Impaired lexical selection with competing distractors: Evidence from left temporal and left prefrontal lesions

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Abstract

According to the competition account of lexical selection in word production, conceptually driven word retrieval involves the activation of a set of candidate words in left temporal cortex, and competitive selection of the intended word from this set, regulated by frontal cortical mechanisms. However, the relative contribution of these brain regions to competitive lexical selection has remained unclear. In the present study, five patients with left prefrontal-cortex lesions (overlapping in ventral and dorsal lateral cortex), eight patients with left lateral temporal-cortex lesions (overlapping in middle temporal gyrus), and 13 matched controls performed a picture-word interference task. Distractor words were the picture name itself (congruent condition), semantically related or unrelated to the picture. Semantic interference (related vs unrelated), tapping into competitive lexical selection, was examined. An overall semantic interference effect was observed for the control and left-temporal groups separately. The left-frontal patients did not show a robust semantic interference effect as a group. The left-temporal patients had increased semantic interference in the error rates relative to controls. Error distribution analyses indicated that these patients had more hesitant responses for the related than for the unrelated condition. We argue that left middle temporal lesions affect the lexical activation component, making lexical selection more susceptible to errors. By contrast, the top-down regulation over competitive lexical selection in picture-word interference does not seem to be dependent on the left lateral prefrontal cortex.

Keywords: Broca’s area; cognitive control; confrontation naming; LIFG

Introduction

It is largely accepted that selecting words for speaking is a competitive process (Levelt, Roelofs, & Meyer, 1999; Roelofs, 1992; Spalek, Damian, & Bölte, 2013) and that not only core language processes, such as lexical retrieval, but also mechanisms for attentional control are involved (Roelofs & Piai, 2011). However, the relative contribution of different brain regions to competitive lexical selection in word production is still unclear. According to the competition view, conceptually driven word retrieval involves the activation of a set of candidate words in left middle temporal cortex. Competitive selection of the intended word from this set is regulated by frontal cortical mechanisms (Roelofs & Piai, 2011). The present study provides lesion evidence for the roles of left lateral prefrontal and temporal cortex to lexical selection.

Picture-word interference is a paradigm often used to investigate lexical and control processes involved in word production. Participants have to name pictures that are presented along with a distractor word. Performance in this task depends on the relationship between the picture name and the distractor word. For example, if the distractor word is incongruent with and unrelated to the picture name (e.g., a pictured pig with distractor “chair”), picture naming is more difficult relative to a congruent distractor (e.g., pictured pig, distractor “pig”), an effect referred to as distractor incongruency (Piai, Roelofs, Acheson, & Takashima, 2013). By contrast, if the distractor is from the same semantic category as the picture (e.g., pictured pig, distractor word “cow”, both animals), picture naming is more difficult relative to unrelated distractors, the so-called semantic interference effect (Glaser & Düngelhoff, 1984). In this case, the semantic relationship between the distractor and the picture makes the distractor a stronger competitor for the picture name relative to a semantically unrelated word (Roelofs, 1992, 2003). Thus, the semantic interference effect has been key for investigating the competitive nature of lexical selection in word production.

Previous neuroimaging studies have provided converging evidence for the involvement of two brain areas in the semantic interference effect from distractor words: left temporal and left frontal cortex. Activity in the left temporal cortex has been shown to decrease with semantically related relative to unrelated distractors (de Zubicaray, Hansen, & McMahon, 2013; Piai et al., 2013; Piai, Roelofs, Jensen, Schoffelen, & Bonnefond, 2014). This decreased activity for the related condition has been interpreted in terms of semantic priming between the picture and the distractor in the lexical-semantic memory system, thus reflecting the lexical activation mechanism (Piai et al., 2013, 2014). By contrast, activity in frontal cortex, in particular superior frontal gyrus and anterior cingulate cortex, has been shown to increase for related relative to unrelated distractors (Piai et al., 2013, 2014; see also de Zubicaray, Wilson, McMahon, & Muthiah, 2001). This increased frontal activity has been interpreted as reflecting the top-down control signal over lexical representations in the temporal cortex.

The lateral prefrontal cortex (PFC) is involved in broad aspects of top-down control over task performance (Petrides, 2005) and the left ventrolateral PFC in particular has been proposed as a key candidate in mediating response selection among semantically related response alternatives (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). The critical involvement of the lateral prefrontal cortex to the resolution of competition in word production has been obtained in some picture-naming tasks with lesion-symptom investigations (Riès, Greenhouse, Dronkers, Haaland, & Knight, 2014; Schnur et al., 2009; Schnur, Schwartz, Brecher, & Hodgson, 2006). However, to date the contribution of this brain area to the semantic interference effect from distractor words has remained elusive (de Zubicaray et al., 2013; Piai, Riès, & Swick, 2016; Piai et al., 2013, 2014). Relevant for the present study, Piai et al. (2016) examined the behavior of six patients with lesions overlapping 100% in the ventrolateral prefrontal cortex in picture-word interference. No differences were observed between patients and controls on error rates. All patients showed longer RTs when naming pictures in the presence of distractor words relative to a neutral string of Xs. However, on the group level, no consistent semantic interference effect was found. Descriptively, three patients showed semantic interference and three patients showed semantic facilitation. Regarding the left temporal cortex, to the best of our knowledge, no picture-word interference study has been published with a group of patients with well-characterized left lateral temporal lesions. So the critical role of the left temporal cortex to the semantic interference effect of distractor words is largely unknown.

In the present study, patients with left lateral temporal lesions and left lateral frontal lesions named pictures while ignoring semantically related, unrelated, and congruent visual distractors. We maximized the amount of competition exerted by the distractor words in different ways. Firstly, distractor and picture were presented simultaneously. Secondly, congruent distractors were included. In the color-word Stroop literature, the presence of congruent trials (e.g., "red" displayed in red ink) adds relevance to the task dimension (here, word reading) that should otherwise be ignored (Lowe & Mitterer, 1982). This manipulation induces a larger Stroop interference effect. We reasoned that a similar attentional mechanism could be at play in picture-word interference, motivating the inclusion of congruent distractors. Finally, distractor words also appeared as pictures in the experiment (i.e., they were part of the response set). The increased interference from response-set members has been shown for tasks such as the color-word Stroop (Klein, 1964; Lamers, Roelofs, & Rabeling-Keus, 2010) and picture-word interference (Piai, Roelofs, & Schriefers, 2012). Note that in Piai et al. (2016), the distractor words were not in the response set nor was the congruent condition included. It could be argued that the materials in Piai et al. (2016) were weak in inducing semantic interference, explaining why the patients with left ventrolateral PFC lesions in that study did not show an abnormally large semantic interference effect. We used mixed-effects modeling (Baayen, Davidson, & Bates, 2008) to be able to statistically analyze all trials of the experiment, rather than performing statistics on the averaged responses of participants. We compared the performance of each patient group relative to their matched controls in terms of error rates and response times.

Method

The study protocol was approved by the University of California, Berkeley Committee for Protection of Human Subjects, following the declaration of Helsinki. Participants gave written informed consent and received monetary compensation for participating.

Participants. Thirteen patients participated. Eight had a main lesion in the left lateral temporal cortex (one female; median age = 70, mean = 67, sd = 8, range = 50-74; mean years of education = 17) and five had a main lesion in the left prefrontal cortex (one male; median/mean age = 64 sd = 9, range = 53-73; mean years of education = 16). Patients were tested at least 16 months post-stroke and were pre-morbidly right handed. Information on the patients' lesions and language ability are shown in Tables 1 and 2. Additionally, 13 controls participated, each matched closely for gender, age, and years of education to their matched patient within ±4 years of age and ±2 years of education (five females; median age = 68, mean = 65, sd = 7.6, range = 50-74, $t(12) = 0$, $p = 1$; mean years of education = 16.6, $t(12) < 1$, $p = .695$). All controls were right-handed. All participants were native speakers of American English. None of the participants had a history of psychiatric disturbances, substance abuse, multiple neurological events, or dementia.

Lesions were transcribed from magnetic resonance imaging scans onto corresponding axial templates by a neurologist for reconstruction. The lesion overlap maps are shown for the frontal and temporal patients separately in Figure 1. In the frontal patients, the damage was centered mainly on the middle frontal gyrus and the most dorsal part of the inferior frontal gyrus (100% overlap). In the patients with temporal lesions, the damage was centered on the middle temporal gyrus (MTG), around the mid portion (100% overlap).

For 11 of the 13 patients, performance on the Western Aphasia Battery (WAB; Kertesz, 1982) was available, shown in Table 2, together with the time elapsed between patients' stroke date and WAB assessment, and between stroke date and the present testing. Four patients had good language abilities (P1, P4, P6, and P9), with performance within normal limits. We note that, although P1 was not assessed on the WAB, he continued performing his occupation without problems, which included academic teaching amongst other tasks. Thus, we are confident that this patient would have been classified as within normal limits by the WAB. Five patients were classified as anomic (P3, P8, P10, P11, and P13), characterized by normal auditory verbal comprehension and repetition, but a relatively impaired word finding ability when speaking. These patients scored at least 8.3 out of 10 on the Naming part of the WAB. One patient was classified as having conduction aphasia (P2), characterized by normal auditory verbal comprehension, but relatively impaired repetition and word-finding abilities. This patient also scored relatively high on the WAB naming (8.6 out of 10). Two patients were classified as having Wernicke's aphasia, characterized by poor auditory verbal comprehension, and impaired repetition and word-finding abilities. These were the two patients with the lowest WAB Naming scores, namely 7.6 (P5) and 4.3 (P7). Finally, a second patient (P12) was not assessed on the WAB. In personal interactions, the patient conversed without difficulty but complained of word-finding problems. As Table 2 shows, this patient had a relatively low error rate in the present experiment (5.65%).

Materials. Fifty-six color pictures were taken from the BOSS database (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010). The pictures belonged to fourteen different semantic categories with four objects pertaining to each category (animal, body part, building, clothing, fruit, furniture, jewelry, kitchenware, music instrument, office article, tool, transport, vegetable, weapon). For each picture, distractor words were chosen that were either the name of the picture ("congruent" condition), from the same semantic category as the picture ("related", the distractor words were the names of the other category-coordinate pictures from our materials), or semantically and phonologically unrelated to the picture ("unrelated", from recombining pictures with distractor words from our materials). Thus, all distractor words belonged to the response set. All participants saw each picture once in each condition. Pictures were presented on a white background on the center of the screen and distractors were presented in font Arial size 30 in white, centered on the picture. The picture-word trials were randomized using Mix (van Casteren & Davis, 2006), with one unique list per participant. Participants were instructed to name the picture and to ignore the distractor word. Both speed and accuracy were emphasized.

Procedure. The presentation of stimuli and the recording of responses were controlled by Presentation Software (Neurobehavioral Systems). Participants were seated comfortably in front of a computer monitor. Vocal responses were recorded with a microphone. The experimenter evaluated the participants' responses online. Trials began with a fixation cross presented for 1 s, followed by the presentation of the picture-word stimulus for 2 s. The inter-trial interval varied between 1.25 and 2 s. No familiarization phase was used because we were concerned that patients would have different memory capacity that could confound the results.

Analysis. Fourteen pictures had poor name agreement (that is, less than 20% of the participants used the expected name) and were therefore removed from all analyses. Thus, the total number of trials analyzed for each participant comprised 42 per condition. Responses were evaluated in real time. Responses containing dysfluencies or errors were coded as incorrect and their corresponding trials excluded from all response time (RT) analyses. Naming RTs were calculated manually using the speech waveform editor Praat (Boersma & Weenink, 2013) before trials were separated by condition. The following responses were classified as errors: 1) the distractor word was named, 2) hesitations (e.g., the response started with filled pauses like "hum" or a poorly articulated initial phoneme), 3) no response was given, 4) phonological paraphasias, 5) a semantically related response (e.g., pictured bus, distractor "car", response "truck"), 6) or another picture name was used than the expected name (e.g., "dish" for the picture [bowl], "lime" for the picture [lemon]). This latter type of error was not considered a semantic error because it is possible that for the participant, that would be the correct label for the picture. Perseverative errors were few (two trials by P2 and one trial by P5) and therefore not analyzed.

Single-trial RTs were analyzed with a linear mixed-effects model and errors with a mixed-effects logistic regression. Models were fitted with the lme4-package (version 1.1.10; Bates, Maechler, Bolker, & Walker, 2015) in R (version 3.2.3, R Core Team, 2015). Single-trial RTs were log-transformed to reduce skewness and approach a normal distribution. In both models (referred to as "full model"), fixed effects for group (controls, temporal, and frontal patients) and distractor condition (related, unrelated, congruent) were included, as well as their interaction, and random intercepts for both participants and items. More complex models with random slope terms failed to converge. For the group factor, the controls were used as the reference level and for distractor condition, unrelated distractors were the reference level. We additionally tested the semantic interference effect for each group separately with separate models (similar to the above, "group model"). Significance of effects was obtained using the Satterthwaite approximation (lmerTest-package version 2.0.30, Kuznetsova, Brockhoff, & Christensen, 2016). Hesitations were the most common error in all three groups (40% of the overall total number of errors and at least 33% of the total number of errors per group). Thus, we examined whether the distribution of hesitations was different between each group of patients relative to the control group with a chi-square test. For each group of patients, we also examined whether the distribution of errors differed between the related and unrelated conditions (i.e., semantic interference).

Results

Individual-averaged as well as group-averaged RTs and error rates are shown in Figure 2. Details on the statistics are shown in Tables 3 and 4.

RTs. Responses were on average 173 ms slower in the unrelated relative to the congruent condition, the incongruency effect ($p < .001$), and slower in the related than in the unrelated condition, the semantic interference effect (52 ms on average, $p < .001$). Frontal patients were on average 334 ms slower than controls ($p < .001$), and so were the temporal patients (279 ms on average, $p < .001$). The incongruency effect was on average 89 ms for the controls, 268 ms for the frontal patients, and 302 ms for the temporal patients. The incongruency effect was statistically larger in the frontal patients than in the controls ($p < .001$), and statistically larger in the temporal patients than in the controls ($p < .001$). The semantic interference effect was on average 77 ms for the controls ($p < .001$), 34 ms for the frontal patients ($p = .198$), and 58 ms for the temporal patients ($p = .027$). There was no evidence for a differential semantic interference effect between the controls and the two patient groups (ps > .109).

Accuracy. More errors were made in the unrelated than in the congruent condition (13% vs 3.5% respectively, $p = .005$). Numerically, more errors were also made in the related than in the unrelated condition (17% vs 13% respectively), but no statistical evidence was found for a difference between the two conditions ($p = .869$) on the overall group level. Temporal patients made more errors than controls (24% vs 4.2% respectively, $p < .001$), but no evidence was found for a difference between frontal patients and controls in the error rates (9.1% vs 4.2% respectively, $p = .381$). The incongruency effect was associated with more errors for the temporal patients than for controls ($p = .001$). No evidence was found for a difference between controls and frontal patients for the incongruency effect ($p = .764$). The temporal patients made more errors in the related than in the unrelated condition ($p < .001$), and so did the frontal patients (p = .037). No evidence was found for a difference between controls and frontal patients for the semantic effect (p > .098). By contrast, temporal patients had a larger semantic interference effect than the controls (p = .027).

The error distribution is shown in Figure 3. Temporal patients showed more hesitations than the control participants (99 vs 21, respectively, X^2 (1) = 50.7, p < .001), whereas the difference in the number of hesitations was not significantly different between frontal patients and controls (28 vs 21, respectively, X^2 (1) = 1, p = .317). For the temporal patients, hesitations were more frequent with related than with unrelated distractors (58 vs 35, respectively, X^2 (1) = 5.7, p = .017). The distributions were not significantly different for the frontal patients (14 vs 10, respectively, X^2 (1) = 0.7, p = .414) nor for the controls (12 vs 5, respectively, X^2 (1) = 2.9, p = .09).

Discussion

In the present study, patients with left lateral temporal lesions and left lateral frontal lesions named pictures while ignoring semantically related, unrelated, and congruent visual distractors. The temporal patients had a significant semantic interference effect both in the error rates and in the RTs. They also had an increased semantic interference effect in the error rates relative to controls. Hesitations in language production have been related to difficulties in lexical selection (Goldman-Eisler, 1968). The analysis of hesitations corroborated the findings of the semantic interference effect in the temporal patients in that more hesitations were present in the responses for the related than for the unrelated condition.

In the RTs, we observed an increased incongruency effect in the patients relative to the controls. This effect seems to be driven by a disproportional slowing in the unrelated condition relative to the congruent condition in the patients (see Figure 2). For the temporal patients, the increased incongruency effect was additionally found in the error rates. The congruent condition was included in the present study in an attempt to maximize the interference from distractor words (cf. Lowe & Mitterer, 1982). Given the theoretical relevance of the *semantic interference effect*, we focus the remainder of the discussion on this effect (i.e., related and unrelated conditions only).

Semantic interference is not only observed in the picture-word interference paradigm. For example, in the cyclic picture-naming task, pictures are presented in semantically homogeneous (e.g., five animals are named in succession) or semantically heterogeneous blocks (i.e., all pictures are from different semantic categories; Kroll & Stewart, 1994). Picture response times (RTs) are typically longer in homogeneous relative to heterogeneous blocks (i.e., the semantic interference effect, e.g., Damian, Vigliocco, & Levelt, 2001). Semantic interference is also observed in a continuous naming paradigm in which pictures from different semantic categories are interleaved with one another (Howard, Nickels, Coltheart, & Cole-Virtue, 2006). The semantic interference effect in this paradigm is cumulative: Picture naming times are increasingly longer for every next named picture from a given semantic category.

It has been previously assumed that the same mechanism underlays the semantic interference effect in all three paradigms. However, lesion-symptom evidence is accumulating suggesting that the semantic interference effect in these three paradigms may be different. Both in Piai et al. (2016) and in the present study, no semantic interference effect was observed on the *group level* for patients with left PFC damage. These results indicate that lesions to the left PFC do not disproportionally affect the competition from semantically related distractors in word production. Using the blocked-cyclic naming paradigm, neuropsychological studies have shown that patients with damage to the left ventrolateral PFC have a larger semantic interference effect than (age-matched) controls or patients with damage to right PFC (Riès et al. 2014; Schnur et al. 2006, 2009). By contrast, in the study of Schnur et al. (2009), the amount of left temporal lobe damage in their patients did not predict increased semantic interference relative to the controls. Finally, using the continuous naming paradigm, left PFC patients were found to be slower and make more errors relative to controls (Riès, Karzmark, Navarrete, Knight, & Dronkers, 2015), but their cumulative semantic interference effect was of similar magnitude as for controls. Together, these findings suggest the semantic interference effect in these three paradigms may emerge due to different cognitive mechanisms (see for discussion Riès et al. 2015), with different underlying interactions between frontal and temporal brain areas involved in word production.

It is assumed that the PFC exerts top-down control over lexical representations in the temporal cortex to aid selection among semantic competitors (Thompson-Schill, D'Esposito, & Kan, 1999). We have not obtained evidence that a top-down control process exercised by the lateral PFC is necessary for resolving competition from semantically related distractors. Otherwise, we should have observed a disproportional semantic interference effect for the PFC patients relative to controls. Alternatively, top-down regulation of lexical selection in the presence of competing semantic distractors might be subserved by a different region. For example, damage to the posterior MTG (along with ventrolateral PFC, and inferior parietal cortex damage) has been associated with deficits in semantic control (Jefferies, 2012). This account would be partly in line with our findings of increased semantic interference in the temporal patients relative to controls. However, semantic control deficits are also associated with ventrolateral PFC (Jefferies, 2012), contrary to our findings. Additionally, MTG activity in functional imaging studies *decreases* with semantically related relative to unrelated distractors (de Zubicaray et al., 2013; Piai et al., 2013, 2014), despite increased RTs and error rates. This decreased activity is difficult to explain if *increased* semantic control is needed. Another possibility is that superior medial-frontal structures regulate competitive lexical selection. This account is based not only on previous neuroimaging studies of picture-word interference (Piai et al., 2013, 2014), but also on neuroimaging and neuropsychological findings on verbal tasks involving control (Alario, Chainay, Lehericy, & Cohen, 2006; Derrfuss, Brass, Neumann, & von Cramon, 2005; Stuss, Floden, Alexander, Levine, & Katz, 2001). Future studies are needed to clarify this issue.

Regarding the left temporal cortex, this is the first study to examine semantic interference in a group of patients with well-characterized lesions. The study of Schnur et al. (2009) reported on left PFC patients whose lesions could include the left temporal cortex (temporal lobe lesions ranged between 0% and 44%). As mentioned above, it was found that only the left PFC, but not the left temporal, lesion was associated with increased semantic interference. However, the fact that the patients in that study had larger PFC than temporal lesions precludes us from drawing comparisons with the present study.

We found that patients with left temporal lesions (overlapping fully in the mid portion of the MTG) made more errors in the presence of semantically related relative to unrelated distractors. Semantic errors in word production are thought to emerge from the incorrect selection of words (i.e., lemmas, Roelofs, 1992). A large literature suggests a critical role for the MTG in naming (Baldo, Arévalo, Patterson, & Dronkers, 2013; Schwartz et al., 2009) and the mid portion of the MTG in particular is thought to subserve word (i.e., lemma) activation and selection (Indefrey & Levelt, 2004). Lexical selection takes place once the activation of the target node exceeds that of all other competitors (by some critical amount, e.g., Roelofs, 1992). Left MTG lesions likely introduce noise to the activation of representations of both target and competitors, making these representations become more similar. Accordingly, selection errors are more likely to occur with noisy competing representations that do not show sufficient activation differences. Our results as well as this interpretation are in line with a previous report on semantic errors in picture naming in relation to mid-MTG lesions (Schwartz et al., 2009).

In conclusion, the middle temporal lobe is a necessary structure for lexical selection in word production. Following the view that conceptually driven word retrieval involves activation of candidate words and competitive selection of the intended word from this set, we argue that left middle temporal lesions affect the lexical activation component. A deficit in this component makes lexical selection more susceptible to errors. By contrast, the top-down regulation over competitive lexical selection in picture-word interference does not seem to be dependent on the lateral prefrontal cortex.

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Figure captions

Figure 1. Lesion overlap map of the five left prefrontal cortex patients (top) and of the eight left temporal cortex patients (bottom). The color scale indicates the amount of overlap in lesion locations, with magenta indicating that only one patient had a lesion in that particular region (i.e., 0% overlap). L = left; R = right.

Figure 2. Individual-averaged (in brown, green, and purple) and group-averaged (in black) response times (RTs) and error rates for the three groups across conditions. Unr = unrelated; Rel = related; Con = congruent.

Figure 3. Error distribution in percentage from the total number of errors for the three groups across conditions. Nam = not the expected name; dis = distractor; hes = hesitation; nres = no response; phon = phonological paraphasia; sem = semantically related response. See Methods section for clarification.

Table 1. Individual lesion volume and percent damage to the left inferior frontal gyrus (IFG), middle frontal gyrus (MFG), superior frontal gyrus (SFG), superior temporal gyrus (STG), and middle temporal gyrus (MTG).

Patient	Lesion volume	IFG	MFG	SFG	STG	MTG
			Left temporal lobe lesions			
1	18.32	0	0	0	34	23.6
2	93.75	0	0	0	87.9	50.4
3	85.82	0	0	0	88.6	82.6
4	4.51	0	0	0	3.2	6.7
5	105.51	7.28	0	0	95.1	71.6
6	36.95	0	0	0	22.3	56.3
7	79.68	0.15	0	0	94.6	76.9
8	103.17	21.4	3.9	0	33.7	17.6
			Left frontal lobe lesions			
9	52.1	59	9.2	0.6	12.9	0
10	131.76	93.01	62.4	13.5	13.1	0.1
11	122.3	55.1	27.9	9.9	49.8	0
12	10.09	4.6	7	0	0	0
13	103.24	77.7	64.2	6.5	10.1	0

Table 2. Language testing data from the Western Aphasia Battery (WAB). Naming = WAB Naming and Word Finding score (maximum = 10). Aphasia Quotient (AQ, maximum = 100). WNL = within normal limit. MPO = months post stroke onset. NA = not assessed on the WAB, see Methods section for language profile.

Patient	Aphasia type	AQ	Naming	MPO at WAB	MPO at testing	Error rate
1	NA	NA	NA	NA	114	2.38
2	Conduction	77.9	8.6	16	23	15.87
3	Anomic	92.9	9.5	290	310	26.98
4	WNL	99.6	10	104	121	1.61
5	Wernicke	79.5	7.6	25	53	42.86
6	WNL	94	8.6	222	230	23.02
7	Wernicke	59.9	4.3	41	54	53.17
8	Anomic	87.8	8.3	47	72	26.19
9	WNL	99.6	9.8	148	174	3.97
10	Anomic	91.6	9.2	67	209	18.25
11	Anomic	87.2	8.9	68	201	4.07
12	NA	NA	NA	NA	12	5.65
13	Anomic	92.1	9.3	34	165	13.49

Table 3. Group-averaged response times in seconds (and standard deviations).

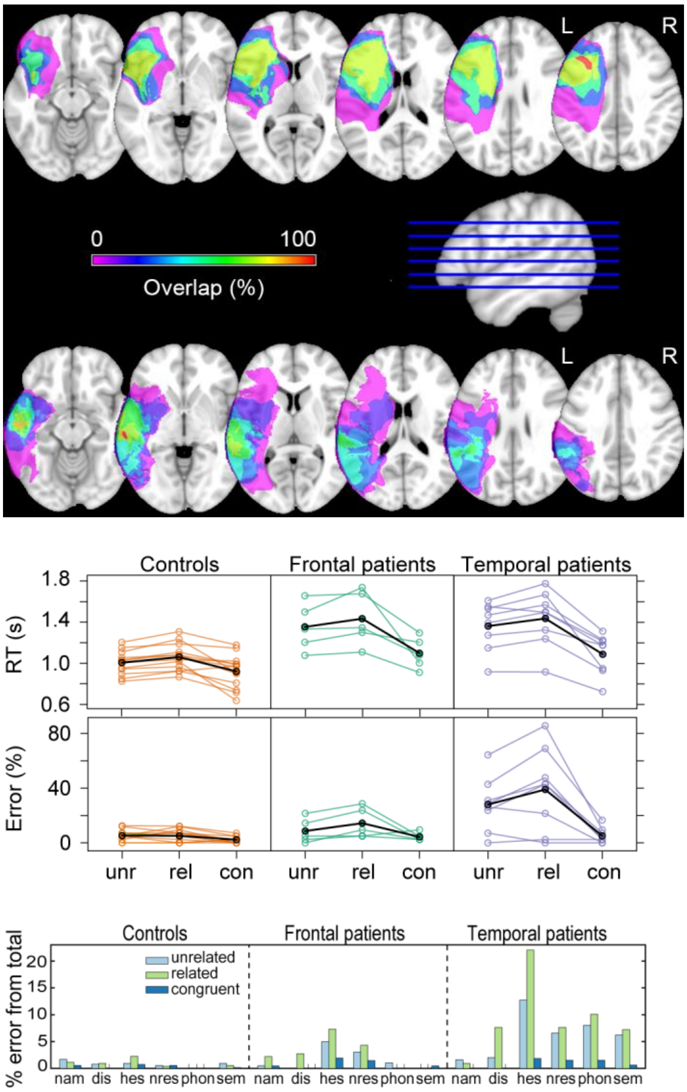
Condition	Controls	Frontal	Temporal
Unrelated	1.04 (0.22)	1.45 (0.42)	1.42 (0.38)
Related	1.12 (0.26)	1.49 (0.41)	1.49 (0.37)
Congruent	0.95 (0.24)	1.19 (0.30)	1.12 (0.28)

Table 4. Results of the inferential statistics for the response times (RT, top) and error rates (bottom). Results obtained from the full model, unless stated otherwise. Results from the group models are indicated by an asterisk. SE = standard error.

RT effect	b	SE	t (df)	p
Congruent vs unrelated	-.098	.012	-8.56 (2813)	< .001
Related vs unrelated	.067	.012	7.75 (2814)	< .001
Frontal vs controls	.323	.078	4.13 (24)	< .001
Temporal vs controls	.308	.067	4.60 (24)	< .001
Related vs unrelated: controls*	.067	.010	6.63 (974)	< .001
Related vs unrelated: frontal*	.029	.022	1.29 (323)	.198
Related vs unrelated: temporal*	.039	.018	2.22 (407)	.027
Congruent vs unrelated: frontal vs controls	-.104	.022	-4.69 (2814)	< .001
Related vs unrelated: frontal vs controls	-.036	.022	-1.60 (2817)	.109
Congruent vs unrelated: temporal vs controls	-.151	.020	7.68 (2816)	< .001
Related vs unrelated: temporal vs controls	-.029	.021	-1.36 (2816)	.173
Error rate effect	**b**	**SE**	**z**	**p**
Congruent vs unrelated	.968	.341	2.822	.005
Related vs unrelated	.044	.269	.165	.869
Left frontal vs controls	-.571	.652	-.876	.381
Left temporal vs controls	-1.938	.543	-3.567	< .001
Related vs unrelated: controls*	.046	.287	.162	.872
Related vs unrelated: frontal*	-.682	.327	-2.087	.037
Related vs unrelated: temporal*	-.707	.197	-3.588	< .001
Congruent vs unrelated: frontal vs controls	-.163	.543	-.300	.764
Related vs unrelated: frontal vs controls	-.699	.422	-1.655	.098

Congruent vs unrelated: temporal vs controls	1.465	.455	3.216	.001
Related vs unrelated: temporal vs controls	-0.734	.332	-2.208	.027

Figures


L
R
0
100
Overlap (%)
L
R
Controls
Frontal patients
Temporal patients
RT (s)
1.8
1.4
1.0
0.6
Error (%)
80
40
0
unr rel con
unr rel con
unr rel con
Controls
Frontal patients
Temporal patients
% error from total
20
15
10
5
0
unrelated
related
congruent
nam dis hes nres phon sem
nam dis hes nres phon sem
nam dis hes nres phon sem