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Word-category violations in patients with Broca's aphasia: An ERP study

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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.

Keywords: Broca's aphasia; Word-category violations; Event-related brain potentials; P600/SPS; (L)AN

1. 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) 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[1], 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

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[1] 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).

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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).

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, 2000; 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 and 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 and 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 between 300 and 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, 2003).

A second ERP effect that has been related to syntactic processing is a late positivity, here termed P600/SPS, that occurs between 500 and 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 and 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 & 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. In the cortical patient group there was only one Broca patient. The results for this patient were similar to the findings of the earlier case report (Friederici et al., 1998).

1.1. This 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 et al. (Hagoort et al., 2003), 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.[2] The word-category violations elicited in these young subjects an anterior negativity between 300 and 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 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.

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.

2. Method

2.1. 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.

[2] 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.

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

Table 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); and severe (41–50). RH patient two 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; and AAT, Aachen Aphasia Test.

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: $F(4,128) = 17.76$; $MSe = 152.53$; $p < .000$; Group: $F(2,32) = 46.90$; $MSe = 364.69$; $p < .000$; and Complexity × Group: $F(8,128) = 4.35$; $MSe = 152.53$; $p < .000$). Post hoc analyses ($\alpha = .05$) 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 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.

2.2. Materials

The stimuli were identical to the stimuli of Experiment 1 from Hagoort et al. (2003) 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 (five 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 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.

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 2. The full set of experimental items is available upon request. 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

Table 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***.)

length for both the congruent and the anomalous items was 7.5 words (range: 5–10 words).

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 four 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.

2.3. Procedure

Subjects 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 s, to inform the subjects that they were allowed to blink and move their eyes. After its offset, an asterisk was displayed for 400 ms, to warn the subjects that they had to fixate their eyes on the 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[3]). The final word was presented together with a period, followed by a blank screen for 1 s before the next trial began.

The testing session began with a short practice block. The experimental trials were presented in four blocks of approximately 10 min each. Subjects were given short breaks between the blocks. To 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.

2.4. EEG-recording

Continuous EEG was recorded from 29 Ag/AgCl-sintered electrodes mounted in an elastic cap, each referred to the left mastoid. Fig. 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, and 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

[3] 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, 1999), and turned out to be a good presentation rate for elderly subjects.

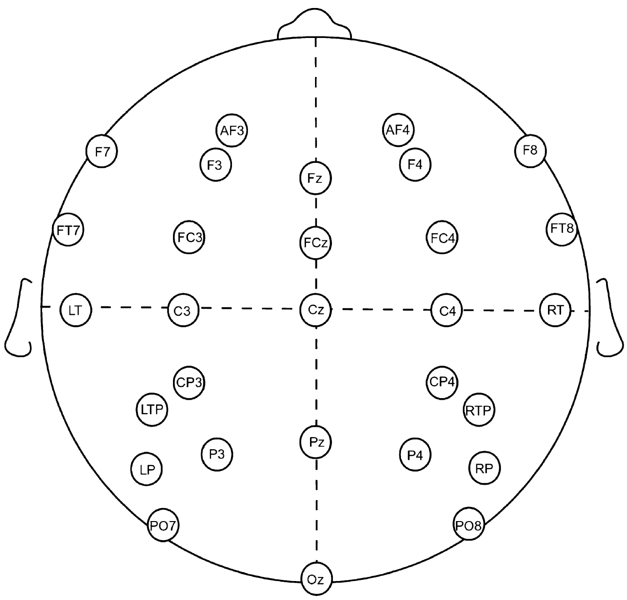

Fig. 1. Distribution of the 29 electrodes across the scalp.

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 0.05–30 Hz. Impedances were kept below 3 kΩ. The EEG and EOG signals were digitized on-line with a sampling frequency of 200 Hz.

2.5. 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 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, and 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 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 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, and FT7), Anterior Right (AR: AF4, F4, F8, FC4, and FT8), Posterior Left (PL: CP3, LTP, P3, LP, and PO7), Posterior Right (PR: CP4, RTP, P4, RP, and PO8). For each subject group, omnibus ANOVAs with Condition, Site (four quadrants: AL, AR, PL, and 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.

3. Results

3.1. Word-category violation condition

3.1.1. Normal control subjects

Fig. 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, and 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

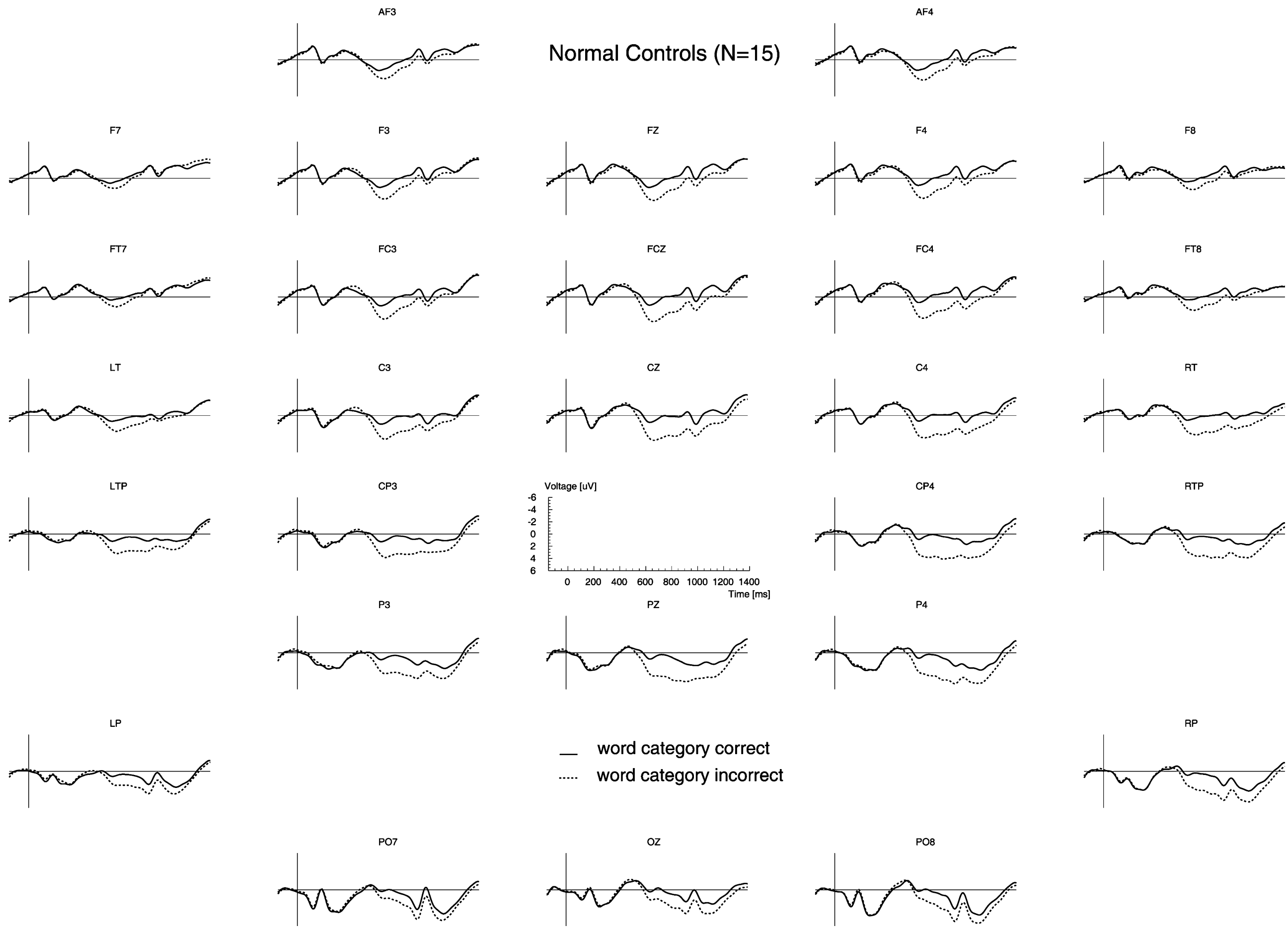

Fig. 2. Grand average ERP waveforms for the group of Normal Control subjects ($N = 15$) for the word category violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the syntactic violation.

to as LAN (*Left Anterior Negativity*) (Friederici & Mecklinger, 1996) or AN (*Anterior Negativity*) (Hagoort et al., 2003).

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 ($F(1, 14) = 20.74$; $MSe = 27.68$; $p = .000$), and a significant Grammaticality by Site interaction ($F(1.95, 27.29) = 6.57$; $MSe = 1.75$; $p = .005$). 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 ($F(1, 14) = 9.75$; $MSe = 1.59$; $p = .007$). In addition, the P600/SPS effect was significantly larger over posterior (PL and PR) than over anterior (AL and AR) scalp regions ($F(1, 14) = 4.96$; $MSe = 3.99$; $p = .043$).

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

3.1.2. RH patients

Fig. 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 ($F(1, 8) = 2.48$; $MSe = 13.55$; $p = .154$). Also the Grammaticality by Site interaction failed to reach significance ($F < 1$). Analyses on individual electrode sites revealed also no significant effects.

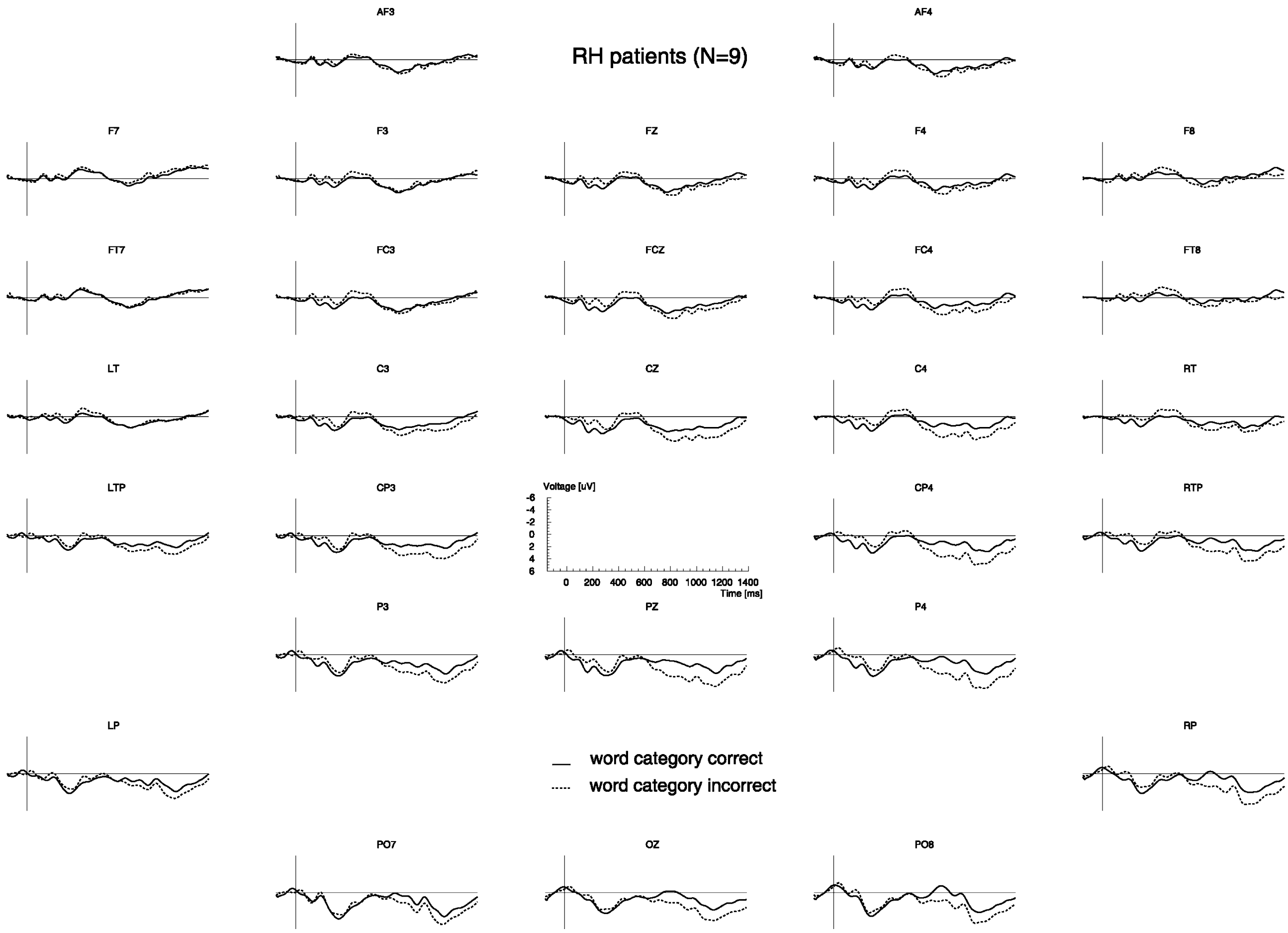

Fig. 3. Grand average ERP waveforms for the group of RH patients ($N = 9$) for the word category violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the syntactic violation.

In the 400–500 ms latency window, the omnibus ANOVA resulted in a significant main effect of Grammaticality ($F(1,8) = 5.97$; $MSe = 9.18$; $p = .040$). 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 ($F(1,8) = 3.12$; $MSe = 19.07$; $p = .115$). The Grammaticality by Site interaction was not significant ($F(1.81, 14.47) = 2.12$; $MSe = 1.61$; $p = .159$). However, the interaction between Grammaticality and Hemisphere was significant ($F(1,8) = 5.99$; $MSe = 2.34$; $p = .040$), 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 ($F(1,8) = 4.67$; $MSe = 15.88$; $p = .063$).

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 ($F(1,22) = 2.02$; $MSe = 25.83$; $p = .170$). 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 ($F(1,22) = 2.99$; $MSe = 41.53$; $p = .098$).

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

3.1.3. Broca patients

In Fig. 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

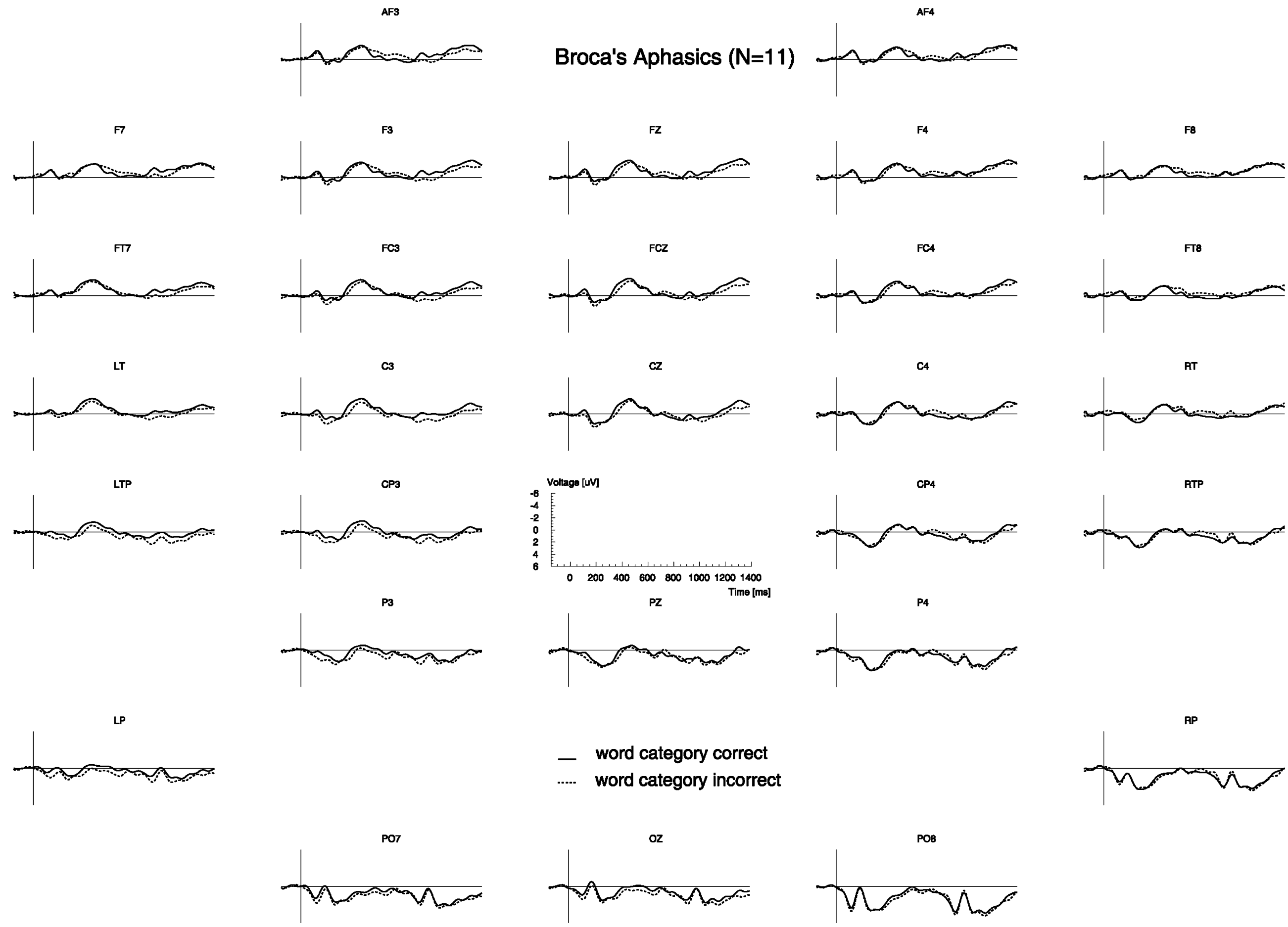

Fig. 4. Grand average ERP waveforms for the group of Broca patients ($N = 11$) for the word category violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the syntactic violation.

(400–500 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 ($F(1,10) = 1.30$; $MSe = 8.88$; $p = .281$). 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 ($F(1.49, 14.90) = 2.72$; $MSe = 1.38$; $p = .109$).

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 ($F(1.62, 16.25) = 2.20$; $MSe = 2.23$; $p = .149$). However, the Grammaticality by Hemisphere interaction reached significance ($F(1,10) = 5.08$; $MSe = 4.07$; $p = .048$), 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 ($F(1,10) = 5.27$; $MSe = 4.86$; $p = .045$). 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.

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 ($F(1,24) = 15.10$; $MSe = 31.45$; $p = .001$).

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.

3.1.4. Individual subject data for the word-category violation condition

Fig. 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, and F8). Averaged over 8 posterior electrodes (Pz, Oz, P3, LP, PO7, P4, RP, and 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.

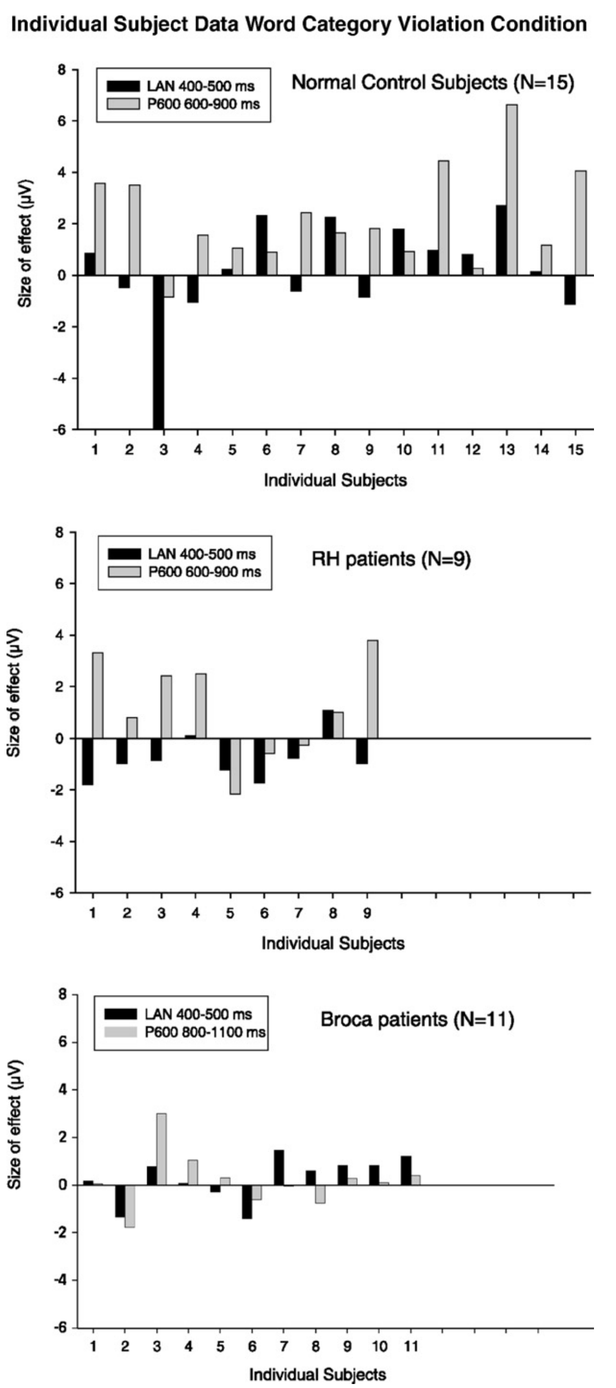

Fig. 5. Mean amplitude of word category violation effects in µV over 8 anterior electrodes (400–500 ms) and 8 posterior electrodes (normal controls and RH patients: 600–900 ms; Broca patients: 800–1100 ms), for each individual subject.

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.

3.2. Semantic violation condition

3.2.1. Normal control subjects

Fig. 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 ($F(1,14) = 19.55$; $MSe = 16.93$; $p = .001$), and a significant Semantic Violation by Site interaction ($F(1.91, 26.71) = 3.52$; $MSe = 4.57$; $p = .046$). This interaction was due to a hemispheric difference: the Semantic Violation by Hemisphere interaction was almost significant ($F(1,14) = 4.27$; $MSe = 3.86$; $p = .058$). 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

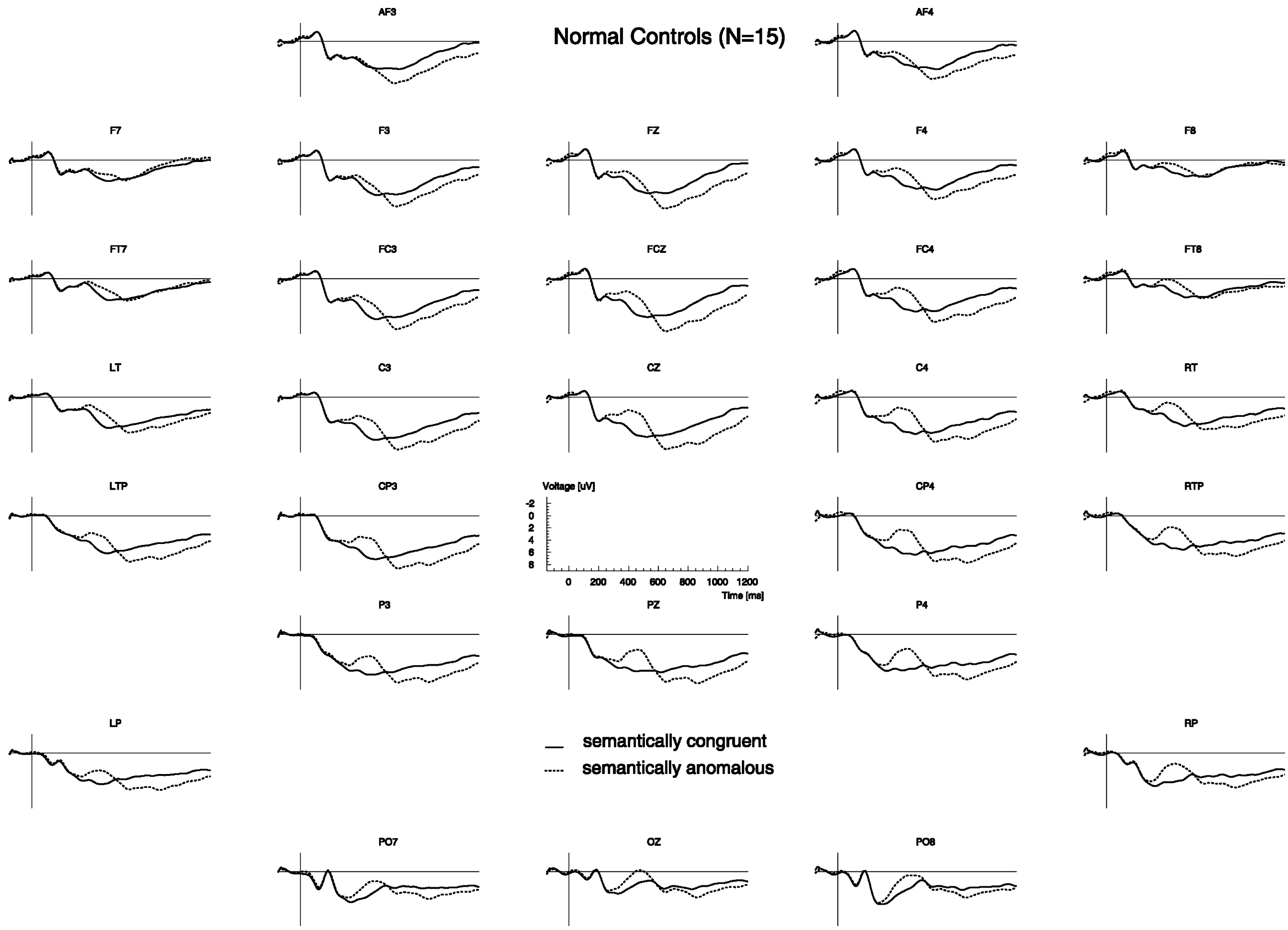

Fig. 6. Grand average ERP waveforms for the group of Normal Control subjects ($N = 15$) for the semantic violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the semantic violation.

Violation ($F(1, 14) = 10.23$; $MSe = 36.74$; $p = .006$). However, the Semantic Violation by Site interaction was not significant ($F(1.51, 21.21) = 1.07$; $MSe = 5.73$; $p = .344$).

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

3.2.2. *RH patients*

Fig. 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. Second, 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 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 ($F(1, 8) = 2.59$; $MSe = 17.84$; $p = .146$), 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 ($F(1, 8) = 4.38$; $MSe = 29.04$; $p = .07$) and a significant Semantic Violation by Site interaction ($F(1.94, 15.52) = 3.74$; $MSe = 5.98$; $p = .048$). 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 ($F(1, 8) = 8.51$; $MSe = 20.58$; $p = .019$). No significant Semantic Violation by Hemisphere interaction was obtained ($F(1, 8) = 2.52$; $MSe = 4.95$; $p = .151$).

In the 700–900 ms latency window, an omnibus ANOVA resulted in a significant main effect of Semantic Violation ($F(1, 8) = 7.00$; $MSe = 24.06$; $p = .029$). In addition, also the Semantic Violation by Site interaction was significant ($F(2.94, 23.55) = 4.22$; $MSe = 2.96$; $p = .016$). This interaction was related to the left posterior topography of the effect.

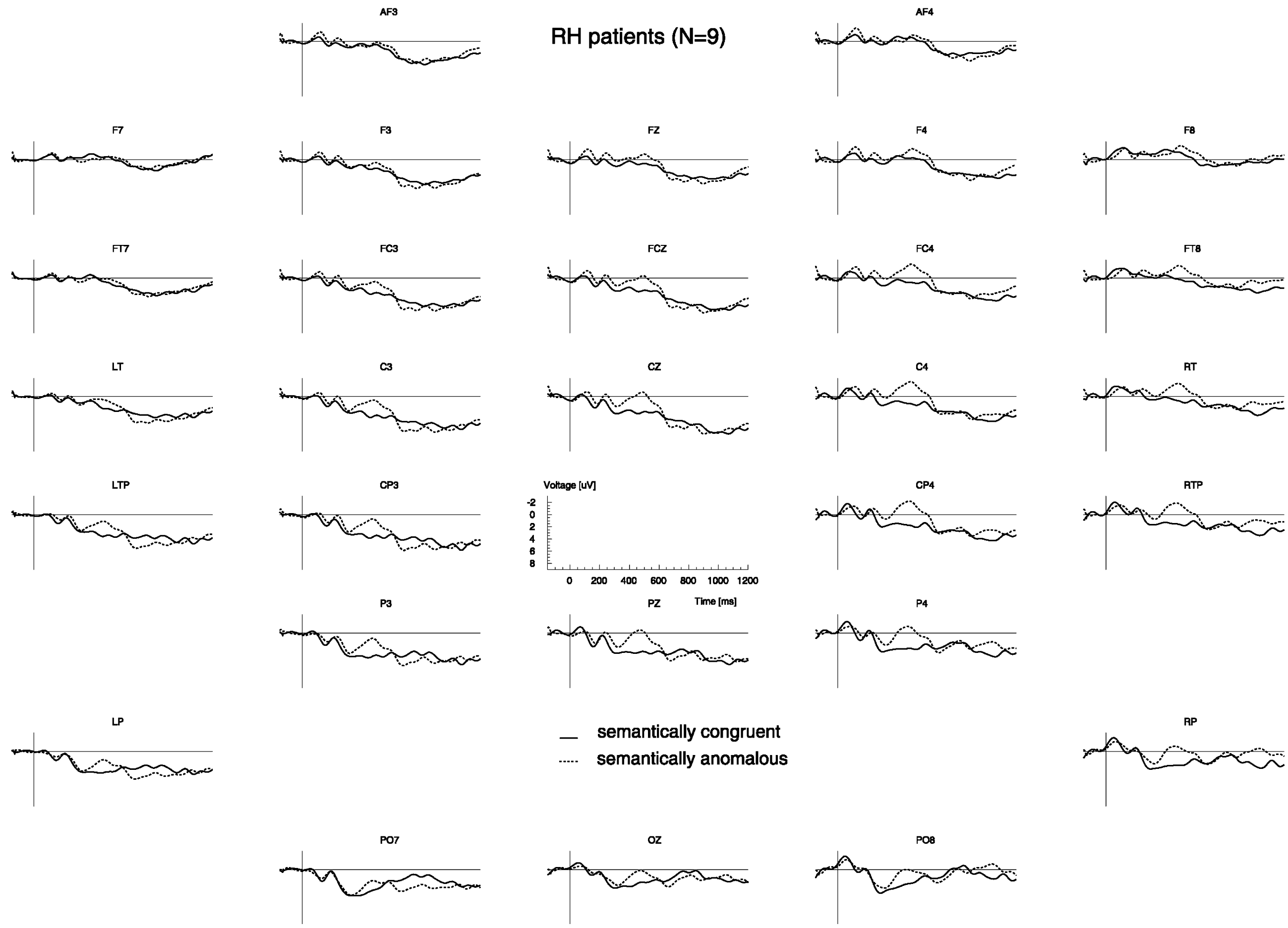

Fig. 7. Grand average ERP waveforms for the group of RH patients ($N = 9$) for the semantic violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the semantic violation.

Omnibus ANOVAs in the 300–500 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.

3.2.3. Broca patients

Fig. 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 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 ($F(1, 10) = 1.53$; $MSe = 31.27$; $p = .245$). However, the Semantic Violation by Site interaction was significant ($F(2.59, 25.86) = 3.54$; $MSe = 4.76$; $p = .034$). This was due to the fact that the semantic violation effect was significantly larger over the right than over the left hemisphere ($F(1, 10) = 7.93$; $MSe = 7.19$; $p = .018$). An additional ANOVA in which only the electrodes over the right hemisphere were included resulted in a marginally significant effect of Semantic Violation ($F(1, 10) = 3.78$; $MSe = 30.35$; $p = .080$).

For the 700–900 ms latency window, the omnibus ANOVA only showed a marginally significant main effect of Semantic Violation ($F(1, 10) = 3.35$; $MSe = 25.48$; $p = .097$). The Semantic Violation by Site inter-

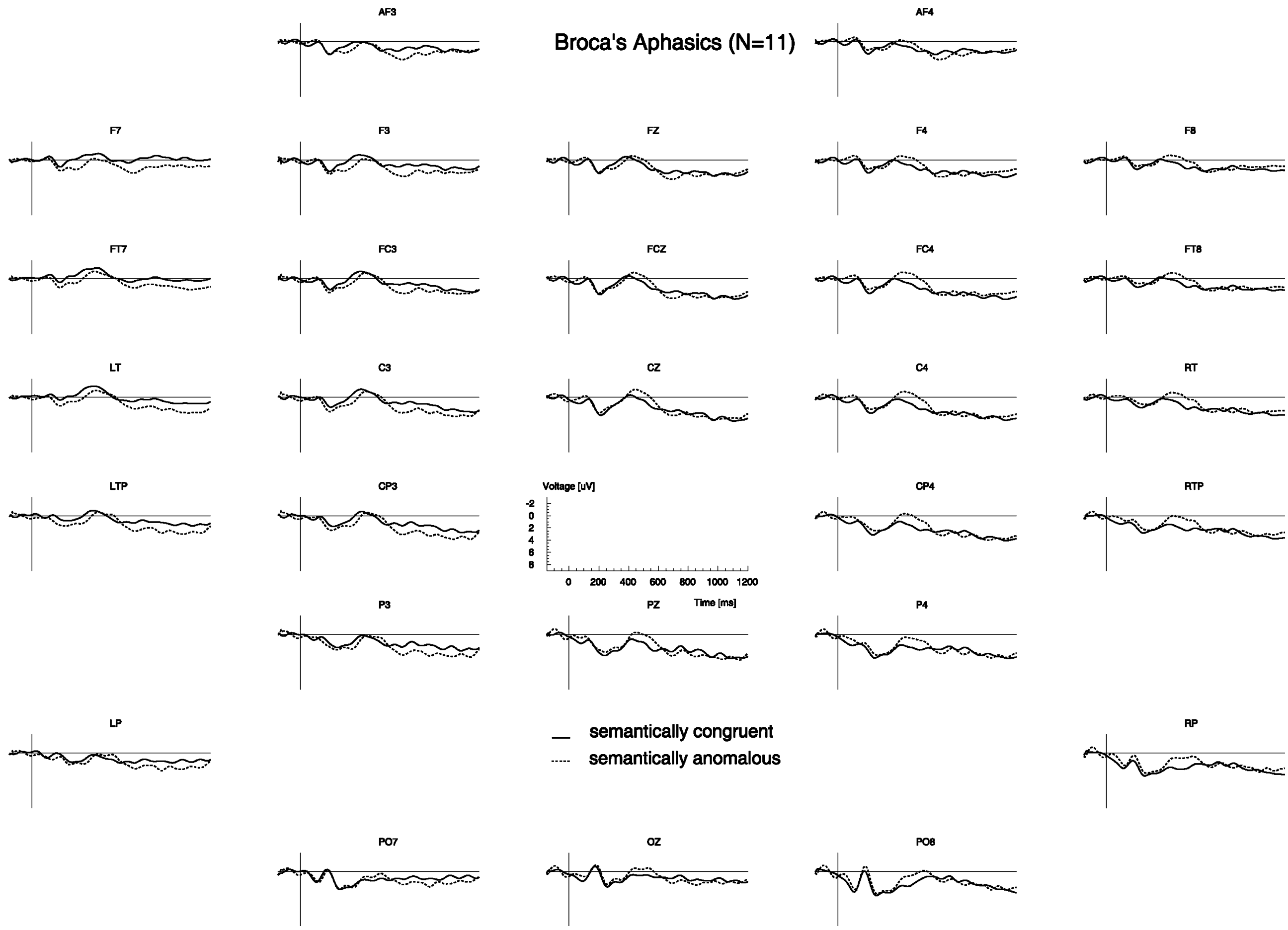

Fig. 8. Grand average ERP waveforms for the group of Broca patients ($N = 11$) for the semantic violations (dotted line) and their correct counterparts (solid line). Zero on the time axis marks the onset of the word presentation that instantiates the semantic violation.

action did not result in a significant interaction ($F(3,30) = 1.40$; $MSe = 5.67$; $p = .262$). However, the Semantic Violation by Hemisphere interaction was marginally significant ($F(1,10) = 3.72$; $MSe = 8.37$; $p = .083$). 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 ($F(1,10) = 6.16$; $MSe = 19.63$; $p = .0032$).

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 ($F(1,24) = 8.59$; $MSe = 335.88$; $p = .007$). This main effect was qualified by a significant Group of Subjects by Semantic Violation interaction ($F(1,24) = 7.90$; $MSe = 29.54$; $p = .010$), 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 ($F(1,24) = 10.24$; $MSe = 274.07$; $p = .004$). However, the Group of Subjects by Semantic Violation interaction was not significant ($F(1,24) = 1.43$; $MSe = 52.69$; $p = .243$).

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.

3.2.4. Individual subject data for the semantic violation condition

Fig. 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, and PO8. Also for the Broca

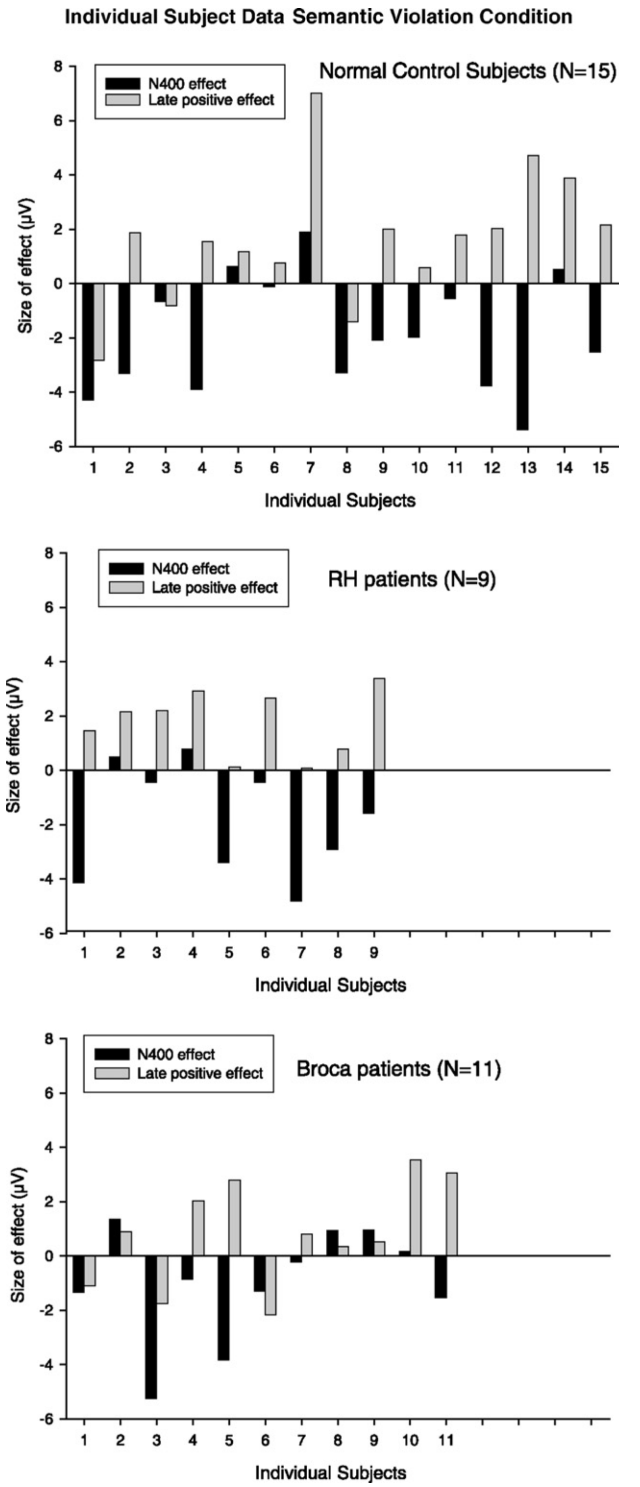

Fig. 9. Mean amplitude of semantic violation effects in μV over 8 posterior electrodes (normal controls and RH patients: 300–500 ms; Broca patients: 400–600 ms) and 700–900 ms, for each individual subject.

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 12 of the 15 normal control subjects, in all RH patients, and in 8 of the 11 Broca patients. Thus, the pattern of results in the group averages was noticeable in most individual subjects.

3.3. 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 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.

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

For the *normal control subjects*, a significant P300 oddball-effect (4.71 μV) was obtained, with a characteristic centro-parietal distribution ($F(1,14) = 39.03$; $Mse = 123.73$; $p = .000$). Also, the P300 effect (4.33 μV) for the *RH patients* was significant ($F(1,8) = 29.89$; $MSe = 82.29$; $p = .001$) 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 ($F(1,9) = 16.09$; $MSe = 38.13$; $p = .003$) and corresponded to a

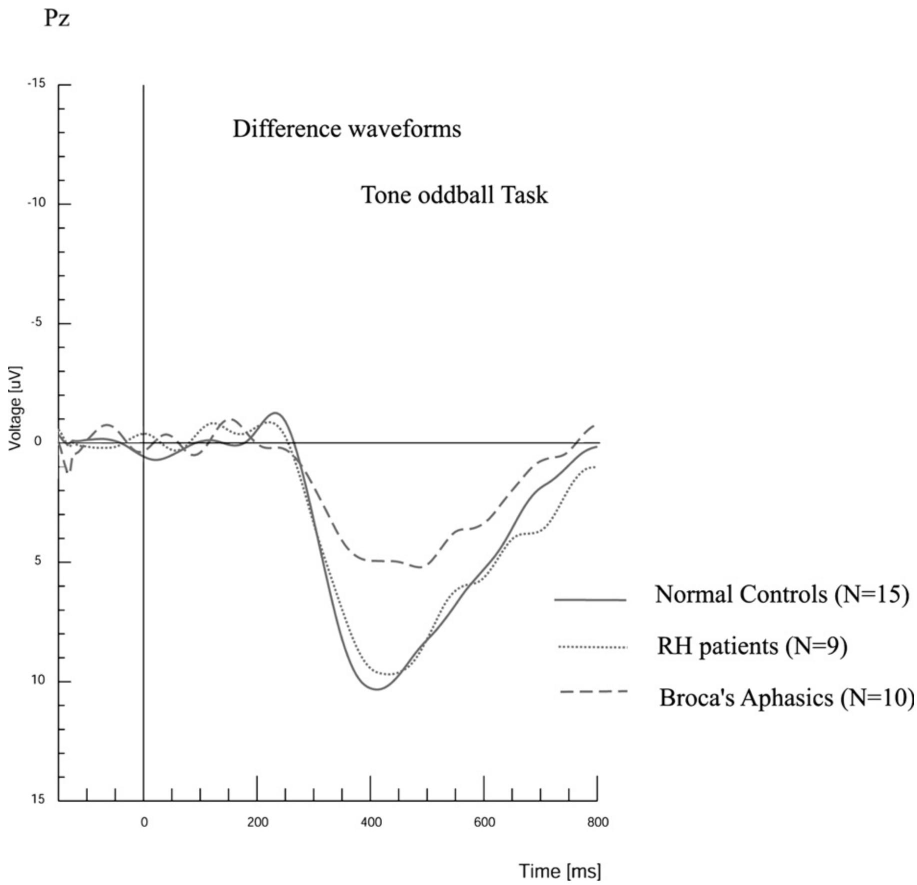

Fig. 10. Grand average difference waveforms tone oddball condition at Pz for Normal Control subjects, RH patients, and Broca patients.

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 ($F(1,23) = 6.80$; $MSe = 90.23$; $p = .016$). 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.

3.4. Questionnaire

The questionnaire was designed to induce the subjects to read the sentences attentively. Subjects knew that questions would be asked, but not when. 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, and Broca patients) as between-subjects factor revealed a significant Group of Subjects effect ($F(2,32) = 5.457$; $MSe = 116.7$; $p = .009$). 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.

4. 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 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 viola-

Table 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	***N400 effect*** 300–500 ms: −1.83 μV	***Delayed/reduced N400 effect*** 400–600 ms: −0.99 μV
	Late positive effect 700–900 ms: 1.67 μV	***Late positive effect*** 700–900 ms: 1.75 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).

tions 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. (2003). 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 and 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., 2003) 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. (2003) did not find an effect of SOA on ERP effects to word-category violations.

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. (2003) 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, 2000; 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 effects in the

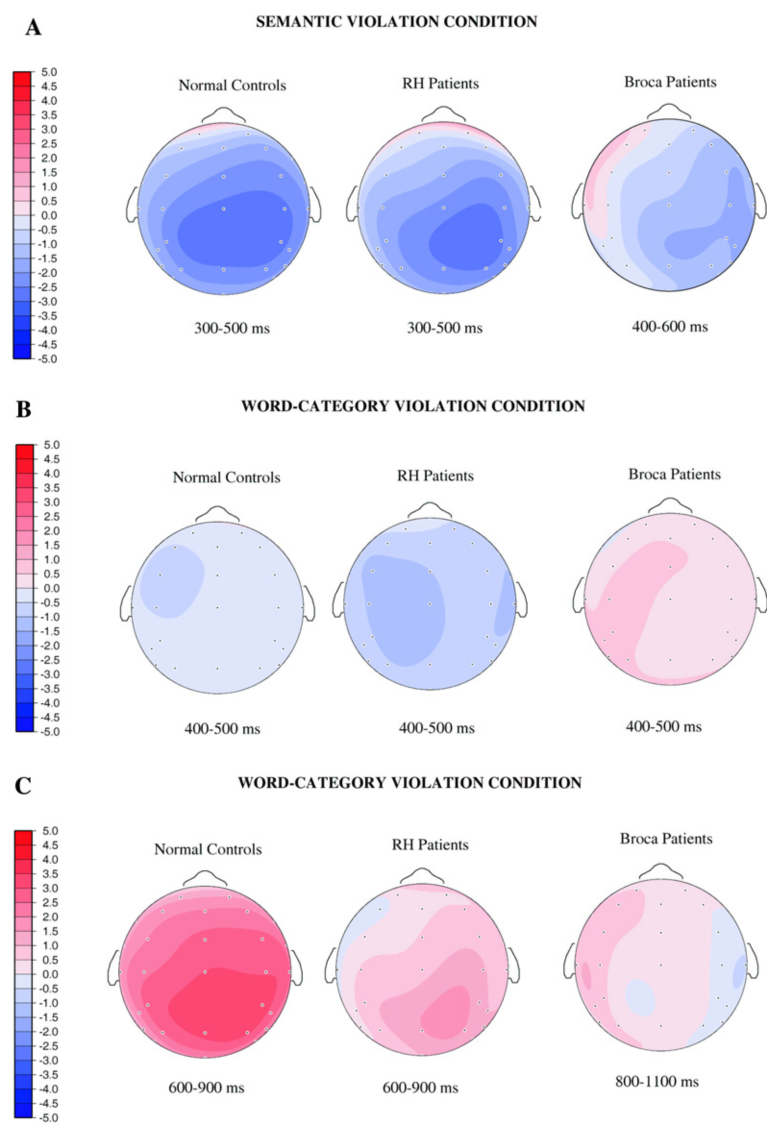

Fig. 11. Scalp distribution of the ERP effects that were obtained for (A) the semantic violations latency window: for normal controls and RH patients 300–500 ms and for Broca patients 400–600 ms; (B) word category violations (latency window: 400–500 ms) and (C) word category violations (latency window: for normal controls and RH patients 600–900 ms and for Broca patients 800–1100 ms). Positive polarity effects are in red, negative-going effects are in blue. Scale values are in μV.

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 temporoparietal 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 ($r = -.11$, $p = .37$). 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 3).

The relative dissociation in semantic versus syntactic processing can also be clearly seen in Fig. 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, 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 et al., 1999, 2002) 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.

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