

How does the brain accommodate to increased task difficulty in word finding?

A functional MRI study

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In functional imaging of the brain, the difficulty of a task may be critical for the pattern of activation. Increased task difficulty could lead to increased activation in task-specific regions or to activation of additional, “compensatory” regions. A previous study with functional transcranial Doppler sonography (fTCD) showed no evidence that increased difficulty in word retrieval leads to a recruitment of areas homologous to language-related regions. The question remains how the brain accommodates increasing task difficulty.

Because of limitations of fTCD method, we used functional magnetic resonance imaging (fMRI) in this study. We manipulated word retrieval difficulty in healthy subjects ($n = 14$) to determine whether the classical language-related brain regions are activated with increasing difficulty in word retrieval.

fMRI demonstrated that with increased task difficulty

- (I) the lateralization of language-associated brain activation remained constant,
- (II) no additional activation of language-related regions of the dominant hemisphere, nor of homologous regions of the subdominant hemisphere, was evident,
- (III) additional activation was found in right posterior parietal cortex—typically associated with sustained attention and executive control.

Thus, increased difficulty in word retrieval leads to coactivation of distinct brain areas, working together in a large cognitive network, rather than to increased activation of typically language-related areas.

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Introduction

Word retrieval has been examined in numerous functional imaging studies, with healthy subjects as well as with patients (Knecht et al., 1998; Pujol et al., 1999; Silvestrini et al., 1995; Warburton et al., 1999). In a previous study, we investigated normal subjects with functional transcranial Doppler sonography (fTCD) but manipulated word retrieval difficulty to mimic word retrieval problems in dysphasic patients. The question was whether increased task difficulty during word retrieval leads to an increased activation of language-related brain areas or to a recruitment of homologous areas of the subdominant hemisphere. However, none of these regions showed task-related perfusion changes within the territory of the middle cerebral artery (MCA), not in the dominant or in the subdominant hemisphere (Dräger and Knecht, 2002).

The question remains, “how the brain accommodates increased task difficulty?” A number of functional neuroimaging studies support the hypothesis that cognitive functions rely on distributed neural networks that are not restricted to a distinct part of the brain (Desmond et al., 1998; Papathanassiou et al., 2000; Stowe et al., 1998). Therefore, manipulation of task difficulty may lead to activation changes in brain regions that are not classically associated with language. This possibility could not fully be investigated with fTCD because of its low spatial resolution with restriction to the territory of the insonated artery. The technique of functional magnetic resonance imaging (fMRI) allows an assessment of more extended brain activation. The current study thus used fMRI to address the question how the brain accommodates increased task difficulty. We manipulated task difficulty in word retrieval in the same way as in our fTCD study: Healthy subjects ($n = 14$) had to generate as many words as possible that start with the displayed word beginnings. In the easy condition, subjects generated many words, that is, showed good performance. For word beginnings with few possible completions, subjects had to try harder and yet produced fewer words.

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We tested two alternative hypotheses on the relation of increased task difficulty and brain activation: (1) either language-related regions “work harder”, or (2) different or additional “compensatory” regions are involved.

Methods

Subjects

Fourteen subjects (aged 19–31 years, eight men) participated in the study. Subjects’ written informed consent was obtained according to the declaration of Helsinki. All participants were native speakers of German and were raised in Germany. Subjects were right-handed, as assessed by the Edinburgh handedness inventory (Oldfield, 1971). None of the subjects had a history of serious medical, neurological, or psychiatric illness, brain pathology, or abnormal brain morphology on T1-weighted MR images. The subjects’ characteristics are presented in Table 1.

Stimulation material

We manipulated word-finding difficulty in a word retrieval task with healthy subjects, the same way as in our fTCD study (Dräger and Knecht, 2002). Briefly, task difficulty was manipulated through frequency of word beginnings. Word beginnings that constitute a complete word or a prefix in German were excluded. Three material sets, representing different levels of difficulty, contained 20 word beginnings each. The items of the easy condition each consisted of one letter. For the moderate condition, 16 word beginnings consisted of 2, and 4 of 3 letters. In the difficult condition, one word beginning consisted of 1 letter, 5 of 2, and 14 of 3 letters. As the results from the fTCD study show, the number of words produced in the easy, moderate, and difficult condition is indeed different. Performance decreased in a linear fashion from easy to difficult. For the fMRI study, eight word beginnings of each material set were chosen randomly for every subject. Thus, every subject got 24 word beginnings. Word beginnings of all conditions were randomly intermixed. To control

for order effects, two versions with different orders were used. A detailed description of stimulus construction is given in Fig. 1.

Paradigm

The experiment consisted of five conditions: three word retrieval tasks (with different difficulty levels), an overt word production task (to ensure subjects’ cooperation), and a simple word repetition task (as baseline condition).

Word retrieval task

Five seconds after an exclamation mark (to inform subjects that an epoch ended and the next will start soon), presented for 0.5 s on a computer screen, subjects saw a word beginning for 2.5 s. They silently had to find as many words as possible starting with the displayed word beginning. After 15 s, another exclamation mark indicated a new session. To avoid effects of sequence and habituation (Lohmann et al., 2004), word beginnings were presented in a random order, and no word beginning was presented more than once. A total of 24 epochs were run: eight with easy to complete word beginnings, eight with moderate to complete word beginnings, and eight with difficult-to-complete word beginnings. Each epoch lasted 20 s.

Overt word production task

Due to scanner noise and to avoid movement artefacts during scanning, it was not possible to control for subjects’ compliance during retrieval. To give subjects a feeling of being controlled, additional epochs with overt word production (two in each retrieval condition) were interspersed in a pseudorandomized order. Subjects were asked to report aloud the words that they had just silently generated on the actual word retrieval trial. The onset of an overt word production trial was indicated by two exclamation marks, presented 15 s after the relevant word onset of the silent trial. Subjects were given 10 s for overt generation.

Baseline task

As a baseline condition, the German word “RUHE” (silence) was presented eight times instead of a word beginning. Subjects had to silently repeat the word. Each epoch lasted 20 s.

A detailed description of the sequence of conditions is given in Fig. 2.

MRI data acquisition

All MRI data were collected with a Siemens Vision 1.5 T whole-body scanner equipped with a standard head coil. Functional images were acquired using a T2*-weighted gradient echo EPI sequence (TE = 60 ms, TR = 2 s, flip angle = 80°, slice thickness = 5 mm, gap = 1 mm, FOV = 200 mm, in-plane resolution = 3.125 × 3.125 mm). Twenty axial slices were taken, oriented in parallel to the AC–PC line, and covered the whole head. In addition, high-resolution anatomical images were acquired for each subject (TE = 3.88 ms, TR = 1790 ms, flip angle = 30°, matrix = 256 × 256, FOV = 256 mm, 160 sagittal slices, slice thickness = 1 mm).

MRI data analysis

fMRI data were analyzed using SPM99 (Wellcome Department of Cognitive Neurology, London, UK; www.fil.ion.ucl.ac.uk/spm).

Table 1
Subjects’ characteristics

Subject No.	Age (years)	Sex	Handedness ^a
01	27	M	85
02	24	F	75
03	24	M	100
04	28	M	100
05	31	M	100
06	20	F	75
07	25	F	83
08	25	M	100
09	19	F	88
10	20	F	100
11	19	F	56
12	22	M	80
13	29	M	89
14	20	M	88

M = male; F = female.

^a Handedness was assessed by the Edinburgh inventory, ranging from –100 (left handedness) to +100 (right handedness).

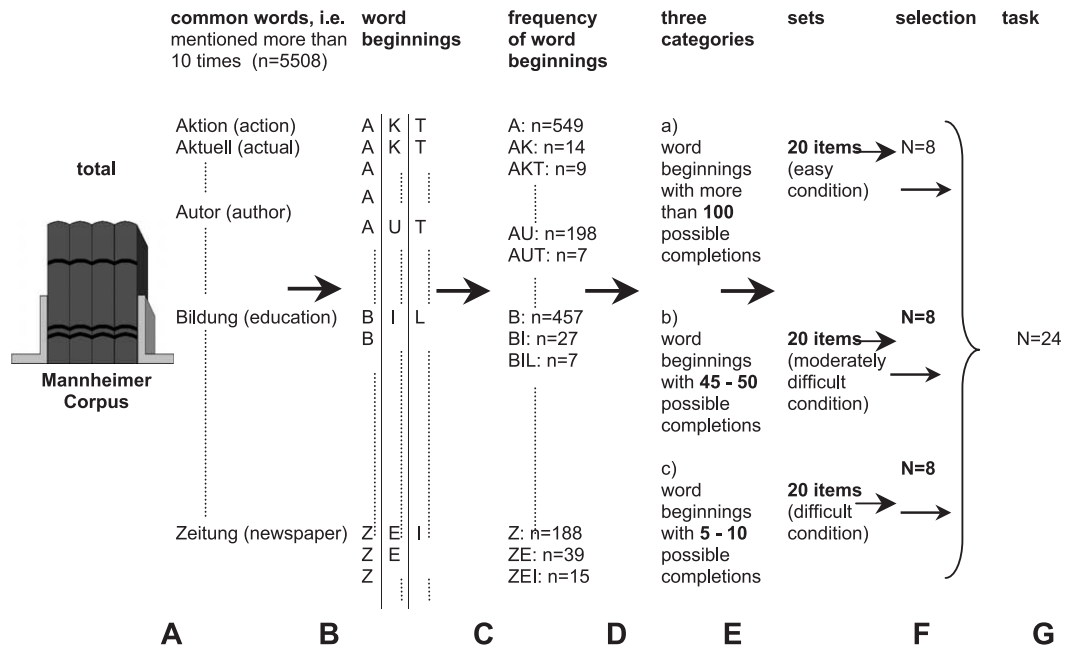


Fig. 1. Construction of stimulation material according to a recent fTCD study (Dräger and Knecht, 2002). In the first step, “common words” were determined by a lemmatized word frequency list based on the German database of the CELEX Corpus (words <1 million; Celex, 1993). All words with a frequency over 10 in the Corpus are considered common words and were included (A). From this list, all word beginnings consisting of one, two, or three letters were taken (B). We then screened how frequently they were a component of the common words (C). Three lists with word beginnings with more than 100 possible completions (easy), word beginnings with 45–50 possible (moderately difficult), and word beginnings with only 5–10 possible completions (difficult) were created (D). For the easy, moderately difficult, and difficult condition, 20 items were selected from each list by randomization (E). For fMRI, eight word beginnings of every set were randomly selected for every subject (F). Thus, every subject received 24 word beginnings in an intermixed order (G).

SPM was used for realignment, normalization, smoothing, and statistical analysis to create statistical parametric maps of significant relative regional BOLD response changes.

We discarded the first five images of each session, during which the MR signal reaches a steady state. The remaining scans of each individual were realigned to the first image (corresponding to the sixth acquired image of the time series) to correct for movement artefacts. Since interpolation was used in the transformation. A mean functional image volume was constructed for each subject from the realigned images. The functional images were normalized to a template brain image created by the Montreal Neurological Institute (MNI) (Evans et al., 1994). The mean image was used to determine the parameters for the spatial normalization process (Friston et al., 1995). The resulting pixel size in standard stereotactic coordinates was $3 \times 3 \text{ mm}^2$, with an interplane distance of 3 mm. The normalized images were smoothed using an isotropic Gaussian kernel (FWHM, 9 mm). This was done (1) to meet the requirements of the Gaussian fields theory assumed by the General Linear Model, employed in SPM99, and (2) to compensate for variations in individual brain anatomy. Treating the volumes as a time series, the data were filtered with a band-pass filter [hemodynamic response function (hrf) as low-pass filter; cut-off period of the high-pass filter was set to 202 s].

The BOLD response for each experimental condition (easy, moderate, and difficult word retrieval task; overt word generation task; baseline task) were modeled using a boxcar function convolved with the canonical hrf employed by SPM99. Statistical analysis was performed in a two-stage, mixed-effects procedure. In a first-level (fixed-effects) analysis, we obtained one statistical parametric map (SPM) and corresponding contrast images for each subject, reflecting the contrasts of interest. These individual

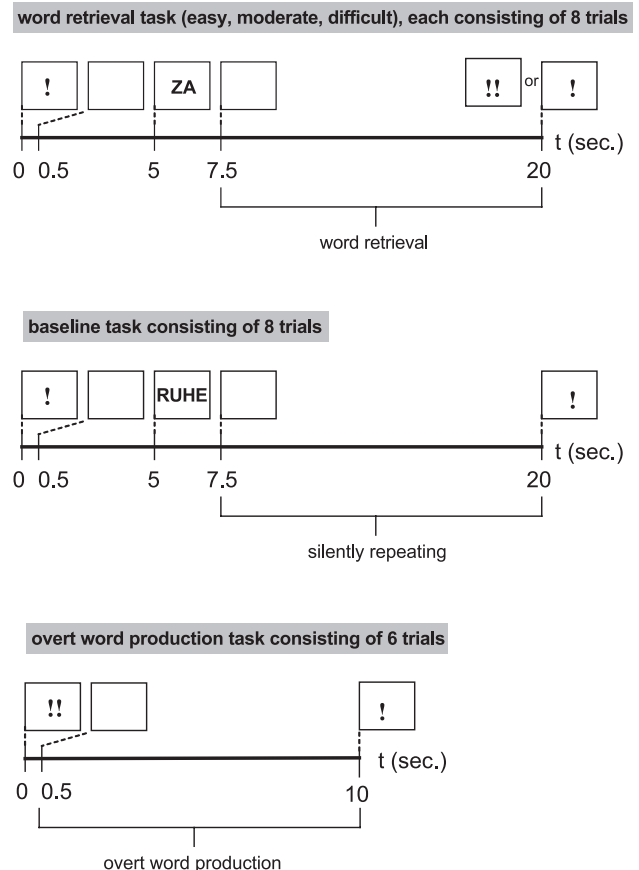


Fig. 2. Sequence of conditions.

contrast images were entered into a second-level (random-effects) analysis using one sample t tests to determine significant activations at a group level. A random-effects model takes into account between-subject variability and allows more generalized inferences from the data than a fixed-effects analysis (Friston et al., 1999a,b). Activations were considered significant at $P = 0.001$ at voxel level, $P < 0.05$ corrected for multiple comparisons at cluster level.

Two contrasts were tested: (1) the main effect of the word retrieval tasks (i.e., word retrieval versus the baseline condition) and (2) differential effects between the three word retrieval difficulty levels.

Localization of activations

Anatomical localizations of activated brain regions were determined by reference to a standard stereotactic atlas (Talairach and Tournoux, 1988), using the T2T applet (<http://neurologie.uni-muenster.de/ger/dienstleistungen/index.html>; Deppe et al., 2003). The Talairach atlas also provides associations between Brodmann areas (BAs) and stereotactic coordinates. Because the MNI template used in SPM99 is different from the Talairach brain, MNI coordinates were first transformed into Talairach coordinates (Brett et al., 2001).

Activation of the subdominant hemisphere

In the fTCD study we did not find any task-related perfusion changes within the territory of the MCAs (Dräger and Knecht, 2002). The main activation centers relevant for word retrieval (see Brain regions associated with word retrieval section) that are within the vascular territories of the MCAs are Broca's area and its right-sided homologue. Thus, the results of the fTCD study demonstrated no greater involvement of Broca's homologue, as compared to Broca's area, with increasing task difficulty.

The current fMRI data showed a similar pattern in the group-level analysis: no significant task-modulated changes in Broca's area or its homologue (see Brain regions associated with changes in task difficulty section). In addition, we calculated an index of laterality (LI) to assess the relative activation of Broca's area and its homologue on an individual level. This approach is considered more sensitive to activation differences in this specific region than the group analysis because there is no need to correct for multiple testings.

LI describes the hemispheric distribution of activated brain regions during the language tasks and was calculated using the following formula:

$$LI = \frac{A_L - A_R}{A_L + A_R}.$$

A_L and A_R refer to measures of fMRI-measured activity for equal regions of interest (ROI) within the left (L) and right (R) hemispheres. A positive value of LI represents left hemispheric dominance; a negative value represents right hemispheric dominance.

There are some possibilities how to create a suitable ROI (Adcock et al., 2003; Jansen et al., 2004). In the present study, we used a functional definition by computing the group random-effect analysis for the contrast "word retrieval tasks – baseline task" (at $P_{\text{voxel}} = 0.001$ and $P_{\text{cluster}} < 0.05$, corrected for multiple comparisons) and choosing the activation cluster corresponding

to the left frontal language region. This region comprised areas surrounding the inferior frontal gyrus, including classical Broca's area. A corresponding right hemispheric ROI was generated by reflecting the left-hemispheric ROI through the midline.

It is still a matter of considerable debate how to describe brain activity within the ROIs (Jansen et al., 2004). Typically, two approaches have been taken in fMRI studies. The first is to measure brain activity based on the extent of the activated brain region, that is, the number of active voxels in a predefined region of interest at a chosen statistical threshold (Desmond et al., 1995; Binder, 1997; Deppe et al., 2000). The second is to measure the magnitude of the fMRI signal change within a region of interest (Adcock et al., 2003; Cohen and DuBois, 1999). For the present study, we chose to calculate A_L and A_R by the volume of significantly activated brain above the statistical threshold ($P_{\text{voxel}} = 0.001$). We did not correct for multiple comparisons at cluster level because this would have resulted in most subjects in left hemispheric brain activation only.

To test if increased word retrieval difficulty results in increased bilaterality, an ANOVA with a trend analysis on the repeated factor difficulty was used. Dependent variables were the lateralization indices as assessed by fMRI for each of the conditions.

Results

Brain regions associated with word retrieval

In a first step, we determined those brain regions that were activated during word retrieval. The activation pattern associated with the word retrieval tasks, relative to the baseline task, is displayed in Fig. 3 (random-effects analysis, $P = 0.001$ at voxel level, $P < 0.05$ at cluster level, corrected for multiple comparisons). An anatomical localization of activated brain regions is given in Table 2.

Brain regions associated with changes in task difficulty

In a second step, we determined those brain regions that were modulated by task difficulty. We performed random-effects analyses to assess differences in brain activation patterns between the three experimental conditions [easy (E), moderate (M), difficult (D)]. We report all activations that survived a statistical threshold of $P = 0.001$ at voxel level, $P < 0.05$ at cluster level, corrected for multiple comparison.

There were no significant activations associated with decreased task difficulty, neither for the easy compared to the moderate condition ($E > M$) nor for the easy compared to the difficult condition ($E > D$) or the moderate compared to the difficult condition ($M > D$).

However, we did find significant differences associated with increased task difficulty. Differences in the amount of activation between the difficult and the easy condition ($D > E$) are shown in Fig. 4. An anatomical localization is given in Table 3.

No significant activation differences were found either between the difficult and moderate ($D > M$) or the moderate and easy ($M > E$) condition. However, at a more liberal statistical threshold ($P = 0.01$ at voxel level), we observed a similar activation pattern for the ($M > E$) contrast as compared to the ($D > E$) contrast [right

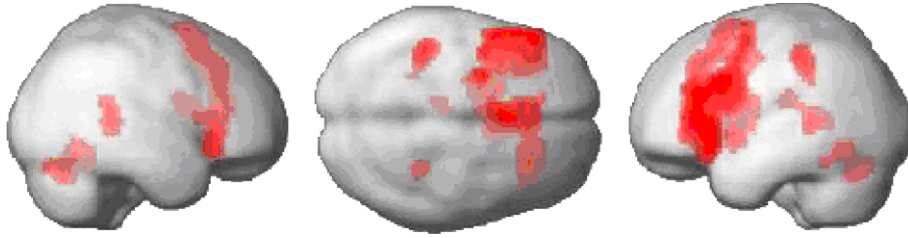


Fig. 3. Activated brain regions associated with the word retrieval, relative to the baseline (random-effects analysis, $P = 0.001$ at voxel level, $P < 0.05$ at cluster level, corrected for multiple comparisons). For an anatomical localization, see Table 2. Activated areas are rendered on the surface of the standard SPM99-template.

hemispheric activation in BA 7 (superior parietal lobule, precuneus); bilateral activation in BA 18 (cuneus)].

Degree of language lateralization

Fig. 5 displays the lateralization indices for all subjects in the three conditions. Analysis of variance with repeated factor “difficulty” yielded no significant effect. Thus, there is no evidence for increased or decreased bilaterality in any condition.

Discussion

An increase in word retrieval difficulty did not lead to an increase in activation of brain regions typically associated with language. Instead, we found an activation of right hemispheric parietal regions. Since these regions are typically associated with attention and executive control, we suggest that increased difficulty in word retrieval leads to an involvement of brain areas associated with additional cognitive functions, but not specifically with language.

Methodological considerations

Paradigm

A word generation paradigm was chosen because it allows for controlled modulation of task difficulty without changing task complexity and task strategies. With the covert word generation task used, it was not possible to assess subjects’ actual performance. However, the fTCD study showed that performance decreased in a linear fashion from the easy to the difficult condition (Dräger and Knecht, 2002). This dependence was assumed for the present study as well.

Subjects

Data on language lateralization in large cohorts show a wide and continuous spectrum of language lateralization in healthy subjects (Frost et al., 1999; Knecht et al., 2000; Pujol et al., 1999; Springer et al., 1999). For the present study, right-handed subjects were recruited to prevent too much heterogeneity in language lateralization. Subjects with right-hemisphere language dominance would have been excluded from further analysis. However, none of the subjects had an atypical language representation.

Table 2
Activated brain regions during word beginning retrieval

Cluster number	Cluster size	Hemisphere	Region of activation	Brodmann area	MNI coordinates			<i>T</i> value
					<i>x</i>	<i>y</i>	<i>z</i>	
1a	1095	left	inferior frontal gyrus	45, 47	−45	21	6	17.74
			middle frontal gyrus	6, 8, 9	−36	21	0	12.24
					−45	12	30	8.14
1b	73	left	middle frontal gyrus		−27	−3	54	6.59
					−27	0	66	5.52
					−24	−3	45	5.08
2	516	left/right	medial frontal gyrus	6	0	15	51	11.15
			cingulate gyrus	32	−6	27	39	9.71
					27	27	9	8.20
3	77	left	inferior parietal lobule	40	−39	−39	42	5.94
					−36	−42	30	5.31
4a	358	left	nucleus lentiformis		−21	6	18	7.20
4b		right	caudatus		−18	3	−6	6.54
					3	12	12	6.10
5	60	right	caudatus		33	−42	12	5.66
6	95	left	caudatus		−30	−42	6	5.96
					−9	−30	15	5.58
					−15	−39	12	5.03
7	257	right	cerebellum		0	−69	−30	7.04
					6	−66	−21	5.80
					6	−54	−12	5.65

Anatomical localization of activated brain regions associated with word retrieval, relative to the baseline (random-effects analysis, $P = 0.001$ at voxel level, $P < 0.05$ at cluster level, corrected for multiple comparisons).

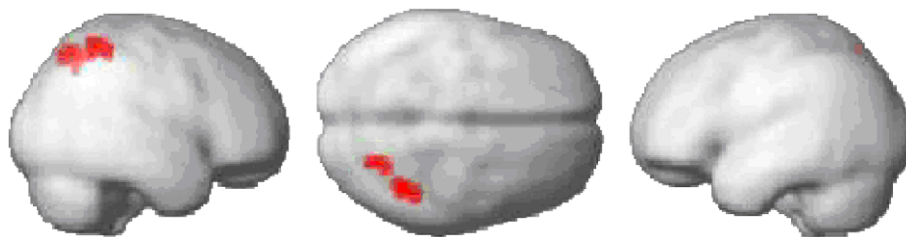


Fig. 4. Activated brain regions for increased task difficulty associated with word retrieval during the difficult compared to the easy condition (random-effects analysis, $P = 0.001$ at voxel level, $P < 0.05$ at cluster level corrected for multiple comparisons). Activations are rendered on the surface of the standard SPM99-template.

A comparison between fTCD and fMRI

We showed in the fTCD study that difficult-to-perform word searches do not lead to an additional involvement of language-related regions of the subdominant hemisphere (Dräger and Knecht, 2002). FTCD can assess changes in language-related areas. However, it is restricted to the vascular territory of the MCAs, which supplies the major language areas of both hemispheres (Van der Zwan et al., 1993). The findings of the fTCD study are replicated here. No differences in degree of language lateralization could be detected in the main activation centers within the territory of the MCA, that is, in Broca and its homologue.

Implications

Activation patterns during all conditions

Word generation in all verbal conditions led to an activation of brain regions typically related to language: unilateral activation of the middle and inferior frontal gyrus, including Broca's area as well as the premotor cortex. Bilateral activation was evident in parts of the medial frontal gyrus or cingulate gyrus. Additional activation was seen bilaterally in the caudatus, the left inferior parietal lobule and the right cerebellum (Table 2, Fig. 2). This pattern corresponds to what has been described by others using word generation tasks (Buckner et al., 1995; Fiebach et al., 2002; Fu et al., 2002; Knecht et al., 2003; Lurito et al., 2000; Menard et al., 1996; Pujol et al., 1999; Schlosser et al., 1998).

Effects of task difficulty

The random-effects analysis did not detect any changes of activation in brain regions classically related to language. In addition, the lateralization of brain activation within Broca's area and its homologue remained constant with increasing task difficulty. These fMRI results are in accordance with the data collected in our fTCD study. Difficult-to-perform word searches did not lead to recruitment of language homologue areas of the subdominant hemisphere. Rather, our results suggest that any type

of word search—be it easy or difficult—engages the same neural language network.

This is contradictory to other studies that manipulate difficulty of language tasks. For example, Just et al. (1996) showed that increasing sentence complexity brings about right-hemisphere activation in areas homologue to classical language areas. In addition, St George et al. (1999) found that reading paragraphs without contextual information from titles leads to an increased right temporal lobe activation.

In these studies, difficulty was mediated—different to our task—by increasing task complexity. This may lead to changes in cognitive strategies, increases in task ambiguity, and consequently an activation of additional neural resources. In the present study, however, we manipulated task difficulty by lowering the number of possible completions to a given word beginning. This seems to allow manipulation of task difficulty without a change in task complexity.

We observed additional activation of right-sided parietal areas (BA 7/40) with increased task difficulty. It is not possible to decide about the exact functional role solely from functional imaging data (Price and Friston, 2002).

Some authors argue that an increase in activation of right hemispheric parietal sites might reflect an increased involvement of right hemispheric language processing (Faure and Blanc-Garin, 1994; Querne et al., 2000). This seems unlikely to apply in our case. Additional recruitment of language regions is more likely to occur within classical language regions. For example, studies that manipulated the complexity of language tasks report activation of additional neural resources within areas homologous to classical language regions (Just et al., 1996; St George et al., 1999). An activation of parietal regions was described in studies involving recovering aphasics, but in the left hemisphere, close to the cerebral infarction (Warburton et al., 1999). Thus, if additional parietal language resources were active in the difficult-to-find word condition, we would expect them to be predominantly near the classical language regions on the left side. A study on acquisition of grammatical rules with visual representation of sentences also

Table 3
Activation associated with increased task difficulty

Cluster size	Hemisphere	Region of activation	Brodmann area	MNI coordinates			T value
				x	y	z	
36	right	superior parietal lobule	7	27	−63	54	5.9
		precuneus		27	−72	51	4.57
38	right	inferior parietal lobule	40	42	−51	60	5.79
		postcentral gyrus		45	−39	57	4.84

Anatomical localization of activated brain regions during the difficult compared to the easy condition (random-effects analysis, $P = 0.001$ at voxel level, $P < 0.05$ at cluster level, corrected for multiple comparisons).

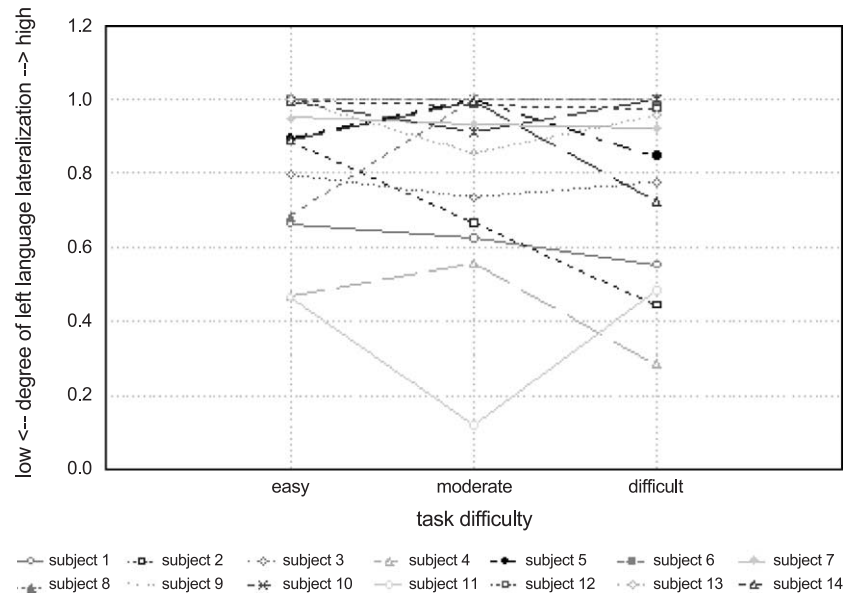


Fig. 5. Differences in the language LIs as assessed by fMRI, as a function of task difficulty, in 14 subjects.

noted right parietal lobe activation (Tettamanti et al., 2002). It can only be speculated that due to the nature of the task, the visual spatial slave system was activated and that difficult word stems require longer representation of the visuospatial sketchpad.

The absence of additional activation of left parietal and prefrontal cortices during the difficult-to-perform word searches suggests that the verbal material used may not have required the phonological loop to a greater extent than during the easy to perform word searches (Baddeley et al., 1999; Jonides et al., 1998; Logie et al., 2003).

We propose following interpretation of the parietal activation: More difficult-to-perform word searches require more sustained attention, working memory, executive response selection, and control. The left hemispheric language systems may be overtaxed by difficult word retrieval. This results in an increase in right hemispheric activation associated with systems more independent of language, namely attention and executive control.

Compatible with this, the right parietal cortex is believed to play a major role in control for selective attention (Pugh et al., 1996). For word-identification tasks, an activation of parietal regions was shown in response to increased demands on different aspects of attentional control (Shaywitz et al., 2001). Processing effort in categorical relations was associated with activation of the right precuneus (Kotz et al., 2002). In addition, a role in maintenance of timekeeping operations in working memory was described for right hemispheric parietal regions (Harrington and Haaland, 1999; Harrington et al., 1998).

Bilateral activation of Brodmann areas 7 and 40 was shown for increased executive control in a random number generation task (Daniels et al., 2003). These areas are also differentially activated during Luria's bimanual movement tasks according to the space-time plan (Fink et al., 1999). It is remarkable that different extents of activation of BA 7 and BA 40 could be observed in moderate and in difficult word searches. It could be that the parietal lobe monitors the performance-time relationship according to a higher output in the easier and to a lower output in the more difficult condition.

Thus, in sum, our results suggest that increasing task difficulty is met by the involvement of additional nonclassical language regions.

Implications for imaging aphasics during recovery

Right hemispheric activation has frequently been observed in patients performing a language task. It is still a matter of debate, whether this might only reflect increased processing demands or might be a result of compensatory changes in neuronal architecture (Heiss et al., 1997; Price and Friston, 1999; Silvestrini et al., 1993; Thulborn et al., 1999; Weiller et al., 1993).

One of multiple deficits in aphasics is word retrieval. In the present study, we increased the word retrieval difficulty to mimic word retrieval problems in dysphasic patients. Thus, the difficult word retrieval condition, in which word production is aggravated for normal subjects, may resemble one deficit in aphasics (Huber et al., 1984). The present study cannot provide direct evidence for the relevance of right hemispheric activation in recovering aphasics. The task in the present study is targeted only for a specific category of word retrieval and can therefore not be generalized. Nevertheless, it supports the view that the activation of right hemispheric language homologous regions during word retrieval in aphasia may not simply result from an overall increase in processing effort. Whether easy or difficult, a netwide activation of the language network is enacted. Activation of homologous regions following stroke may therefore reflect a functionally relevant reorganization of the language system.

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