The Determiner Congruency Effect in Language Production Investigated With Functional MRI

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Abstract: In language production, naming a picture with a gender-marked determiner phrase is faster in the presence of a distractor noun with the same grammatical gender (congruent condition) as compared with a different grammatical gender (incongruent condition). We investigated the neural correlates of this determiner congruency effect in German with functional magnetic resonance imaging (fMRI). Participants named pictures of real objects with determiner phrases (e.g. “der Tisch”—the table) in the presence of a gender-congruent or gender-incongruent distractor noun. Different comparisons allow the following functional segregation within the prefrontal cortex. First, the comparison between picture naming versus rest revealed a steeper slope of the haemodynamic response function (HRF) in the gender-congruent than the gender-incongruent condition in the left BA 44, suggesting the involvement of BA 44 in determiner selection. HRF amplitude differences between the congruent and the incongruent condition were observed outside the language network in the right fronto-median wall (congruent > incongruent), and in the left premotor cortex, middle frontal gyrus, cerebellum, and inferior parietal lobe (incongruent > congruent). The latter regions are known to be involved in the processing of incongruence and conflict in general. The data thus reveal the involvement of the left BA 44 in the selection of determiners for language production. *Hum Brain Mapp* 30:928–940, 2009. ©2008 Wiley-Liss, Inc.

Key words: language production; functional magnetic resonance imaging; gender congruency effect; determiner congruency effect; syntax; gender; speech latencies; overt speech; picture word interference paradigm; fMRI

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INTRODUCTION

Many languages such as German, Dutch, French, Italian, and Spanish have grammatical gender as an abstract syntactic property of nouns to achieve agreement. The number of genders varies between languages. For example, Dutch and French have two genders (common and neuter in Dutch; masculine and feminine in French), whereas German has three genders (masculine, feminine, and neuter) (see “Abbreviations”). The assignment of gender to artificial objects is to a large extent arbitrary [Corbett, 1991; e.g. *der Stuhl*—the_{masc} chair] as opposed to the gender of some

nouns with natural gender (e.g. *der Mann*—the_{masc} man). Moreover, gender assignment may vary between languages; e.g. the lexical entry of the concept “car” has masculine gender in Spanish (*el coche*), feminine gender in French (*la voiture*), neuter gender in German (*das Auto*), and common gender in Dutch (*de auto*).

In gender-marking languages, speakers also use gender information to indicate the correspondence between nouns and e.g. adjectives or pronouns. Consider the following German examples:

1. Das Auto parkt vor der Garage. Es ist grün.
(The_{neut,NOM} car parks in front of the_{fem,DAT} garage.
It_{neut,NOM} is green.)
2. Das Auto parkt vor der Garage. Sie ist grün.
(The_{neut,NOM} car parks in front of the_{fem,DAT} garage.
It_{fem,NOM} is green.)

In Examples (1) and (2), the pronoun “it” in the English sentence “It is green” may refer to both, “car” or “garage”. In contrast, in the German sentences, the syntactic gender of the pronoun agrees with the gender of either *Auto* or *Garage*, resolving the ambiguity encountered in English. Example (3) demonstrates that words such as adjectives and determiners, which are syntactically dependent on the noun, take the noun’s gender. This is expressed by the gender-marking via the corresponding morphological form of the determiner or the inflection of the adjective.

3. Das grüne Auto parkt vor der roten Garage.
(The_{neut,NOM} green_{neut,NOM} car parks in front of the_{fem,DAT} red_{fem,DAT} garage.)

Schriefers [1993] investigated the use of grammatical gender information during language production by measuring speech latencies in the picture–word interference paradigm. Dutch participants named coloured pictures presented on a computer screen with a noun phrase (NP) consisting of the definite determiner, a (non-gender-marked, prenominal) colour adjective, and the noun (e.g. *de rode auto*—the_{com} red car; *het rode huis*—the_{neut} red house; Experiment 1), or only the (gender-marked) adjective and the noun (e.g. *rode auto*—red_{com} car; *rood huis*—red_{neut} house; Experiment 2). In addition to the pictures to be named, written distractor words which had the same (congruent condition) or a different (incongruent condi-

tion) grammatical gender as the target picture name were presented on the computer screen. Participants were required to name the pictures and ignore the distractor words. Congruent distractors speeded up naming latencies relative to gender-incongruent distractors. This effect was termed the “gender congruency effect” in language production. Since the work of Schriefers [1993], this effect has been replicated in several behavioural studies in Germanic languages [Dutch: 2006; La Heij et al., 1998; Schiller and Caramazza 2003; Schiller and Caramazza 2003; Schiller and Costa 2006; Van Berkum, 1997; German: Schriefers and Teruel 2000] and in Croatian [Costa et al., 2003].¹

In the literature, there are two alternative hypotheses for the origin of the gender congruency effect locating the effect at different levels in the process of language production. The *Gender Selection Interference Hypothesis* (GSIH) explains the gender congruency effect in the framework of the model of language production by Levelt et al. [1999; Fig. 1]. It is assumed that both the target noun (i.e. the picture name) and the (gender-congruent) distractor activate the same gender node at the lemma level. Thus, the target noun and the distractor activate the gender node more than each single item alone. As a consequence, access to the phonological code (e.g. of the gender-marked adjective) is facilitated relative to picture naming with a gender-incongruent distractor, a control condition (e.g. a row of X’s), or no distractor.

Alternatively, the determiner selection interference hypothesis [DSIH; Schiller and Caramazza, 2003] proposes that the gender congruency effect does not result from competition between abstract gender features of target and distractor on the lemma level, but rather from competition between determiner word forms on the lexeme level when the forms of the determiners are selected.

Schiller and Caramazza [2003] tested the DSIH against the GSIH by varying the number (singular/plural) of the target picture name and/or of the distractor in German and Dutch. In both languages, the singular determiners are different for all genders (German: *der*—the_{masc}, *die*—the_{fem}, *das*—the_{neut}; Dutch: *de*—the_{com}, *het*—the_{neut}), whereas the plural determiners have the same form for all genders (German: *die*; Dutch: *de*). In case of the GSIH, the form of the determiner should have no influence on the production process, resulting in a gender congruency effect independent of the number of the target and/or the distractor. In contrast, in case of the DSIH, the number of

Abbreviations

com	common gender
DAT	dative
det	determiner
fem	feminine gender
masc	masculine gender
neut	neuter gender
NOM	nominative

¹Interestingly, studies in Romance languages failed to replicate the effect [Alario and Caramazza, 2002; Costa et al., 1999; Miozzo and Caramazza 1999]. This conflicting pattern of results can be accounted for by the fact that German, Dutch, and Croatian are “early selection languages” in which the selection of freestanding morphemes (e.g. determiners) can be initiated as soon as the gender of the noun (together with other relevant grammatical and semantic features) is retrieved [for a description of early- and late-selection languages cf. Caramazza et al., 2001; Costa et al., 1999; for further discussion see Costa et al., 2003; Miozzo et al., 2002].

Figure 1.

The serial model of language production by Levelt et al. (1999). Semantics (concept), syntactic gender (lemma), and the form of a word (lexeme) are retrieved during different stages of the production process.

the target and the congruence vs. incongruence of the distractor should interact. In a series of experiments, Schiller and Caramazza [2003] observed an interaction between number of the target and congruence/incongruence, obtaining a gender congruency effect only for singular but not plural targets. This pattern of results was taken as evidence in favour of the DSIH, indicating that the gender congruency effect is in fact a determiner congruency effect occurring at the morpho-phonological level in the production process instead of the lemma level. Evidence in favour of this interpretation comes from a number of recent studies demonstrating determiner interference also in pure picture naming tasks using singular and plural target names [e.g. Janssen and Caramazza, 2003; Lemhöfer et al., 2006; Schriefers et al., 2002, 2005]. In the remainder of the present article, we will consequently refer to the effect as the *determiner congruency effect*.

The present event-related functional magnetic resonance imaging (fMRI) study aimed at identifying the neural basis of the determiner congruency effect in order to investigate the neural mechanisms by which the lexical form of a determiner is selected during language production. The neural correlates of the selection of the determiner form may then be compared to and dissociated from those related to lexical retrieval, lemma selection and retrieval, phonological code retrieval, syllabification, and articulation, as reflected e.g. in the neurocognitive model of language production by Indefrey and Levelt [2004] and more recent literature. The findings of the present study thus add to understanding the language production network in the brain by either demonstrating that additional regions which were not previously considered must be included into this network, or by showing that brain regions previously related only to one aspect of language production contribute also to the selection of free-standing morphemes.

When contrasting the production of determiner phrases (with any type of distractor) against rest, the whole language production network should be activated, since all core processes are sequentially recruited during picture naming [Levelt et al., 1999]. The neural correlates specifically involved in the selection of the determiner form will be revealed as a difference in the fMRI signal within this network in the contrast of the congruent with the incongruent condition (see Materials and Methods section).

In addition, there might be effects in other brain regions which do not specifically support the retrieval of the lexical determiner form per se but rather play a more general role in resolving picture-word interference. Previous fMRI studies have investigated overt language production in the picture-word interference paradigm with distractor words that were either semantically [De Zubicaray et al., 2001] or phonologically [De Zubicaray et al., 2002] related to the target picture name. In both studies, brain regions showing amplitude differences between congruent and incongruent distractor conditions included the left superior temporal gyrus, right superior frontal gyrus, right occipital lobe, and the anterior cingulate. As a consequence, one may speculate that these regions could be part of a network involved in the processing of information interfering with the intended speech utterance. Accordingly, effects in these brain regions could also be observed when investigating the neural mechanisms underlying the determiner congruency effect in language production. From the two studies by De Zubicaray et al. [2001, 2002], it cannot be derived whether the gender-congruent or the gender-incongruent condition should express a stronger effect in the present experiment, because only F tests were reported which provide no information about the direction of the effect.

With respect to the nature of the neurofunctional correlates of the determiner congruency effect different hypotheses are conceivable. Usually, neuroimaging studies as the studies by De Zubicaray et al. [2001, 2002] investigate *amplitude differences* in the fMRI signal. This implies that one

brain region is activated more strongly in one condition than in the other. Alternatively, activation in a brain region may have the same amplitude but exhibit a *latency difference*, i.e. an earlier increase of the activation in one condition as compared to the other. A latency difference can be detected via the first temporal derivative of the fMRI signal (e.g. Ford et al., 2005; Henson et al., 2002). Because the determiner congruency effect manifests in a latency difference in the speech onset times, it is likely that the underlying neural mechanisms were also based on the delayed increase of brain activation in one condition. Finally, both amplitude differences and latency differences could be observed either jointly or separately in different brain regions. As a consequence, in the present study we investigated amplitude and latency differences in the fMRI signal when contrasting the gender-congruent with the gender-incongruent condition.

MATERIALS AND METHODS

Participants

Sixteen healthy right-handed participants (mean age 26.9 years; range 22.2–33.9 years; eight women) participated in the experiment. They were all native German speakers and had normal or corrected-to-normal vision. Participants had no known history of neurological or psychiatric disorders. Informed consent was obtained from all participants. The experimental standards were approved by the ethics committee of the University of Leipzig.

Stimulus Materials and Procedure

We used the same target picture names, distractor nouns, and target-distractor pairings as Schiller and Caramazza [2003]. Their study included each 20 picture names with masculine, feminine, and neuter gender. As in the Schiller and Caramazza [2003] study, our participants were familiarised with the picture stimuli and their names before the experiment. Each picture was presented twice to each participant, once combined with a gender-congruent distractor noun and once with a gender-incongruent distractor noun. For each participant, there were 60 congruent (CON) and 60 incongruent (INC) trials. Moreover, in order to increase the statistical power of the study [Friston et al., 1999], we included 60 null events (NULL) as a resting baseline during which no stimulus or distractor was presented.

The stimuli were presented on a computer screen using the ERTS software package (BeriSoft cooperation, Frankfurt, Germany). The pictures had a size of $\sim 7 \text{ cm} \times 7 \text{ cm}$. Distractor nouns were presented in Sans Serif font in varying positions above, below, or superimposed on the target pictures. Care was taken that the distractor nouns did not obscure the pictures or vice versa. Participants named the pictures overtly with determiner phrases (e.g. *die Birne*—the_{fem} pear) during the silent periods of a sparse-sampling

Figure 2.

A bunched-early EPI sequence was used for the acquisition of the fMRI data. All slices were recorded in the first half of the TR, resulting in a silent period in the second half of the TR. During this silent period, the participants named the pictures. Thus, the speech response signal is clearly discernable, since it is not obscured by the scanner noise.

EPI sequence [see Fig. 2 and the section “Data Acquisition and Analysis”; cf. Christoffels et al., 2007; De Zubicaray et al., 2001, 2002; Heim et al., 2002]. The speech signal was recorded in order to assess the speech latencies in the congruent and incongruent conditions. Because the determiner congruency effect had only been observed in the singular in the Schiller and Caramazza [2003] study, we only used singular utterances in order to keep the experiment short enough for additionally including the null events.

The study employed an event-related design. Stimuli and conditions were presented in a pseudo-randomised order, with different randomisations for each participant. There was a minimum of four trials gap between the first and the second presentation of a particular picture stimulus. The target picture names had the same grammatical gender in no more than two successive trials.

The experiment started with a written instruction presented for 12 s (2 scans) before the experimental trials started. Each trial lasted 6 s. In the first 3 s of each trial, the fMRI data were acquired (see below). During this time, the screen remained blank for 2,000 ms, followed by a fixation cross in the centre of the screen for 1,000 ms. The fixation cross was then presented for additional 0, 500, or 1,000 ms, thus introducing a temporal jitter in the stimulus presentation for the sake of a higher sampling rate for the fMRI data. After the fixation cross, the picture and distractor word were presented simultaneously (i.e. stimulus onset asynchrony or SOA = 0 as in the Schiller and Caramazza, 2003 study) for 1,000 ms. Then the screen turned blank for the rest of each trial.

The picture stimuli were named overtly by the participants as soon as they were presented on the screen. Since participants were not used to speaking in the scanner, they were familiarised with the paradigm while lying in the

scanner before the start of the experiment proper. During the familiarisation phase, other stimuli than those used in the experiment were presented.

Data Acquisition and Analysis

Functional and anatomical data

The fMRI experiment was carried out on a 3T Siemens Trio scanner. A standard birdcage head coil was used. Visual stimuli were presented on a screen positioned at the head end of the magnet bore. Participants viewed the screen through mirror glasses. Foam paddings were used to reduce head motion.

T1-weighted MDEFT [Ugurbil et al., 1993] images (matrix 256×256 , TR = 1.3 s, TE = 10 ms) were obtained with a non-slice-selective inversion pulse followed by a single excitation of each slice [Norris, 2000]. The functional data were recorded from 36 slices in ascending order using a gradient-echo EPI sequence with TE = 30 ms, flip angle = 90° , TR = 6 s, acquisition bandwidth 116 kHz. The sagittal orientation of the slices was chosen in order to correct head motion in-plane, which is highest in the y - z plane. Acquisition of the slices within the TR was arranged so that the slices were all rapidly acquired in the first 3 seconds followed by a 3 seconds period of no acquisition to complete the TR. The matrix acquired was 64×64 with a FOV of 19.2 cm, resulting in an in-plane resolution of $3 \text{ mm} \times 3 \text{ mm}$. The slice thickness was 3 mm with an inter-slice gap of 1 mm.

The data processing was performed using MATLAB 6.5 (The Mathworks, Natick), and SPM2 (Wellcome Department of Cognitive Neurology, UK). A total of 182 functional scans were acquired for each participant. Dummy scans in the first 12 s before the beginning of the experiment were discarded to allow for magnetic saturation. Data pre-processing included the standard procedures of realignment, slice-time correction, normalisation to the SPM2 EPI template, and spatial smoothing (FWHM = 8 mm).

For the statistical analysis at the single participant level, the δ -function of the stimulus onsets for each condition was convolved with the canonical haemodynamic response function (HRF) and its first temporal derivative (HRF') to account for minor latency differences [Friston et al., 1998]. The predictors for the contribution of the HRF' and a constant for global mean activation per participant were included in the model. Specific effects were tested by applying appropriate linear contrasts to the parameter estimates for each condition. For each participant, the contrasts CON > NULL, INC > NULL, CON > INC, INC > CON, HRF'_CON > HRF'_INC, and HRF'_INC > HRF'_CON were calculated. Although the contrast CON > INC and INC > CON reflect amplitude differences in the HRF, the contrasts HRF'_CON > HRF'_INC and HRF'_INC > HRF'_CON reflect differences in the slope of the HRF. These slope differences are indicative of (onset) latency differences when they are observed in concert with (and thus validated by) reaction time differences in the

behavioural data [Ford et al., 2005]. For the group analysis, the individual contrast images were entered into one-sample t -tests as a second level random effects analysis. This allows making inferences about the general population. The resulting F - and t -statistics constitute a statistical parametric map, which was then interpreted by referring to the probabilistic behaviour of Gaussian random fields [Worsley et al., 1996].

Because the determiner congruency effect is supposed to occur due to a delayed selection of the determiner form, which is part of the picture naming process, we analysed differences between gender-congruent and gender-incongruent trials in those brain regions that were involved in the normal picture naming process as revealed by the two baseline contrasts. Therefore, in the first step of the analysis, differential effects were analysed for those parts of the brain that yielded a significant effect ($P < 0.05$ FWE-corrected) in at least one of the two baseline contrasts CON > NULL or INC > NULL. For this purpose, a mask was generated from the two baseline contrasts by thresholding each contrast at the significance level of $P < 0.05$ (FWE-corrected), adding the two thresholded images and identifying all positive voxels in the resulting image. Thus, in this mask image all voxels significantly activated in at least one baseline contrast were included. This mask was then used as the search volume for any differences in amplitude or latency between CON and INC. Consequently, the relative contrasts CON > INC and INC > CON as well as HRF'_CON > HRF'_INC and HRF'_INC > HRF'_CON, which were supposed to reveal the neural correlates underlying the determiner congruency effect, were then masked with this image.

Second, differential effects between congruent and incongruent trials were analysed in the entire brain including regions outside those generically involved in speech production. In contrast to the former analysis, this latter statistics is supposed to reveal the involvement of the brain in processing incongruency in general which is not only related to the selection of the determiner form but may also be found in the processing of conflicting phonological or semantic information (e.g. De Zubizaray et al., 2001, 2002).

Anatomical localization of the fMRI data

For the anatomical localisation of the neural correlates of the determiner congruency effect we used cytoarchitectonic probability maps [Amunts et al., 2004; Schleicher et al., 1999; Zilles et al., 2002]. These maps are based on an observer-independent analysis of the cytoarchitecture in a sample of 10 postmortem brains. They provide information about the location and variability of cortical regions in a standard reference space (the MNI space). For the assignment of coordinates to cytoarchitectonically defined regions, we used the SPM2 Anatomy Toolbox [Eickhoff et al., 2005; available with all published cytoarchitectonic maps from www.fz-juelich.de/ime/spm_anatomy_toolbox].

Figure 3.

Mean speech latencies and standard errors of mean as a function of grammatical gender (masc, masculine; fem, feminine; neut, neuter) and condition. Speech latencies were longer in gender-incongruent as compared with gender-congruent trials.

Speech latencies

The participants' overt speech responses were recorded using the built-in microphone mounted on the head coil. The cable from the microphone to the patient intercom in the MR control room was plugged there into a splitter, from which one cable led to the intercom and one to the line-in port of an external sound card attached to a Toshiba notebook. This notebook was then used for the digital recording of the participants' responses.

The speech latencies were assessed off-line after the fMRI session in a reaction time lab (cf. De Zubicaray et al., 2001, 2002). For this purpose, we re-ran the experiments with each participant's randomisation, with emulated triggers mimicking the triggers sent by the MR scanner. The participant's speech recording was played starting synchronously with the experiment. The line-out port of the laptop used for playing the speech recording was connected with a cable to a voice key, which was part of the ERTS hardware setup in the reaction time lab. The speech latencies were assessed with the voice key. ERTS was programmed such that the voice key was ready only after the offset of the scanner noise, i.e. 3 s after trial onset which was indicated by a trigger.

In two cases, the speech recordings were not suitable for this procedure because the speech signal was not strong enough. Consequently, the speech latencies of these two participants were not analysed.

For the statistical analysis, speech latencies smaller than 300 ms were excluded as outliers. Missing values were replaced separately for each participant by the individual cell mean. The speech latencies were entered in a 2×3 repeated-measures ANOVA with the factors CONGRUENCY (congruent vs. incongruent) and GENDER (masculine vs. feminine vs. neuter).

Head motion

The feasibility of employing speaking aloud in fMRI experiments has been demonstrated earlier (e.g. Barch et al., 1999; Birn et al., 1999; Christoffels et al., 2007; De Zubicaray et al., 2001, 2002; Gracco et al., 2005; Heim et al., 2006a; Palmer et al., 2001; Riecker et al., 2000). Some of these studies explicitly investigated the amount of head motion during overt speech production [Gracco et al., 2005; Heim et al., 2006a]. In both studies, mean head translation was within the range of 1 mm.

To establish the comparability of the present fMRI study to earlier studies, the amount of head motion was assessed. The realignment parameters including translation along the x , y , and z axis and the rotation around these axes (i.e. pitch, roll, and yaw) were extracted from the `rp*.txt` protocol files provided by SPM2. The mean and maximum values were estimated for each single parameter.

RESULTS

Speech Latencies

In the ANOVA, there was a significant main effect of CONGRUENCY ($F_{1,13} = 5.14$; $P < 0.05$). The main effect for GENDER and the interaction term CONGRUENCY $\times$ GENDER were not significant (GENDER: $F_{2,26} = 2.13$; $P > 0.05$; CONGRUENCY $\times$ GENDER: $F_{2,26} < 1$).

The mean speech latencies for each syntactic gender and each congruency condition are displayed in Figure 3.

Figure 4.

Mean and maximum head motion (translation and rotation) parameters along and around the x , y , and z axis.

TABLE I. Local maxima in the contrast CON > NULL, i.e. the baseline contrast for picture naming with gender-congruent distractors

Cluster	Structure	<i>x</i>	<i>y</i>	<i>z</i>	<i>t</i> _{max}
1 (4032 voxels)	L putamen	-32	-14	-6	16.72
	R putamen	26	-4	6	10.12
	L thalamus	-14	-24	2	12.98
	R thalamus	10	-14	0	14.00
	L postcentral gyrus	-54	-2	16	15.21
	L superior temporal gyrus	-60	-8	2	13.09
	L insula	-36	-20	4	12.35
	L rolandic operculum	-50	6	2	10.33
	cerebellum	4	-38	-6	12.20
2 (1803 voxels)	L fusiform gyrus	-30	-60	-10	22.12
	L inferior temporal gyrus	-40	-40	-14	11.70
	L inferior occipital gyrus	-42	-82	-8	16.69
	L middle occipital gyrus	-34	-92	-2	13.06
	L lingual gyrus	-20	-68	-12	11.10
3 (570 voxels)	R lingual gyrus	20	-62	0	12.23
	R fusiform gyrus	22	-48	-12	10.14
4 (468 voxels)	L calcarine gyrus	-16	-66	12	15.95
	R calcarine gyrus	6	-64	16	15.55
	L cuneus	-6	-76	24	9.66
	R cuneus	20	-64	20	8.82
5 (455 voxels)	R supplementary motor area	10	14	58	12.27
	L superior medial gyrus	-6	32	32	11.02
	R middle cingulate cortex	6	28	32	10.49
6 (398 voxels)	L superior parietal lobule	-18	-76	48	12.71
	L middle occipital gyrus	-28	-86	36	11.09
	L superior occipital gyrus	-20	-88	26	10.64
7 (205 voxels)	R superior parietal lobule	28	-52	64	12.60
	R postcentral gyrus	28	-40	64	12.00
8 (187 voxels)	R cerebellum	10	-68	-14	10.63
9 (84 voxels)	R superior occipital gyrus	22	-82	36	10.25
	R cuneus	18	-80	26	9.45
10 (52 voxels)	R paracentral lobule	14	-30	56	10.91
	R supplementary motor area	12	-26	50	10.00
11 (49 voxels)	L insula	-30	26	6	12.16
12 (28 voxels)	L supplementary motor area	-12	2	66	10.46
13 (23 voxels)	R supplementary motor area	10	4	70	8.98
14 (18 voxels)	L precentral gyrus	-42	4	36	8.89
15 (14 voxels)	L inferior frontal gyrus	-62	10	14	10.94
16 (11 voxels)	R inferior frontal gyrus	46	14	14	10.13
17 (10 voxels)	R postcentral gyrus	48	-28	58	9.33

The coordinates (*x*, *y*, *z*) refer to standard MNI space as used in SPM2. L, left; R, right; *t*_{max}, maximum *t* value in the anatomical structure.

Overall, there was an advantage of 15 ms in the gender-congruent condition (mean ± SEM: 626 ± 9 ms) over the gender-incongruent condition (641 ± 12 ms).

Head Motion

The mean and maximum head motion parameters are given in Figure 4. All translations were below 1 mm, and all rotations had values of less than 0.015°.

fMRI Data

Baseline contrasts

In the fMRI data, the baseline contrasts CON > NULL and INC > NULL both revealed significant effects at *P* < 0.05 (FWE-corrected for multiple comparisons, extent

threshold *k* ≥ 10 voxels) in widely distributed brain networks including amongst others BA 44 in the left IFG, the left Rolandic operculum, left insula, left inferior and superior temporal gyri, bilateral fusiform gyri, and the cerebellum (see Tables I and II). Both contrasts largely activated the same brain regions (see Fig. 5).

Determiner-congruency effect in the speech network

Within the part of the brain that was significantly activated in at least one baseline contrast (see Fig. 3) there was no significant difference in the amplitude of the fMRI signal (*P* < 0.001 uncorrected, *k* ≥ 10 voxels) in the contrast INC > CON or CON > INC. Instead, an onset latency difference was observed in the first temporal derivative of the HRF. The derivative was higher in the congruent than in the incongruent condition, indicating a steeper slope

TABLE II. Local maxima in the contrast INC > NULL, i.e. the baseline contrast for picture naming with gender-incongruent distractors

Cluster	Structure	<i>x</i>	<i>y</i>	<i>z</i>	<i>t</i> _{max}
Cluster 1 (4234 voxels)	L thalamus	-12	-22	2	15.16
	R thalamus	10	-12	0	11.93
	L inferior frontal gyrus	-50	4	4	10.05
	L rolandic operculum	-62	-2	4	14.46
	L precentral gyrus	-44	4	38	10.01
	L postcentral gyrus	-54	-2	16	14.37
	L insula	-36	10	8	12.72
	L superior temporal gyrus	-66	-28	12	14.32
	amygdala	-30	-4	-12	10.02
	cerebellar vermis	2	-40	-2	11.72
	L fusiform gyrus	-34	-60	-10	18.20
	L inferior occipital gyrus	-26	-92	-12	14.64
	L middle occipital gyrus	-38	-86	22	10.51
	L superior occipital gyrus	-22	-82	24	10.65
Cluster 2 (2920 voxels)	R superior occipital gyrus	22	-80	38	10.71
	L calcarine gyrus	-14	-68	12	15.75
	R calcarine gyrus	6	-66	16	12.25
	L cuneus	-6	-76	22	12.00
	R cuneus	6	-82	32	11.24
	L superior parietal lobule	-18	-76	48	14.64
	L lingual gyrus	-24	-62	-2	13.69
	R lingual gyrus	10	-86	-4	12.06
	R fusiform gyrus	24	-72	-6	11.88
	R cerebellum	26	-42	-22	8.49
	R supplementary motor area	10	14	58	12.82
	L supplementary motor area	-12	4	68	10.19
	L superior medial gyrus	2	24	38	9.26
	R cerebellum	8	-70	-16	12.02
Cluster 5 (207 voxels)	L cerebellum	-2	-60	2	12.03
Cluster 6 (134 voxels)	R superior parietal lobule	32	-46	60	9.40
Cluster 7 (73 voxels)	R pallidum	22	2	4	10.69
Cluster 8 (56 voxels)	R superior occipital gyrus	28	-88	30	8.98
Cluster 9 (31 voxels)	R middle occipital gyrus	32	-86	30	8.96
Cluster 10 (23 voxels)	L inferior temporal gyrus	-40	-44	-14	10.01
Cluster 11 (22 voxels)	R calcarine gyrus	26	-92	2	9.96
	R middle occipital gyrus	24	-94	4	9.17
Cluster 12 (19 voxels)	L cerebellum	-38	-56	-46	12.41
Cluster 13 (15 voxels)	L inferior frontal gyrus	-40	14	30	9.61
Cluster 14 (11 voxels)	R superior parietal lobule	26	-70	50	9.07

For details cf. the legend of Table I.

and thus a shorter latency of the HRF in the congruent condition. This latency effect was exclusively located in the posterior-inferior part of the left BA 44 (Fig. 6 and Table V).

Effects of incongruency in other parts of the brain

Comparing incongruent vs. congruent trials yielded amplitude differences ($P < 0.001$ uncorrected; $k \geq 10$ voxels) in the left precentral gyrus (PrCG), left middle frontal gyrus (MFG), and right cerebellum (Table III). The reverse contrast was significant only in the right fronto-medial wall in the cingulate sulcus/frontomarginal gyrus (Table IV).

Further differences in the HRF' (CON > INC) were observed in the left inferior parietal lobe in the supramarginal gyrus (SMG), and area OP2 (identified with cytoarchitectonic probability maps; Eickhoff et al., 2006) as part of

the left parietal operculum ($P < 0.001$ uncorrected; $k \geq 10$ voxels; see Table V and Fig. 7). The reverse contrast was not significant.

DISCUSSION

We used fMRI to investigate the neural correlates of the determiner congruency effect in language production reflecting the selection of the form of the determiner. Using overt picture naming in fMRI, we behaviourally replicated the determiner congruency effect [Schiller and Caramazza 2003] that was based on faster speech latencies when pictures were paired with gender-congruent as compared with gender-incongruent written distractor words. In the imaging data, the analysis of the realignment parameters revealed that speaking-induced head motion was

Figure 5.

Activation in the contrasts CON > NULL (red; gender-congruent trials vs. null events), INC > NULL (green; gender-incongruent trials vs. null events), and brain regions significantly activated ($P < 0.05$ FWE corrected) in both contrasts (overlapping effect in yellow). The effects are rendered on the SPM2 single participant template brain. All images follow the neurological convention, i.e. left-hemisphere activation is displayed on the left side of the brain. Abbreviations: L, left; R, right; A, anterior; P, posterior.

very small, with maximum translations below 1 mm, which is in accordance with previously reported data [e.g. Gracco et al., 2005; Heim et al., 2006a] and uncritical for the interpretation of the activation effects. The fMRI data supported our hypothesis that the determiner congruency effect was supported by left BA 44. Most interestingly, the effect was due to a difference in the first temporal derivative of the HRF rather than in the HRF itself between the gender-congruent and the gender-incongruent condition. We found that the HRF had a steeper slope in gender-congruent than in gender-incongruent trials. In other words, the haemodynamic response increased faster when the pic-

ture name and the distractor had the same gender. Such steeper slope may be interpreted as a shorter latency of the HRF [Henson et al., 2002], in particular when it is also reflected in the behavioural data [Ford et al., 2005]. Considering that the cognitive basis of the determiner congruency effect is a delayed retrieval of the determiner form [Schiller and Caramazza, 2003, 2006], one might speculate that the delay for the incongruent condition in fMRI data reflects the longer time interval for the selection of the determiner form. Admittedly, whereas the timing difference in the speech latencies was only in the range of milliseconds, the temporal resolution in fMRI is rather in the range of seconds. Yet, earlier work has shown that the timing of neural responses at a millisecond scale [as identified with event-related brain potentials or magnetoencephalography; cf. Friederici 2002; Levelt et al., 1998] may translate to the scale of seconds in fMRI data [Heim and Friederici 2003; Thierry et al., 1999]. Additional work is required in order to further elucidate the relationship between the timings of behavioural responses, electrophysiological brain responses, and haemodynamic brain responses [for a recent discussion cf. Linden 2007].

The brain activation effects related to the determiner congruency effect within the brain network for speech production were localised in the left BA 44 as indicated by the cytoarchitectonic probability map of this region. Previous neuroimaging studies revealed that left BA 44 supports the retrieval of bound morphemes [Longoni et al., 2005; Marangolo et al., 2006] as well as the access to syntactic properties of nouns [grammatical gender and syntactic category of words: e.g. Heim et al., 2003a] and their phonological forms [e.g. Burton et al., 2000; Heim et al., 2003b]. The literature-based neurocognitive model of language production by Indefrey and Levelt [2004] associated the posterior IFG with syllabification. The present finding adds to these data by showing that the selection of the form of determiners, i.e. the retrieval of freestanding morphemes, is also supported by left BA 44.

However, the available neuroimaging studies suggest a more fine-grained functional segregation of the left BA 44. Whereas the retrieval of bound morphemes and of phonological codes tends to involve the superior portion of BA 44 [e.g. Heim et al., 2003b, 2005; Longoni et al., 2005; Marangolo et al., 2006; Miceli et al., 2002], syntactic processing (e.g. of grammatical gender or syntactic category of words) appears to recruit its inferior portion (e.g. Heim et al., 2003a, 2005; Longoni et al., 2005). Because the determiner congruency effect is taken to reflect the retrieval of the determiner form [Schiller and Caramazza, 2003, 2006], its neural correlates would be expected rather in the superior portion of left BA 44. However, the fMRI effect was observed in the posterior-inferior portion of BA 44 which is more related to syntactic gender processing.

An explanation for this discrepancy might be that the latency effect in the present study reflects gender selection occurring prior to the selection of the determiner form. Although behavioural studies presently provide no sup-

Figure 6.

Latency effect of the fMRI signal in gender-incongruent vs. gender-congruent trials in two local maxima at the border of the left inferior frontal gyrus (IFG) and the left Rolandic operculum (top). The cytoarchitectonic probability map of Brodmann's area (BA) 44 (blue) demonstrates the localisation of the effect in this region (bottom; displayed on four axial slices in ascending order indicated by the corresponding z coordinates). The bar graph in the upper right corner shows the positive differences of the beta estimates of the first temporal derivative of the HRF ($\text{HRF}'_{\text{CON}} > \text{HRF}'_{\text{INC}}$) at the two local maxima in BA 44.

port for this notion, it might be possible that gender selection during target picture naming is also influenced by the gender of the distractor, resulting in increased latency of gender selection in gender-incongruent trials. In the behavioural literature, there is an ongoing discussion about this question [e.g. Schiller and Caramazza, 2003, 2006; Schriefers et al., 2002, 2005]. One counter-argument for the gender selection interpretation is that, if gender-incongruent distractors interfered with gender selection, this effect should be observed when target pictures are named with both singular and plural determiner phrases. Instead, interference from gender-incongruent distractors was only observed for singular but not for plural determiner phrases [Schiller and Caramazza, 2003]. Nonetheless, it could be that aspects of gender selection are also present in plural utterances but are obscured by a general tendency for overall faster responses for plural forms evidenced by faster speech latencies of determiner phrase production for plural target picture names than for singular determiner phrase production. This is possibly due to the fact that in plural determiner phrases the determiners in German all have the same form [i.e. *die*—the_{masc,NOM,PL} = the_{fem,NOM,PL} = the_{neut,NOM,PL}], which facilitates the

Figure 7.

Differences in HRF amplitude between congruent and incongruent trials ($t > 3.73$; $P < 0.001$ uncorrected; $k \geq 10$ voxels). Abbreviations: L, left; R, right; MFG, middle frontal gyrus; PrCG, precentral gyrus.

access to the determiner form (e.g. Schiller and Caramazza, 2003, 2006; Schriefers et al., 2002, 2005). At present, no behavioural data are available to answer the question if the gender of the distractor interferes with *both* the gender selection and the determiner selection when naming pictures with determiner phrases in the singular (but see Vigliocco et al., 2004). The localisation of the latency effect in BA 44 in the present fMRI study could be taken to suggest that the effect reflects syntactic gender selection (supporting the claim of the GSIH) rather than the selection of the determiner form (as claimed in the DSIH). This hypothesis, however, remains to be explicitly tested.

Furthermore, it should be noted that the functional segregation of BA 44 into a superior and an inferior portion, which support phonological or form-related vs. syntactic processing, respectively, is so far only well-established for language comprehension (e.g. Friederici, 2002). A compara-

TABLE III. Local maxima in the contrast INC > CON

Cluster	Structure	x	y	z	$t_{\max}$
Cluster 1 (46 voxels)	L precentral gyrus	-50	-8	46	5.70
Cluster 2 (33 voxels)	R cerebellum	14	-40	-48	5.94
Cluster 3 (23 voxels)	L middle frontal gyrus	-32	36	38	6.23

For details cf. the legend of Table 1.

TABLE IV. Local maxima in the contrast CON > INC

Cluster	Structure	x	y	z	$t_{\max}$
Cluster 1 (26 voxels)	R fronto-median wall	6	56	-4	4.77

For details cf. the legend of Table I.

TABLE V. Local maxima in the first derivative of the HRF (CON > INC)

Cluster	Structure	x	y	z	$t_{\max}$
Cluster 1 (27 voxels)	L inferior frontal gyrus (BA 44)	-50	-8	46	4.89
Cluster 2 (14 voxels)	L supramarginal gyrus	-46	-32	26	4.48
Cluster 3 (10 voxels)	L parietal operculum (Area OP2)	-34	-22	22	5.70

For details cf. the legend of Table I.

ble segregation for phonological or form-related vs. syntactic processing remains to be demonstrated for language production.

Interestingly, the left BA 44 was the only region within the network involved in picture naming that showed a differential effect of determiner congruency. Many of these other regions in this network have been reported in previous neuroimaging studies of word production (for a review of object naming studies cf. Price et al., 2005). Whereas some of them have specific functions in picture naming (e.g. visual object recognition or articulation), none responded differentially in gender-congruent vs. gender-incongruent trials—none except for BA 44. One may therefore deduce the particular importance of BA 44 for the selection of the determiner form within the cortical network for picture naming. This finding is in accordance with previous observations that BA 44 is selectively involved in the production of the definite determiner of a noun during picture naming [Heim et al., 2002] or syntactic gender decisions during language production [Heim et al., 2006b]. It might be suspected that the fact that no other part of the language network responded differently to congruent and incongruent trials was due to the particular experimental design of this study, especially to the slightly longer TR than the usual 2–4 s which may have obliterated subtle differences [Constable and Spencer 2001]. However, it should be noted here that De Zubicaray et al. [2001] obtained reasonable results with the same type of paradigm (overt picture naming with written distractor words) even with a TR of 15 seconds (i.e. 2.5 times the TR

used in the present study), rendering this suspicion rather unlikely.

Outside the network activated in the baseline contrasts for picture naming, amplitude differences were observed in the right fronto-median wall (congruent > incongruent), and in the left PrCG, MFG, and cerebellum (incongruent > congruent). Another latency effect (incongruent > congruent) was observed in the left inferior parietal lobe. As argued above, one might suppose that these brain regions have a more unspecific function related to the processing of “(in)congruency” in general or, similarly, the resolution of conflict. This argument is corroborated by a study investigating incongruent vs. congruent cueing of targets requiring either left or right button presses [Thiel et al., 2004]. Incongruently cued trials elicited higher activation than congruent trials in the left inferior parietal lobe (SMG, IPS, and angular gyrus) and left middle frontal gyrus. The fronto-median wall was activated in another fMRI study employing the picture-word interference task [De Zubicaray et al., 2001]. This finding may suggest that the effect in the fronto-median wall in the present study is related to the paradigm itself or the more general processing of “incongruency” rather than to the selection of the determiner form. The effect could possibly reflect some more general, language-unspecific aspects of conflict processing and cognitive control (see e.g. Johnston et al., 2007; Mitchell et al., 2007; Sohn et al., 2007). A candidate process could be the successful incorporation of contextual information (cf. e.g. Wakusawa et al., 2007) which is stronger in congruent than in incongruent trials.

Future neuroimaging studies may directly and simultaneously investigate the successful processing of conflicting contextual information with different paradigms. For the scope of the present study, it is more important to note that left cytoarchitectonic BA 44 was the only part of a brain network for language production that responded differentially to gender-congruent and gender-incongruent distractor nouns.

CONCLUSION

We demonstrated that in language production determiner selection recruits left BA 44, a part of Broca's speech region. In the present study, and in addition to the previously documented functions of BA 44, we showed that the facilitated retrieval of the form of a determiner, which was indicated by shorter speech latencies for determiner phrases in the gender-congruent condition, goes along with a steeper increase of the haemodynamic response in BA 44. Based on this result, future studies may address the neurofunctional interplay within the volume of cytoarchitectonic BA 44 of the temporally serial processes of syntactic gender retrieval, determiner form encoding, and phonological encoding.

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