Time Course of Evoked-potential Changes in Different Forms of Anomia in Aphasia

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Abstract

■ Impaired word production after brain damage can be due to impairment at lexical–semantic or at lexical–phonological levels of word encoding. These processes are thought to involve different brain regions and to have different time courses. The present study investigated the time course of electrophysiological correlates of anomia in 16 aphasic speakers, divided in two subgroups according to their anomic pattern (8 with lexical–semantic impairment and 8 with lexical–phonological impairment), in comparison to 16 healthy control subjects performing the same picture naming task. Differences in amplitudes and in topographic maps between groups were differently distributed when the whole heterogeneous group of aphasic patients was compared to the control group and when the two more homogeneous subgroups of anomic patients were analyzed. The entire aphasic group expressed different waveforms and topographic patterns than the control group starting about 100 msec after picture presentation. When two subgroups of aphasic patients are considered according to the underlying cognitive impairment, early event-related potential (ERP) abnormalities (100–250 msec) appeared only in the lexical–semantic subgroup, whereas later ERP abnormalities (300–450 msec) occurred only in the lexical–phonological subgroup. These results indicate that the time windows of ERP abnormalities vary depending on the underlying anomic impairment. Moreover, the findings give support to current hypotheses on the time course of processes involved in word production during picture naming. ■

INTRODUCTION

Retrieving and producing a word during picture naming is a task that speakers perform rapidly and easily in most cases. This fast-flowing activity implies complex cognitive processes spreading from visual recognition to articulation, through several stages, which include conceptual preparation, lexical retrieval, phonological encoding, and phonetic encoding (Levelt, Roelofs, & Meyer, 1999). This system can break down after brain damage, resulting in impaired word production (anomia). Different anomic patterns attributed to impairment at distinct processes of word encoding have been identified in aphasic patients. Two different kinds of pure forms of anomia, reflecting impaired lexical–semantic or lexical phonological processes, have been described. Cases of anomic patients producing mainly semantic paraphasias with selective damage to conceptual information and preserved phonological code have been reported (Hillis, Rapp, Romani, & Caramazza, 1990; Warrington, 1975). The opposite pattern of anomia is characterized by selective difficulties in accessing phonological information of words and the production of phonological paraphasias in the presence of preserved semantics (Caramazza, Papagno, & Ruml, 2000; Hillis, Boatman, Hart, & Gordon, 1999). Although these pure anomic patterns are rare, an underlying predominant lexical–semantic or lexical–phonological impairment can be identified in many cases of anomia on the basis of error distribution during picture naming and of specific failures in tasks assessing associated functions, in particular, semantic competence (Schwartz, Dell, Martin, Gahl, & Sobel, 2006; Laine, Tikkala, & Juhola, 1998; Kay & Ellis, 1987).

The semantic and phonological processes underlying word production involve different regions in the brain (Mechelli, Joseph, Lambon Ralph, McClelland, & Price, 2007; Price, Devlin, Moore, Morton, & Laird, 2005; Poldrack et al., 1999; Price, Moore, Humphreys, & Wise, 1997; Démonet et al., 1992). Magnetoencephalographic (MEG) studies in healthy speakers (Vihla, Laine, & Salmelin, 2006; Levelt, Praamstra, Meyer, Helenius, & Salmelin, 1998; Salmelin, Hari, Lounasmaa, & Sams, 1994) showed that activation during naming proceeds from occipital visual areas to bilateral parietal and left temporal areas, then to premotor frontal areas in the first 400–500 msec following picture presentation. Although none of these studies provided direct evidence for a differential time course of each encoding process, Indefrey and Levelt (2004) tried to derive specific spatio-temporal correlates of the different processes implied in speech production based on a meta-analysis of functional imaging

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and MEG studies. Based on a model of serial encoding during speech production (Levelt et al., 1999), the authors estimated that picture naming starts with visual and conceptual processes in the first 175 msec after picture presentation, followed by lexical retrieval (the retrieval of semantic and syntactic properties of the word) until about 250 msec. The encoding of word form (phonological encoding) was estimated to be accomplished between 250 and 450 msec and, finally, phonetic encoding after 450 msec.

If different anomic profiles reflect impairment at different encoding processes, they should correspond to abnormal temporal correlates during word production in different time windows when compared to healthy controls. Although several electrophysiological studies have compared aphasic patients to healthy controls using language comprehension tasks, which differentiated between specific semantic and syntactic processes during word or sentence comprehension (Wassenaar & Hagoort, 2005; Hagoort, Wassenaar, & Brown, 2003; Friederici, von Cramon, & Kotz, 1999; Hagoort, Brown, & Swaab, 1996), only a few studies have investigated the time course of impaired word production (Angrilli, Elbet, Cusumano, Stegagno, & Rockstroh, 2003; Cornelissen et al., 2003; Dobel et al., 2001). Cornelissen et al. (2003) used MEG to analyze picture naming in three aphasic speakers before and after a therapy period. The authors reported therapy-linked changes in a left inferior parietal source, starting at about 300 msec after picture presentation. Two ERP studies used semantic, syntactic, and phonological judgment tasks with pictures (Dobel et al., 2001) or words (Angrilli et al., 2003). Despite greatly different paradigms, both studies reported differences on mean amplitudes between aphasic patients and controls starting 300 msec after stimulus presentation. The apparent convergence between these studies reporting similar time windows of abnormalities or changes in aphasic patients during word encoding is puzzling when considering the different tasks (monitoring for specific linguistic properties, targeting different encoding processes—semantic, syntactic, phonological—and naming), and heterogeneous aphasic profiles used in these studies. Indeed, according to the arguments developed above on the time course of the processes implied in word production, one would expect different electrophysiological correlates (1) in tasks tapping into different encoding processes and (2) in aphasic patients with anomia due to disruption of the different cognitive processes underlying word production.

In the present study, we explored whether the temporal course of electrocortical activation during picture naming varies according to the underlying anomic profile. We contrasted analyses carried out on a heterogeneous group of patients to those carried out on two groups of aphasic patients, classified according to their anomic subtype. We expected ERP correlates in aphasic patients with lexical–semantic anomia and patients with lexical–phonological impairment to diverge from healthy controls in different time windows. We combined waveform and topographic analyses in order to distinguish between differences reflecting simple latency shifts of processes implying similar brain areas and those reflecting topographic differences among groups.

METHODS

Participants

Anomic Patients

Sixteen aphasic patients aged from 34 to 79 years (mean = 54.8 years, *SD* = 11.7) participated in the study. All were right-handed native or proficient French-speakers with at least 11 years of education. They were selected according to the following criteria. They suffered from anomia among other aphasic symptoms, and presented either a predominance of semantic errors over phonological errors or the opposite pattern. Their demographic data and aphasia subtype are presented in Table 1, and the lesion sites of each patient are shown in Figure 1. Aphasia was assessed with the Montreal–Toulouse 86 Aphasia Battery (Nespoulous et al., 1992) and naming tests used in previous studies on anomia (Laganaro, Di Pietro, & Schnider, 2006a, 2006b).

A double criterion was used to determine subtypes of anomia. Patients were first selected and assigned to the lexical–semantic or the lexical–phonological subgroup according to their error distribution in naming tasks and their performance on the semantic assessment tasks. Semantic deficits were evaluated using the Pyramid and Palms test (Howard & Patterson, 1992) and the French adaptation of an intracategorical word-to-picture matching tasks (Laiacona, Capitani, & Barbarotto, 1993). This especially allowed to determine which patients displayed a semantic impairment. We then applied to each patient's error distribution in the experimental naming task (see below) the Web-based semantic–phonological fitting routine developed by Dell, Lawler, Harris, and Gordon (2004) and Foygel and Dell (2000) (http://langprod.cogsci.uiuc.edu/cgi-bin/webfit.cgi). This interactive activation model accounts for patterns of aphasic errors by altering the normal parameters of connections between semantic and lexical nodes (semantic weights) or the connections between lexical and phonological nodes (phonological weights). The Web-based automated data-fitting program calculates the defective values of each parameter: The lowest values indicate the most impaired connections.

The two subgroups of anomic patients are presented in Table 2. The *lexical–semantic subgroup* included eight patients (Patients P1 to P8) producing a preponderant proportion of semantic, verbal, and omission errors and with impaired connections between semantic and lexical nodes (lower values for lexical–semantic weights than for lexical–phonological weights). These

Table 1. Patients' Demographic Data

	Sex	*Age*	*Etiology*	*Lesion*	*Time Postonset*	*Aphasia Subtype*
P1	M	49	TBI	L frontal and temporal contusions and axonal lesions of the internal and external capsule	3 months	anomic
P2	M	34	CVA	temporal and insular bilateral predominant L and parahippocampal	3 months	transcortical sensory
P3	F	54	herpes encephalopathy	temporal bilateral predominant L, orbito-frontal and cingulate gyrus	3 months	transcortical sensory
P4	F	53	CVA	L parieto-occipital and internal temporal	2 months	anomic
P5	M	57	CVA	L thalamic	2 months	anomic
P6	M	56	CVA	L fronto-parietal	2 months	transcortical sensory
P7	M	65	CVA	L fronto-opercular	1 month	Wernicke
P8	M	34	TBI	diffuse axonal, predominant L fronto-parietal	4 years	anomic
P9	M	68	CVA	L fronto-parietal	4 months	Wernicke
P10	F	46	CVA	L fronto-parietal	2 months	Broca
P11	F	58	CVA	left temporal–parietal–occipital	3 months	anomic
P12	F	79	CVA	L parietal	2 months	conduction
P13	M	55	CVA	L temporo-parietal	4 months	conduction
P14	M	67	CVA	L parietal	5 years	conduction
P15	F	49	CVA	L internal capsule and caudate nucleus	2 years	anomic
P16	M	54	CVA	L temporal–parietal	6 years	conduction

M = male; F = female; CVA = cerebrovascular accident; TBI = traumatic brain injury; L = left.

patients also displayed semantic impairment or marginal scores in the semantic assessment tasks (see Table 2). The other eight patients produced mainly phonological and formal paraphasias and presented impaired connections between lexical and phonological nodes; they constituted the *lexical–phonological subgroup* (Patients P9 to P16).

Healthy Control Subjects

The control subjects were 16 healthy volunteers aged from 32 to 73 years (mean = 54.7 years, *SD* = 10.5), matched on age and education to the patient group. They performed the naming task very easily (98% correct, *SD* = 3%).

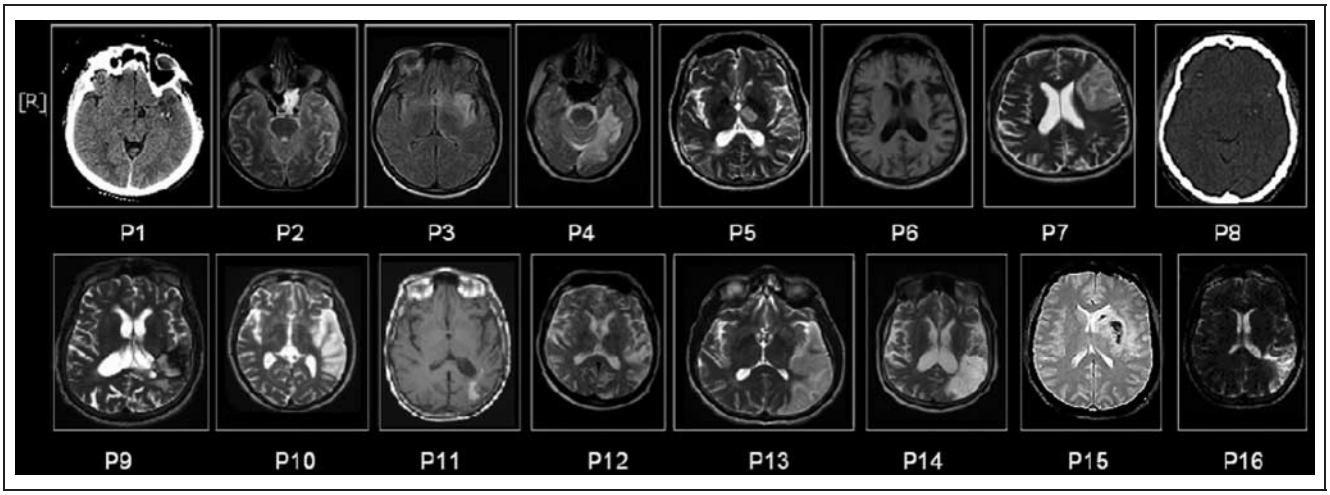


Figure 1. Site of lesion of each patient (MRI or CT scan).

Table 2. Error Distribution for Each Patient in the Experimental Naming Task and Fits of the Semantic–Phonological Models

		Error Distribution (%)						Fits of the Semantic–Phonological Model		Semantic Assessment (%)	
	% Correct	Semantic	Formal	Mixed	Unrelated	Phonological, Neologism	No Response	Lexical–Semantic Weights	Lexical–Phonological Weights	PPT (pict.)	Intracat. Matching
P1	73	28	0	4	1	0	67	**0.023**	0.038	88	83
P2	31	29	0	1	3	4	64	**0.012**	0.300	60	50
P3	46	30	1	0	1	2	67	**0.017**	0.033	75	72
P4	62	9	0	2	0	0	89	**0.027**	0.041	90	88
P5	86	41	0	0	8	0	51	**0.024**	0.040	90	85
P6	82	48	11	0	0	4	37	**0.021**	0.032	84	50
P7	67	24	6	0	31	6	33	**0.015**	0.300	90	72
P8	83	16	4	4	8	4	64	**0.026**	0.035	>90	87
P9	14	2	2	0	2	33	60	0.097	**0.001**	>90	>90
P10	8	0	4	0	3	71	21	0.067	**0.001**	>90	>90
P11	28	4	4	1	0	32	59	0.028	**0.011**	>90	>90
P12	48	1	16	2	3	77	1	0.033	**0.010**	>90	>90
P13	44	2	23	0	1	73	2	0.036	**0.009**	>90	>90
P14	74	5	3	0	0	51	41	0.063	**0.009**	>90	>90
P15	87	5	5	0	1	11	79	0.045	**0.022**	>90	>90
P16	78	5	5	0	0	27	64	0.046	**0.018**	>90	>90

Semantic = words with a semantic relationship to the target; formal = word substitution error with no semantic relationship to the target, sharing at least the first phoneme or the stressed vowel or at least one segment per syllable with the target word; mixed = a formal error with semantic relationship to the target (ex. *couteau–ciseaux* [kuto]–[sizo]); unrelated = a word without semantic or phonological relationship; phonological = all nonwords responses; no response = include no responses and circumlocutions; PPT (pict) = Pyramid and Palms test scores on pictures (Howard & Patterson, 1992); Intracat. Matching = French adaptation of an intracategorical word-to-picture matching tasks (Laiacona et al., 1993).

All subjects gave written informed consent to participate in the study, which was approved by the local ethical committee.

Experimental Procedure

High-resolution electroencephalogram (EEG) was recorded during a delayed picture naming task. The stimuli were 144 line drawings selected from French databases (Bonin, Peerman, Malardier, Méot, & Chalard, 2003; Alario & Ferrand, 1999). Each trial had the following structure: first, a "+" sign was presented for 500 msec, then a picture appeared on screen for 2000 msec, followed by a response cue (question mark). The participants were asked to name aloud the picture only when the question mark appeared on the screen. This procedure was adopted to avoid possible artifacts during motor preparation for overt naming.

All but two aphasic patients were recorded on two sessions, 1 to 3 weeks apart, with the same experimental procedure and pictures set in order to obtain sufficient EEG data. Patients P8 and P14 and control subjects were recorded once.

EEG Acquisition and Preprocessing

EEG was recorded continuously using the Active-Two BioSemi EEG system (BioSemi V.O.F., Amsterdam, Netherlands) with 128 channels covering the entire scalp. Signals were sampled at 512 Hz with filters set at 0 to 134 Hz. Epochs of EEG from −100 to 600 msec relative to picture onset were averaged for each subject. All trials were visually inspected, and epochs contaminated by eye blinking or movements were rejected and excluded from averaging. The data were baseline corrected using the 100-msec prestimulus period. Before group averaging, individual data were recalculated against the average reference and were band-pass filtered to 1–30 Hz. After exclusion of contaminated trials, a minimum of 83 epochs was retained per subject (139 and 140 epochs in average for each patient subgroup and 97 for the control group) when correct and erroneous responses were averaged

together. Separate averaging of correct and erroneous trials was also carried out for each patient's subgroup. The number of epochs in one or the other condition (correct responses or naming errors) was bound to be limited for some patients according to their behavioral results (from a minimum of 18 to a maximum of 187 retained epochs). Therefore, successful and erroneous responses were averaged separately only for a marginal analysis, which was carried out in order to replicate previous results indicating very similar divergent electrophysiological patterns for correct and for erroneous responses in individual aphasic patients (Laganaro et al., in press; Cornelissen et al., 2003). All other analyses were carried on the entire set of trials.

EEG Analyses

The ERPs were first subjected to waveform analysis to determine the time periods where amplitude differences over all electrodes were found between groups. However, the differences observed on amplitudes can follow from a modulation in the strength of the electric field, from a topographic change of the electric field (revealing distinguishable brain generators) as well as latency shifts in brain processes. To differentiate these effects, topographic analyses were also performed. This approach allows to summarize ERP data into a limited number of electrocortical map configurations and identifying time periods during which different populations (control subjects and anomic subtypes) evoke different electrocortical configurations.

Waveform Analysis

Waveform analysis was carried out in the following way: two-sample *t* tests were computed on amplitudes of the evoked-potentials between groups at each electrode and time frame (every 2 msec) over the whole period (0 to 600 msec). Only differences over at least three electrodes from the same region out of six regions (left and right anterior, central, posterior) and extending over at least 10 msec were retained, and Bonferroni correction was applied on the number of electrodes from each of the six regions.

Topographic Analysis

The second analysis was a topographic (map) pattern analysis. This method is independent of the reference electrode (Michel et al., 2001, 2004) and insensitive to pure amplitude modulations across conditions (topographies of normalized maps are compared). A modified spatial *k*-means cluster analysis was used to determine the most dominant electrocortical map configurations (Michel et al., 2001; Pascual-Marqui, Michel, & Lehmann, 1995). A modified cross-validation criterion determined the optimal number of maps that best explained the group-averaged datasets. Statistical smoothing was used to eliminate temporally isolated maps with low strength. This procedure is described in detail in Pascual-Marqui et al. (1995). Additionally, a given topography had to be present for at least 15 time frames (30 msec).

Then, the pattern of maps observed in the averaged data was statistically tested by comparing each of these maps with the moment-by-moment scalp topography of individual subject's ERPs from each group. Each time point was labeled according to the map with which it best correlated spatially, yielding a measure of map presence. This procedure, referred to as ''fitting,'' allowed us to establish how well a cluster map explained individual patterns of activity (GEV: global explained variance) and its duration. These latter values were used for statistical analysis.

This approach has been used in other cognitive domains with groups of healthy subjects (Schnider, Mohr, Morand, & Michel, 2007; Murray, Camen, Gonzalez Andino, Bovet, & Clarke, 2006) as well as with brain-damaged patients (Laganaro, Morand, Schwitter, Zimmermann, & Schnider, 2008; Lehmann, Morand, James, & Schnider, 2007).

RESULTS

Lexical–semantic and Lexical–phonological Subgroups

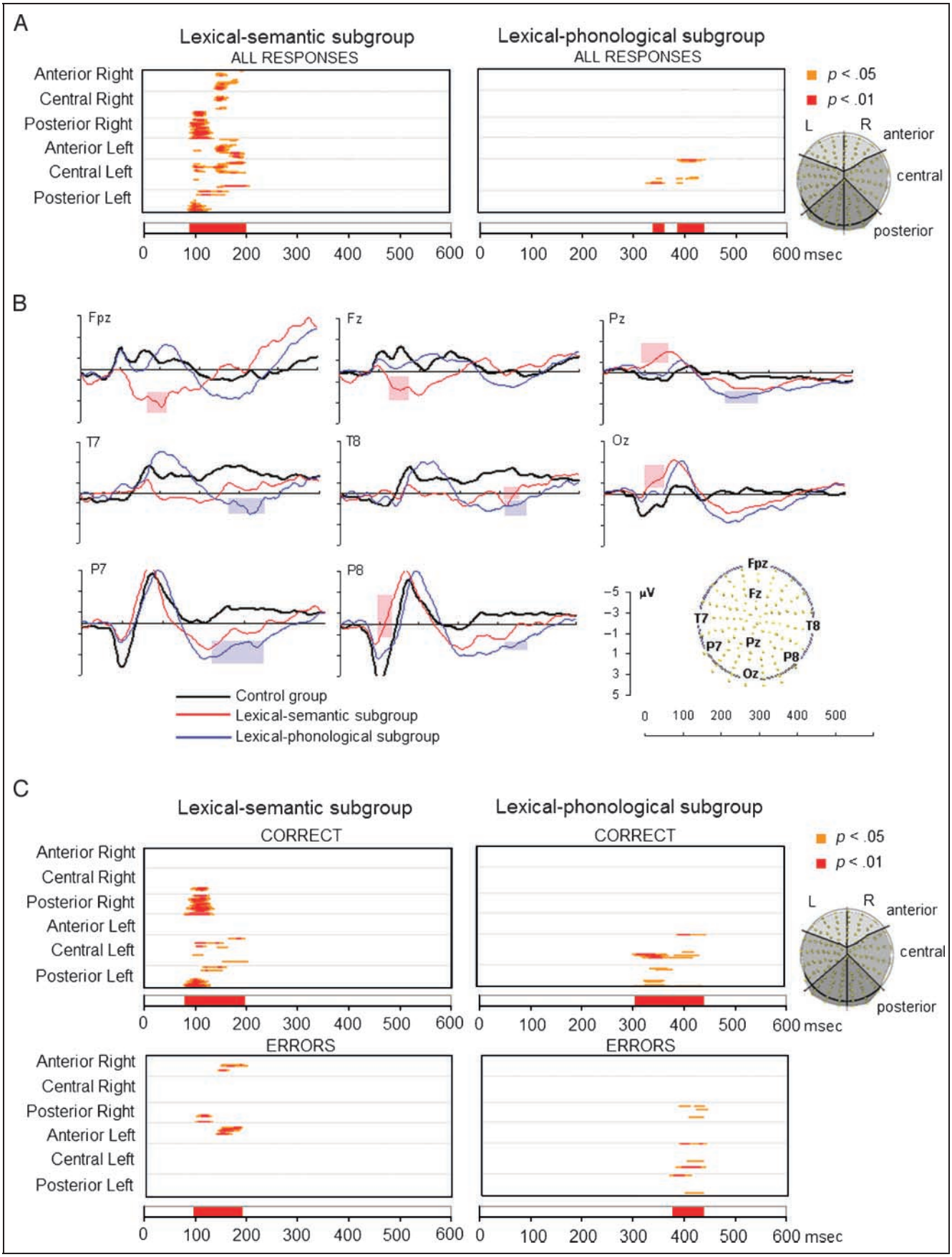
The following analyses compared the two subgroups of anomic patients (lexical–semantic and lexical phonological anomia) separately with the control group.

Waveforms Analysis

The ERP differences on amplitudes between controls and aphasic patients were differently distributed in the two anomic subgroups (Figure 2). Divergent amplitudes started at about 90 msec to about 200 msec over the entire scalp in the lexical–semantic subgroup. Differences between the lexical–phonological subgroup and controls appeared in a later time window, from 340 msec to about 430 msec. These differences were limited to electrodes from the left central region.

Although the time windows of differences between each subgroup and the controls are clearer in the analysis on the entire set of electrodes (Figure 2A), analysis on single electrodes (Figure 2B) also indicated two periods of different amplitudes between subgroups.

When comparisons between the control group and each aphasic subgroup were carried out separately on correct and on erroneous trials, differences were distributed in the same time windows as in the previous analyses (see Figure 2C compared to Figure 2A). In the lexical–semantic subgroup, differences appeared from


A
Lexical-semantic subgroup
ALL RESPONSES
Lexical-phonological subgroup
ALL RESPONSES
Anterior Right
Central Right
Posterior Right
Anterior Left
Central Left
Posterior Left
p < .05
p < .01
L
R
anterior
central
posterior
0 100 200 300 400 500 600
0 100 200 300 400 500 600 msec
B
Fpz
Fz
Pz
T7
T8
Oz
P7
P8
−5 −3 −1 1 3 5
μV
Fpz
Fz
T7
T8
P7
Pz
P8
Oz
0 100 200 300 400 500
Control group
Lexical-semantic subgroup
Lexical-phonological subgroup
C
Lexical-semantic subgroup
Lexical-phonological subgroup
CORRECT
CORRECT
Anterior Right
Central Right
Posterior Right
Anterior Left
Central Left
Posterior Left
p < .05
p < .01
L
R
anterior
central
posterior
0 100 200 300 400 500 600
0 100 200 300 400 500 600 msec
ERRORS
ERRORS
Anterior Right
Central Right
Posterior Right
Anterior Left
Central Left
Posterior Left
0 100 200 300 400 500 600
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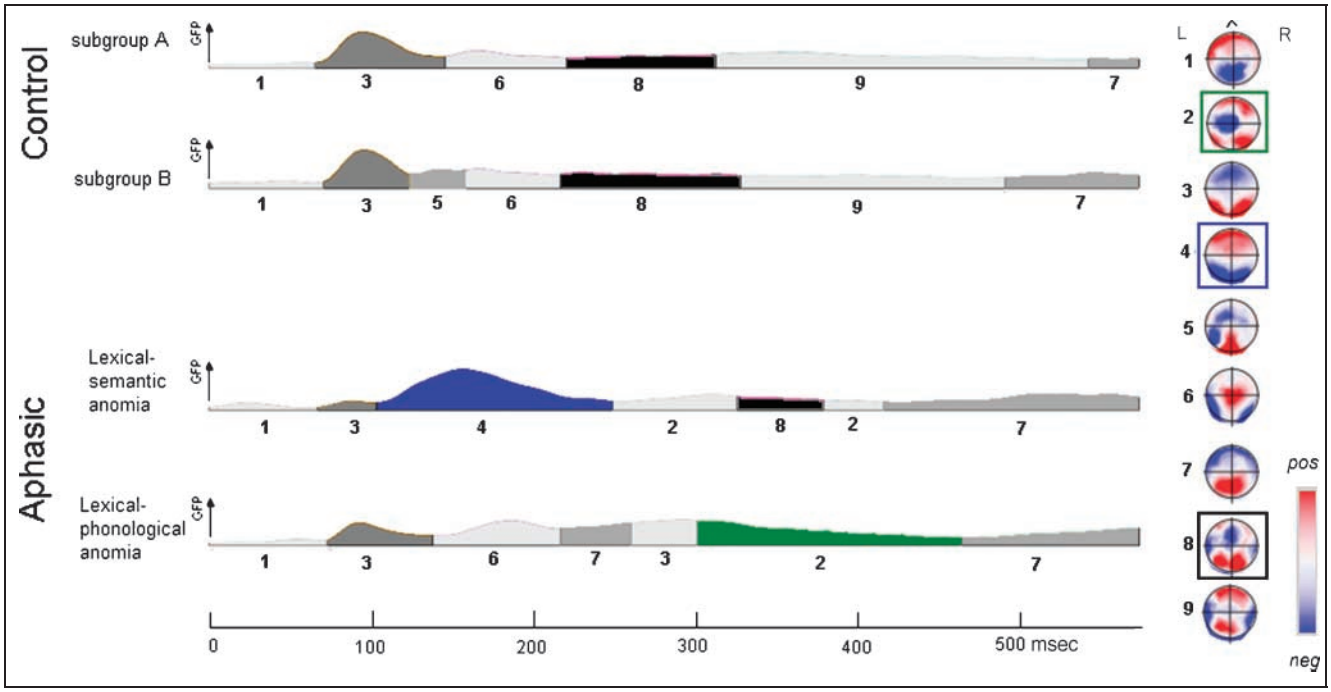

Figure 3. Results of topographic pattern analysis on the four subgroups and topographic maps for each of the nine stable topographies. Only time periods where the electrical field distribution on the scalp significantly differed between groups regarding the fitting parameters (GEV and duration) are marked in color (Maps 2, 4, and 8).

90 msec to about 200 msec for successful and for erroneous naming (Figure 2C). Differences between the lexical–phonological subgroup and the control group were observed from 300 msec to about 430 msec in the correct trials and from 370 msec to about 430 msec in the erroneous trials.

Paired *t* tests calculated between correct responses and errors for each subgroup of aphasic patients revealed no significant differences in either subgroup.

In order to analyze whether differences between groups might also be present between subgroups of healthy subjects, two-sample *t* tests were computed twice on the data of two randomly determined subgroups of eight healthy subjects. The first comparison revealed no significant difference between subgroups; the second one revealed minute differences limited to three nonadjacent electrodes, extending over five time frames (10 msec) only.

Topographic Analysis

A topographic pattern analysis was performed on the grand average of the two aphasic subgroups and of two randomly determined subgroups of control subjects. The results of the spatio-temporal segmentation are presented in Figure 3.

The analysis identified nine different periods of stable electric field configurations in the 600-msec poststimulus period, accounting for 88% of the variance. The same sequence of topographic maps appeared in the two control subgroups with the exception of a map lasting approximately 34 msec, which was present only in Group B (Map 5, Figure 3). However, there was neither an interaction between Map 5 and the four subgroups when fitting the data in the individuals [fitting from 0 to 120 msec: $F(3, 28) < 1$], nor between Maps 4 and 5 and the two control subgroups in the fitting from 80 to 120 msec [$F(1, 14) < 1$].

The map templates were fitted to the individual data from each subgroup with the two following periods: from 0 to 230 msec (Maps 1, 3, 4, 5 and 6) and from 230 to 600 msec (Maps 2, 3, 7, 8, 9). Significant differences between groups on each of the two fitting parameters (duration and GEV) appeared for Map 3 [$F(3, 28) = 4.9$, $p < .01$ and $F(3, 28) = 5.9, p < .01$ on duration and GEV, respectively], Map 4 [duration: $F(3, 28) = 9.6, p < .001$; GEV: $F(3, 28) = 6.0, p < .01$], and Map 8 [$F(3, 28) = 3.4$,

Figure 2. (A) Electrodes yielding significant paired *t*-test values in the comparison between each aphasic subgroup and the control group (top) and time windows of significant differences (bottom). (B) Evoked-potentials recorded in aphasic subgroups and in the control group. Negative is plotted in the upward direction. Color bars indicate the time windows of significant differences (at $p < .01$) between the lexical–semantic subgroup and controls (red) and between the lexical–phonological subgroup and controls (blue). In the lower right corner of the figure, the arrangement of the 128 electrodes and the electrode positions of the displayed waveforms are presented. (C) Electrodes yielding significant paired *t*-test values in the comparison between the control group and each aphasic subgroup separately for correct and erroneous trials and time windows of significant differences for each comparison.

$p < .05$ and $F(3, 28) = 3.96$, $p < .02$ on duration and GEV, respectively]. Fisher's post hoc test revealed a significant difference (at $p < .01$) for Map 3 and Map 4 between the lexical–semantic subgroup and each of the two subgroups of control subjects, indicating that the map (Map 3) had lower GEV and appeared during a shorter time period in this aphasic subgroup, whereas the topographic Map 4, characterized by posterior bilateral negativity and positivity in the anterior region, was specific to the subgroup with lexical–semantic anomia. For Map 4, the difference was also significant between the two aphasic subgroups on GEV ($p = .027$), but not on duration ($p = .15$). For Map 8, a significant difference appeared between the lexical–phonological subgroup and each control subgroup on duration and GEV (all $p < .05$).

No significant difference appeared between groups on Map 2 on the large fitting period ($F = 1$), but a trend for difference between the four groups appeared in the fitting of templates 2, 8, 9 from 300 to 430 msec [$F(3, 28) = 2.8$, $p = .06$ for duration and GEV]. Fisher's comparison revealed significant difference between the lexical–phonological subgroup and each control subgroups at $p < .05$, indicating longer-lasting and higher GEV for Map 2 (characterized by anterior and posterior bilateral but predominant right positivity and central left negativity) in this group of aphasic patients in comparison to the control subjects.

Whole Aphasic Group versus Controls

In order to compare the previous results with the patterns issued from the comparison of a heterogeneous group of aphasic patients and a control group, the following analyses were carried out on the whole group of 16 aphasic patients and the 16 control subjects.

Waveforms Analysis

Results of the two-sample t tests computed between the two groups indicated two periods of different amplitudes between the controls and the aphasic subjects (Figure 4A). The first difference appeared in the time window from 90 to 160 msec, distributed over posterior regions from 90 to 120 msec and over the right and left anterior and central regions between 120 and 160 msec. The second time window of significant differences started at about 390 msec until 440 msec over the central (right and left) electrodes.

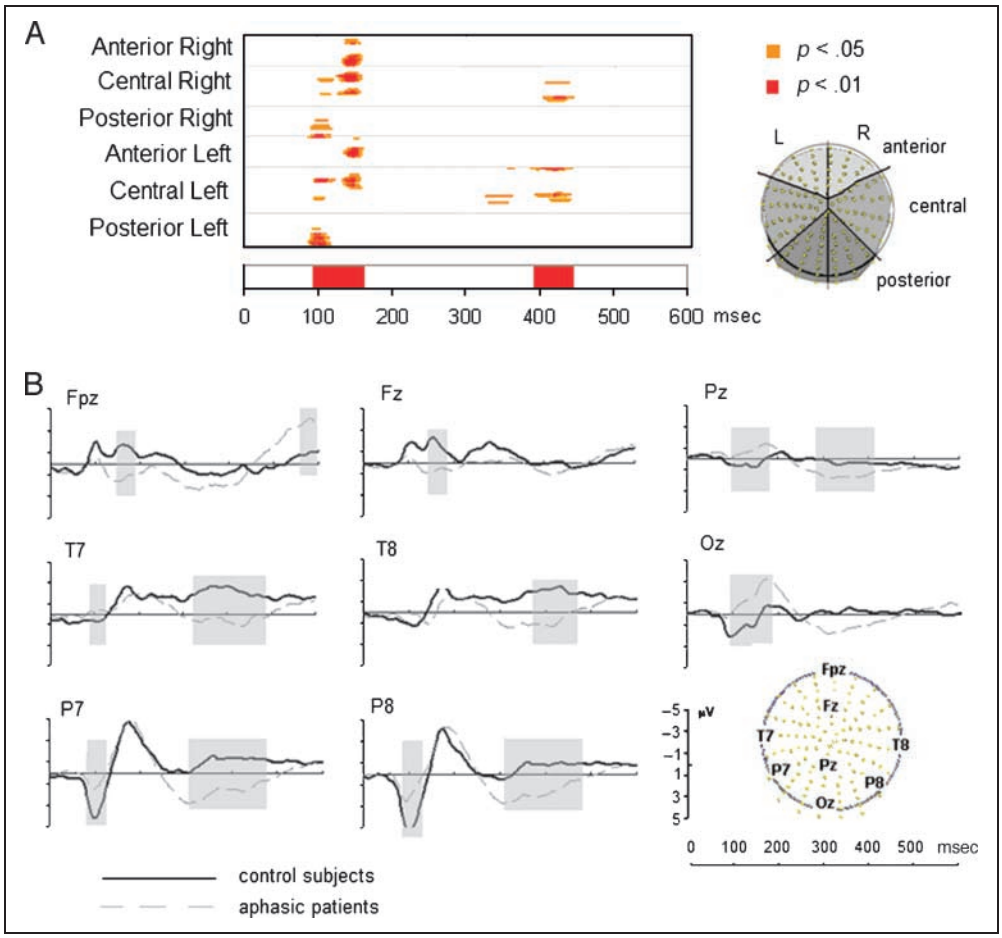

Figure 4. (A) Electrodes yielding significant paired t-test values in the comparison between groups (top) and time windows of significant differences (bottom). (B) Evoked-potentials recorded in patients and control groups. Negative is plotted in the upward direction. Gray bars indicate the time windows of significant differences between groups (at $p < .01$). In the lower right corner of the figure, the arrangement of the 128 electrodes and the electrode positions of the displayed waveforms are presented.

Although the time windows of differences between the two groups are clearer in the analysis on the entire set of electrodes, analysis on single electrodes (Figure 4B) also indicated two periods of different amplitudes between groups.

Topographic Analysis

Figure 5 shows the result of the spatio-temporal segmentation computed on the averaged data of the healthy controls and aphasic subjects groups. The topographic pattern analysis identified nine different periods of stable electric field configurations at the scalp in the 600-msec poststimulus period, accounting for 90.5% of the variance. The same topographic maps appeared from 0 to 120 msec and from 240 to 270 msec. Different topographic maps appeared in the other time windows. The fitting procedure in individual data indicated that Maps 4, 7, and 9 were specific to the control group and Maps 3, 6, and 8 explained the data from the aphasic group. ANOVAs were computed with duration or GEV of maps as within-participants repeated measures and group as between-participants factor for the following maps and fitting periods: Maps 3 and 4 from 120 to 240 msec; Maps 5, 6, and 7 appearing between 240 and 470 msec; and Maps 7, 8, and 9 from 470 to 600 msec. An interaction between groups and the presence of Maps 3 and 4 from 120 to 240 msec appeared on the two fitting parameters [GEV: $F(1, 30) = 8.9$, $p < .01$; duration: $F(1, 30) = 16.4$, $p < .001$]. The interaction between groups and duration of Maps 5, 6, and 7 between 230 and 470 msec was close to significance on duration [$F(2, 60) = 2.9$, $p = .06$] and was significant on GEV [$F(2, 60) = 3.96$, $p < .05$].

Direct comparison on each map indicated higher GEV for Maps 5 and 7 in the healthy control group [respectively $t(30) = -2.4$, $p < .05$ and $t(30) = -2.1$, $p < .1$] and longer duration for Map 6 in the aphasic group [$t(30) = 2.3$, $p < .05$]. An interaction was also found between groups and Maps 7, 8, and 9 in the 460–600 msec time window [GEV: $F(2, 60) = 6.15$, $p < .01$; duration: $F(2, 60) = 8.6$, $p < .001$]. Direct comparison between groups on each map indicated that Map 8 lasted longer and had higher GEV in the aphasic group [duration: $t(30) = 3.9$, $p < .001$; GEV: $t(30) = 2.6$, $p < .05$] and the opposite was seen for Map 9 [duration: $t(30) = -3.4$, $p < .01$; GEV: $t(30) = -2.9$, $p < .01$].

In summary, different topographic maps appear in the two groups from 120 msec to the end of the recording period.

DISCUSSION

This study shows that impaired word production in aphasic patients is associated with different electrophysiological patterns depending on the type of anomic impairment. Differences in amplitudes and in topographic maps were differently distributed when the whole heterogeneous group of aphasic patients was compared to a healthy control group and when more homogeneous subgroups of anomic patients were analyzed. Aphasic patients with lexical–semantic impairment differed from control subjects in early time windows from about 90 to 200 msec on amplitudes and displayed different topographic maps from 100 to 250 msec. The aphasic subgroup with lexical–phonological impairment differed from controls in later time widows, starting at about 340 to 430 msec in the waveform comparison and from 300 to 450 msec in topographic maps. By contrast, activity before 300 msec was normal in this anomic subgroup and activity was normal from 0 to 100 msec and after 250 msec in the former subgroup.

The observed differences between the control group and each aphasic subgroup appeared in the same time windows whether the analyses were carried out on all responses or separately on correct and erroneous trials. Similar electrophysiological activation between correct and erroneous responses has already been reported in previous studies with aphasic patients (Laganaro et al., in press; Cornelissen et al., 2003), suggesting that a specific impaired word encoding process generates a given rate of errors and of correct productions.

The present results partly diverge from previous electrophysiological studies, which reported different ERPs

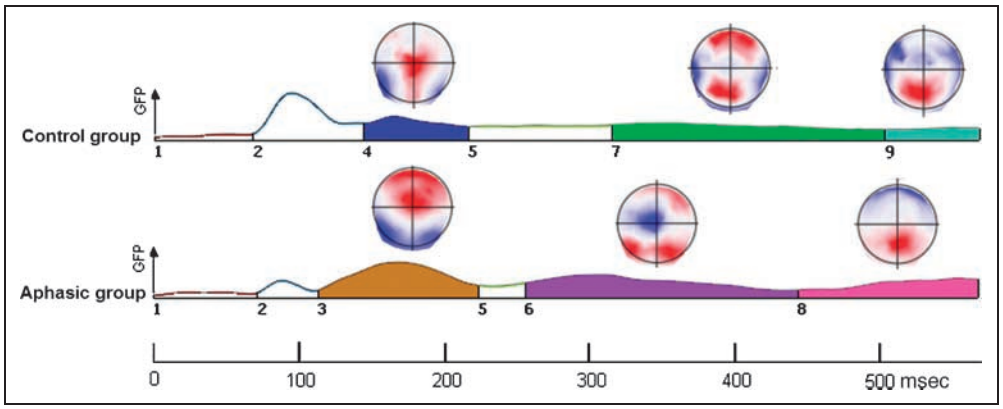

Figure 5. Results of spatio-temporal analysis for the healthy controls and the aphasic patients groups. Topographic maps (3, 4, 6, 7, 8, and 9) for which differences were found between the two groups are illustrated (positive values in red and negative values in blue).

between control groups and aphasic speakers during production tasks only after 300 msec (Angrilli et al., 2003; Dobel et al., 2001). However, previous studies used judgment tasks and explored aphasic patients with heterogeneous profiles. The 10 chronic patients in the study by Angrilli et al. (2003) were classified as Broca aphasics in the acute stage, but no details were provided about their performance on single-word production. More importantly, and surprisingly, the observed differences between controls and aphasic subjects were reported in the same time window in the two analyzed tasks, a semantic and a phonological judgment task, which are thought to reflect different encoding processes (Indefrey & Levelt, 2004). A heterogeneous group of aphasic subjects was enrolled in Dobel et al.'s (2001) study. Divergent amplitudes were reported in a similar time window after 300 msec in two different tasks: a syntactic judgment task (judging the gender of German words from pictures) and a semantic judgment task. These results may be interpreted as evidence in favor of parallel syntactic, semantic, and phonological encoding (as proposed in the framework of interactive activation models; Dell, 1986; Stemberger, 1985), all starting at about 300 msec after picture or word onset. Following this reasoning, this time window would represent the inferior time limit of divergent ERPs in aphasic patients with impaired word production. Our observation that earlier divergent ERPs correlates both in the whole group of aphasic patients and in the lexical–semantic subgroup is at odds with this interpretation. It is possible that in the above studies, the proportion of patients with impaired lexical–semantic processes was too small to detect the early alterations found in our study.

The identified time windows of abnormal ERPs in the lexical–semantic and the lexical–phonological aphasic subgroups are compatible with the estimated time course during normal picture naming in MEG studies (Vihla et al., 2006; Maess, Friederici, Damian, Meyer, & Levelt, 2002) and in the meta-analysis by Indefrey and Levelt (2004). Semantic encoding was found to occur between 150 to 225 msec after picture presentation, as deduced from a semantic interference task during picture naming (Maess et al., 2002). Vihla et al. (2006) reported differences in activation at about 300 msec between tasks requiring phonological processing (overt naming and phonological monitoring) and a semantic categorization task, and suggested that semantic processes, common to all these tasks, take place before 300 msec. Also compatible with our results are those obtained by Cornelissen et al. (2003). The three patients in that study suffered from lexical–phonological anomia; changes associated with recovery observed during picture naming between 300 and 700 msec were interpreted as reflecting changes in word form retrieval and encoding. Similarly, ERP changes linked to recovery from anomia were observed starting about 300 msec after picture presentation in three out of four aphasic patients in the study by Laganaro et al. (2008), whereas the only patient with semantic impairment presented changes linked to recovery in an earlier time window, during the first 300 msec.

The present study is the first to analyze electrophysiological correlates of impaired picture naming in precisely defined subgroups of aphasic subjects. Along with the observations that different kinds of anomia are associated with disruption of different brain areas (DeLeon et al., 2007; Hillis et al., 2001; Raymer et al., 1997), we demonstrated that the time course of brain activity during impaired picture naming reflects the disrupted process underlying different anomic behaviors. Divergent electrocortical processing starting after 100 msec appeared in patients having a lexical–semantic impairment, indicating impairment in the processes preceding word form encoding. In contrast, patients having a lexical–phonological deficit had abnormal ERP responses starting around 300, indicating that word form encoding processes normally occur at this late stage. These two patterns of abnormal ERPs appeared on amplitudes and on topographic maps, showing that the differences between groups were attributable to activation of a different cortical network in control subjects and in aphasic subjects rather than to simple delay in the processes involved in word production.

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