOVAs in the 450-700 ms latency range following the acoustic onset of the *auxiliary verb* for the semantically reversible passive sentences.

Subject group	source	df	F	p
Normal Control Subjects	*Omnibus ANOVA*			
	Mat	1, 14	6.53	0.023*
Non-aphasic RH Controls	*Omnibus ANOVA*			
	Mat	1, 7	3.39	0.108
Non-aphasic RH Controls	*Omnibus ANOVA*			
600 – 850 ms	Mat	1, 7	4.95	0.062
	Left electrodes			
	Mat	1, 7	5.82	0.047*
Broca Patients	*Omnibus ANOVA*			
	Mat	1, 9	1.33	0.278
Normal Controls vs. RH Controls	*Omnibus ANOVA*			
	Group	1, 21	6.43	0.019*
	Mat	1, 21	9.85	0.005*
	Group x Mat	1, 21	0.34	0.564
Normal Controls vs. Broca Patients	*Omnibus ANOVA*			
	Group	1, 23	15.94	0.001**
	Mat	1, 23	6.25	0.020*
	Group x Mat	1, 23	1.35	0.257

Note. Mat= Matching type (matching versus mismatching).* $p < 0.05$; ** $p \leq 0.001$. Omnibus ANOVA: 29 electrodes; Left Hemisphere electrodes: 10 electrodes.

Table 5-11. Mean ERP amplitude ANOVAs in the 400-700 ms latency range following the acoustic onset of the *sentence-final noun* for the semantically reversible passive sentences.

Subject group	source	df	F	p
Normal Control Subjects	*Omnibus ANOVA*			
	Mat	1, 14	2.46	0.139
	Quadrant ANOVA			
	Mat x Site	1.80, 25.15	0.64	0.519
Non-aphasic RH Controls	*Omnibus ANOVA*			
	Mat	1, 7	22.98	0.002*
	Quadrant ANOVA			
	Mat x Site	3, 21	0.20	0.896
Broca Patients	*Omnibus ANOVA*			
400-700 ms	Mat	1, 9	0.70	0.426
Broca Patients	*Omnibus ANOVA*			
200-500 ms	Mat	1, 9	0.76	0.405
Normal Controls vs. RH Controls	*Omnibus ANOVA*			
	Group	1, 21	0.03	0.864
	Mat	1, 21	20.06	0.000**
	Group x Mat	1, 21	6.49	0.019*
Normal controls vs. Broca patients	*Omnibus ANOVA*			
	Group	1, 23	0.37	0.550
	Mat	1, 23	2.65	0.117
	Group x Mat	1, 23	0.25	0.620

Note. Mat= Matching type (matching versus mismatching).* $p < 0.05$; **$p \leq 0.001$. Omnibus ANOVA: 29 electrodes; Quadrant ANOVA: 4 x 5 electrodes.

DISCUSSION

The present study was designed to investigate possible impairments in the on-line thematic role assignment in patients with Broca's aphasia. For that purpose, ERPs were recorded while subjects were engaged in sentence-picture matching. In addition, reaction time and accuracy were measured. In Table 5-12, the ERP results of the experiment are summarized for the three different subject groups.

Table 5-12. Summary of ERP results.

	Normal Controls (N=15)	RH patients (N=8)	Broca patients (N=10)
I: Sem. Irrev. Act.	**Verb, 100-200 ms**: negative effect **Verb, 500-800 ms:** positive effect **Noun2, 250-600 ms:** negative effect	**Verb, 100-200 ms:** - **Verb, 500-800 ms:** positive effect **Noun2, 250-600 ms:** negative effect	**Verb, 100-200 ms:** - **Verb, 800-1100 ms:** positive effect **Noun2, 250-600 ms:** -
II: Sem. Rev. Act.	**Verb, 150-300 ms:** negative effect **Verb, 500-700 ms:** - **Noun2, 250-600 ms:** negative effect	**Verb, 150-300 ms:** negative effect **Verb, 500-700 ms:** - **Noun2, 250-600 ms:** negative effect	**Verb, 150-300 ms:** - **Verb, 500-700 ms:** - **Noun2, 250-600 ms:** negative effect
III: Sem. Rev. Pas.	**Aux Verb, 250-350 ms:** negative effect **Aux Verb, 450-700 ms:** positive effect **Noun2, 400-700 ms:** -	**Aux Verb, 250-350 ms:** - **Aux Verb, 600-850 ms:** positive effect **Noun2, 400-700 ms:** negative effect	**Aux Verb, 250-350 ms:** - **Aux Verb, 450-700 ms:** - **Noun2, 400-700 ms:** -

The ERP data of the normal elderly controls showed on-line sensitivity to a mismatch between a picture and a sentence. As soon as the (auxiliary) *verb* was heard, the ERP signature showed a negative effect. Except for the semantically reversible active sentences, this effect was followed by a positive shift. In addition, for the active sentences, a negative effect was also elicited by the sentence-final noun. The size and to a certain extent also the topographic distributions of the effects differed as function of sentence type. Before focussing on the *immediate* character of the thematic role assignment process in the normal controls, we will first address the issue of what kind of ERP componentry seems to be involved in these effects.

It is not immediately clear how to label the early negative effect that was found in the three sentence conditions, also because of the fact that the topographic distribution of the early negative effects differed along sentence type. The anterior distribution of the effect for the semantically irreversible sentences (sentence type I) makes it at first sight less likely that this effect reflects an N400 effect, which has characteristically a centro-posterior distribution. Furthermore, the onset of the effect for sentence type I seems also rather early for being an N400. However, the early negative effects found for both types of reversible sentences (type II and III) do have a posterior maximum. We cannot exclude the possibility that the underlying distribution of the early negative effect for sentence type I also has a posterior maximum, but that the partly overlapping posteriorly distributed positivity has masked the posterior contribution of the negative shift.

Interestingly, also D'Arcy and Connolly (1999) found, with an ERP version of the Token Test, an early negative effect (followed by a positive shift) when a spoken sentence contained a word that incorrectly described the previous studied visuospatial animation (for instance "touched the small blue circle and the large *green* square" instead of "touched the small blue circle and the large *red* square"). D'Arcy and Connolly interpreted this early negative effect as an N2b reflecting a deviation in the incoming speech stimuli from an active cognitive template formed from the visual information. In this view, the early negative effect reflected primarily attentional detection rather than language processing. Certainly, our present experiment shares task requirements with the experiment of D'Arcy and Connolly, namely analysis of visual information, maintenance of that information in working memory, and matching of incoming spoken input to the information in working memory. However, whereas the primary cognitive process in their experiment was a match-to-sample detection of incorrect words, our present experiment required an analysis of thematic roles.

The positive effect shift that was present for sentence type I and III in the normal control subjects (see Table 5-12), resembled both in terms of scalp distribution and time course a P600/SPS effect. Recently, Kuperberg et al. (2003) found a P600/SPS effect when subjects were presented with sentences containing thematic role animacy violations. They interpreted this P600/SPS as a result of the discrepancy between the probable thematic role and the actual assigned thematic role. It is interesting to see that in our present study we found not only a P600/SPS effect to the critical verb of the sentences that contained a thematic role animacy violation itself (sentence type I). A P600/SPS effect was also found for sentences that were acceptable in itself, but contained thematic roles that were contradictory to thematic information perceived from the previously presented picture (sentence type III). The question of what process is indexed by this P600/SPS effect cannot be directly answered from this experiment. One option is that the mismatch between the conceptual representation the subject has in mind, and the actual sentence, is the event underlying the P600/SPS effect (Kolk et al., 2003). Another possibility is that the P600/SPS reflects an online attempt to reassign thematic roles (Kuperberg et al., 2003). In this latter account, amplitude size of the P600/SPS effect is seen as a function of how effortful the reassignment process is. This might be a tentative explanation for the fact that amplitude size of the P600/SPS effects in the current study differed as a function of sentence type. We should, however, consider yet another explanation for the elicitation of the P600/SPS effect. It is possible that the strong thematic bias emanating from the picture, makes it more difficult to assign grammatical roles onto sentences that are in conflict with the perceived information. In this view, the P600/SPS effect would reflect the effortful process of assigning grammatical roles. This grammatical role assignment is harder if semantic biases are in favour of an alternative syntactic choice.

For sentence type I and II, a negative effect was elicited to the sentence-final noun. In sentence-final positions, an N400-like effect is often seen as result of a processing-problem somewhere earlier in the sentence (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992, 1993). The sentence-final negativities in our current study seem to suggest that a sentence is often more difficult to process in the context of contradictory visual input compared to the situation in which visual input matches a spoken sentence. We can offer, however, no explanation why this sentence-final negativity is absent in sentence type III.

Regardless of the precise functional interpretation of the ERP effects mentioned above, the crucial aspect of the ERP pattern in the normal controls is, that they showed sensitivity to a picture-sentence mismatch as soon as the *verb* was heard. This suggests that the mismatch between the representation of the presented picture and the unfolding sentence was being detected on-line. The fact that ERP effects were obtained at the position of the verb implies that, given the visual context of the picture, thematic roles were assigned immediately, thus as soon as, or in case of auxiliaries even before, the argument structure belonging to the main verb was available. Thus, subjects did not have to wait for the full lexical information that was to be associated with the thematic grid. Instead, relevant visual context (i.e. the picture) was immediately taken into account during the process of real time language comprehension. This enabled subjects to detect a picture-sentence mismatch when encountering the verb. Early integration of visual context during on-line comprehension has been demonstrated before in eye-movement studies (e.g. Spivey et al., 2002; Tanenhaus et al., 1995). Of special interest for this discussion is a recent eye-movement study of Knoeferle, Crocker, Scheepers & Pickering (2005). They investigated whether visual role information provided by agent-action-patient events as depicted in event scenes (i.e. a picture), would guide thematic-role assignment during on-line auditory comprehension. They found anticipatory eye-movements in the event scenes to the appropriate role filler *once the verb* had referred to the depicted action. This was interpreted by the authors as an on-line influence of depicted events on incremental thematic role assignment. Both these eye-movement data and the ERP results of our present study support the idea that thematic role assignment is an incremental process, with early integration of visual contextual information. These features of the thematic role assignment process certainly contribute to the amazing speed with which neurologically unimpaired subjects can comprehend everyday language in the context of visual information. A cognitive architecture with a close communication between visual and language processing seems for this ability to be required.

The ERP results of the RH patients bear clear resemblance to the data of the normal controls in the sense that both groups of subjects showed sensitivity to a picture-sentence mismatch as soon as the verb was heard. Although there were some differences (see Table 5-12), the most important finding is that also in the RH patients thematic role assignment in the context of visual information seemed to be an immediate process.

The ERP results of the Broca's aphasics were clearly different from those of the other two subject groups (see Table 5-12). Whereas for both control groups ERP effects were obtained at the position of the verb (for all sentence conditions), the Broca's aphasics showed an ERP effect (i.e. a positive shift) time-locked to the onset of the verb only for the semantically irreversible sentences. Moreover, this effect was, when compared to the control groups, reduced and considerably delayed. For the semantically reversible active sentences, a negative ERP effect was found only for the sentence-final noun. For the semantically reversible passive sentences, no ERP effects were obtained at all. Together, these ERP data indicate that the Broca's aphasics did not show such an *on-line* sensitivity to the picture-sentence mismatch as displayed by the control groups. Since, ERP effects time-locked to the onset of the verb were either delayed (semantically irreversible active sentences) or even absent (both types of semantically reversible sentences). This suggests that the process of thematic role assignment in the context of visual information was, at the very least, not as immediate as in the healthy control subjects. The ERP pattern of the Broca patients seemed also differentially affected by semantic (ir)reversibility and syntactic complexity, with the largest deviation from the normal controls for the semantically reversible passive sentences. For this latter sentence type, no electrophysiological indication of on-line thematic role assignment was found. Before further discussing the implications of these ERP results, we will first take the off-line behavioral results of the Broca patients into consideration.

To summarize the behavioral results, Broca patients responded considerably slower than both normal controls and RH patients, with a tendency in the Broca patients for response latency to be longest for the reversible passive sentences. Broca patients made also far more errors than both control groups, with high error rates for the non-matching irreversible active sentences. In addition, there were a large number of errors for the matching passive sentences.

The overall longer decision times in the Broca patients cannot exclusively be ascribed to a general consequence of brain damage. Since, brain-damaged controls without aphasia, i.e. the RH patients, showed much faster RTs that could not statistically be distinguished from the normal controls. This fact, together with Broca patients' increasing RTs with increasing syntactic complexity, suggest that the longer decision times more likely are related to the underlying language processing deficit rather than an aspecific consequence of brain lesion.

The relatively high error rates for the non-matching irreversible active sentences deserve particular attention. Recall, this was the condition in which for instance a picture was presented containing a woman reading a book, while the sentence contained a selectional restriction violation "The book on this picture reads the woman". Also Saffran, Schwartz, & Linebarger (1998) reported that agrammatic comprehenders, when tested with a speeded *plausibility judgement task*, found it very hard to reject sentences like *#The deer shot the hunter*, even though this is a simple active sentence. To explain this result, the authors proposed that *semantic* constraints contribute to the assignment of NPs to thematic roles in normal sentence processing, and that this influence is much stronger in Broca patients as a result of a decrease in the syntactic contribution to this process. In this respect we would like to call attention to a previous ERP study of ours (Hagoort, Wassenaar, & Brown, 2003b). In that study, Broca patients with a severe syntactic comprehension impairment showed, in response to word-order violations, an N400-effect instead of a syntax-related ERP effect. Such an N400 effect is usually observed to *semantic* binding operations during on-line language comprehension. This result suggested that these Broca patients seemed to compensate for their syntactic deficit by relying stronger on *semantic* information during on-line sentence comprehension. Returning to the present experiment, it is conceivable that, in the context of visual information, a bias in the Broca patients to accept an interpretation suggested by the semantics of the content words, although being inconsistent with the sentence's syntactic form, is even enhanced. It is interesting that also in the normal controls the highest error rates were induced by the mismatching semantically irreversible sentences. This seems to be in line with the suggestion that a strong conceptual bias can modulate or even overrule syntactic structure (cf. Kolk et al., 2003).

The relatively large numbers of errors for the *matching* passive sentences suggest some tendency to interpret these passive sentences as actives. This tendency in Broca patients toward thematic reversals in the comprehension of semantically reversible passive sentences has been frequently observed. It is noteworthy that the Broca patients from our present study however still performed above chance level for the passive sentences.

To conclude, although their error rates were much higher and their response times much slower, the performance of the Broca patients was, except for the mismatching irreversible sentences, still above chance. This implies that the Broca patients showed, to a certain extent, *off-line* behavioral sensitivity to sentence-picture mismatches.

When we compare the on-line ERP signatures of the thematic role assignment process in the Broca patients to their off-line behavioural pattern, it is striking that there seems to be a dissociation between their on- and off-line sensitivity. That is, for both types of reversible sentences, no ERP effects at the verb's position were elicited, but the off–line performance for these sentences was still above chance. In addition, for the semantically irreversible sentences an ERP effect was found at the verb's position (although reduced and delayed) while the off-line performance showed relatively high error rates. Caplan and Waters (2003) state that studies of syntactic processing by aphasic patients show often complex relationships between on-line and off-line performances. They re-examined therefore the question of the relationship between on-line and off-line processing of syntactic structure in aphasic patients using an auditory moving window task. The Broca patients in that study, but *not* the fluent aphasics, showed a correspondence between impaired off-line performance in syntactic comprehension and disorders in on-line syntactic processing. Such a correspondence suggests that in these patients on-line processing deficits underlied the observed off-line impairments.

The data of our present experiment seem to indicate that Broca patients' problems with assigning thematic roles in visual context already manifested themselves during on-line processing. Nevertheless, the off-line responses for the reversible sentences were actually better than one would have expected on the basis of their on-line ERP profile. This implies that the Broca patients were, to a certain extent, able to detect a sentence-picture mismatch. But, this detection did not happen on-line. The very long response latencies in the Broca patients make it likely that off-line response 'strategies' have been adopted to decide whether a sentence and a picture matched or not. The exact nature of these response strategies cannot be unraveled from this experiment. It is possible that, at the moment that patients were required to give their match/non-match decision, fragments of a sentence were still present as an auditory trace in working memory. Their off-line performance could be partly based on a 'strategic' consultation of the auditory trace for matching/mismatching information. For the reversible passive sentences, it is not unlikely that an 'agent-first' strategy was involved given the relatively large percentage of errors for the matching sentences.

If the syntactic contribution to the on-line language comprehension process is decreased in the Broca patients, thematic information can dominate syntactic information. Under the assumption that the P600/SPS effect, as obtained in the control groups, reflects effortful assignment of grammatical roles in the context of contradictory thematic information, an absence of such a P600/SPS effect in the Broca patients becomes understandable. A preponderant reliance on thematic information during on-line comprehension will prevent syntactic information to play a noticeable role. The data demonstrate furthermore that, although Broca patients are impaired in their ability to assign thematic roles in real-time, they can reduce the consequences of the deficit to a certain extent by adopting off-line response strategies. Thus, aphasic off-line performance reveals the end product of the comprehension process consisting of contributions of both residual on-line comprehension abilities and compensations (Caplan, Waters, DeDe, Michaud, & Reddy, 2004). This implies that response patterns from classical sentence-picture matching tasks can mask the nature of underlying on-line processing deficits.

To conclude, the results of this study showed that in neurologically unimpaired individuals thematic role assignment in the context of visual information was an immediate process. This in contrast to patients with Broca's aphasia who demonstrated no signs of *on-line* sensitivity to the picture-sentence mismatches. The syntactic contribution to the thematic role assignment process seemed to be diminished given the reduction and even absence of P600/SPS effects. Nevertheless, Broca patients showed some off-line behavioral sensitivity to the sentence-picture mismatches. Longer response latencies make it likely that off-line response strategies are used.

SUMMARY AND CONCLUSIONS

CHAPTER 6

It hardly needs saying that language comprehension is essential to everyday human communication. Generally speaking, we scarcely experience any difficulty in understanding sentences that are expressed in our native language. However, such a remark does not apply to aphasic patients. For instance, patients with Broca's aphasia can have serious struggle with understanding sentences that require a full analysis of the syntactic structure for correct interpretation. The research presented in this dissertation intended to gain more insight into syntactic comprehension problems in patients with Broca's aphasia by using event-related brain potentials (ERPs). In this final chapter, the main findings of the electrophysiological data on on-line syntactic processing as obtained in the different studies, are summarized. Conclusions are drawn as to what the different experiments have revealed about syntactic comprehension deficits in patients with Broca's aphasia.

SUMMARY OF RESULTS

The first experiment (**Chapter 2**) was designed to investigate whether patients with Broca's aphasia were sensitive to *violations of subject-verb agreement*. ERPs were recorded while participants (normal elderly controls, patients with a RH lesion, and patients with Broca's aphasia) listened to sentences that were either syntactically correct or contained violations of subject-verb agreement (e.g., "De vrouwen betalen de bakker en <u>neemt</u> het brood mee naar huis)". Syntactic complexity of the sentences was varied by including not only conjoined sentences as the above-mentioned example, but also sentences with a more complex embedded structure as "De vrouwen die de bakker betalen, <u>neemt</u> het brood mee naar huis". Healthy control subjects showed, irrespective of syntactic complexity, a P600/SPS effect as response to the agreement violations. Non-aphasic patients with a RH lesion showed essentially the same pattern. The overall group of Broca patients did not show this sensitivity.

However, the sensitivity appeared to be modulated by the *severity* of the syntactic comprehension impairment. When the group of Broca patients was divided into two subgroups based on their performance on a syntactic off-line test, it appeared that the group with a relatively severe syntactic comprehension impairment did not show an agreement effect. This in contrast to the group with a milder syntactic comprehension impairment that did show an agreement effect, albeit reduced in comparison to the control subjects. There was however no shift in the onset latency of the effect. An effect of complexity could not be demonstrated. It was concluded that deviations from the standard P600/SPS effect in the Broca patients reflected difficulties with carrying the activation of number information across clausal boundaries for establishing subject-verb agreement. For the Broca patients with a less severe syntactic comprehension impairment, this resulted in a reduction of the P600/SPS effect. In the case of the more severely impaired patients, this even resulted in an absence of the effect.

Chapter 3 presented an experiment in which I studied the on-line processing of *violations of word order* in Broca patients. The violation at stake concerned a violation in the relation between the head of a phrase and its arguments (e.g., "De dief steelt de <u>dure erg klok</u> uit de woonkamer"). ERPs were recorded while participants (normal controls, RH patients, and patients with Broca's aphasia) listened to sentences that were either syntactically correct or contained violations of word order. The results for the Broca patients were analyzed according to the severity of their syntactic comprehension impairment. When listening to the sentences with violations of word order, the non-aphasic brain damaged patients and the Broca patients with a light syntactic comprehension deficit showed a P600/SPS effect that was comparable to that of the neurologically unimpaired subjects. The Broca patients with a relatively more severe syntactic comprehension impairment did not show a syntax-related ERP effect. Instead, they showed a meaning-related ERP effect, possibly reflecting their attempt to achieve understanding by the use of a semantic processing route. It was concluded that although agrammatic comprehenders are impaired in their ability to exploit syntactic information in real time, they can reduce the consequences of a syntactic deficit to a certain extent by relying on processing options that are still available to the impaired language comprehension system.

Chapter 4 described a study on the on-line sensitivity to *violations of word-category* in Broca patients. The term violation of word-category refers to the situation in which the syntactic context requires a word of a certain syntactic class (e.g. a noun in the context of a preceding article and adjective), but in fact a word of a different syntactic class is presented (e.g. a verb). An example of such a violation is “De houthakker ontweek de ijdele schroeft op dinsdag”. In the grammatically correct version of this sentence the word ‘schroef’ instead of ‘schroeft’ was used. In addition, there was also a condition with a semantic violation (e.g., “Het meisje stopte een snoepje in haar bloem”) to see whether, in the same subjects, semantic anomalies would result in a classical N400-effect to track possible dissociations in the sensitivity to semantic and syntactic information in the Broca patients. ERPs were recorded while participants were visually presented with the sentences, word by word. Both control groups (normal elderly controls and RH patients) appeared to be sensitive to the violations of word-category, as shown by clear P600/SPS effects. The Broca patients displayed only a very reduced and delayed P600/SPS effect; the N400-effect as response to the semantic violation condition was somewhat delayed and reduced. However, the relative reduction in size and delay were more substantial for the P600/SPS than for the N400 effect. It was concluded that Broca patients are hindered to detect on-line violations of word-category, if word-class information is incomplete or delayed available.

Chapter 5 concerned a study on on-line thematic role assignment during sentence-picture matching in patients with Broca’s aphasia. Subjects saw a picture that was followed by an auditorily presented sentence. The sentence either matched the picture or mismatched the visual information depicted. Sentences differed in complexity, and ranged from simple active semantically irreversible sentences to passive semantically reversible sentences. ERPs were recorded while participants were engaged in sentence-picture matching. In addition, reaction time and accuracy were measured. The results of this study showed that in normal elderly controls, thematic role assignment in the context of visual information was an immediate process. ERP effects were obtained at the position of the verb, which implies that, given the visual context of the picture, thematic roles were assigned immediately, thus as soon as, or in case of auxiliaries even before, the argument structure belonging to the main verb was available. It was assumed that the P600/SPS effect, as obtained in the normal controls, reflected effortful assignment of grammatical roles in the context of contradictory thematic information. Also in the RH patients, thematic role assignment seemed to be an immediate process. This in contrast to the patients with Broca's aphasia who demonstrated no signs of on-line sensitivity to the sentence-picture mismatches. The on-line syntactic contribution to the thematic role assignment process seemed to be diminished given the reduction and even absence of P600/SPS effects. Nevertheless, Broca patients showed some off-line behavioral sensitivity to the sentence-picture mismatches. The long response latencies made it likely that off-line response strategies were used.

CONCLUSIONS

The different experiments described in this dissertation provided a range of electrophysiological data on on-line syntactic processing in patients with Broca's aphasia. In this section, results of the experiments will be lumped together: what have the different experiments revealed about syntactic comprehension deficits in patients with Broca's aphasia? Successively, the topics of *severity, decay and delay, and multiple-route plasticity* are addressed. These conclusions will be preceded by two preambulatory remarks on control measurements and functional significance of syntax-related ERP effects.

Control measurements

The general rationale behind all studies was that deviant patterns of syntax-related ERP-effects in patients with Broca's aphasia can be informative about impaired syntactic processing. It is important to note that such an interpretation of deviant syntax-related ERP effects presupposes that observed changes are most likely not a non-specific effect of brain-damage, but are related to the nature of the syntactic processing impairment. Therefore, in order to be able to reliably interpret deviant syntax-related ERP patterns in Broca patients, I included in this dissertation several control measurements. In all experiments, a group of non-aphasic patients with a right hemisphere lesion was tested to control for non-specific effects of brain damage on syntax-related ERP effects. P600/SPS effects in these RH patients were relatively normal, showing that brain lesions in itself do not necessarily result in major changes in size and/or latency of syntax-related ERP effects. Secondly, in the chapters 2 and 4 also a non-linguistic control experiment was added. The use of a non-linguistic control task must be viewed as follows. If changes in syntax-related ERP effects are *exactly matched* by changes in ERP effects obtained in the classical oddball paradigm (P300 effect), then the changes in the language-related componentry might be indicative of a general, aspecific lesion effect, *equally affecting* different endogenous ERP components. In the experiments described in the chapters 2 and 4 however, I found significant P300 effects in the Broca patients that allow to say that general non-linguistic processing was decent. But, notwithstanding this main P300 effect in the Broca patients, the effect was, when compared to the other groups, reduced. This suggests that these subjects did not suffer from a linguistic deficit exclusively. However, since this reduction had no predictive value with respect to the pattern of results for the syntax-related P600/SPS effect, these results can not *only* be explained in terms of a non-specific consequence of brain lesion. Taken together, the results of the control measurements indicated that observed changes in the syntax-related ERP effects of the Broca patients should be interpreted in terms of their language deficit. To prevent misunderstandings: I certainly do not claim that the one and only deficit in Broca patients is a linguistic one. Indeed, a cerebro-vascular accident is often accompanied by a number of concomitant deficits. In this study however, I was particularly interested in syntax-related phenomena. Therefore I used syntax-related ERP effects as a tool to study syntactic processing in Broca patients. This is not to say that these language-related ERP components are language-specific. However, under conditions of language input as in the described experiments, changes in syntax-related ERP effects were exploited to study syntactic comprehension in patients with Broca's aphasia.

Functional significance of syntax-related ERP effects

There is yet another issue that directly relates to the implications of the electrophysiological findings in this study. Inferences about altered syntactic processing, as apparent from changes in syntax-related ERP effects, are complicated by the fact that the precise functional significance of the two classes of syntax-related ERP effects, namely (E)LAN and P600/SPS, is not yet agreed upon. In the literature, different positions have been taken (e.g. Friederici, 2002; Hagoort, 2003a; Kolk et al., 2003). Results from previous ERP studies on syntactic processing beyond the lexical-syntactic level in Broca patients (Friederici, Hahne & von Cramon, 1998; Friederici, von Cramon & Kotz, 1999) have been interpreted in terms of a serial, syntax-first model. Here I will discuss the observed changes in syntax-related ERP effects against the background of an account (see also chapter 4) of syntax-related ERP effects as formulated by Hagoort (2003a), in which syntax-related ERP effects have been related to a lexicalist parsing model (Vosse & Kempen, 2000).

Severity

Between-subject variation in sentence comprehension of Broca's aphasics has been demonstrated in several *behavioral* studies (e.g. Schwartz, Saffran & Marin, 1980; Kolk & Van Grunsven, 1985), successfully simulated in computer simulation studies (e.g. Haarmann & Kolk, 1991a; Vosse & Kempen, 2000; Saffran, Dell & Schwartz, 2000), and has been interpreted as a reflection of different degrees of severity in the underlying impairment. Severity variation has also been taken as strongly favouring the view that agrammatic comprehenders have a problem in *processing* syntactic knowledge. In the chapters 2 and 3 of this dissertation, the impact of severity of the syntactic comprehension impairment on ERP effects was addressed. To separate Broca patients that were severely agrammatic in their comprehension from the other Broca patients, their performance on a syntactic off-line test determined the assignment to either the group of Low or High Comprehenders. One could raise the objection that this dichotomy is rather artificial. Carrying out ERP group studies however requires a certain number of subjects per group, in consideration of statistical power and an acceptable signal to noise ratio. This precluded a more fine-grained division of categories of severity. Nevertheless, results from this dissertation revealed that differences in syntactic comprehension impairment severity were indeed reflected *electrophysiologically*. Severity variation was reflected in the ERP response such that the largest deviation from normal syntax-related ERP effects was observed for those patients with the most severe comprehension deficit (see Chapters 2 and 3). The implication of this finding is that authors of (syntax-related) ERP studies on aphasia always should provide readers with a clear indication of the severity of the syntactic comprehension impairment of the patients involved. This will enable readers to gain an insight into what type of patients the ERP results are related to.

Decay and delay

In accounts that view the syntactic comprehension impairment as a processing deficiency, one of the hypotheses, among others, is that syntactic comprehension deficits in Broca patients are caused by problems with (the temporal organization of) the activation of lexical and/or syntactic information. In this context, three possibilities can be distinguished: (i) in patients there is *delayed* activation, i.e. the information becomes available too late (e.g. Friederici, 1988; Friederici & Kilborn, 1989; Haarmann & Kolk, 1991a, 1991b; Burkhardt, Piñango, & Wong, 2003); (ii) there is an accelerated *decay* of activation, i.e. the information is usable for too short a period of time (e.g. Haarmann & Kolk, 1994); (iii) there is *insufficient* activation, i.e. the incoming information cannot be supplied with enough activation to be used effectively. One of the strengths of the ERP method is that it provides an on-line and continuous record of neural activity underlying language processing with a temporal resolution in the order of milliseconds. This allows inferences about (changes in) the time course of language processing in aphasic patients. What insights can be derived from the different experiments with respect to temporal limitations on parsing/language processing? Both instantiations of temporal disturbance, viz. decay and delay were encountered. In chapter 2, I found for the patients with a less severe syntactic comprehension impairment a P600/SPS effect to violations of subject-verb agreement, albeit reduced in amplitude size when compared to the control subjects, but nevertheless showing up with the same time course as the control group. Thus, in that study I found no evidence for delayed activation, since there was no sign of a shift in the onset latency of the effect. The amplitude reduction was taken as indicative for a weakened sensitivity to morphosyntactic number information, due to an accelerated decay of this information. Also in chapter 3 I found that patients with a less severe syntactic comprehension impairment showed a P600/SPS effect to violations of word-order with the same onset latency of the effect as for the normal elderly control subjects. Although somewhat reduced in amplitude, again no sign of delayed activation showed up. Importantly, in both experiments, I neither found onset latency shifts for the more severely impaired patients. For these patients, ERP effects were either further reduced (chapter 2) or qualitatively different (chapter 3). However, in chapter 4, when patients were presented with word-category violations, I did find, not only a reduced but also a delayed P600/SPS effect with an onset latency shift of about 250 ms. In addition, also in chapter 5 with a sentence-picture matching paradigm an about 350 ms delayed and reduced P600/SPS effect was observed (for one condition; in the other conditions the P600/SPS effect was absent altogether). The overall picture that emerged from the different experiments is that both types of activation disturbance, viz. decay and delay were found in syntax-related ERP patterns of the Broca patients. How can this reduction and delay be interpreted against the background of Hagoorts (2003a) account of the P600/SPS effect? In this account, the P600/SPS *effect* is considered as being related to the (additional) time it takes to build-up binding links of sufficient strength between lexically specified syntactic frames. The finding that Broca patients showed a reduction of the P600/SPS effect in some experiments suggests that syntactic information might not be available with the right level of activation, to enable these binding operations to occur smoothly. A too fast decay of activation could result either from reduced initial levels of activation, a faster-than-normal decay rate, or a combination of these two. A delay of the P600/SPS effect as observed in other experiments suggests that unification strength might build up at too slow a rate. Both disturbances can have disruptive effects on syntactic comprehension. When syntactic information is not available with the right level of activation (decay), it will be more difficult to combine it with information that comes in later. When unification strength builds up at a too slow rate (delay), this will result in many weak, not stably connected links.

The different experiments described in this dissertation thus lead up to different conclusions with respect to the absence/presence of accelerated decay and delayed activation. However, there is nothing new under the aphasiological sun: also Haarmann (1993) found seemingly contradictory findings with respect to indications of slow activation and fast decay. To explain these results, Haarmann and Kolk (1994) hypothesized a trade-off mechanism between too-slow activation and too-fast decay, being dependent on different task demands. Simulation results of agrammatic sentence analysis by Vosse & Kempen (2000) required an adjustment of both decay rate and spontaneous build-up of binding strength (next to a parameter of inhibition strength). This suggests that at least both kinds of temporal disturbance are involved in the agrammatic impairment. The question then becomes why in some studies primarily the decay aspect was picked up, whereas in the other studies also the delay aspect became apparent. It is imaginable that the different studies seized at different facets of the processing of syntactic information. For instance, in the agreement violation study particularly the decay aspect might come to the fore, since especially a too fast decay is an impediment for backward checking of morphosyntactic number information. In the word-category violation study however, patients would in particular be hindered to detect on-line violations of word-category if a word's lemma information, including word category is incompletely and delayed available. This is reflected in the results.

Finally, in this dissertation, deviations from language-related ERP effects in the Broca patients were not limited to the P600/SPS effect. From chapter 4 it appeared that also the N400 effect was somewhat reduced and delayed. This is consistent with earlier ERP studies on semantic violations in Broca patients (Swaab, 1996; Swaab, Brown, & Hagoort, 1997). However, chapter 4 showed that the relative reduction and delay were far more substantial for the P600/SPS effect than for the N400 effect, suggesting that syntactic processing seemed more affected than semantic processing in these patients.

Multiple-route plasticity

It is commonly acknowledged in clinical practice that aphasic patients can compensate for their linguistic deficit. Encouraging the use of different expressive communicative channels for instance is a significant component of aphasia therapy. Compensation can however also manifest itself at the level of sentence reception. It has been widely assumed that aphasic patients with a syntactic comprehension impairment stronger rely on semantic information, viz. on the linear order and meaning of content words. In that context, one often refers to the use of word order strategies. These strategies can account for the regularly better performance on canonical structures than on non-canonical structures, as has been demonstrated so far in various *behavioral* studies. Interestingly, in chapter 3, *electrophysiological* evidence was found for *real-time* semantic compensation in patients with a severe syntactic comprehension impairment. These Broca patients seemed to compensate for their syntactic deficit by relying stronger on semantic information during on-line sentence comprehension. Also in chapter 5, during on-line sentence-picture matching, thematic information seemed to dominate syntactic information in the Broca patients. These results together point to multiple-route plasticity (cf. Kolk, 2000): a different route is favored to compensate for a syntactic deficit. Next to these indications of on-line compensation, behavioral data from chapter 5 showed also the presence of off-line compensation: Broca patients seemed to reduce the consequences of their on-line deficit by adopting off-line response strategies. It is an interesting question whether these forms of compensation originate from either automatic or strategic selection (Kolk, 2000). The speed at which the on-line compensation happened seems to be indicative of automatic selection whereas the off-line compensation with the concomitant long response latencies seems to originate from strategic selection.

Nature of deficit

The experiments in this dissertation support the idea that syntactic comprehension deficits in Broca patients result from a processing deficit. Both the observed severity variation (chapters 2 and 3) and between-sentence variation (chapter 5) are far more easily to be reconciled with the view that Broca patients suffer from some processing deficit rather than from a loss of syntactic knowledge. The results of all experiments together seem to indicate that Broca patients can be impaired in constructing a representation spanning the whole utterance when syntactic information is not available with the right level of activation and not available at the right moment in time. The precise underlying mechanism that causes these disturbances of the syntactic comprehension process cannot be inferred from the present data. However, it is conceivable, as has been proposed in the literature previously (e.g. Haarmann, Just, & Carpenter, 1997; Miyake, Carpenter, & Just, 1994, 1995; Kolk & Van Grunsven, 1985; Hagoort, 1990) that this timing deficit is caused by a pathological reduction in computational resources (‘poor competitiveness’ in the terminology of Vosse & Kempen, 2000). This processing capacity hypothesis seems to account for both the variation in degree of severity that was found in the experiments and for the observed compensation strategies: the degree of severity could vary with the amount of reduction of capacity, and compensation could occur as adaptation to lack of processing capacity.

Future research

One of the unexpected findings in chapter 4 was that in the elderly controls the manipulation of word category did not result in a LAN effect. This forced me to confine my conclusions with respect to the data of the Broca patients to their P600/SPS effect. The absence of the LAN effect in the elderly controls was remarkable since a previous study with exactly the same experimental materials (Hagoort, Wassenaar, & Brown, 2003a), elicited in college-aged participants not only a P600/SPS effect but also a LAN effect. However, the effects of aging on syntax-related ERP effects have not been systematically investigated. This in contrast to the N400 effect (Kutas & Iragui, 1998). Future research should therefore unravel whether and/or how with aging the overall pattern of syntax-related ERP effects changes, both in the auditory and visual domain. This would also enable conclusions as to whether, and if so in what respect, the LAN effect is affected by aphasia.

The electrophysiological demonstration of multiple-route plasticity shows that the brain is not a passive victim of brain damage (cf. Kolk, 2000). The question presents itself how this mechanism develops after the onset of a CVA. All patients I tested were in a chronic phase of aphasia. A longitudinal study could contribute to answering this question.

Final remark

This dissertation focused on syntactic comprehension problems in patients with Broca's aphasia from an electrophysiological perspective. Results from the different experiments revealed on the one hand changes in syntactic information activation, on the other hand the existence of compensation mechanisms. Conversations with these patients and their family members however revealed a yearning for the days of yore before dark clouds of aphasia gathered over them. May further research contribute to lighten this darkness.

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APPENDICES

APPENDIX 1

Experimental materials used in Chapter 2

SUBJECT-VERB AGREEMENT VIOLATIONS (CONJOINED SENTENCES)

1. De groenteboer groet de klanten en *vraagt/vragen* het kind niet zoveel lawaai te maken.
2. De agent hoort de dieven en *probeert/proberen* de deur zo zachtjes mogelijk te sluiten.
3. De professor verbetert de studenten en *schrijft/schrijven* het vraagstuk op het schoolbord.
4. De soldaten gehoorzamen de sergeant en *marcheren/marcheert* naar het schietterrein.
5. De vrouwen betalen de bakker en *nemen/neemt* het brood mee naar huis.
6. De buren bellen de loodgieter en *onderhandelen/onderhandelt* over de kosten van de reparatie.
7. De matrozen roepen de kapitein en *eisen/eist* een lekkere fles rum.
8. De kapers gijzelen de piloot en *veroorzaken/veroorzaakt* een noodlanding midden in het weiland.
9. De kelner bedient de gasten en *hoort/horen* de kok heel hard roepen.
10. De zeilers zien de zwemmer en *vrezen/vreest* een botsing midden op het meer.
11. De wandelaars volgen de reisleider en *dragen/draagt* een rugzak tijdens de wandeling.
12. De oppas straft de kinderen en *vertelt/vertellen* de moeder precies wat er gebeurd is.
13. De dokters onderzoeken de patiënt en *tillen/tilt* het been een beetje omhoog.
14. De leidsters zoeken de kleuter en *roepen/roept* na een dag de hulp van de politie in.
15. De dames bezoeken de man en *kopen/koopt* een bosje bloemen voor hem.
16. De bewoners waarschuwen de buurman en *bellen/belt* de brandweer vanuit een telefooncel.
17. De kardinaal ontvangt de bisschoppen en *bespreekt/bespreken* het probleem van de kerkverlating.
18. De collega's feliciteren de jubilaris en *drinken/drinkt* een glas wijn tijdens de receptie.
19. De slager bedankt de jongens en *geeft/geven* de peuter een stukje worst om op te eten.
20. De boer verbergt de onderduikers en *beluistert/beluisteren* het laatste nieuws via de radio.
21. De overvallers bedreigen de winkelier en *grijpen/grijpt* het geld uit de kassa.
22. De stuurman redt de drenkelingen en *juicht/juichen* van vreugde na de angstige nacht.
23. De honden bijten de postbode en *rennen/rent* snel naar de overkant van de straat.
24. De familieleden troosten de weduwe en *halen/haalt* herinneringen aan haar man op.
25. De oma verwent haar kleindochters en *geniet/genieten* enorm van hun jeugdig enthousiasme.
26. De lijfwacht bewaakt de prinsen en *rookt/roken* sigaretten in de paleistuin.
27. De pubers plagen de docent en *schreeuwen/schreeuwt* luid tijdens de les.
28. De journalist ondervraagt de wethouders en *verlangt/verlangen* opheldering van het gifschandaal.
29. De fietsers passeren de voetganger en *zwaaien/zwaait* naar de man met de paraplu.
30. De dirigent complimenteert de koorleden en *leest/lezen* de recensie uit de krant voor.
31. De komiek amuseert de toeschouwers en *lacht/lachen* zelf luidkeels.
32. De portier verwelkomt de sollicitanten en *begint/beginnen* over het weer te praten.
33. De apen zien het publiek en *eten/eet* de bananen met smaak op.
34. De rechter veroordeelt de inbrekers en *verlaat/verlaten* zwijgend de rechtszaal.
35. De misdadigers ontvoeren het meisje en *overnachten/overnacht* in een oude schuur.
36. De chirurg opereert de slachtoffers en *zweet/zweten* in de warme operatiekamer.
37. De tennisspelers beledigen de scheidsrechter en *weigeren/weigert* de wedstrijd voort te zetten.
38. De minister ontmoet de vakbondsleiders en *praat/praten* over de toegenomen werkeloosheid.
39. De kok begeleidt de stagiaires en *proeft/proeven* van de goed bereide soep.
40. De nichtjes omhelsen de tante en *popelen/popelt* van ongeduld om het snoep op te eten.
41. De conducteur controleert de reizigers en *telt/tellen* het aantal passagiers.
42. De opa kust de kleinkinderen en *sjouwt/sjouwen* de koffer naar de auto toe.
43. De caféhouder tracteert de bezoekers en *brengt/brengen* een toast uit op het nieuwe jaar.
44. De poes ziet de honden en *vlucht/vluchten* snel een steegje in.

45. De fysiotherapeut masseert de voetballers en *kletst/kletsen* aan een stuk door.
46. De zakkenrollers bestelen de toerist en *hollen/holt* naar de uitgang van de winkel.
47. De dominee zegent de kerkgangers en *wenst/wensen* iedereen een fijne zondag toe.
48. De werkster ontdekt de muizen en *loopt/lopen* haastig naar buiten.
49. De jagers zien het hert en *verschuilen/verschuilt* zich achter een boom.
50. De secretaresses helpen de directeur en *bladeren/bladert* in de agenda.
51. De kinderen pesten de zwerver en *verzinnen/verzint* allerlei scheldwoorden.
52. De huurders verrassen de huisbaas en *verven/verft* het trappenhuis geel.
53. De bioloog bekijkt de vogels en *opent/openen* de snavels om er voer in te stoppen.
54. De zendeling bekeert de stamhoofden en *organiseert/organiseren* een kerkdienst in het dorp.
55. De orkestleden begeleiden de violist en *zorgen/zorgt* voor een prachtig concert.
56. De padvinders helpen de grijsaard en *duwen/duwt* de winkelwagen in de supermarkt.
57. De boswachter berispt de kampeerders en *ruimt/ruimen* het afval mopperend op.
58. De verpleegsters bewonderen de baby en *strelen/streelt* zijn geinige snoetje.
59. De slaven haten de baas en *bedenken/bedenkt* een plan om te vluchten.
60. De werkgever ontslaat de arbeiders en *betaalt/betalen* zijn schuld aan de belastingdienst.

SUBJECT-VERB AGREEMENT VIOLATIONS (EMBEDDED SENTENCES)

1. De groenteboer die de klanten groet, *vraagt/vragen* het kind niet zoveel lawaai te maken.
2. De agent die de dieven hoort, *probeert/proberen* de deur zo zachtjes mogelijk te sluiten.
3. De professor die de studenten verbetert, *schrijft/schrijven* het vraagstuk op het schoolbord.
4. De soldaten die de sergeant gehoorzamen, *marcheren/marcheert* naar het schietterrein.
5. De vrouwen die de bakker betalen, *nemen/neemt* het brood mee naar huis.
6. De buren die de loodgieter bellen, *onderhandelen/onderhandelt* over de kosten van de reparatie.
7. De matrozen die de kapitein roepen, *eisen/eist* een lekkere fles rum.
8. De kapers die de piloot gijzelen, *veroorzaken/veroorzaakt* een noodlanding midden in het weiland.
9. De kelner die de gasten bedient, *hoort/horen* de kok heel hard roepen.
10. De zeilers die de zwemmer zien, *vrezen/vreest* een botsing midden op het meer.
11. De wandelaars die de reisleider volgen, *dragen/draagt* een rugzak tijdens de wandeling.
12. De oppas die de kinderen straft, *vertelt/vertellen* de moeder precies wat er gebeurd is.
13. De dokters die de patiënt onderzoeken, *tillen/tilt* het been een beetje omhoog.
14. De leidsters die de kleuter zoeken, *roepen/roept* na een dag de hulp van de politie in.
15. De dames die de man bezoeken, *kopen/koopt* een bosje bloemen voor hem.
16. De bewoners die de buurman waarschuwen, *bellen/belt* de brandweer vanuit een telefooncel.
17. De kardinaal die de bisschoppen ontvangt, *bespreekt/bespreken* het probleem van de kerkverlating.
18. De collega's die de jubilaris feliciteren, *drinken/drinkt* een glas wijn tijdens de receptie.
19. De slager die de jongens bedankt, *geeft/geven* een stukje worst om op te eten.
20. De boer die de onderduikers verbergt, *beluistert/beluisteren* het laatste nieuws via de radio.
21. De overvallers die de winkelier bedreigen, *grijpen/grijpt* het geld uit de kassa.
22. De stuurman die de drenkelingen redt, *juicht/juichen* van vreugde na de angstige nacht.
23. De honden die de postbode bijten, *rennen/rent* snel naar de overkant van de straat.
24. De familieleden die de weduwe troosten, *halen/haalt* herinneringen aan haar man op.
25. De oma die haar kleindochters verwent, *geniet/genieten* enorm van hun jeugdig enthousiasme.
26. De lijfwacht die de prinsen bewaakt, *rookt/roken* sigaretten in de paleistuin.
27. De pubers die de docent plagen, *schreeuwen/schreeuwt* luid tijdens de les.
28. De journalist die de wethouders ondervraagt, *verlangt/verlangen* opheldering van het gifschandaal.
29. De fietsers die de voetganger passeren, *zwaaien/zwaait* naar de man met de paraplu.
30. De dirigent die de koorleden complimenteert, *leest/lezen* de recensie uit de krant voor.
31. De komiek die de toeschouwers amuseert, *lacht/lachen* zelf luidkeels.
32. De portier die de sollicitanten verwelkomt, *begint/beginnen* over het weer te praten.
33. De apen die het publiek zien, *eten/eet* de bananen met smaak op.
34. De rechter die de inbrekers veroordeelt, *verlaat/verlaten* zwijgend de rechtszaal.
35. De misdadigers die het meisje ontvoeren, *overnachten/overnacht* in een oude schuur.
36. De chirurg die de slachtoffers opereert, *zweet/zweten* in de warme operatiekamer.
37. De tennisspelers die de scheidsrechter beledigen, *weigeren/weigert* de wedstrijd voort te zetten.
38. De minister die de vakbondsleiders ontmoet, *praat/praten* over de toegenomen werkeloosheid.
39. De kok die de stagiaires begeleidt, *proeft/proeven* van de goed bereide soep.
40. De nichtjes die de tante omhelsen, *popelen/popelt* van ongeduld om het snoep op te eten.
41. De conducteur die de reizigers controleert, *telt/tellen* het aantal passagiers.

42. De opa die de kleinkinderen kust, *sjouwt/sjouwen* de koffer naar de auto toe.
43. De caféhouder die de bezoekers tracteert, *brengt/brengen* een toast uit op het nieuwe jaar.
44. De poes die de honden ziet, *vlucht/vluchten* snel een steegje in.
45. De fysiotherapeut die de voetballers masseert, *kletst/kletsen* aan een stuk door.
46. De zakkenrollers die de toerist bestelen, *hollen/holt* naar de uitgang van de winkel.
47. De dominee die de kerkgangers zegent, *wenst/wensen* iedereen een fijne zondag toe.
48. De werkster die de muizen ontdekt, *loopt/lopen* haastig naar buiten.
49. De jagers die het hert zien, *verschuilen/verschuilt* zich achter een boom.
50. De secretaresses die de directeur helpen, *bladeren/bladert* in de agenda.
51. De kinderen die de zwerver pesten, *verzinnen/verzint* allerlei scheldwoorden.
52. De huurders die de huisbaas verrassen, *verven/verft* het trappenhuis geel.
53. De bioloog die de vogels bekijkt, *opent/openen* de snavels om er voer in te stoppen.
54. De zendeling die de stamhoofden bekeert, *organiseert/organiseren* een kerkdienst in het dorp.
55. De orkestleden die de violist begeleiden, *zorgen/zorgt* voor een prachtig concert.
56. De padvinders die de grijsaard helpen, *duwen/duwt* de winkelwagen in de supermarkt.
57. De boswachter die de kampeerders berispt, *ruimt/ruimen* het afval mopperend op.
58. De verpleegsters die de baby bewonderen, *strelen/streelt* zijn geinige snoetje.
59. De slaven die de baas haten, *bedenken/bedenkt* een plan om te vluchten.
60. De werkgever die de arbeiders ontslaat, *betaalt/betalen* zijn schuld aan de belastingdienst.

APPENDIX 2

Experimental materials used in Chapter 3

WORD ORDER VIOLATIONS

1. Het meisje zit tevreden naar het *netjes gestreken/gestreken netjes wasgoed* te kijken.
2. De leraar betrekt de *enigszins verlegen/verlegen enigszins puber* bij de discussie.
3. Het publiek moet lachen om de *omlaag zakkende/zakkende omlaag broek* van de clown.
4. De dokter vertelt de vrouw over haar *uitermate geringe/geringe uitermate kans* op herstel.
5. De echtgenoot schrikt van de *nogal emotionele/emotionele nogal reactie* van zijn vrouw.
6. De jongen haalt beteuterd de *dunnetjes belegde/belegde dunnetjes boterham* uit zijn broodtrommel.
7. De verpleegster troost het *zachtjes huilende/huilende zachtjes kind* in het ziekenhuis.
8. De oppas kijkt tevreden naar de *stilletjes spelende/spelende stilletjes peuter* in de box.
9. De resultaten van het *zojuist afgeronde/afgeronde zojuist onderzoek* zullen gauw gepubliceerd worden.
10. De verkoper verstaat de *zachtjes sprekende/sprekende zachtjes klant* nauwelijks.
11. De metselaar kon de *plotseling vallende/vallende plotseling balk* gelukkig ontwijken.
12. De brandweerman kijkt tevreden naar het *bijna gebluste/gebluste bijna vuur* in de school.
13. Na de aardbeving vond men in de *totaal verwoeste/verwoeste totaal dorpen* geen overlevenden.
14. Het orkest speelde voor een *vrijwel lege/lege vrijwel zaal* in Nijmegen.
15. De leraar kan zijn ergernis over de *dikwijls rumoerige/rumoerige dikwijls leerling* goed verbergen.
16. De journalist schrijft over de *nogal kritieke/kritieke nogal situatie* in het Midden Oosten.
17. De huisvrouw vertelt over haar *uitermate slechte/slechte uitermate ervaring* met het wasmiddel.
18. De tante noemt de *nagenoeg vergeten/vergeten nagenoeg ruzie* ieder jaar.
19. De leerling krijgt straf voor de *nogal brutale/brutale nogal vraag* tijdens de les.
20. Mijn tante is bezorgd over het *enigszins schuwe/schuwe enigszins zoontje* van haar buurman.
21. De kapitein waarschuwt het *voorbij varende/varende voorbij schip* via zijn mobilofoon.
22. De kinderen bezoeken het *alom bekende/bekende alom circus* in de vakantie.
23. De jager schiet op het *snel rennende/rennende snel hert* in het bos.
24. Het meisje bekijkt de *vooraan liggende/liggende vooraan boeken* heel aandachtig.
25. De legerarts opereert de *ernstig gewonde/gewonde ernstig soldaat* zonder een verdoving.
26. De leraar kijkt de *zojuist gemaakte/gemaakte zojuist toets* snel na.
27. De leraar groet het *achteraan huppelende/huppelende achteraan meisje* van een afstand.
28. De kraamvisite kijkt vertederd naar de *zoetjes slapende/slapende zoetjes baby* in de wieg.
29. De jongen bezoekt zowel de film als het *daarna gehouden/gehouden daarna feest* met plezier.
30. De juwelier bekijkt de *nogal beschadigde/beschadigde nogal armband* onder een vergrootglas.
31. Een cameraman filmt de *voorop rennende/rennende voorop atleet* in het stadion.
32. De verkoopster bekijkt de kandelaar en de *daarbij geleverde/geleverde daarbij kaarsen* zeer nauwkeurig.
33. Onze hond bijt de *achterom kijkende/kijkende achterom wandelaar* in zijn been.
34. De technicus repareert de *nogal verouderde/verouderde nogal antenne* van de radio.
35. De kranten schrijven over het *dikwijls moedige/moedige dikwijls ingrijpen* van de politie.
36. De gasten bestellen het menu en de *daarbij aanbevolen/aanbevolen daarbij huiswijn* uit de Elzas.
37. De politie arresteert de *plotseling gevluchte/gevluchte plotseling dief* na een zoektocht.
38. De huurbaas bestrijdt de *nogal agressieve/agressieve nogal ratten* met gif.
39. Mijn broer at de soep en de *daarna opgediende/opgediende daarna gerechten* helemaal op.
40. De man brengt zijn *aldoor blaffende/blaffende aldoor hond* naar het asiel.
41. De loodgieter vervangt de *aldoor lekkende/lekkende aldoor gootsteen* in de keuken.
42. Het publiek prijst de *voorop rijdende/rijdende voorop wielrenner* in de gele trui.
43. De vrouw ontwijkt de *plotseling overstekende/overstekende plotseling auto* net op tijd.
44. De jongen stort geld om het *alom getroffen/getroffen alom Afrika* te kunnen helpen.

45. De schutting beschermt het verkeer tegen de *omlaag vallende/vallende omlaag stenen* tijdens de verbouwing.
46. Mijn tante verdraagt het *alsmaar toenemende/toenemende alsmaar lawaai* niet langer.
47. De dame zwaait naar het *vooraan zittende/zittende vooraan echtpaar* in de schouwburg.
48. De secretaresse raakt overspannen van de *alsmaar groeiende/groeiende alsmaar stapel* met brieven.
49. De minister luistert naar de *enigszins overdreven/overdreven enigszins kritiek* van zijn collega.
50. De dokter reageert niet op het *nogal overdreven/overdreven nogal verzoek* van de vrouw.
51. Mijn broer gebruikt een *nogal oude/oude nogal computer* voor zijn studie.
52. De conciërge draagt de *netjes opgevouwen/opgevouwen netjes jassen* naar boven.
53. De kapper test de haarlak en de *daarmee opgemaakte/opgemaakte daarmee pruiken* zeer grondig.
54. Mijn ouders amuseren zich op de *hartstikke gezellige/gezellige hartstikke avond* van het buurthuis.
55. De jongen koopt voor zijn vriendin een *hartstikke duur/duur hartstikke horloge* bij de juwelier.
56. Mijn oma legt een *netjes gesteven/gesteven netjes servet* naast haar bord.
57. Het publiek geeft de *vrijwel uitgeputte/uitgeputte vrijwel schaatser* een applaus.
58. Mijn moeder vernaait mijn *vrijwel versleten/versleten vrijwel blouse* nog eenmaal.
59. De politie arresteert de *nogal brutale/brutale nogal supporter* na de wedstrijd.
60. De docent straft de *voorover gebogen/gebogen voorover student* wegens spieken.

APPENDIX 3

Experimental materials used in Chapter 4

WORD CATEGORY VIOLATIONS

1. Erik bemerkte de giftige *jager / jagen* tussen de bomen.
2. Kees vertelde de anonieme *adem / ademen* over de orkaan.
3. De man zag de moderne *bloei / bloeien* op de camping.
4. De indiaan keek naar de vrolijke *melk / melken* bij het kampvuur.
5. De vrouw hoorde de formele *regen / regenen* achter het sportveld.
6. De jongen bekeek de dappere *spiegel / spiegelen* in Parijs.
7. Marijn vond de sierlijke *mest / mesten* in de kerk.
8. Evelien luisterde naar de schuine *ijzel / ijzelen* aan de kust.
9. Janneke zag de trouwe *zegen / zegenen* bij de rivier.
10. De jongen ontdekte de openbare *bagger / baggeren* op televisie.
11. De jongen belde de zieke *winkel / winkelen* tijdens een verbouwing.
12. Mirjam bekeek de ijverige *bundel / bundelen* met een glimlach.
13. Miep besprak de unanieme *lepel / lepelen* op de snelweg.
14. Meike liep naar de ijskoude *bouw / bouwen* achter de rozenstruik.
15. Het meisje bemerkte de lege *fixatie / fixeren* halverwege de klim.
16. Jos negeerde de marmeren *beslissing / beslissen* bij Alkmaar.
17. Karin beschouwde de zinkende *tel / telt* op het voordek.
18. De jongeman beschreef de zoete *irritatie / irriteert* op de rotonde.
19. De tuinman ontweek de vergeefse *huur / huurt* tijdens de oorlog.
20. Pepijn lachte om de krakende *vouw / vouwt* in de spiegel.
21. Albert keek naar de botte *klap / klapt* in zijn toetje.
22. Het meisje voelde aan de verlegen *kluif / kluift* op school.
23. Marieke keurde de bazige *grens / grenst* op het kruispunt.
24. Annelies voelde de koude *twijfel / twijfelt* in de helicopter.
25. De stukadoor ontdekte de hollende *lijm / lijmt* naast zijn bed.
26. De journalist noteerde de rose *gooi / gooit* in het park.
27. De houthakker ontweek de ijdele *schroef / schroeft* op dinsdag.
28. De serveerster beschreef de galante *veiling / veilt* met stijl.
29. Het kuiken negeerde de fiscale *grimeur / grimeert* onder het zand.
30. De tandarts probeerde de riante *speurder / speurt* aan de overkant.
31. De voorman bekeek de roestige *tekening / tekent* zeer nauwkeurig.
32. Het meisje luisterde naar de kosmische *acteur / acteert* in de hal.
33. De jongen gaf de objectieve *schok / schokte* een peer.
34 Jan verwacht de gelukkige *oogst / oogstte* meestal later.
35. Betty ziet de angstige *barst / barstte* in de kelder.
36. Oma wist van de barse *knal / knalde* rond Kerstmis.
37. De vrouw leert over de stoffige *groet / groette* in Turkije.
38. Valerie hoort van de sluwe *zaag / zaagde* op de werkvloer.
39. Het jongetje las over de listige *zeef / zeefde* in een reisgids.
40. Niemand bekijkt de voedzame *rem / remde* op de berg.
41 Iedereen zag de knusse *knuppel / knuppelde* onder het geraamte.
42. Sommigen kenden de uitvoerige *puzzel / puzzelde* nog van vroeger.
43. Weinigen weten van de ongeboren *fiets / fietste* en zijn moeder.
44. Rudi kijkt op van de koortsige *bel / belde* in zijn kopje.

45. Renee doet de gloeiende *moord / moordde* in een theezeefje.
46. De robot zag de maximale *griezel / griezelde* op de torenspits.
47. De moeder ontdekt de donkere *groei / groeide* naast de baksteen.
48. De vader bezag de norse *knoop / knoopte* in de genen.
49. Oom Henk bemerkt de gehoorzame *produkties / produceren* op de Noordpool.
50. Tante Julia besprak de bekwame *correcties / corrigeren* bij de groenteboer.
51. Neef Guus verhaalde van de holle *trainers / trainen* in het pakhuis.
52. Mijn nichtje omzeilde de verliefde *douches / douchen* voor het feest.
53. De peuter vertelde over de intense *bedriegers / bedriegen* in de politiek.
54. De consument overzag de steile *adopties / adopteren* in de film.
55. De commentator roddelde over de verticale *leugens / liegen* in het hotel.
56. De zakenvrouw studeerde op de rotsige *beloftes / beloven* in de krant.
57. De filmster bestelde de bedrijvige *klachten / klagen* op de bruiloft.
58. De held verzon de tengere *reparaties / repareren* op kantoor.
59. De modekoning belde over de gulle *verplegers / verplegen* in het ziekenhuis.
60. De kok onthield de zeezieke *oefeningen / oefenen* in de woestijn.
61. De heks keek op van de belezen *evacuaties / evacueren* onder water.
62. De drummer luistert naar de ruime *zwervers / zwerven* op het politieburo.
63. De postbode bekeek de wakkere *afdalingen / afdalen* in de toekomst.
64. De olifant bemerkt de sappige *afspraken / afspreken* op de tennisbaan.
65. De lerares verhaalt van de stroeve *blokkades / blokkeert* in de natuur.
66. De huisarts overzag de failliete *beloningen / beloont* in de kliniek.
67. Het kindje kijkt naar de dubbele *bewakers / bewaakt* in het paviljoen.
68. Iedereen ziet de natte *debatten / debatteert* in de biobak.
69. Niemand besprak de boze *decoraties / decoreert* in de studio.
70. Sommigen vinden de kleverige *dirigenten / dirigeert* in het keukenkastje.
71. Weinigen onthouden de ovale *evaluaties / evalueert* uit het journaal.
72. Enkelen beschreven de vlammende *examens / examineert* in de herfst.
73. Meneer Dijkstra overziet de ronde *excuses / excuseert* op tafel.
74. Marjan vergeet de gulzige *exposities / exposeert* op de poster.
75. De knecht liep naar de draadloze i*mitaties / imiteert* in de duinen.
76. De ambtenaar hoort de trotse *massages / masseert* elke ochtend.
77. Anne bestelt de losse *spionnen / spioneert* per telefoon.
78. De student keurt de bonte *deserteurs / deserteert* in de ballon.
79. De man roddelt over de defecte *bezoekers / bezoekt* op de stoomboot.
80. De vrouw lacht om de spoedige *bewegingen / beweegt* in de folder.
81. Het ventje voelde aan de afbetaalde *tennissers / tenniste* in het lesboek.
82. De dochter noteert de vlijtige *uitingen / uitte* op een bananenschil.
83. De grijsaard bemerkt de verkouden *adviezen / adviseerde* in de handleiding.
84. Het elfje keek op van de innerlijke *saboteurs / saboteerde* in de auto.
85. De buurman ontdekt de doffe *stakingen / staakte* in het land.
86. De prins beschrijft de fruitige *prestaties / presteerde* op het schoolkamp.
87. De burger zag de nauwe *musici / musiceerde* in de kerk.
88. De molenaar droomt over de mentale *telers / teelde* in de wolken.
89. De dwerg noteerde de logische *meditaties / mediteerde* tijdens de cursus.
90. De bullebak vergat de penetrante *metselaars / metselde* tijdens zijn middagslaap.
91. Het lieverdje aanschouwt de mannelijke *leningen / leende* op het strand.
92. De grapjas negeerde de intacte *reizigers / reisde* op de ijsschots.
93. De man leek op de kruimige *roddelaars / roddelde* tijdens de verhuizing.
94. De vrouw droomde over de onderste *stichters / stichtte* op de kermis.
95. De clown ontdekte de uiterlijke *aanbidders / aanbad* in de kroeg.
96. Jelle besprak de tijdige *dromers / droomde* bij de koffie.

SEMANTICALLY CONGRUENT SENTENCES

1. De timmerman kreeg een compliment van zijn *baas*.
2. Met mooi weer huurt de man vaak een *boot*.
3. De kleuter had een gat in zijn *broek*.
4. Op het nachtkastje in de hotelkamer ligt een *bijbel*.
5. Het meisje speelt vaak bij de *buren*.
6. De flatbewoner zit graag op het *balkon*.
7. De buurman brouwt sinds kort zijn eigen *bier*.
8. Dit eiland is goed te bereiken via een *brug*.
9. Ik koop altijd mijn brood bij een warme *bakker*.
10. De kleine jongen speelde met een *bal*.
11. De poes sprong op het *dak*.
12. De jongen droogde zich af met een *doek*.
13. De radio werd verpakt in een *doos*.
14. Veel sprekers meldden zich voor het *congres*.
15. Ik ga elke maand naar de *kapper*.
16. Geduldig luisterde de ober naar de *klant*.
17. De vrome jongen ging op zijn achttiende in het *klooster*.
18. De bejaarde vrouw droeg de zware *koffer*.
19. Met zijn allen stonden de kinderen in een *kring*.
20. De schrijfster kan slecht tegen *kritiek*.
21. De vrouw eet meestal in de *keuken*.
22. Het snoepje bleef steken in zijn *keel*.
23. De zwerver heeft geen geld voor nieuwe *kleren*.
24. Op de veiling kocht de miljonair een *klok*.
25. Er stond een schildwacht bij het *kasteel*.
26. De zakenman kocht een mooie stropdas voor zijn *pak*.
27. De eend zwom in de vijver van het *park*.
28. De moeder verzorgde de billetjes van de baby met *poeder*.
29. Stef bespreekt met zijn baas een mooi *plan*.
30. De dominee klom de kansel op voor de *preek*.
31. Veel boeren halen het water uit een *put*.
32. Het meisje heeft een nieuwe mand voor haar *poes*.
33. De oude poes zat op de *plank*.
34. De voetballers wonnen het *toernooi*.
35. De oude man heeft maar twee *tanden*.
36. Er rijden steeds vaker conducteurs mee op de *tram*.
37. Overdag drinkt mijn oma weinig *thee*.
38. De roeier verhoogde allengs zijn *tempo*.
39. Per ongeluk trapte Rene op mijn kleine *teen*.
40. De jager stopte de patronen in zijn *tas*.

SEMANTICALLY ANOMALOUS SENTENCES

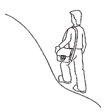
1. Het meisje stopte het snoepje in haar *bloem*.
2. De kok eet zijn macaroni met een *kaars*.
3. De toneelspeler kleedde zich uit achter het *bloed*.
4. Het gereedschap wordt bewaard in de *kaas*.
5. Opa vertelde aan zijn kleinkind een fantastisch *bureau*.
6. Met haar verjaardag krijgt het meisje vaak een *kelder*.
7. De familiefoto staat op de *traan*.
8. De agenten doorzochten het *klimaat*.
9. De koningin bezocht de uitvoering van het *puin*.
10. De hond slaapt meestal in de *toerist*.
11. Anne kraste haar naam in de deur met een *tomaat*.

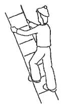
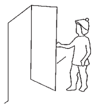
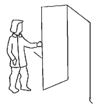
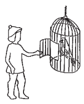
12. Met gemak sprong Annette over de brede *kliniek*.
13. De jongen maakte een dreigende beweging met zijn *plein*.
14. De wesp viel bij mijn zusje in de *dijk*.
15. De baby lag heerlijk te slapen in de *drank*.
16. Als hij in de tuin werkt draagt Sjors *brood.*
17. Er komen steeds meer zieke kinderen voor in de *brief*.
18. De dief kwam het huis binnen via het *publiek*.
19. De oude dame kocht maar een halve *droom*.
20. In de speeltuin roept het meisje haar *beker*.
21. De verhuizer zette het schilderij tegen de *kogel*.
22. De dief verstopte zich in de *duivel*.
23. Eline lijmde snel haar kapotte *knecht*.
24. De japanse toneelspeler droeg een bijzonder *terras*.
25. Er zit een vliegje in mijn *dans*.
26. De moeder troost haar kind altijd met een *drempel*.
27. De matroos heeft erge pijn in zijn *kraag*.
28. Wij gaan iedere week naar de *boter*.
29. Het warenhuis heeft een speciale afdeling voor de *planeet*.
30. Tegenwoordig drinken de kinderen veel *koper*.
31. Langzaam reed de vrachtwagen door de *tekst*.
32. De jongen botste hard tegen de *pruik*.
33. De leraar gaf het kind een *keizer*.
34. De hongerige man verlangde naar een boterham met *pakjes*.
35. De emmer zit vol met *koorts*.
36. De gevaarlijke dieren zitten in een *pater*.
37. De olifant ging slapen in de *prins*.
38. In bedrukte stemming stonden de mannen rond het *potlood*.
39. Mijn oom schreeuwde hard tegen zijn *baard*.
40. De mooie valk zit op het *bedrag*.

APPENDIX 4

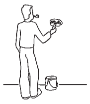
Experimental materials used in Chapter 5

Semantically irreversible active sentences:

Picture		Sentence	
1)		matching: mismatching:	De jonge vrouw op dit plaatje knipt het kleine boeket Het kleine boeket op dit plaatje knipt de jonge vrouw
2)		matching: mismatching:	De jonge vrouw op dit plaatje knipt het kleine boeket Het kleine boeket op dit plaatje knipt de jonge vrouw
3)		matching: mismatching:	De jonge vrouw op dit plaatje snijdt het verse brood Het verse brood op dit plaatje snijdt de jonge vrouw
4)		matching: mismatching:	De jonge vrouw op dit plaatje snijdt het verse brood Het verse brood op dit plaatje snijdt de jonge vrouw
5)		matching: mismatching:	De jonge vrouw op dit plaatje leest het spannende boek Het spannende boek op dit plaatje leest de jonge vrouw
6)		matching: mismatching:	De jonge vrouw op dit plaatje leest het spannende boek Het spannende boek op dit plaatje leest de jonge vrouw
7)		matching: mismatching:	De jonge vrouw op dit plaatje leest de interessante krant De interessante krant op dit plaatje leest de jonge vrouw
8)		matching: mismatching:	De jonge vrouw op dit plaatje leest de interessante krant De interessante krant op dit plaatje leest de jonge vrouw
9)		matching: mismatching:	De lange man op dit plaatje beklimt de steile berg De steile berg op dit plaatje beklimt de lange man
10)		matching: mismatching:	De lange man op dit plaatje beklimt de steile berg De steile berg op dit plaatje beklimt de lange man

11)		matching:	De lange man op dit plaatje beklimt de steile ladder
		mismatching:	De steile ladder op dit plaatje beklimt de lange man
12)		matching:	De lange man op dit plaatje beklimt de steile ladder
		mismatching:	De steile ladder op dit plaatje beklimt de lange man
13)		matching:	De jonge vrouw op dit plaatje begiet het kleine bloemperk
		mismatching:	Het kleine bloemperk op dit plaatje begiet de jonge vrouw
14)		matching:	De jonge vrouw op dit plaatje begiet het kleine bloemperk
		mismatching:	Het kleine bloemperk op dit plaatje begiet de jonge vrouw
15)		matching:	De jonge vrouw op dit plaatje begiet de lage struik
		mismatching:	De lage struik op dit plaatje begiet de jonge vrouw
16)		matching:	De jonge vrouw op dit plaatje begiet de lage struik
		mismatching:	De lage struik op dit plaatje begiet de jonge vrouw
17)		matching:	Het kleine meisje op dit plaatje opent de smalle deur
		mismatching:	De smalle deur op dit plaatje opent het kleine meisje
18)		matching:	Het kleine meisje op dit plaatje opent de smalle deur
		mismatching:	De smalle deur op dit plaatje opent het kleine meisje
19)		matching:	Het kleine meisje op dit plaatje opent de mooie kooi
		mismatching:	De mooie kooi op dit plaatje opent het kleine meisje
20)		matching:	Het kleine meisje op dit plaatje opent de mooie kooi
		mismatching:	De mooie kooi op dit plaatje opent het kleine meisje
21)		matching:	Het kleine meisje op dit plaatje plant de mooie bloem
		mismatching:	De mooie bloem op dit plaatje plant het kleine meisje
22)		matching:	Het kleine meisje op dit plaatje plant de mooie bloem
		mismatching:	De mooie bloem op dit plaatje plant het kleine meisje
23)		matching:	Het kleine meisje op dit plaatje plant de jonge boom
		mismatching:	De jonge boom op dit plaatje plant het kleine meisje
24)		matching:	Het kleine meisje op dit plaatje plant de jonge boom
		mismatching:	De jonge boom op dit plaatje plant het kleine meisje
25)		matching:	De lange man op dit plaatje verft het oude hek
		mismatching:	Het oude hek op dit plaatje verft de lange man
26)		matching:	De lange man op dit plaatje verft het oude hek
		mismatching:	Het oude hek op dit plaatje verft de lange man

27) 
matching: De lange man op dit plaatje verft de grote muur
mismatching: De grote muur op dit plaatje verft de lange man

28) 
matching: De lange man op dit plaatje verft de grote muur
mismatching: De grote muur op dit plaatje verft de lange man

29) 
matching: De jonge vrouw op dit plaatje wast de vuile auto
mismatching: De vuile auto op dit plaatje wast de jonge vrouw

30) 
matching: De jonge vrouw op dit plaatje wast de vuile auto
mismatching: De vuile auto op dit plaatje wast de jonge vrouw

31) 
matching: De jonge vrouw op dit plaatje wast de vuile kleding
mismatching: De vuile kleding op dit plaatje wast de jonge vrouw

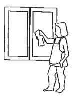
32) 
matching: De jonge vrouw op dit plaatje wast de vuile kleding
mismatching: De vuile kleding op dit plaatje wast de jonge vrouw

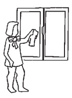
33) 
matching: Het kleine meisje op dit plaatje draagt de lege mand
mismatching: De lege mand op dit plaatje draagt het kleine meisje

34) 
matching: Het kleine meisje op dit plaatje draagt de lege mand
mismatching: De lege mand op dit plaatje draagt het kleine meisje

35) 
matching: Het kleine meisje op dit plaatje draagt de nieuwe bal
mismatching: De nieuwe bal op dit plaatje draagt het kleine meisje

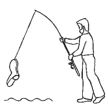
36) 
matching: Het kleine meisje op dit plaatje draagt de nieuwe bal
mismatching: De nieuwe bal op dit plaatje draagt het kleine meisje

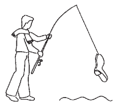
37) 
matching: Het kleine meisje op dit plaatje poetst het vuile raam
mismatching: Het vuile raam op dit plaatje poetst het kleine meisje

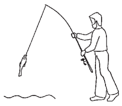
38) 
matching: Het kleine meisje op dit plaatje poetst het vuile raam
mismatching: Het vuile raam op dit plaatje poetst het kleine meisje

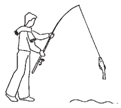
39) 
matching: Het kleine meisje op dit plaatje poetst het vieze gebit
mismatching: Het vieze gebit op dit plaatje poetst het kleine meisje

40) 
matching: Het kleine meisje op dit plaatje poetst het vieze gebit
mismatching: Het vieze gebit op dit plaatje poetst het kleine meisje

41) 
matching: De lange man op dit plaatje vangt de natte laars
mismatching: De natte laars op dit plaatje vangt de lange man

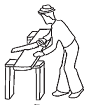
42)  matching: De lange man op dit plaatje vangt de natte laars
mismatching: De natte laars op dit plaatje vangt de lange man

43)  matching: De lange man op dit plaatje vangt de grote vis
mismatching: De grote vis op dit plaatje vangt de lange man

44)  matching: De lange man op dit plaatje vangt de grote vis
mismatching: De grote vis op dit plaatje vangt de lange man

45)  matching: De lange man op dit plaatje zaagt de dikke boom
mismatching: De dikke boom op dit plaatje zaagt de lange man

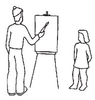
46)  matching: De lange man op dit plaatje zaagt de dikke boom
mismatching: De dikke boom op dit plaatje zaagt de lange man

47)  matching: De lange man op dit plaatje zaagt de dikke plank
mismatching: De dikke plank op dit plaatje zaagt de lange man

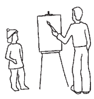
48)  matching: De lange man op dit plaatje zaagt de dikke plank
mismatching: De dikke plank op dit plaatje zaagt de lange man

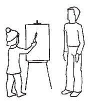
Semantically reversible active sentences:

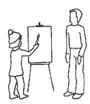
Picture Sentence

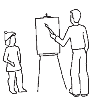
1)  matching: De lange man op dit plaatje schildert het kleine meisje

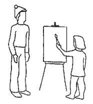
2)  mismatching: De lange man op dit plaatje schildert het kleine meisje

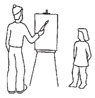
3)  matching: De lange man op dit plaatje schildert het kleine meisje

4)  mismatching: De lange man op dit plaatje schildert het kleine meisje

5)  matching: Het kleine meisje op dit plaatje schildert de lange man

6)  mismatching: Het kleine meisje op dit plaatje schildert de lange man

7)  matching: Het kleine meisje op dit plaatje schildert de lange man

8)  mismatching: Het kleine meisje op dit plaatje schildert de lange man

9)  matching: De jonge vrouw op dit plaatje kamt de lange man

10)  mismatching: De jonge vrouw op dit plaatje kamt de lange man

11)  matching: De jonge vrouw op dit plaatje kamt de lange man

12)  mismatching: De jonge vrouw op dit plaatje kamt de lange man

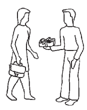
13)  matching: De lange man op dit plaatje kamt de jonge vrouw

14)  mismatching: De lange man op dit plaatje kamt de jonge vrouw

15)  matching: De lange man op dit plaatje kamt de jonge vrouw

16)  mismatching: De lange man op dit plaatje kamt de jonge vrouw

17)  matching: De jonge vrouw op dit plaatje verrast de lange man

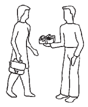
18)  mismatching: De jonge vrouw op dit plaatje verrast de lange man

19)  matching: De jonge vrouw op dit plaatje verrast de lange man

20)  mismatching: De jonge vrouw op dit plaatje verrast de lange man

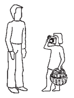
21)  matching: De lange man op dit plaatje verrast de jonge vrouw

22)  mismatching: De lange man op dit plaatje verrast de jonge vrouw

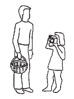
23)  matching: De lange man op dit plaatje verrast de jonge vrouw

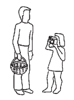
24)  mismatching: De lange man op dit plaatje verrast de jonge vrouw

25)  matching: De lange man op dit plaatje fotografeert het kleine meisje

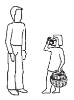
26)  mismatching: De lange man op dit plaatje fotografeert het kleine meisje

27)  matching: De lange man op dit plaatje fotografeert het kleine meisje

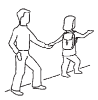
28)  mismatching: De lange man op dit plaatje fotografeert het kleine meisje

29)  matching: Het kleine meisje op dit plaatje fotografeert de lange man

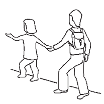
30)  mismatching: Het kleine meisje op dit plaatje fotografeert de lange man

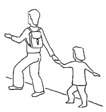
31)  matching: Het kleine meisje op dit plaatje fotografeert de lange man

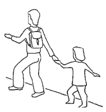
32)  mismatching: Het kleine meisje op dit plaatje fotografeert de lange man

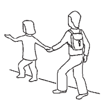
33)  matching: Het kleine meisje op dit plaatje trekt de lange man

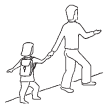
34)  mismatching: Het kleine meisje op dit plaatje trekt de lange man

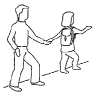
35)  matching: Het kleine meisje op dit plaatje trekt de lange man

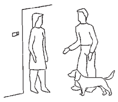
36)  mismatching: Het kleine meisje op dit plaatje trekt de lange man

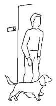
37)  matching: De lange man op dit plaatje trekt het kleine meisje

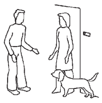
38)  mismatching: De lange man op dit plaatje trekt het kleine meisje

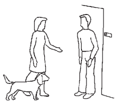
39)  matching: De lange man op dit plaatje trekt het kleine meisje

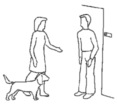
40)  mismatching: De lange man op dit plaatje trekt het kleine meisje

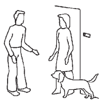
41)  matching: De lange man op dit plaatje bezoekt de jonge vrouw

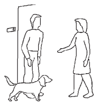
42)  mismatching: De lange man op dit plaatje bezoekt de jonge vrouw

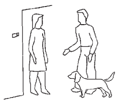
43)  matching: De lange man op dit plaatje bezoekt de jonge vrouw

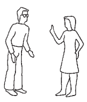
44)  mismatching: De lange man op dit plaatje bezoekt de jonge vrouw

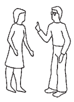
45)  matching: De jonge vrouw op dit plaatje bezoekt de lange man

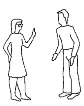
46)  mismatching: De jonge vrouw op dit plaatje bezoekt de lange man

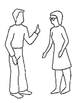
47)  matching: De jonge vrouw op dit plaatje bezoekt de lange man

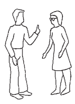
48)  mismatching: De jonge vrouw op dit plaatje bezoekt de lange man

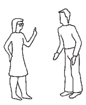
49)  matching: De jonge vrouw op dit plaatje waarschuwt de lange man

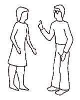
50)  mismatching: De jonge vrouw op dit plaatje waarschuwt de lange man

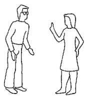
51)  matching: De jonge vrouw op dit plaatje waarschuwt de lange man

52)  mismatching: De jonge vrouw op dit plaatje waarschuwt de lange man

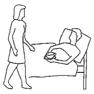
53)  matching: De lange man op dit plaatje waarschuwt de jonge vrouw

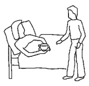
54)  mismatching: De lange man op dit plaatje waarschuwt de jonge vrouw

55)  matching: De lange man op dit plaatje waarschuwt de jonge vrouw

56)  mismatching: De lange man op dit plaatje waarschuwt de jonge vrouw

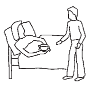
57)  matching: De lange man op dit plaatje verzorgt de jonge vrouw

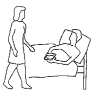
58)  mismatching: De lange man op dit plaatje verzorgt de jonge vrouw

59)  matching: De lange man op dit plaatje verzorgt de jonge vrouw

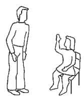
60)  mismatching: De lange man op dit plaatje verzorgt de jonge vrouw

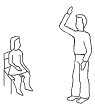
61)  matching: De jonge vrouw op dit plaatje verzorgt de lange man

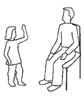
62)  mismatching: De jonge vrouw op dit plaatje verzorgt de lange man

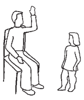
63)  matching: De jonge vrouw op dit plaatje verzorgt de lange man

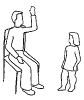
64)  mismatching: De jonge vrouw op dit plaatje verzorgt de lange man

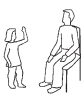
65)  matching: Het kleine meisje op dit plaatje begroet de lange man

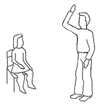
66)  mismatching: Het kleine meisje op dit plaatje begroet de lange man

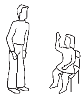
67)  matching: Het kleine meisje op dit plaatje begroet de lange man

68)  mismatching: Het kleine meisje op dit plaatje begroet de lange man

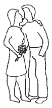
69)  matching: De lange man op dit plaatje begroet het kleine meisje

70)  mismatching: De lange man op dit plaatje begroet het kleine meisje

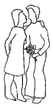
71)  matching: De lange man op dit plaatje begroet het kleine meisje

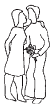
72)  mismatching: De lange man op dit plaatje begroet het kleine meisje

73)  matching: De lange man op dit plaatje kust de jonge vrouw

74)  mismatching: De lange man op dit plaatje kust de jonge vrouw

75)  matching: De lange man op dit plaatje kust de jonge vrouw

76)  mismatching: De lange man op dit plaatje kust de jonge vrouw

77)  matching: De jonge vrouw op dit plaatje kust de lange man

78)  mismatching: De jonge vrouw op dit plaatje kust de lange man

79)  matching: De jonge vrouw op dit plaatje kust de lange man

80)  mismatching: De jonge vrouw op dit plaatje kust de lange man

81)  matching: De jonge vrouw op dit plaatje duwt de lange man

82)  mismatching: De jonge vrouw op dit plaatje duwt de lange man

83)  matching: De jonge vrouw op dit plaatje duwt de lange man

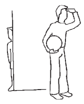
84)  mismatching: De jonge vrouw op dit plaatje duwt de lange man

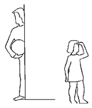
85)  matching: De lange man op dit plaatje duwt de jonge vrouw

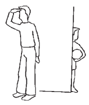
86)  mismatching: De lange man op dit plaatje duwt de jonge vrouw

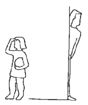
87)  matching: De lange man op dit plaatje duwt de jonge vrouw

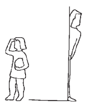
88)  mismatching: De lange man op dit plaatje duwt de jonge vrouw

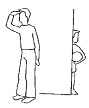
89)  matching: De lange man op dit plaatje zoekt het kleine meisje

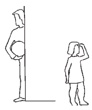
90)  mismatching: De lange man op dit plaatje zoekt het kleine meisje

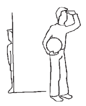
91)  matching: De lange man op dit plaatje zoekt het kleine meisje

92)  mismatching: De lange man op dit plaatje zoekt het kleine meisje

93)  matching: Het kleine meisje op dit plaatje zoekt de lange man

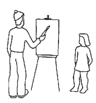
94)  mismatching: Het kleine meisje op dit plaatje zoekt de lange man

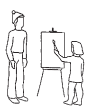
95)  matching: Het kleine meisje op dit plaatje zoekt de lange man

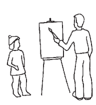
96)  mismatching: Het kleine meisje op dit plaatje zoekt de lange man

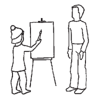
Semantically reversible passive sentences:

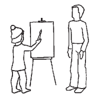
Picture Sentence

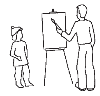
1)  matching: Het meisje op dit plaatje wordt geschilderd door de lange man

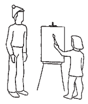
2)  mismatching: Het meisje op dit plaatje wordt geschilderd door de lange man

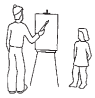
3)  matching: Het meisje op dit plaatje wordt geschilderd door de lange man

4)  mismatching: Het meisje op dit plaatje wordt geschilderd door de lange man

5)  matching: De man op dit plaatje wordt geschilderd door het kleine meisje

6)  mismatching: De man op dit plaatje wordt geschilderd door het kleine meisje

7)  matching: De man op dit plaatje wordt geschilderd door het kleine meisje

8)  mismatching: De man op dit plaatje wordt geschilderd door het kleine meisje

9)  matching: De man op dit plaatje wordt gekamd door de jonge vrouw

10)  mismatching: De man op dit plaatje wordt gekamd door de jonge vrouw

11)  matching: De man op dit plaatje wordt gekamd door de jonge vrouw

12)  mismatching: De man op dit plaatje wordt gekamd door de jonge vrouw

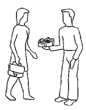
13)  matching: De vrouw op dit plaatje wordt gekamd door de lange man

14)  mismatching: De vrouw op dit plaatje wordt gekamd door de lange man

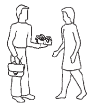
15)  matching: De vrouw op dit plaatje wordt gekamd door de lange man

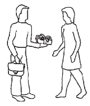
16)  mismatching: De vrouw op dit plaatje wordt gekamd door de lange man

17)  matching: De man op dit plaatje wordt verrast door de jonge vrouw

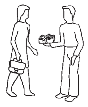
18)  mismatching: De man op dit plaatje wordt verrast door de jonge vrouw

19)  matching: De man op dit plaatje wordt verrast door de jonge vrouw

20)  mismatching: De man op dit plaatje wordt verrast door de jonge vrouw

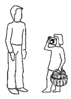
21)  matching: De vrouw op dit plaatje wordt verrast door de lange man

22)  mismatching: De vrouw op dit plaatje wordt verrast door de lange man

23)  matching: De vrouw op dit plaatje wordt verrast door de lange man

24)  mismatching: De vrouw op dit plaatje wordt verrast door de lange man

25)  matching: Het meisje op dit plaatje wordt gefotografeerd door de lange man

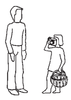
26)  mismatching: Het meisje op dit plaatje wordt gefotografeerd door de lange man

27)  matching: Het meisje op dit plaatje wordt gefotografeerd door de lange man

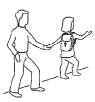
28)  mismatching: Het meisje op dit plaatje wordt gefotografeerd door de lange man

29)  matching: De man op dit plaatje wordt gefotografeerd door het kleine meisje

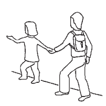
30)  mismatching: De man op dit plaatje wordt gefotografeerd door het kleine meisje

31)  matching: De man op dit plaatje wordt gefotografeerd door het kleine meisje

32)  mismatching: De man op dit plaatje wordt gefotografeerd door het kleine meisje

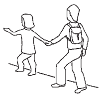
33)  matching: De man op dit plaatje wordt getrokken door het kleine meisje

34)  mismatching: De man op dit plaatje wordt getrokken door het kleine meisje

35)  matching: De man op dit plaatje wordt getrokken door het kleine meisje

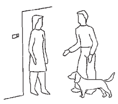
36)  mismatching: De man op dit plaatje wordt getrokken door het kleine meisje

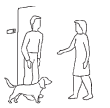
37)  matching: Het meisje op dit plaatje wordt getrokken door de lange man

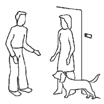
38)  mismatching: Het meisje op dit plaatje wordt getrokken door de lange man

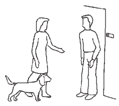
39)  matching: Het meisje op dit plaatje wordt getrokken door de lange man

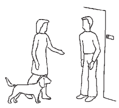
40)  mismatching: Het meisje op dit plaatje wordt getrokken door de lange man

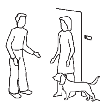
41)  matching: De vrouw op dit plaatje wordt bezocht door de lange man

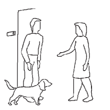
42)  mismatching: De vrouw op dit plaatje wordt bezocht door de lange man

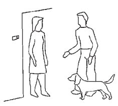
43)  matching: De vrouw op dit plaatje wordt bezocht door de lange man

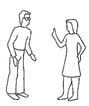
44)  mismatching: De vrouw op dit plaatje wordt bezocht door de lange man

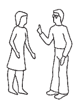
45)  matching: De man op dit plaatje wordt bezocht door de jonge vrouw

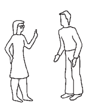
46)  mismatching: De man op dit plaatje wordt bezocht door de jonge vrouw

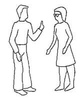
47)  matching: De man op dit plaatje wordt bezocht door de jonge vrouw

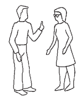
48)  mismatching: De man op dit plaatje wordt bezocht door de jonge vrouw

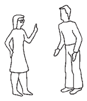
49)  matching: De man op dit plaatje wordt gewaarschuwd door de jonge vrouw

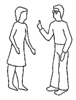
50)  mismatching: De man op dit plaatje wordt gewaarschuwd door de jonge vrouw

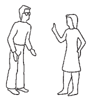
51)  matching: De man op dit plaatje wordt gewaarschuwd door de jonge vrouw

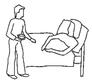
52)  mismatching: De man op dit plaatje wordt gewaarschuwd door de jonge vrouw

53)  matching: De vrouw op dit plaatje wordt gewaarschuwd door de lange man

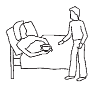
54)  mismatching: De vrouw op dit plaatje wordt gewaarschuwd door de lange man

55)  matching: De vrouw op dit plaatje wordt gewaarschuwd door de lange man

56)  mismatching: De vrouw op dit plaatje wordt gewaarschuwd door de lange man

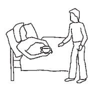
57)  matching: De vrouw op dit plaatje wordt verzorgd door de lange man

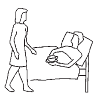
58)  mismatching: De vrouw op dit plaatje wordt verzorgd door de lange man

59)  matching: De vrouw op dit plaatje wordt verzorgd door de lange man

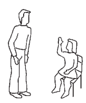
60)  mismatching: De vrouw op dit plaatje wordt verzorgd door de lange man

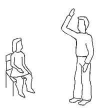
61)  matching: De man op dit plaatje wordt verzorgd door de jonge vrouw

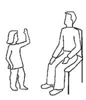
62)  mismatching: De man op dit plaatje wordt verzorgd door de jonge vrouw

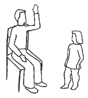
63)  matching: De man op dit plaatje wordt verzorgd door de jonge vrouw

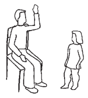
64)  mismatching: De man op dit plaatje wordt verzorgd door de jonge vrouw

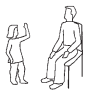
65)  matching: De man op dit plaatje wordt begroet door het kleine meisje

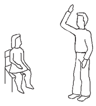
66)  mismatching: De man op dit plaatje wordt begroet door het kleine meisje

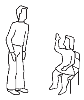
67)  matching: De man op dit plaatje wordt begroet door het kleine meisje

68)  mismatching: De man op dit plaatje wordt begroet door het kleine meisje

69)  matching: Het meisje op dit plaatje wordt begroet door de lange man

70)  mismatching: Het meisje op dit plaatje wordt begroet door de lange man

71)  matching: Het meisje op dit plaatje wordt begroet door de lange man

72)  mismatching: Het meisje op dit plaatje wordt begroet door de lange man

73)  matching: De vrouw op dit plaatje wordt gekust door de lange man

74)  mismatching: De vrouw op dit plaatje wordt gekust door de lange man

75)  matching: De vrouw op dit plaatje wordt gekust door de lange man

76)  mismatching: De vrouw op dit plaatje wordt gekust door de lange man

77)  matching: De man op dit plaatje wordt gekust door de jonge vrouw

78)  mismatching: De man op dit plaatje wordt gekust door de jonge vrouw

79)  matching: De man op dit plaatje wordt gekust door de jonge vrouw

80)  mismatching: De man op dit plaatje wordt gekust door de jonge vrouw

81)  matching: De man op dit plaatje wordt geduwd door de jonge vrouw

82)  mismatching: De man op dit plaatje wordt geduwd door de jonge vrouw

83)  matching: De man op dit plaatje wordt geduwd door de jonge vrouw

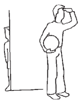
84)  mismatching: De man op dit plaatje wordt geduwd door de jonge vrouw

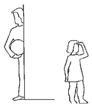
85)  matching: De vrouw op dit plaatje wordt geduwd door de lange man

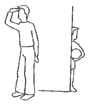
86)  mismatching: De vrouw op dit plaatje wordt geduwd door de lange man

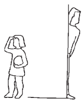
87)  matching: De vrouw op dit plaatje wordt geduwd door de lange man

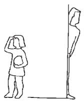
88)  mismatching: De vrouw op dit plaatje wordt geduwd door de lange man

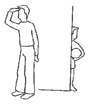
89)  matching: Het meisje op dit plaatje wordt gezocht door de lange man

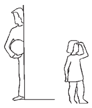
90)  mismatching: Het meisje op dit plaatje wordt gezocht door de lange man

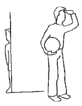
91)  matching: Het meisje op dit plaatje wordt gezocht door de lange man

92)  mismatching: Het meisje op dit plaatje wordt gezocht door de lange man

93)  matching: De man op dit plaatje wordt gezocht door het kleine meisje

94)  mismatching: De man op dit plaatje wordt gezocht door het kleine meisje

95)  matching: De man op dit plaatje wordt gezocht door het kleine meisje

96)  mismatching: De man op dit plaatje wordt gezocht door het kleine meisje

SAMENVATTING

AGRAMMATISCH TAALBEGRIP:
EEN ELECTROFYSIOLOGISCHE BENADERING

Normaal gesproken, kost het begrijpen en produceren van talige boodschappen ons weinig moeite. Mensen verwonderen zich eigenlijk maar zelden over de complexiteit van de processen die zich hierbij in ons brein afspelen. Dat taalverstaan helemaal geen vanzelfsprekende zaak is, wordt echter pijnlijk duidelijk ervaren door mensen met *afasie*. Afasie is een stoornis in het begrijpen en/of produceren van taal tengevolge van een verworven hersenbeschadiging. Bij rechtshandigen betreft dit meestal een beschadiging van de linkerhersenhelft. Deze beschadiging kan het gevolg zijn van bijvoorbeeld een cerebrovasculair accident (CVA), in de omgangstaal vaak 'beroerte' genoemd. Patiënten met afasie vertonen onderling verschillen voor wat betreft de ernst en aard van hun taalstoornis. Alle taalmodaliteiten (spreken, luisteren, schrijven, lezen) kunnen aangedaan zijn en de problemen kunnen zich voordoen op diverse linguïstische nivo's (fonologie, morfologie, semantiek en syntaxis). Op basis van de symptomen die afasiepatiënten vertonen, kunnen verschillende afasiesyndromen worden onderscheiden. Deze dissertatie richt zich, vanuit een electrofysiologisch perspectief, op syntactische taalbegripsproblemen bij patiënten met een afasie van Broca ten gevolge van een CVA. In het onderzoek werd gebruik gemaakt van het meten van hersenpotentialen, ofwel Event-related brain potentials (ERPs). Doel van het onderzoek was om na te gaan wat syntax-gerelateerde ERP-effecten aan het licht kunnen brengen over de aard van syntactische taalbegripsproblemen bij deze groep afasiepatiënten.

Kenmerkend voor de afasie van Broca is de trage, moeizame taalproductie. De geproduceerde zinnen zijn veelal kort en eenvoudig. Vaak worden lidwoorden, voorzetsels en andere functiewoorden weggelaten en ontbreken verbuigingen van werkwoorden. Deze manier van spreken, die doet denken aan de stijl waarin men een telegram zou versturen, wordt aangeduid met *agrammatisme*. In ernstige gevallen bestaat de spontane taal voornamelijk uit één- en tweewoordsuitingen. Ter illustratie: een van de deelneemsters aan ons onderzoek antwoordde op de vraag hoe zij ziek geworden was met ".. ja .. eh .. bloeding". Agrammatisme in de taalproductie gaat bij patiënten met een afasie van Broca nogal eens samen met agrammatisch taalbegrip. Met de term agrammatisch taalbegrip wordt bedoeld dat er problemen zijn met het begrijpen van zinnen waarvan de betekenis alleen vastgesteld kan worden op grond van syntactische informatie. De syntactische begripsstoornis bij patiënten met een afasie van Broca wordt vooral duidelijk in zinnen waar de betekenis geen compenserende rol kan spelen. Zo hebben deze patiënten meer moeite met semantisch omkeerbare zinnen zoals "De jongen plaagt het meisje" (het meisje had ook de jongen kunnen plagen) dan met semantisch onomkeerbare zinnen, zoals "De aap eet een banaan" (een banaan kan geen aap eten). Behalve omkeerbaarheid speelt ook grammaticale complexiteit een rol. In het algemeen geldt dat patiënten met een syntactische taalbegripsstoornis relatief veel moeite hebben met omkeerbare passieve zinnen.

De aanduiding a-grammatisch begrip wekt overigens onbedoeld de suggestie dat de syntactische begripsproblemen het gevolg zouden zijn van een totaal verlies van syntactische kennis. In de loop der jaren is duidelijk geworden dat de problemen veeleer optreden door het onvermogen deze syntactische kennis op te halen en te gebruiken bij het interpreteren van talige uitingen. Vanuit die optiek moet agrammatisch begrip niet gezien worden als kennisverlies, maar als een verwerkingsstoornis.Verschillende verklaringen zijn gegeven voor de syntactische taalbegripsproblemen bij patiënten met een afasie van Broca. Zo is ondermeer voorgesteld dat het syntactische verwerkingsproces niet langer automatisch zou verlopen. Een andere hypothese veronderstelt dat het probleem niet zozeer gelegen is in de opbouw van een syntactische representatie, alswel in het proces van het matchen van thematische rollen van het werkwoord ("wie doet wat en waarmee") met de syntactische structuur van een zin. Anderen menen dat de syntactische begripsproblemen vooral samenhangen met een reductie in de voor taalverstaan vereiste verwerkingscapaciteit. Ook worden veranderingen in de temporele organisatie van het syntactische verwerkingsproces verantwoordelijk gehouden voor de syntactische begripsproblemen. Zo zou syntactische informatie te traag actief worden, dan wel te snel weer vervallen.

De klassieke benadering van taalstoornissen is relatief blind geweest voor de mogelijkheid van temporele afwijkingen als belangrijke factor in taalstoornissen. Immers, een veel gebruikte procedure om syntactische taalbegripstoornissen te onderzoeken is om patiënten een afbeelding te laten aanwijzen die met een gehoorde zin correspondeert (de zogenaamde sentence-picture matching taak). Zo'n procedure let niet op het tijdsverloop van de bij het luisteren betrokken deelprocessen, maar slechts op het eindresultaat. Methoden van onderzoek die wel de temporele aspecten van het te onderzoeken proces registreren noemt men *on-line* methoden. Het registreren van hersenpotentialen (de zogenaamde *event-related brain potentials* of *ERPs*) is een voorbeeld van zo'n methode. Van deze methode is gebruik gemaakt in alle studies die in deze dissertatie beschreven zijn.

De continue electrische activiteit van de hersenen kan gemeten worden met behulp van electroden die op de schedel geplaatst zijn: het electro-encephalogram (EEG). Indien men het EEG registreert bij iemand die naar een bepaalde stimulus luistert of kijkt en dit EEG vervolgens middelt over een aantal aanbiedingen van die stimulus, dan ontstaat in het EEG-signaal een patroon van negatieve en positieve pieken. Deze pieken zijn de zogenaamde ERP-componenten. Deze componenten geven onder andere informatie over de aard van bepaalde cognitieve processen. In deze dissertatie is vooral naar ERP-*effecten* gekeken, dat wil zeggen naar het verschil in amplitude van ERP-signalen tussen verschillende experimentele condities in een bepaald tijdsinterval.

Het gebruik van de ERP-methode binnen taalpsychologisch onderzoek heeft aan het licht gebracht, dat kwalitatief verschillende ERP-componenten opgewekt kunnen worden door de verwerking van verschillende soorten linguïstische informatie. Zo blijkt de *N400* een ERP-component die gevoelig is voor *semantische* informatie. Onderzoek naar *syntactische* verwerking heeft twee andere ERP-effecten opgeleverd die kwalitatief verschillend zijn van de N400, teweten de *P600/SPS* en de *LAN* (Left Anterior Negativity). Het P600/SPS-effect is een positieve shift die in het ERP-signaal optreedt zo'n 500 ms na de onset van een woord dat een syntactisch verwerkingsprobleem oplevert. Het LAN-effect is een negatief ERP-effect dat (links) frontaal op de schedel tussen de 300-500 ms de maximale amplitude bereikt. Overigens moet wel bedacht worden dat van geen van deze taal-relevante ERP-effecten geclaimd kan worden dat zij zuiver taal-specifiek zijn. Dit laat echter onverlet dat de gevoeligheid van bepaalde ERP-effecten voor verschillende taalverwerkingsprocessen in taalpsychologisch onderzoek uitgebuit kan worden.

De ERP-methode heeft een aantal eigenschappen dat zeer van pas komt bij het doen van onderzoek naar taalbegripsproblemen bij afasie. Ten eerste kan men betrouwbare ERP-effecten verkrijgen zonder dat iets anders van de patiënt wordt gevraagd dan bijvoorbeeld naar woorden of zinnen te luisteren. Dat men bij het meten niet afhankelijk is van additionele taken, heeft als voordeel dat men geen last heeft van interferentie van een taak met het te onderzoeken taalbegripsproces. Het houdt tevens in dat ook patiënten met zwaardere begripsproblemen getest kunnen worden. Ten tweede voorzien ERPs in een on-line en continue registratie van neurale activiteit die aan taalverwerkingsprocessen ten grondslag ligt met een temporele precisie in de orde van milliseconden. Daarmee kunnen ook eventuele veranderingen in het tijdsverloop van het taalverwerkingsproces bij afasiepatiënten aangetoond worden. Ten derde, aangezien er kwalitatief verschillende hersenpotentialen gevonden zijn voor semantische en syntactische aspecten van taalverwerking, kunnen ERPs ook informatief zijn met betrekking tot de vraag of syntactische aspecten van taalverwerking bijvoorbeeld ernstiger gestoord zijn dan semantische aspecten.

In het onderzoek naar syntactische taalbegripsstoornissen van patiënten met een afasie van Broca is de ERP-methode nog niet op grote schaal gebruikt. Deze dissertatie beoogde om verder na te gaan wat syntax-gerelateerde ERP-effecten aan het licht kunnen brengen over de aard van syntactische taalbegripsproblemen bij deze groep afasiepatiënten. Veranderingen in het proces van syntactische verwerking ten gevolge van afasie kunnen syntax-gerelateerde ERP-effecten op verschillende manieren beïnvloeden. Wanneer de on-line gevoeligheid voor syntactische informatie verminderd is kan er een reductie van de effectgrootte optreden. Indien de snelheid waarmee syntactische informatie verwerkt wordt verminderd is, kan er een latentieverschuiving van een effect plaatsvinden. Ten slotte, de afwezigheid van een effect kan er op duiden dat het syntactische verwerkingsproces ernstig verstoord is.

In de hoofdstukken 2 tot en met 5 van deze dissertatie wordt verslag gedaan van een viertal experimenten. In alle daarin beschreven experimenten is een aantal controle metingen opgenomen. Om te controleren voor het effect van veroudering werd in alle ERP-experimenten een groep proefpersonen zonder hersenbeschadiging getest met gemiddeld dezelfde leeftijd en vergelijkbaar opleidingsnivo als de afasiepatiënten. Naast deze normale controlegroep werd ook in alle ERP-experimenten steeds een groep patiënten getest met een hersenbeschadiging in de *rechter*hersenhelft. Bij deze controle groep (de RH patiënten) was er geen sprake van afasie. Deze groep werd getest om na te gaan of eventuele veranderingen in de ERP-effecten zoals geconstateerd bij de afasiepatiënten samenhingen met de afasie en niet alleen maar toe te schrijven waren aan een hersenbeschadiging als zodanig. Om vast te kunnen stellen of veranderingen in syntax-gerelateerde ERP-effecten gedissocieerd konden worden van algemene effecten van hersenschade op cognitieve ERP-componenten, werden in de hoofdstukken 2 en 4 alle proefpersonen ook getest met een niet-talig controle experiment (tone oddball paradigma).

Hoofdstuk 2 van deze dissertatie beschrijft een studie waarin is onderzocht of patiënten met een afasie van Broca gevoelig waren voor schendingen van de congruentie tussen het getal van het grammaticaal subject en de persoonsvorm. Een voorbeeld van zo'n 'subject-verb-agreement'-schending is: "De vrouwen betalen de bakker en <u>neemt</u> het brood mee naar huis". De syntactische complexiteit van de zinnen werd gevarieerd door niet alleen zinnen van bovenstaand type op te nemen maar ook door complexere, ingebedde structuren te gebruiken zoals "De vrouwen die de bakker betalen, <u>neemt</u> het brood mee naar huis". ERPs werden gemeten terwijl de proefpersonen naar zinnen luisterden die ofwel grammaticaal correct waren ofwel bovengenoemde schending bevatten. De normale controle proefpersonen lieten als reactie op de agreement schendingen een P600/SPS-effect zien, ongeacht de syntactische complexiteit. De groep RH-patiënten vertoonde in essentie hetzelfde patroon. Als geheel was de groep patiënten met een afasie van Broca niet gevoelig voor de agreement-schendingen, blijkens de afwezigheid van P600/SPS-effecten. Echter, deze gevoeligheid bleek beïnvloed te worden door de *ernst* van de syntactische begripsstoornis. Wanneer de patiënten met een afasie van Broca in twee subgroepen verdeeld werden op basis van hun prestatie op een syntactische off-line test, bleek dat de groep met een ernstige syntactische begripsstoornis geen agreement effect liet zien. De groep met een mildere begripsstoornis liet wél een agreement effect zien. Weliswaar was dit effect gereduceerd ten opzichte van de normale controle groep maar er was geen sprake van een latentieverschuiving. Een effect van complexiteit kon niet aangetoond worden. In deze studie werden ook ERPs gemeten in een tone oddball paradigma. Net zoals beide controle groepen (normale ouderen, RH-patiënten) liet de groep patiënten met een afasie van Broca een standaard P300-effect zien. Dit wees erop dat afasie als zodanig niet tot een algemene reductie van alle cognitieve ERP-effecten leidt. Geconcludeerd werd dat het on-line vasthouden van de getalsinformatie voor patiënten met een afasie van Broca moeilijk is wegens te snel verval (decay) van dit soort morfosyntactische informatie. Dit resulteerde voor de patiënten met een milde begripsstoornis in een reductie van het P600/SPS-effect, en voor de patiënten met een ernstige begripsstoornis zelfs in een afwezigheid van het effect.

Hoofdstuk 3 beschrijft een studie waarin gekeken is naar de on-line verwerking van woordvolgorde-schendingen bij patiënten met een afasie van Broca. Een voorbeeld van zo'n zin met foutieve woordvolgorde is "De dief steelt de dure erg klok uit de woonkamer". ERPs werden gemeten terwijl de proefpersonen naar zinnen luisterden die ofwel grammaticaal correct waren ofwel een foutieve woordvolgorde bevatten. De resultaten van de patiënten met een afasie van Broca werden geanalyseerd naar de ernst van hun syntactische taalbegripsstoornis gebaseerd op hun prestatie op een syntactische off-line test. Als reactie op de gepresenteerde woordvolgorde fouten vertoonde de groep normale gezonde ouderen een P600/SPS-effect. Dit effect werd ook gevonden bij de groep RH-patiënten en de Broca-patiënten met een milde syntactische taalbegripsstoornis. Echter, de Broca-patiënten met een ernstige syntactische begripsstoornis lieten geen syntax-gerelateerd ERP-effect zien. In plaats daarvan vertoonden zij een semantiek-gerelateerd ERP-effect. Dit duidt er mogelijk op dat deze groep patiënten de zin probeerden te begrijpen langs een semantische verwerkingsroute. Zo'n semantische route zou begunstigd worden ter compensatie van een syntactische verwerkingsstoornis. De manier waarop verschillende bronnen van talige informatie gecombineerd worden om tot een zo goed mogelijke interpretatie te komen lijkt dus afgestemd te worden op de verwerkingsopties die voor het gestoorde taalsysteem beschikbaar zijn.

In **hoofdstuk 4** is onderzocht of patiënten met een afasie van Broca on-line gevoelig waren voor woordcategorie-schendingen. De term woordcategorie-schending verwijst naar de situatie waarin de syntactische context een woord van een bepaalde syntactische klasse vereist (bijvoorbeeld een zelfstandig naamwoord in de context van een voorafgaand lidwoord en bijvoeglijk naamwoord) terwijl feitelijk een woord uit een andere syntactische klasse wordt gepresenteerd (bijvoorbeeld een werkwoord). Een voorbeeld van zo'n woordcategorie-schending uit ons experiment is "De houthakker ontweek de ijdele schroeft op dinsdag". Het werkwoord ‘schroeft’ staat op een plek waar dit grammaticaal incorrect is. In de grammaticaal correcte versie werd het zelfstandige naamwoord ‘schroef’ gebruikt. Het experiment bevatte tevens een conditie met een semantische schending (bijvoorbeeld: “Het meisje stopte een snoepje in haar bloem”) om te zien of semantische schendingen bij de Broca-patiënten in een klassiek N400-effect zouden resulteren. Dit om mogelijke dissociaties in de gevoeligheid voor semantische en syntactische informatie bij Broca-patiënten op te sporen. ERPs werden gemeten terwijl proefpersonen de zinnen visueel, woord voor woord, gepresenteerd kregen. Beide controle groepen (normale ouderen en RH-patiënten) bleken gevoelig voor de woordcategorie-schendingen blijkens een duidelijk P600/SPS-effect. De groep Broca-patiënten vertoonde echter een zeer gereduceerd, maar ook vertraagd P600/SPS-effect. In deze studie werden ook ERPs gemeten in een tone oddball paradigma. Dit resulteerde voor de Broca-patiënten in een enigszins gereduceerd (maar niet vertraagd) P300-effect. De grootte van het P300-effect correleerde echter niet met het syntax-gerelateerde P600/SPS-effect. Het leek daarom onwaarschijnlijk om veranderingen in het P600/SPS-effect volledig toe te schrijven aan aandachtsstoornissen. Het N400-effect als reactie op de semantische schendingen was enigszins vertraagd en gereduceerd. Echter de relatieve reductie van de effectgrootte en de latentieverschuiving, ten opzichte van de normale ouderen, waren veel substantiëler voor het P600/SPS-effect dan voor het N400-effect. Geconcludeerd werd dat Broca-patiënten gehinderd worden in het on-line detecteren van woordcategorie schendingen, indien informatie over woordklasse incompleet of te laat beschikbaar is.

Hoofdstuk 5 beschrijft een experiment waarin een on-line versie van een sentence-picture matching taak ontwikkeld is. Doel van het experiment was om on-line thematische roltoekenning bij patiënten met een afasie van Broca te onderzoeken. Proefpersonen zagen een plaatje en hoorden daarna een zin terwijl ERPs gemeten werden. Zinnen verschilden in complexiteit. Zo waren er a) actieve, semantisch onomkeerbare zinnen (“De jonge vrouw op dit plaatje leest het spannende boek”); b) actieve, semantisch omkeerbare zinnen (“De jonge vrouw op dit plaatje duwt de lange man”); c) passieve, semantisch omkeerbare zinnen (“De vrouw op dit plaatje wordt geduwd door de lange man”). Een zin kwam al dan niet overeen met het getoonde plaatje. Na afloop van de zin moesten proefpersonen door middel van een druk op een knop aangeven of de zin overeenkwam met het plaatje of niet. Van deze responsen werd de reactietijd en accuratesse gemeten. De resultaten van deze studie lieten zien dat bij normale gezonde ouderen thematische roltoekenning in de context van visuele informatie een onmiddellijk proces was. ERP-effecten werden verkregen op de positie van het werkwoord. Dit impliceert dat, gegeven de visuele context van het plaatje, thematische rollen onmiddellijk werden toegekend, dus zodra, of in het geval van een hulpwerkwoord zelfs nog eerder, de argument structuur horend bij het hoofdwerkwoord beschikbaar was. Er werd verondersteld dat het P600/SPS-effect, zoals de normale gezonde ouderen dit lieten zien voor zinnen die niet met de afbeelding overeenstemden, weergaf dat het toekennen van grammaticale rollen moeilijker was in de tegenwoordigheid van tegenstrijdige thematische informatie. Ook voor de groep RH-patiënten leek het proces van thematische roltoekenning onmiddellijk te zijn. Dit in tegenstelling tot de groep Broca-patiënten die geen tekenen van on-line gevoeligheid lieten zien voor een mismatch tussen een afbeelding en een zin. De on-line syntactische bijdrage aan het proces van thematische roltoekenning leek verminderd te zijn gegeven de reductie en zelfs afwezigheid van P600/SPS-effecten. Desalniettemin, de gedragsdata van de Broca-patiënten lieten enige off-line gevoeligheid zien voor de mismatches tussen een afbeelding en een zin. De langere responstijden doen vermoeden dat hiervoor off-line strategieën zijn aangewend.

In het slothoofdstuk zijn de voornaamste resultaten van het onderzoek, zoals gerapporteerd in de hoofdstukken 2 tot en met 5, samengevat. Geconcludeerd werd dat variatie in de *ernst* van een syntactische taalbegripsstoornis ook electrofysiologisch waarneembaar was, en wel zo dat de grootste afwijking van normale syntax-gerelateerde ERP-effecten gevonden werd voor patiënten met de grootste syntactische begripsstoornis. Dit impliceert dat auteurs van syntax-gerelateerde ERP-studies op het gebied van afasie er goed aan doen om hun lezers van duidelijke informatie te voorzien omtrent de ernst van de syntactische taalbegripsstoornis van patiënten die aan het onderzoek mee hebben gedaan. Zo wordt duidelijker aan welke groep patiënten de ERP-data gerelateerd zijn.

De resultaten van de ERP-experimenten leidden tot verschillende conclusies ten aanzien van veranderingen in de *temporele organisatie* van het syntactische verwerkingsproces. In de hoofdstukken 2 en 3 lieten de Broca-patiënten het beeld zien van een te snel verval van syntactische activatie (*decay*). In de hoofdstukken 4 en 5 lieten de patiënten daarnaast ook een vertraging in de verwerking van syntactische informatie zien (*delay*). Geconcludeerd werd dat waarschijnlijk beide vormen van temporele verstoring betrokken zijn bij de syntactische taalbegripsproblemen. Welke temporele verstoring in een experiment op de voorgrond treedt lijkt af te hangen van op welk facet van syntactische verwerking een bepaald experiment een beroep doet.

In hoofdstuk 3 werd bij patiënten met een ernstige syntactische begripsstoornis electrofysiologisch bewijs gevonden voor real-time *semantische compensatie*. Deze patiënten leken dus te compenseren voor hun syntactische stoornis door tijdens het proces van zinsverwerking sterker te steunen op semantische informatie. Ook in hoofdstuk 5, tijdens het on-line matchen van een zin met een plaatje, leek in de Broca-patiënten thematische informatie over syntactische informatie te domineren. Deze resultaten duiden op zogenaamde multiple-route plasticiteit: een andere verwerkingsroute wordt begunstigd ter compensatie van de syntactische stoornis.

De resultaten van alle experimenten tesamen lijken erop te duiden dat patiënten met een afasie van Broca problemen kunnen hebben met het opbouwen van een syntactische representatie die een hele uiting omvat, indien syntactische informatie niet beschikbaar is met de juiste hoeveelheid activatie en niet beschikbaar is op het juiste moment. Het preciese onderliggende mechanisme dat deze verstoringen in het taalbegripsproces te weeg brengt kan niet uit de data afgeleid worden. Echter, het is voorstelbaar dat zulke verstoringen veroorzaakt worden door een pathologische reductie van de voor taalverstaan vereiste verwerkings-capaciteit. Deze hypothese zou zowel de variatie in ernst als de compensatie-mechanismen kunnen verklaren.

Tenslotte: dit proefschrift richtte zich op patiënten met een afasie van Broca vanuit een electrofysiologisch perspectief. De fatische stoornis werd hierin als het ware teruggebracht tot milliseconden, microvolts en topografische plots. Maar microvolts en milliseconden zijn te klein om de grote impact van een afasie op het leven van patiënten en hun familieleden uit te kunnen drukken. Moge verder onderzoek bijdragen aan het verlichten van deze problematiek.

CURRICULUM VITAE

Marlies Wassenaar werd op 24 april 1968 te Amsterdam geboren als dochter van Pieter Wassenaar en Johanna de Buck. In 1986 behaalde zij haar Gymnasium-β diploma aan de Christelijke Scholengemeenschap Buitenveldert te Amsterdam. Vervolgens studeerde zij Logopedie en Akoepedie aan de Hogeschool van Amsterdam. Na haar diplomering in 1990 toog zij naar Nijmegen om aldaar met de studie Spraak- en Taalpathologie aan de (toen nog) Katholieke Universiteit van Nijmegen een aanvang te maken. In 1993 rondde zij het doctoraalexamen van deze studie cum laude af. In de zomer van 1993 was zij waarnemend logopedist bij de Stichting Afasietherapie Amsterdam. Van november 1993 tot en met december 2002 was zij (part-time) werkzaam als onderzoeker bij het Neurocognition of Language Processing Research Project van het Max Planck Instituut voor Psycholinguïstiek (MPI) te Nijmegen (NWO grant 400-56-384). In augustus 2000 besloot zij om toch nog een dissertatie te gaan schrijven. In de periode 1993 – 2002 werden niet alleen de experimenten opgezet en uitgevoerd waarover in dit proefschrift verslag wordt gedaan, maar aanschouwden bovenal *Bart*, *Hanna*, *Eefje* en *Julia* het levenslicht. In de periode augustus 2003 – januari 2004 werkte zij als logopedist bij Stichting Pantein Verpleging en Verzorging. Vanaf januari 2004 wijdde zij zich naast de zorg voor haar gezin aan de voltooiing van deze dissertatie. Thans bevindt zij zich “tussen twee banen in” (Balkenende, mondelinge mededeling 2005).

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