Neuropsychologia 45 (2007) 954–965

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Lesion-site affects grammatical gender assignment in German: Perception and production data

Juliane Hofmann[a,b,*], Sonja A. Kotz[b,c], Anke Marschhauser[c], D. Yves von Cramon[b,c], Angela D. Friederici[b]

[a] *Experimental Neuropsychology Unit, Saarland University, P.O. Box 151150, 66041 Saarbruecken, Germany*
[b] *Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstrasse 1a, 04103 Leipzig, Germany*
[c] *Day Care Clinic of Cognitive Neurology, Liebigstrasse 21, 04103 Leipzig, Germany*

Received 23 August 2006; accepted 28 August 2006
Available online 13 November 2006

Abstract

Two experiments investigated phonological, derivational–morphological and semantic aspects of grammatical gender assignment in a perception and a production task in German aphasic patients and age-matched controls. The agreement of a gender indicating adjective (feminine, masculine or neuter) and a noun was evaluated during perception in Experiment 1 (grammaticality judgment). In Experiment 2 the same participants had to produce the matching definite article to a noun. In the perception task patients with left frontal lesions (LF) made more errors during phonological gender assignment as compared to derivational–morphological and semantic gender assignment, while patients with lesions of the posterior superior temporal gyrus (pSTG) made more errors in derivational–morphological gender assignment as compared to phonological and semantic gender assignment. In the production task no differences between patient groups were found. These data support previous evidence that left frontal brain areas are critically involved in phonological processing. The pSTG on the other hand may be critically engaged in the integration of phonological and lexical information essential for phonological and derivational–morphological gender assignment.

Keywords: Grammatical gender; Phonology; Derivational morphology; Semantics

1. Introduction

While both speaking and understanding appears to be simple and intuitive, language processing can be a rather complex and complicated process because different types of information have to be integrated on-line. In everyday life we do not think about this learned, habituated and automatized skill, we use language easily. Only in the case of language breakdown, specific functions of different information types become visible. Brain injured patients with particular language deficits can give us information about the nature of language processing. For example, a small, grammatical feature such as the grammatical lexical gender of nouns can provoke difficulties in sentence production and perception or object naming after brain insult. In German, the noun's gender defines the form of the determiner, of its case markings and the adjective forms modifying the noun. Case, determiner and adjective form one unit and agree within a noun phrase. Therefore, a gender mismatch in a phrase or sentence can misguide the understanding of a sentence content. Acute aphasic patients often use wrong determiners in German. Aphasic patients with left frontal lesions are reported to show deficits inserting and producing the determiner in sentences with the exception of natural gender (personal communication with A. Marschhauser).

Across languages two distinct notions of gender, a lexical-syntactic property of a noun, are known: grammatical gender and natural gender. In some gender systems, e.g., English (i.e., him/her), they are correlated, but in other systems grammatical and natural gender do not coincide (e.g., *Mädchen*—girl is neuter and not feminine in German), and grammatical gender is arbitrary (for more details see Corbett, 1991). Rather than a simple and transparent pronominal gender system like English,[1]

* Corresponding author at: Experimental Neuropsychology Unit, Saarland University, P.O. Box 151150, 66041 Saarbruecken, Germany.
Tel.: +49 681 30264365; fax: +49 681 3026516.
E-mail address: j.hofmann@mx.uni-saarland.de (J. Hofmann).

[1] Gender is reflected only in personal, possessive, and reflexive pronouns (see for example Corbett, 1991, p. 12).

0028-3932/$ – see front matter
doi:10.1016/j.neuropsychologia.2006.08.029

German adheres to three different assignment rules or principles, which can be determined by semantics, morphological form and specific phoneme combinations of a noun. Semantic principles assign the grammatical gender to a certain noun because of its meaning and its belonging to a specific category (e.g., biological or natural gender, chemicals). Gender assignments by semantic principles are certain and exceptions can be found rarely (see Köpcke, 1982). Morphological principles are based on the form of a noun, such as affixes and suffixes (e.g., word stem + ending:-*chen* is neuter, see *Mädchen*). Specifically derivational–morphological rules are unequivocal and without exceptions (see Fleischer & Barz, 1995). Phonological principles are determined by certain vowel combinations in the noun's initial and/or final phonemes (e.g., initial sound: *Kn*- is often masculine, final sound: -*et* is often neuter). The latter gender type is probabilistic in nature. Exceptions can be found always, but can be explained usually by semantic or (derivational–) morphological rules (e.g., *der Wicht*—the $_{masc}$ little imp$_{masc}$ is phonologically marked at the ending with fricative + *t* for feminine nouns, but has masculine grammatical gender because it is a term for a human being).[2] Furthermore, combinations of these rules are possible (e.g., *Tante*—aunt is grammatically feminine and includes the ending -*e* which often determines feminine gender; additionally, the biological gender is also feminine). The more principles are involved and agree the more certain the gender assignment is (Köpcke, 1982). All in all, gender assignment of 70–80% of German nouns can be explained by the three gender principles (see Köpcke & Zubin, 1996).

Current psycholinguistic intra-lexical models of language production and perception (Friederici, von Cramon, & Kotz, 1999; Levelt, Roelofs, & Meyer, 1999) assume that grammatical gender is stored as a property of a noun. A bidirectional connection between gender node and lemma node would allow facilitation effects by gender priming. Nevertheless, morpho-phonological gender features could not facilitate gender processing as the lemma-lexeme connection was thought to be unidirectional.

In contrast to such intra-lexical models, interactive models (Bates, Devescovi, Hernandez, & Pizzamiglio, 1996; Bates, Devescovi, Pizzamiglio, D'Amico, & Hernandez, 1995) allow interaction of syntactic and lexical information. They assume that lexical candidates are predicted on the basis of semantic or syntactic context information that reduce the search area for possible elements in the mental lexicon. Gender information pre-activate a subgroup of lexical elements. Thus, facilitation effects are assumed for congruent gender information and inhibition or prolongation effects for incongruent gender information. Caused by the interactive activation and feedback loops morpho-phonological gender markings would help to predict gender on-line and may lead to facilitation effects.

It seems conceivable though that frequent, unequivocal gender principles may lead to facilitation effects during production and comprehension according to interactive models. It may also be possible that during comprehension the given additional morpho-phonological gender information has to be matched with the lexical gender entry by a post-lexical matching process similar to a post-lexical checking mechanism which evaluates gender congruency of a given element (see Friederici & Jacobsen, 1999).

In recent years effects of grammatical gender on lexical access or gender priming have been demonstrated across several languages and tasks. For gender priming in speech production, slower reaction times manifested in inhibition were reported for gender incongruent prime-target pairs as compared to gender congruent pairs (so called gender congruency effect) or neutral pairs in the visual and the auditory domain in picture naming tasks (Bentrovato, Devescovi, D'Amico, & Bates, 1999; Jacobsen, 1999; Jescheniak, 1999; van Berkum, 1997), in word repetition (Bates et al., 1996), as well as in cued shadowing for Russian (Akhutina et al., 2001; Akhutina, Kurgansky, Polinsky, & Bates, 1999). The latter effect using cued shadowing was not replicated in Serbo-Croatian (Carello, Lukatela, & Turvey, 1988). In addition, gender transparency results in a smaller congruency effect for opaque nouns (nouns without unequivocal morphophonological gender marking) as compared to transparent nouns in cued shadowing (Akhutina et al., 1999), an effect that is also shown for markedness, a feature for transparency and frequency in Russian (Akhutina et al., 2001).

In perception, slowed reaction times (RT) and higher error rates were also observed for gender incongruent as compared to gender congruent conditions in lexical decision tasks (Carello et al., 1988; Gurjanov, Lukatela, Lukatela, Savic, & Turvey, 1985), grammaticality judgments (Akhutina et al., 2001; Bates et al., 1996), and in gender monitoring (Bates et al., 1996). As in speech production, the RT congruency effects were more reduced in atypical phonologically marked possessive adjective-noun pairs, opaque and unmarked nouns than in typical, transparently marked pairs or transparent nouns (Akhutina et al., 2001; Bates et al., 1996; Gurjanov et al., 1985). Thus, an additional factor – phonological gender marking or transparency – leads to facilitated responses (see also Bates et al., 1995).

Friederici and Jacobsen (1999) explained the robust reaction time slowing effect of congruency with post-lexical checking processes that evaluate the gender congruency of an incoming word. They proposed that in language comprehension gender information (i.e., definite determiner or adjective) may not preselect gender congruent lexical candidates. Studies in Roman languages showed that additionally to the lexical gender information of primes and targets, listeners can exploit phonological gender agreement cues "on-line", helping them to process an upcoming word and to check gender congruency post-lexically (Bates et al., 1995, 1996). All reported studies showed that determiners prime a following noun, as gender matching determiners lead to facilitated reactions in contrast to determiners with mismatching gender, and that phonological gender cues can modulate the post-lexical congruency checking subtle.

On the other hand, studies with brain-injured patients have yielded mixed results. Overall higher error rates and longer reaction times were observed for aphasics in comparison to

[2] Köpcke (1982) analyzed a corpus of monosyllabic words. The proportion of exceptions to phonological rules varied between 3% and 36% per rule.

healthy controls in different languages and tasks (see for example, Akhutina et al., 2001; Bates & Dick, 2001; Devescovi et al., 1997; Jakubowicz & Goldblum, 1995; Perlak & Jarema, 2003; Vigliocco & Franck, 1999). In speech production, gender priming was observed for Russian aphasics in a cued shadowing task (Akhutina et al., 2001), whereas no priming was observed for Italian aphasics in gender monitoring (Bates & Dick, 2001). Nevertheless, Italian aphasics and French fluent aphasics benefited from conceptual and morpho-phonological gender information (Bates & Dick, 2001; Jakubowicz & Goldblum, 1995; Vigliocco & Franck, 1999), whereas Russian aphasics failed to show the markedness effect (Akhutina et al., 2001). In perception, a RT congruency effect was observed for Russian aphasics in a grammaticality judgement (Akhutina et al., 2001), while a percentage correct congruency effect was observed for Italian aphasics judging grammaticality (Bates & Dick, 2001). No markedness effect was revealed for Polish aphasics in a lexical decision task (Perlak & Jarema, 2003) and for Russian aphasics in a grammaticality judgment (Akhutina et al., 2001), whereas Italian nonfluent aphasics benefited from phonological gender markings in a grammaticality judgment (Bates & Dick, 2001). To summarize, aphasic patients show deficits during gender processing (in comprehension and production), but results are inconclusive across patient groups and languages. Factors, such as lesion sites, task type and language may have contributed to this.

Functional imaging investigating gender and phonological processing has implicated two brain structures, the left inferior frontal gyrus (IFG) and the left posterior superior temporal gyrus (pSTG). The posterior and dorsal region of the left IFG, corresponding to superior BA 44/45, may be specialized for phonological processing whereas the anterior region of the IFG, corresponding to BA 47/45, may be specialized for semantic processing (Fiez, 1997). FMRI studies utilizing different phonological tasks revealed activation in the posterior and dorsal region of the left IFG (syllable counting: Poldrack et al., 1999; sound judgement requiring sound segmentation: Burton, Small, & Blumstein, 2000; sequence manipulation and matching: Gelfand & Bookheimer, 2003; phonological decision: Gold & Buckner, 2002; Heim, Opitz, Müller, & Friederici, 2003; gender selection–determiner production: Heim, Opitz, & Friederici, 2002). One can conclude that the left posterior IFG is not necessary for processing sound structure per se, but rather for sequential operations that may underlie the ability to form words from dissociable elements (Gelfand & Bookheimer, 2003) and for segmentation processes in speech perception (Poldrack et al., 1999).

Next to activations of the left IFG (BA45/47 and BA44), left posterior frontal (BA6) and parietal cortex (BA40, near supramarginal gyrus) as well as pSTG were found to be active in phonological decision tasks (Gold & Buckner, 2002; Heim et al., 2003). Posterior STG activation was also reported in studies with semantic, syntactic, and pragmatic violation processing (Friederici, Rüschemeyer, Hahne, & Fiebach, 2003; Kuperberg et al., 2000), and it was proposed that pSTG supports a processing stage during which different types of information, e.g. semantic, syntactic and pragmatic, are mapped onto each other to achieve a final interpretation (Friederici et al., 2003; Kuperberg et al., 2000).

To investigate differences in the involvement of both critical brain regions (left pSTG and IFG) in gender processing related to morpho-phonological or lexical-semantic markings, two patient groups with lesions only in the left pSTG or lesions in the left IFG (also combined with temporal lesions) were tested. In the present study, both patient groups and age-, gender- and education-matched control subjects participated in a gender perception and a gender production task. To control stimuli for conceptual-semantic, morphological and phonological information, specific German gender principles were chosen. The material consisted of items following: (A) phonological principles marked by a phoneme-sequence and (B) derivational–morphological principles marked by a suffix, or following (C) semantic principles carrying only lexical-semantic information (for further details see Section 2). Thus, it is possible to study the involvement of lexical-semantic and phonological gender information, with lesion site controlled. The following predictions were made for perception and production: as indicated by fMRI studies, the left IFG may appear to be engaged in phonological sequencing, thus, LF patients may show deficient processing in particular for phonological gender requiring "fine-grained" phoneme sequencing and discrimination. In contrast, the pSTG is known to be involved in the integration of different information types. Therefore, pSTG patients may show deficient processing of either gender principle.

2. Methods

2.1. Participants

Ten male patients with unilateral brain lesions (4 with left-hemisphere and 1 left-handed patient with right-hemisphere damage [inverse language structure, Patient 2] of the posterior superior temporal gyrus [pSTG], 5 with left-hemisphere damage in anterior brain areas [LF]) as well as 10 male age- and education-matched controls were tested (see Table 1). As the left-handed patient had inverse language organization and showed no deviant deficiency pattern from left hemisphere patients, he was included in the analysis (see for example, Alexander, Fischette, & Fischer, 1989 and Winkelman & Glasson, 1984). All patients were native speakers of German. The patients were tested at a chronic stage post-incident. The average time since lesion in the LF group was: 16 months (range: 7–24 months) and in the pSTG group: 16 months (range: 4–25 months). Lesions primarily resulted from left hemisphere ischemic strokes and left hemisphere hemorrhage (1 right hemisphere hemorrhage). Lesion sites were determined by (T1- and T2-weighted) anatomical MRI datasets from a 3.0 T system (Bruker 30/100 Medspec) and evaluated by an experienced neurologist. Figs. 1 and 2 depict individual lesions and Fig. 3 shows the lesion composite for STG and LF patients separately. The individual patient information is listed in Table 1. Patient 4 with pSTG lesion has an auditory agnosia. Thus, the score of the Token Test is not objective. The Token Test provides only mild or no impairments for all patients. The Aachen Aphasia Test AAT (Huber, Poeck, Weniger, & Willmes, 1983), for example, shows no visual comprehension deficits and classifies the aphasia for all patients as residual. Speech was not affected in all patients. Nevertheless, the patients show small grammatical deficits in spontaneous speech (personal

Table 1
Patient history: descriptions of lesions for each individual patient

pSTG controls				Patients with pSTG lesions				Test time	Lesion site	Token test[a]	AAT (VIS)[a]	Aphasia syndrome
Control group	Sex	Age	Edu	Patient group	Sex	Age	Edu					
1	M	37	10	1	M	37	10	25	L pSTG	2	58/60	Residual
2	M	42	12	2	M	44	12	21	R pSTG	17	49/60	Residual
3	M	67	12	3	M	68	12	20	L pSTG	12	57/60	Residual
4	M	38	12	4	M	38	12	10	L pSTG, SMG	33	57/60	Residual
5	M	36	12	5	M	36	12	4	L pSTG	2	60/60	Residual
LF controls				Patients with LF lesions				Test time	Lesion site	Token test[a]	AAT (VIS)[a]	Aphasia syndrome
Control group	Sex	Age	Edu	Patient group	Sex	Age	Edu					
6	M	21	10	6	M	20	10	24	IFG, L aINS	2	60/60	Residual
7	M	36	12	7	M	37	10	23	IFG, FPOC, L INS, pMTG	2	54/60	Residual
8	M	62	12	8	M	62	12	15	MFG, LPMC	0	58/60	Residual
9	M	26	10	9	M	28	10	10	IFG, FPOC, L aINS	9	57/60	Residual
10	M	47	10	10	M	49	10	7	IFG, FPOC, L INS	4	57/60	Residual

Edu: school education in years; test time: in months post-lesion; L, left; R, right; pSTG, posterior superior temporal gyrus; SMG, supramarginal gyrus; IFG, inferior frontal gyrus; aINS, only anterior insula; INS, insula; FPOC, fronto-parietal opercular cortex; pMTG, posterior middle temporal gyrus; MFG, middle frontal gyrus; LPMC, lateral premotor cortex.

[a] Indication of severity or degree of the language comprehension disorder: A, number of mistakes in token test: no/very mild (0–6); mild (7–23); moderate (24–39); severe (>40); B, visual comprehension scores of the Aachen Aphasia Test (AAT) based on a total of 60 points.

communication with A. Marschhauser). Furthermore, patients and controls were tested with LeMo (De Bleser, Cholewa, Stadie, & Tabatabaie, 2004) for reading and discriminating words, discriminating words and pseudo-words, visual digit span and visual word span indicating no deficits. All subjects were screened for neglect/neglect dyslexia.

2.2. Materials

Four hundred and sixty-four German nouns matched in number of syllables (mean = 2.2, range: 1–3 syllables) and word frequency (mean = 8.3/mill, range: 0–100/mill) were used. Number of syllables and word frequency were controlled and matched for each gender type and each gender rule. The presented nouns were of all three German gender types (feminine, masculine, neuter) and of all three gender rules (phonological, derivational–morphological, semantic; see Table 2 for details). Two noun lists were constructed. One list consisted of 120 derivational–morphologically marked nouns (40 per gender type) and 112 semantically marked nouns (32 feminine, 40 masculine, 40 neuter); the other list consisted of 120 phonologically marked nouns (40 per gender type) and 112 semantically marked nouns (32 feminine, 40 masculine, 40 neuter). The presentation order of the lists was counterbalanced across the participants. As fillers, pseudowords derived from these German nouns were formed by changing one vowel (e.g., *der Tang*—the seaweed ⇒ *der Tong*) preserving marked endings.

3. Experiment 1

3.1. Experimental procedure

Participants were seated 1 m in front of a SONY monitor. They used a keyboard with three buttons (left and right button for the gender congruency judgement counterbalanced across the experiment, middle button to start the experiment). A written instruction was given before each experimental run. Additionally, the instruction was repeated acoustically to ensure understanding. A short training block consisting of 20 trials, with verbal feedback after the training, was administered preceding the experimental blocks. The training block ensured that all participants became accustomed with the grammaticality judgment, especially for the filler items.

Experiment 1 utilized a gender congruency task. One of three possible gender indicating adjectives *weiblich*—feminine, *männlich*—masculine, *sächlich*—neuter and subsequent nouns or pseudowords were presented. The participants had to decide whether the presented gender type agreed with the noun's gender by pressing the left or the right button, respectively. They were asked to respond as quickly and correctly as possible. Reaction times (RT) and percentage of correct responses were recorded online via an ERTS keyboard and ERTS control software (Beringer, 1995). The trial sequence consisted of fixation cross (1000 ms), adjective (500 ms), inter-stimulus-interval (300 ms), noun/pseudoword (500 ms), response time (2000 ms) and inter-trial-interval (1000 ms).

Table 2
Overview of the gender assignment categories

Gender category	Gender type	Word ending/rule	Examples
Phonological (Phon)	Feminine	⇐ fricative + *t*	Lu*ft* (air)
	Masculine	⇐ nasal + consonant	Empfa*ng* (reception)
	Neuter	⇐-et	Quart*ett* (quartet)
Morphological (Morph)	Feminine	⇐ -ei	Bäcker*ei* (bakery)
	Masculine	⇐ -(n)er	Pfört*ner* (gate keeper)
	Neuter	⇐ -lein	Näs*lein* (little nose)
Semantic (Sem)	Feminine	⇐ natural gender	Tochter (daughter)
	Masculine	⇐ natural gender	Onkel (uncle)
	Neuter	⇐ chemicals	Eisen (iron)

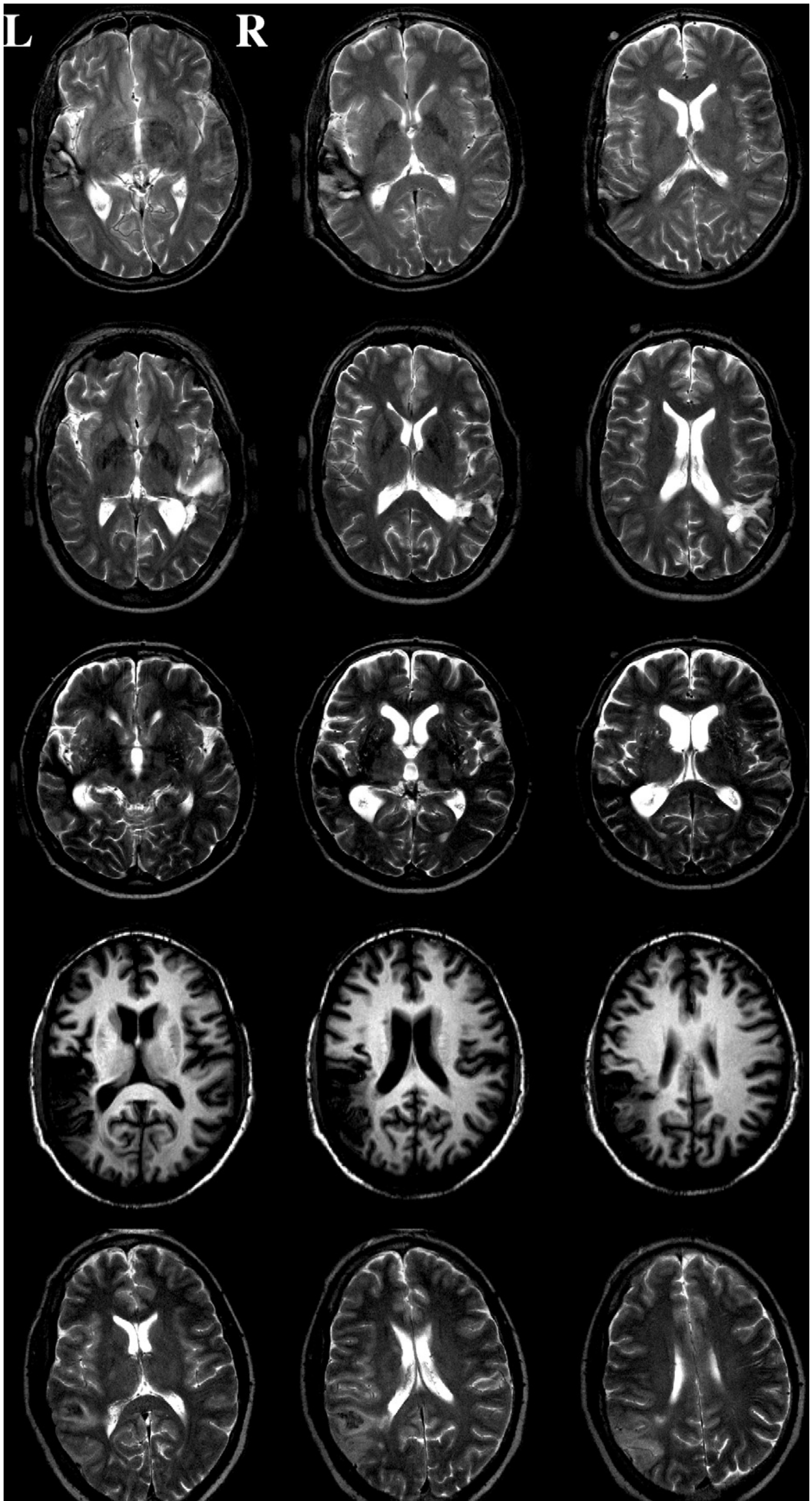

Fig. 1. Anatomical datasets for STG patients (1–5) with three different horizontal slices. The second STG patient shows lesions in the right hemisphere.

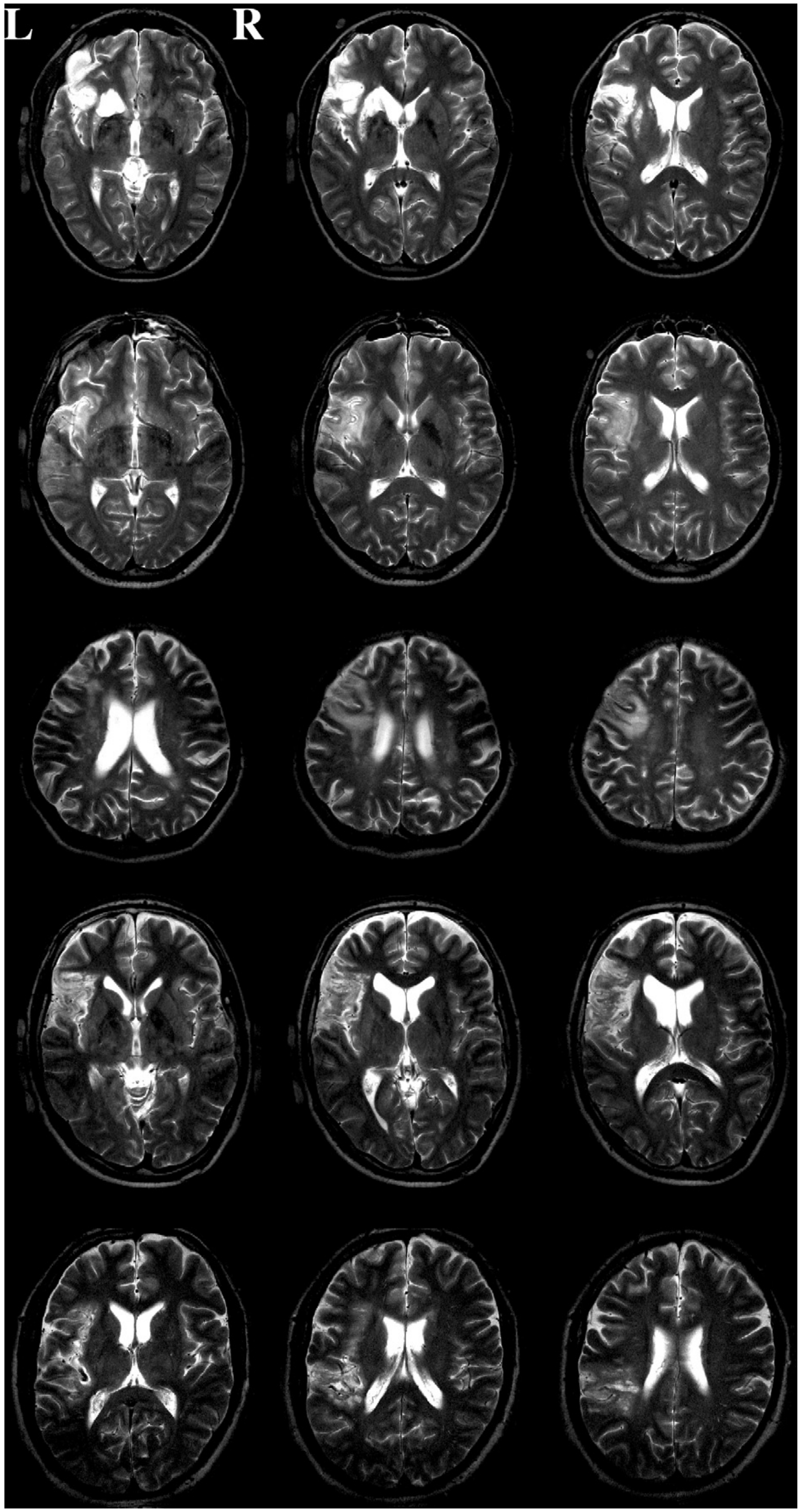

Fig. 2. Anatomical datasets for LF patients (6–10) with three different horizontal slices.

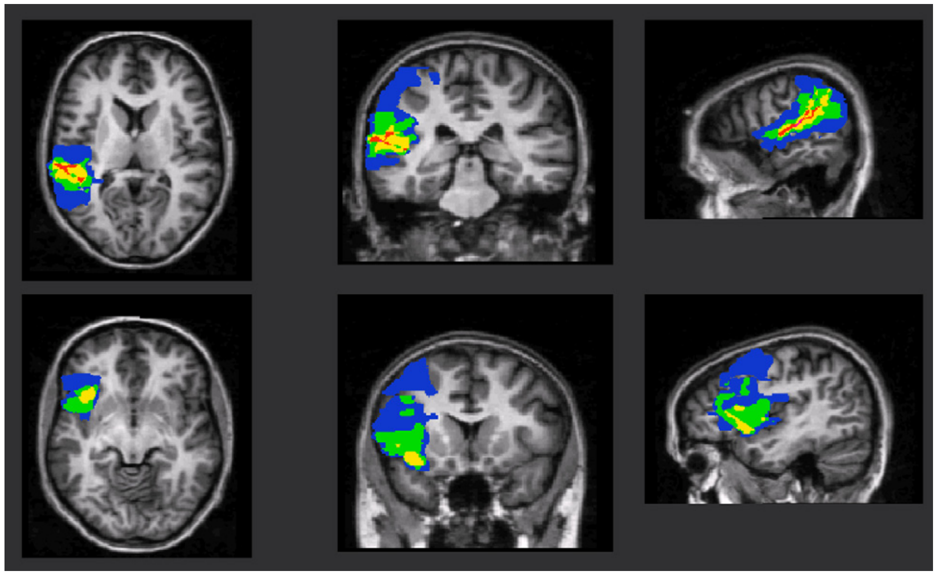

Fig. 3. Lesion overlap for STG patients (top) and LF patients (bottom) with blue color indicating minimum overlap and yellow–red color indicating maximum lesion overlap.

3.2. Data analysis

Analyses of RTs corrected to 2 S.D./norm and percentage of correct responses of Experiment 1 were performed off-line after the data survey. Individual performance patterns were inspected to ensure the behavioral homogeneity in both patient groups. Patients of the same lesion type showed always the same performance pattern, thus, no subject had to be excluded. Group differences between both LF and pSTG controls were not observed and, henceforth, not mentioned. An ANOVA with group as between-factor (LF patients versus LF controls, pSTG patients versus pSTG controls, LF patients versus pSTG patients), and rule (with three levels: phonological—Phon, derivational–morphological—Morph, semantic—Sem) and congruency (with two levels: gender congruent, gender incongruent) as within-factors was calculated. The gender congruency effect is reflected in higher RTs and less correct responses for incongruent conditions as compared to congruent conditions. Therefore, the differences between incongruent and congruent conditions of the congruency effect are positive for RTs and negative for percentage of correct responses. Significant effects are reported as $p < 0.05$ and non-significant effects as $p > 0.05$. Based on the posed hypotheses, only significant effects and interactions with the between factor group as well as resolutions of these interactions will be reported descriptively (for statistical values see Table 4). Thus, the non-significant interaction of group and congruency as well as the non-significant three-way group × congruency × rule interaction occur not in Table 4. Significant group independent effects and interactions will be listed separately (see Table 5).

3.3. Reaction times

LF aphasics showed slower reaction times (1075 ms) compared to their controls (879 ms; see Table 3). Both groups responded faster to congruent than incongruent targets (LF controls difference: 68.4 ms; LF patients difference: 76.2 ms). There were no main effects of rule nor any significant interactions ($p > 0.05$) (Table 4).

Posterior STG aphasics responded slower (1053 ms) compared to their controls (763 ms; see Table 3). Only controls reacted significantly faster to congruent than incongruent targets (difference: 70.6 ms; see Table 4), whereas pSTG patients showed no difference between both target types. There were no main effects of rule nor any significant interactions ($p > 0.05$).

Both patient groups responded comparably (LF: 1075 ms; pSTG: 1053 ms; see Table 3). Thus, no significant effects of group, rule nor any interactions were maintained ($p > 0.05$). Although different congruency effects were found in LF and pSTG patients, this pattern was not reflected in an interaction of group and congruency due to high standard deviations.

In summary, patients reacted slower than controls in the perception task. For both control groups (LF and pSTG) and LF patients significant congruency effects were observed resulting in longer reaction times for gender incongruent items as compared to gender congruent items. Posterior STG patients showed no congruency effect. No rule effects were observed for reaction times in patients and controls.

3.4. Correct responses

LF patients reacted less accurately (65.7%) than their control subjects (88.8%; see Table 3). Additionally, the group ×

Table 3
Mean reaction times and proportions of correct responses as well as standard errors in brackets for each group in the perception task

Group	Reaction time (ms)	Correct responses (%)
LF controls	879 (19)	89 (2)
STG controls	763 (38)	92 (2)
LF patients	1075 (39)	66 (5)
STG patients	1053 (36)	67 (4)

Table 4
Statistical analyses for perception and production of group dependent effects

Source	Comparison/group	d.f.	Perception		Production	
			RT (*F*)	CORR (*F*)	RT (*F*)	CORR (*F*)
Gr	LF Pat vs. Con	1, 8	6.53*	6.68*	1.67	3.22
	STG Pat vs. Con	1, 8	9.91*	10.29*	15.02*	2.69
	Pat LF vs. STG	1, 8	0.06	0.01	0.03	0.97
Gr×Ru	LF Pat vs. Con	2, 16	0.89	5.80*	1.14	2.00
	STG Pat vs. Con	2, 16	0.89	5.76*	2.68	2.26
	Pat LF vs. STG	2, 16	0.19	4.42*	1.38	0.84
Ru	LF Con	1, 4	0.07	0.17	0.72	0.52
	STG Con	1, 4	0.35	0.85	3.38	2.88
	LF Pat	1, 4	1.24	8.30*	1.21	4.09
	STG Pat	1, 4	1.02	6.03*	3.56	2.00
Co	LF Con	1, 4	8.02*	2.02		
	STG Con	1, 4	13.56*	1.08		
	LF Pat	1, 4	9.78*	1.14		
	STG Pat	1, 4	1.72	0.01		
Ru×Co	LF Con	2, 8	1.00	3.44		
	STG Con	2, 8	1.17	0.27		
	LF Pat	2, 8	0.69	0.52		
	STG Pat	2, 8	4.52	3.66		

Gr, group; Ru, rule; Co, congruency; *F*, *F* value; $^{*}p < 0.05$.

rule interaction gave evidence for different rule effects. Control subjects responded comparably correct across all gender principles (see Table 4). LF patients gave less correct answers to phonological gender as compared to derivational–morphological and semantic gender (Phon versus Morph: $F(1, 4) = 12.09$, $p = 0.0254$, difference: 11.4%; Phon versus Sem: $F(1, 4) = 12.61$, $p = 0.0238$, difference: 9.9%). There was no difference between Morph and Sem ($p > 0.05$, difference: 1.5%; see Fig. 4). No congruency effects nor interactions were observed for both LF patients and controls ($p > 0.05$, see Table 4).

Posterior STG patients responded less accurately (66.5%) than their control subjects (91.6%; see Table 3). The main effect of group was underlined by an interaction of group and rule (see Table 4). Control subjects responded comparably accurate across all gender principles (see Table 4). Posterior STG patients reacted less accurately to both gender rules with phonological markings (Phon and Morph) as compared to semantic markings (Phon versus Sem: $F(1, 4) = 8.21$, $p = 0.0457$, difference: 10.8%; Morph versus Sem: $F(1, 4) = 20.98$, $p = 0.0102$, difference: 11.1%). There was no difference between phonological and derivational–morphological gender ($p > 0.05$, difference: 0.3%; see Fig. 4). No congruency effects nor interactions were observed for both pSTG patients and controls ($p > 0.05$, see Table 4).

The between-group comparison of LF and pSTG aphasics maintained no significant effect of group (LF: 65.7%; pSTG: 66.5%; see Table 3), but an interaction of group and rule (see

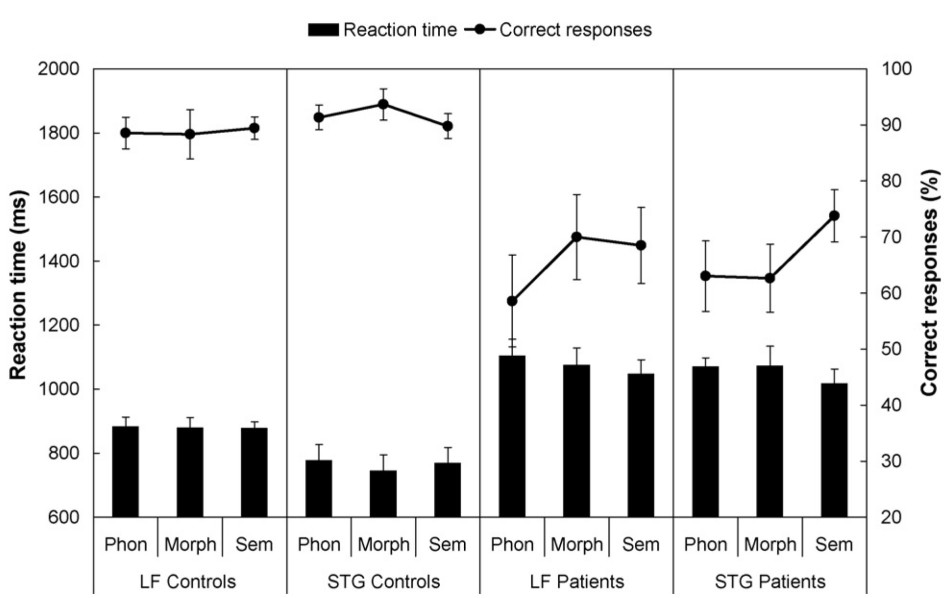

Fig. 4. Reaction times (in ms) and correct responses (in %) are plotted for all groups and gender rules in the perception task.

Table 4). This underlines the differences of the rule effects observed in the analyses for each patient group (see Fig. 4). LF patients showed less correct responses for phonological gender and pSTG patients showed less correct responses for phonological and derivational–morphological gender (see above).

In summary, patients reacted less accurately than controls in perception. LF patients reacted less accurately to phonological gender as compared to derivational–morphological and semantic gender. Posterior STG patients reacted less accurately to phonological and derivational–morphological gender as compared to semantic gender. No congruency effects were observed in patients and controls ($p > 0.05$).

3.5. Discussion

As expected, we obtained significant differences between patients and controls, with patients reacting slower and making more errors than controls. Robust congruency effects were found in *reaction times* for normal controls and patients with left frontal lesions. We interpret these data as a manifestation of post-lexical checking mechanisms (as reported in many studies, see for example Friederici & Jacobsen, 1999; Jacobsen, 1999) evaluating the gender congruency of the incoming words and resulting in slower reaction times for gender incongruent items as compared to gender congruent items. The congruency effect was *not* found in patients with posterior STG lesions. This may indicate that post-lexical checking or matching is impaired in pSTG patients. A similar effect for *percentage of correct responses* was not observed. Deficits related to particular gender rules only became apparent in both patient groups for *percentage of correct responses*. LF patients were more deficient in phonological gender as compared to derivational–morphological and semantic gender. For the processing of phonological gender with phoneme combinations at the word ending "fine grained" phoneme sequencing seems necessary and not processing of phonological gender information and gender marking per se, as more correct responses for derivational–morphological gender as compared to less correct responses for phonological gender were observed. The data thus support our hypothesis that if the left IFG is responsible for sequencing, phonological gender should be affected more than other gender principles. Posterior STG patients were deficient in processing gender when marked by phonological form (i.e. sequence) or morphological form (i.e. suffix) as compared to semantic content.[3] On the basis of the reaction time data (missing congruency effect) it seems plausible that post-lexical checking mechanisms are affected in these patients. Such mechanisms may include the matching or integration of phonological information (i.e. phonological sequence) and lexical information (i.e. entire word) in case of phonological gender, and of morphological (i.e. suffix) and lexical (word stem) information in case of derivational–morphological gender. A phonologically marked "clearness" or transparency effect for *reaction times* and *percentage of correct responses* was not supported by the current data neither for controls nor for patients.

[3] As gender differences in the processing of semantic gender have been previously reported, it is highly unlikely that the semantic gender effect reported here is due to the gender of the participants.

4. Experiment 2

4.1. Experimental procedure

Experiment 2 used a gender production task. All subjects had to produce the correct determiner for the presented nouns controlled for the three gender types and gender principles (see Section 2 for further details). Participants were seated 1 m in front of a SONY monitor. The same nouns as in Experiment 1 were presented. The trial sequence consisted of cross (1000 ms), noun (500 ms), response time (2000 ms) and an inter-trial-interval (1000 ms). The answer was given by speaking the definite article into a microphone linked to the ERTS keyboard. The voice functioned as a button press and RTs were registered online, whereas CORR were noted manually.

4.2. Data analysis

Analyses of RT and CORR were performed off-line after the data survey similar to Experiment 1. An ANOVA with group as between-factor (LF patients versus LF controls, pSTG patients versus pSTG controls, LF patients versus pSTG patients) and rule (with three levels: phonological—Phon, derivational–morphological—Morph, semantic—Sem) as within-factors was calculated. Significant effects are reported as $p < 0.05$ and non-significant effects as $p > 0.05$. Based on the hypotheses, only significant effects and interactions with the between factor group as well as resolutions of these interactions will be reported descriptively (for statistical values see Table 4). Significant group independent effects and interactions will be listed separately (see Table 5).

4.3. Reaction times

In the between-group analysis of left frontal patients with their controls and of both patient groups no group effects were maintained ($p > 0.05$, see Table 4). Due to the high patient's standard deviation, group effects were not significant. After visual inspection one can, however, observe that left frontal patients (1196 ms) reacted slower than controls (957 ms) across all conditions (Table 6 and Fig. 5).

Only in the between-group analysis comparing pSTG aphasics and controls a significant main effect of group was observed (see Table 4). Posterior STG patients (1163 ms) reacted slower than control subjects (726 ms; see Table 6).

All by-group analyses revealed no significant rule effects for both patient and control groups (see Fig. 4).

4.4. Correct responses

As can be seen in Table 4 and 5 all between-group and by-group comparisons maintained no significant main effects of group and rule nor interaction. Statistically, due to high patient's standard deviation, patients reacted as accurately as controls. But

Table 5
Statistical analyses for perception and production of group independent effects

Source	Comparison	d.f.	Perception		Production	
			RT (*F*)	CORR (*F*)	RT (*F*)	CORR (*F*)
Ru	LF Pat vs. Con	2, 16	1.28	6.17*	1.23	2.31
	STG Pat vs. Con	2, 16	0.54	2.12	4.40*	2.15
	Pat LF vs. STG	2, 16	2.03	9.50*	1.48	3.75
Co	LF Pat vs. Con	1, 8	17.77*	2.11		
	STG Pat vs. Con	1, 8	9.09*	0.19		
	Pat LF vs. STG	1, 8	8.62*	0.82		
Ru × Co	LF Pat vs. Con	2, 16	0.20	2.81		
	STG Pat vs. Con	2, 16	5.38*	2.97		
	Pat LF vs. STG	2, 16	3.30	2.25		

Ru, rule; Co, congruency; *F*, *F* value; $^{*}p < 0.05$.

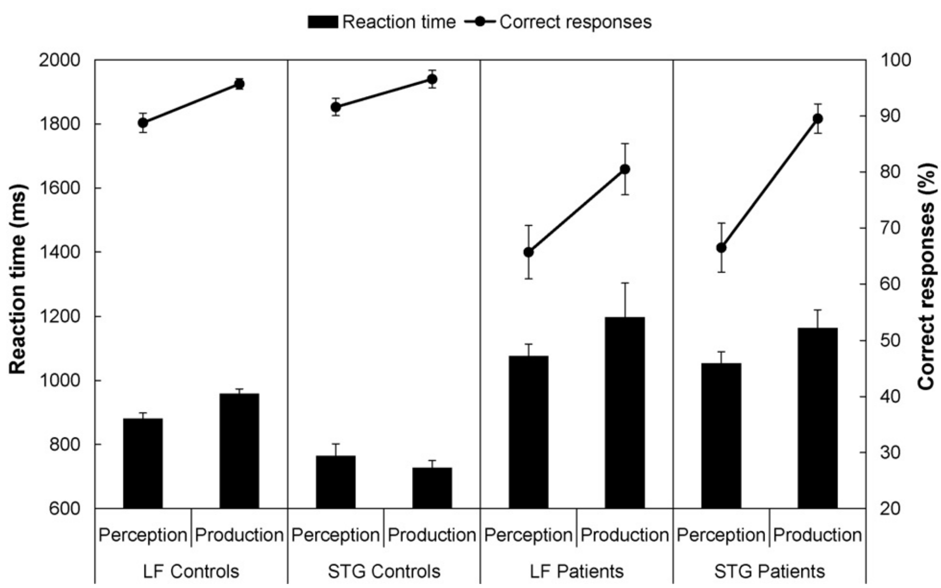

Fig. 5. Reaction times (in ms) and correct answers (in %) are plotted for all groups dependent on task type.

after visual inspection one can observe that LF patients (80.5%) reacted less accurately than LF controls (95.7%) and posterior STG patients (89.5%) reacted nearly as accurately as their controls (96.6%) (Fig. 6).

4.5. Discussion

In production, pSTG patients reacted slower than controls. LF patients seem to respond slower than controls, but statistical values failed to reach significance due to high standard errors (LF patients: 107; LF controls: 17). This problem also occurred for *percentage of correct responses* (LF patients: 4.8; LF controls: 0.9). Both patient groups did not differ significantly from controls. Thus, one can state that patients are not significantly deficient in production of gender congruent determiners. Rule effects of *reaction times* and *correct responses* were not found. In contrast, facilitation for phonologically marked, transparent gender or inhibition for opaque gender was reported in the literature for normals as well as for aphasics (e.g., in Russian, Akhutina et al., 1999, 2001; in Italian, Bates et al., 1995, 1996; Bates & Dick, 2001; Vigliocco & Franck, 1999; in French, Jakubowicz & Goldblum, 1995). As mentioned in Experiment 1 transparency effects occur in languages with frequent unequivocal phonological gender markings which are not highly frequent in German. Thus, it is possible that a transparency effect cannot be established in general.

Table 6
Mean reaction times and proportions of correct responses as well as standard errors in brackets for each group in the production task

Group	Reaction time (ms)	Correct responses (%)
LF controls	967 (17)	96 (1)
STG controls	726 (23)	97 (2)
LF patients	1196 (107)	81 (5)
STG patients	1163 (58)	90 (3)

5. General discussion

Taken together, the data from the current experiments support different roles of left pSTG and the left IFG in gender processing related to phonological, morphological, and lexical-semantic markings in perception and in production.

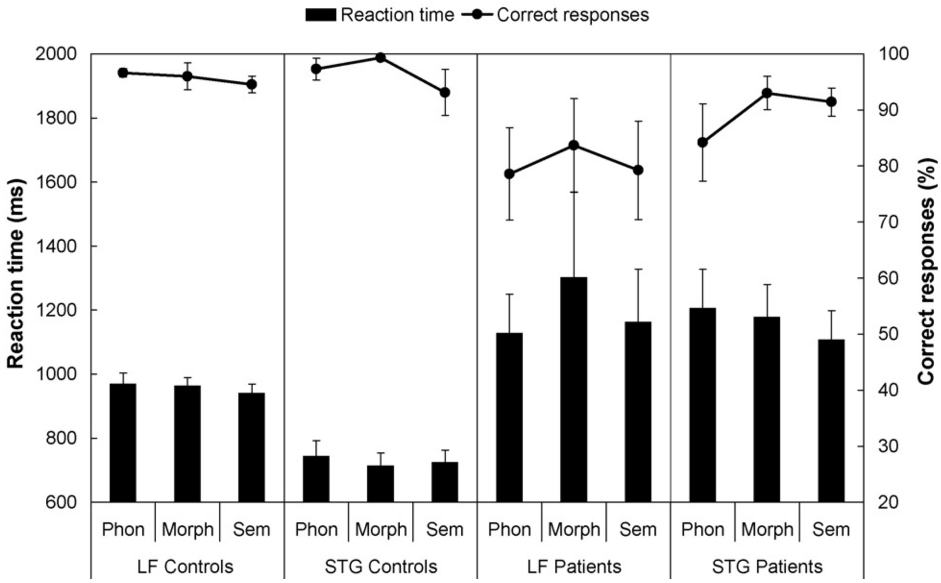

Fig. 6. Reaction times (in ms) and correct answers (in %) are plotted for all groups and gender rules in the production task.

To explain the RT congruency effect in the perception experiment we referred to an account by Friederici and Jacobsen (1999), who proposed a post-lexical checking mechanism. This mechanism leads to slower reaction times for gender incongruent items, which was reported in many studies for healthy subjects (e.g., for German, Jacobsen, 1999; Jescheniak, 1999; for Dutch, van Berkum, 1997; for Italian, Bates & Dick, 2001; Bentrovato et al., 1999; Vigliocco & Franck, 1999; for Russian, Akhutina et al., 2001; for Serbo-Croatian, Carello et al., 1988; Gurjanov et al., 1985).

Only pSTG patients did not reveal the congruency effect in the perception task. This may indicate a deficit with post-lexical checking or matching. The deficit goes hand in hand with the reported percent correct pattern for gender principles of this patient group. We propose that information about the phonological form has to be integrated or matched with the lexical information post-lexically for both phonological and derivational–morphological gender principles. This integration process seems to be deficient in pSTG patients. In these patients the white matter connection (arcuate fasciculus) from posterior to frontal brain areas is partially or completely interrupted. This possible white matter disconnection could cause: (1) integration failures as lexical-semantic and/or phonological information from posterior brain areas cannot be matched with lexical-semantic and/or phonemic information processed in frontal brain areas, or (2) interaction failures between posterior and frontal brain areas. To determine the integrative or interactive nature of this failure more investigations are necessary. In production, no rule effect was observed for pSTG patients in *percentage of correct responses* and *reaction times*. This underlines the distinctiveness of perception processes (checking and integration) and production processes (phonological generation). In perception, the first analysis concerns the phonological information of the incoming word, which has to be matched to the lexical gender information. This checking or matching mechanism fails for form-based principles (i.e. phonological and morphological principles), but is not necessary for lexical-semantic principles, and therefore leaves the latter domain intact. In production, according to the language production model of Levelt and colleagues (Levelt, 1989; Levelt et al., 1999), the first step is lexical selection leading to the lexical entry with its syntactic properties of the noun (e.g. grammatical gender), then morphological encoding and phonological encoding takes place. If gender information is already available early during such a process, that is, after lexical selection, this may ease correct gender production in these patients.

LF patients showed the RT congruency effect for perception. This indicates that post-lexical checking is intact. They revealed a percentage correct deficit for phonological gender in perception. LF brain areas are often discussed to be involved in phoneme discrimination or sequencing (Burton et al., 2000; Gelfand & Bookheimer, 2003; Poldrack et al., 1999), which would be necessary for the correct perceptual processing of phonological gender in contrast to derivational–morphological and semantic gender. Derivational–morphological gender carries phonological gender information, which does not need fine phoneme sequencing (the *whole* suffixed syllable determines gender marking) and which is additionally stored in the lexicon (in German, derivational–morphological information is lexical). This is an advantage, which results in more correct responses for derivational–morphological gender as compared to phonological gender.

To conclude, in perception, posterior STG and left IFG may need to be functionally interconnected more strongly as this is necessary for post-lexical integration of different information types than in production. Lesion location plays an important role in German gender processing, as different lesions lead to different deficit patterns for the three gender rules. Lesions of left IFG seem to impair phonological sequencing, while pSTG lesions seem to restrict the integration of different information types (phonological and lexical) within the pSTG or the interaction between pSTG and frontal areas caused by a complete or partial interruption of the arcuate fasciculus.

References

Akhutina, T., Kurgansky, A., Kurganskaya, M., Polinsky, M., Polonskaya, N., Larina, O., et al. (2001). Processing of grammatical gender in normal and aphasic speakers of Russian. *Cortex*, *37* (3), 295–326.

Akhutina, T., Kurgansky, A., Polinsky, M., & Bates, E. (1999). Processing of grammatical gender in a three-gender system: Experimental evidence from Russian. *Journal of Psycholinguistic Research*, *28* (6), 695–713.

Alexander, M. P., Fischette, M. R., & Fischer, R. S. (1989). Crossed aphasias can be mirror image or anomalous. *Brain*, *112* (4), 953–973.

Bates, E., Devescovi, A., Hernandez, A., & Pizzamiglio, L. (1996). Gender priming in Italian. *Perception and Psychophysics*, *58* (7), 992–1004.

Bates, E., Devescovi, A., Pizzamiglio, L., D'Amico, S., & Hernandez, A. (1995). Gender and lexical access in Italian. *Perception and Psychophysics*, *57* (6), 847–862.

Bates, E., & Dick, F. (2001). Linguistic and nonlinguistic priming in aphasia. *Brain and Language*, *76*, 62–69.

Bentrovato, S., Devescovi, A., D'Amico, S., & Bates, E. (1999). Effect of grammatical gender and semantic context on lexical access in Italian. *Journal of Psycholinguistic Research*, *28* (6), 677–693.

Beringer, J. (1995). *ERTS: Experimental Run Time System. Frankfurt am Main*. BeriSoft Cooperation.

Burton, M. W., Small, S. L., & Blumstein, S. E. (2000). The role of segmentation in phonological processing: An fMRI investigation. *Journal of Cognitive Neuroscience*, *12* (4), 679–690.

Carello, C., Lukatela, G., & Turvey, M. T. (1988). Rapid naming is affected by association but not by syntax. *Memory and Cognition*, *16* (3), 187–195.

Corbett, G. G. (1991). *Gender*. Cambridge: Cambridge University Press.

De Bleser, R., Cholewa, J., Stadie, N., & Tabatabaie, S. (2004). *LEMO—Lexikon modellorientier: Einzelfalldiagnostik bei Aphasie, Dyslexie und Dysgraphie*. München: Elsevier, Urban und Fischer.

Devescovi, A., Bates, E., D'Amico, S., Hernandez, A., Marangolo, P., Pizzamiglio, L., et al. (1997). An on-line study of grammaticality judgements in normal and aphasic speakers of Italian. *Aphasiology*, *11* (6), 543–579.

Fiez, J. A. (1997). Phonology, semantics, and the role of the left inferior prefrontal cortex. *Human Brain Mapping*, *5*, 79–83.

Fleischer, W., & Barz, I. (1995). *Wortbildung der deutschen Gegenwartssprache*. Tübingen: Max Niemeyer Verlag.

Friederici, A. D., & Jacobsen, T. (1999). Processing grammatical gender during language comprehension. *Journal of Psycholinguistic Research*, *28* (5), 467–484.

Friederici, A. D., Rüschemeyer, S. -A., Hahne, A., & Fiebach, C. J. (2003). The role of left inferior frontal and superior temporal cortex in sentence comprehension: Localizing syntactic and semantic processes. *Cerebral Cortex*, *13*, 170–177.

Friederici, A. D., von Cramon, D. Y., & Kotz, S. A. (1999). Language related brain potentials in patients with cortical and subcortical left hemisphere lesions. *Brain*, *122*, 1033–1047.

Gelfand, J. R., & Bookheimer, S. Y. (2003). Dissociating neural mechanisms of temporal sequencing and processing phonemes. *Neuron*, *38* (5), 831–842.

Gold, B. T., & Buckner, R. L. (2002). Common prefrontal regions coactivate with dissociable posterior regions during controlled semantic and phonological tasks. *Neuron*, *35* (4), 803–812.

Gurjanov, M., Lukatela, G., Lukatela, K., Savic, M., & Turvey, M. T. (1985). Grammatical priming of inflected nouns by gender of possessive adjectives. *Journal of Experimental Psychology, Learing, Memory, and Cognition*, *11* (4), 692–701.

Heim, S., Opitz, B., & Friederici, A. D. (2002). Broca's area in the human brain is involved in the selection of grammatical gender for language production: Evidence from event-related functional magnetic resonance imaging. *Neuroscience Letters*, *328*, 101–104.

Heim, S., Opitz, B., Müller, K., & Friederici, A. D. (2003). Phonological processing during language production: fMRI evidence for a shared production-comprehension network. *Cognitive Brain Research*, *16* (2), 285–296.

Huber, W., Poeck, K., Weniger, D., & Willmes, K. (1983). *Aachener Aphasie-Test* (*AAT*). Göttingen: Hogrefe.

Jacobsen, T. (1999). Effects of grammatical gender on picture and word naming: Evidence from German. *Journal of Psycholinguistic Research*, *28* (5), 499–514.

Jakubowicz, C., & Goldblum, M. C. (1995). Processing of number and gender inflections by French-speaking aphasics. *Brain and Language*, *51* (2), 242–268.

Jescheniak, J. D. (1999). Gender priming in picture naming: Modality and baseline effects. *Journal of Psycholinguistic Research*, *28* (6), 729–737.

Köpcke, K. -M. (1982). *Untersuchungen zum Genussystem der deutschen Gegenwartssprache. vol. 122*, Linguistische Arbeiten. Tübingen: Niemeyer.

Köpcke, K. -M., & Zubin, D. (1996). Prinzipien für die Genuszuweisung im Deutschen. In: E. Lang, & G. Zifonun (Eds.), *Deutsch-typologisch*. Berlin, New York: Walter de Gruyter. pp.473–491

Kuperberg, G. R., McGuire, P. K., Bullmore, E. T., Brammer, M. J., Rabe-Hesketh, S., Wright, I. C., et al. (2000). Common and distinct neural substrates for pragmatic, semantic, and syntactic processing of spoken sentences: An fMRI study. *Journal of Cognitive Neuroscience*, *12* (2), 321–341.

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge: MIT Press.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*, 1–75.

Perlak, D., & Jarema, G. (2003). The recognition of gender-marked nouns and verbs in polish-speaking aphasic patients. *Cortex*, *39* (3), 383–403.

Poldrack, R. A., Wagner, A. D., Prull, M. W., Desmond, J. E., Glover, G. H., & Gabrieli, J. D. (1999). Functional specialization for semantic and phonological processing in the left inferior prefrontal cortex. *Neuroimage*, *10* (1), 15–35.

van Berkum, J. J. A. (1997). Syntactic processes in speech production: The retrieval of grammatical gender. *Cognition*, *64* (2), 115–152.

Vigliocco, G., & Franck, J. (1999). When sex and syntax go hand in hand: Gender agreement in language production. *Journal of Memory and Language*, *40* (4), 455–478.

Winkelman, M. D., & Glasson, C. C. (1984). Unilateral right cerebral representation of reading in a familial left-hander. *Neuropsychologia*, *22* (5), 621–626.