

Two Distinct Neural Networks Support the Mapping of Meaning to a Novel Word

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Abstract: Children can learn the meaning of a new word from context during normal reading or listening, without any explicit instruction. It is unclear how such meaning acquisition is supported and achieved in human brain. In this functional magnetic resonance imaging (fMRI) study we investigated neural networks supporting word learning with a functional connectivity approach. Participants were exposed to a new word presented in two successive sentences and needed to derive the meaning of the new word. We observed two neural networks involved in mapping the meaning to the new word. One network connected the left inferior frontal gyrus (LIFG) with the middle frontal gyrus (MFG), medial superior frontal gyrus, caudate nucleus, thalamus, and inferior parietal lobule. The other network connected the left middle temporal gyrus (LMTG) with the MFG, anterior and posterior cingulate cortex. The LIFG network showed stronger interregional interactions for new than real words, whereas the LMTG network showed similar connectivity patterns for new and real words. We proposed that these two networks support different functions during word learning. The LIFG network appears to select the most appropriate meaning from competing candidates and to map the selected meaning onto the new word. The LMTG network may be recruited to integrate the word into sentential context, regardless of whether the word is real or new. The LIFG and the LMTG networks share a common node, the MFG, suggesting that these two networks communicate in working memory. *Hum Brain Mapp* 32:1081–1090, 2011. © 2010 Wiley-Liss, Inc.

Key words: meaning acquisition; frontal cortex; basal ganglia; thalamus; fMRI; functional connectivity

Additional Supporting Information may be found in the online version of this article.

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INTRODUCTION

To acquire the meaning of a novel word, learners need to establish an arbitrary correspondence between a concept and the particular sign or sound. Children can learn as many as 3,000 words every year between the age of 8 and 17 years but only a small proportion of this growth (about 200–300 words per year) is due to formal vocabulary instruction [Nagy and Anderson, 1984]. Most of these words must be learned from context during normal reading and listening [Nagy et al., 1987]. However, it is still unclear how this process is supported and achieved in the human brain.

Recent studies have used the human simulation paradigm [Gillette et al., 1999; Mestres-Missé et al., 2007] to mimic contextual word learning processes. In this paradigm participants are exposed to a novel word that appears in successive sentences with increasing contextual constraint, and they can thus derive the meaning of the hidden word. For example,

Sentence 1: She likes people with nice and clean *tankies*

Sentence 2: After the meals you should brush your *tankies*.

Hidden word: teeth

A first fMRI study revealed a distributed set of brain areas as being modulated by the meaning acquisition process comprising the left inferior frontal gyrus (LIFG, BA 45), the left middle temporal gyrus (LMTG, BA 21), the parahippocampal gyrus, and subcortical structures (thalamus and striatum) [Mestres-Missé et al., 2008]. Subsequent studies contrasted the acquisition of abstract and concrete nouns [Mestres-Missé et al., 2009] and verbs and nouns [Mestres-Missé et al., 2010] and again identified the LIFG and LMTG as major hubs in the process of mapping a meaning onto a novel word.

These activation patterns were obtained by contrasting sentences ending in a novel word with sentences ending in a real word as well as by contrasting the first and the second exposures to a novel word. The question arises how the different brain areas work together. We therefore subjected the data obtained by Mestres-Missé et al. [2009, 2010] to a functional connectivity analysis using the two most prominently activated brain areas (LIFG and LMTG) as seed regions. Specifically, we applied the “ β series correlation” method proposed by Rissman et al. [2004]. This method is implemented on the basis of a general linear model, using separate covariates to model hemodynamic responses of a particular stage in each single trial and giving rise to series of parameter estimates (β values) for the stage. If two regions are functionally connected within a network, their β series should be strongly correlated.

A brain network was considered to be involved in mapping a meaning onto a novel word, if the connectivity in this network was stronger for the presentation of new

words than for the presentation of real words. Moreover, a stronger connectivity pattern for the first presentation of a novel word, i.e. when the sentential context might license more than one possible word, than for the second presentation would further support a role of the network in the meaning mapping process.

METHODS

fMRI data used for the functional connectivity analysis were acquired by Mestres-Missé et al. [2010] in 21 healthy participants (11 women, mean age 24 ± 1.8 years). A second data set using a similar paradigm was also subjected to the connectivity analysis and is reported as Supporting Information (univariate analyses reported in Mestres-Missé et al. [2009]).

Stimuli and Task

Participants read pairs of sentences in each functional run and completed a forced-choice task and a recognition task after each run. There were two conditions, each comprising 80 pairs of sentences. In the experimental condition, the two sentences ended with the same new word. Participants had to discover the meaning of the hidden word (see example, given in the Introduction section). In the control condition, the two sentences ended with the same real word. Participants were asked to think about a semantically related word of the terminal word. Half of the new and the real words were nouns (Nn for new nouns and Rn for real nouns) and the other half were verbs. In the present study we focus on nouns, as the mapping of noun concepts and the mapping of verb concepts have been shown to recruit different brain areas [Mestres-Missé et al., 2010]. The contextual constraint was increased from the first Nn sentence (low constraint) to the second Nn sentence (high constraint). Thus, it is more likely to derive an appropriate meaning after the second presentation of a novel word (for details of the stimulus construction, see the Supporting Information).

Each trial began with a fixation period of 500 ms. The stem of the first sentence (all words except the terminal word) was then displayed centrally for 2,000 ms. After a variable interval of 1,000 to 2,000 ms, the terminal word was displayed for 500 ms. The second sentence was presented in the same fashion after another variable interval of 1,000 to 6,000 ms. Following each functional run, a forced-choice task was carried out to test whether participants assigned correct meanings to the new words [Mestres-Missé et al., 2010].

Data Analysis

Data were collected on a 3T Siemens Trio system. Functional images were acquired using a T2*-weighted echo planar imaging (EPI) sequence, with 2,000-ms time repetition, 30-ms time echo, and 80° flip angle, in eight runs.

Each functional image consisted of 32 transversal slices, with 64×64 matrix, 224×224 mm field of view, 4-mm thickness, no gap, and 3.5×3.5 mm inplane resolution.

Data were analyzed with SPM5 (available at: <http://www.fil.ion.ucl.ac.uk/spm>). The first four volumes were discarded owing to equilibration effects. Functional images were first phase-shifted with reference to the first slice to correct differences in slice acquisition time. They were then realigned with a least squares approach and a rigid body spatial transformation to remove movement artifacts. Realigned images were normalized to the EPI-derived MNI template (ICBM 152, Montreal Neurological Institute) and resampled to $4 \times 4 \times 4$ mm³ voxel size. Normalized images were finally smoothed with a Gaussian kernel of 8 mm full-width half-maximum and filtered with a high-pass filter of 128 seconds.

The functional connectivity analysis was performed to examine neural networks supporting the mapping of meaning onto a novel word. This approach is based on the hypothesis that if two regions interact within a network, their activity patterns should be strongly correlated [Rissman et al., 2004]. This analysis was implemented on the basis of a general linear model by using separate covariates to model hemodynamic responses of each terminal word in each single sentence. Estimated movement parameters (six per image: x , y , z , pitch, roll, and yaw) were included in the model to minimize signal-correlated motion effect. For each participant, estimated β values were extracted to form a set of condition-specific β series. Two seeds were defined as spheres with 4-mm radius: one in the LIFG (coordinates in MNI: $-44, 20, 20$) and the other in the LMTG ($-64, -40, -4$). The coordinates were taken from the activation peaks observed in Mestres-Missé et al. [2010]. For each seed, the β series were averaged across voxels within the critical region and correlated with beta series of every other voxel in the whole brain. We first calculated maps of correlation coefficients separately for Nn and Rn but across the word in the first sentence and that in the second sentence to examine what regions are functionally connected with the LIFG or the MTG during the mapping of meaning. The correlation maps were normalized by using an arc-hyperbolic tangent transform on the subject level. To show interregional interactions for Nn and for Rn, we entered the correlation maps into one-sample t tests on the group level and considered resulting maps at $P < 0.0005$ (family-wise error correction, FWE-corrected) with a minimum cluster size of 100 voxels. To show interregional interaction stronger for Nn than Rn, we entered the correlation maps into paired-sample t tests ($Nn > Rn$) and considered differences at $P < 0.05$ (uncorrected) with a minimum cluster size of 5 voxels. Then we calculated correlation maps separately for the new noun in the first sentence (1Nn) and that in the second sentence (2Nn) to examine how the LIFG and the LMTG networks change during the exploration of new words. The correlation maps were normalized by using an arc-hyperbolic tangent transform on the subject level. To show interre-

gional interactions for 1Nn and for 2Nn, we entered the correlation maps into one-sample t tests on the group level and considered resulting maps at $P < 0.0005$ (FWE-corrected) with a minimum cluster size of 100 voxels. To show interregional interaction stronger for 1Nn than 2Nn, we entered the correlation maps into paired-sample t tests ($1Nn > 2Nn$) and considered differences at $P < 0.05$ (uncorrected) with a minimum cluster size of 5 voxels.

RESULTS

Behavioral results indicated that participants assigned appropriate meanings to the new words and did pay attention to the real words in sentences (for details, see Mestres-Missé et al. [2010]).

Figure 1 shows regions interacting with the LIFG and/or the LMTG during the mapping of meaning. Remarkably, the functional connectivity analysis revealed two distinct neural networks. The LIFG network showed significant differences between the new and the real nouns (Fig. 1A). For Nn, the LIFG strongly interacted with the medial superior frontal gyrus/supplementary motor area (mSFG/SMA), the bilateral middle frontal gyrus (MFG), the left inferior parietal lobule (IPL), the caudate nucleus, and the medial thalamus. Among these areas, only the caudate nucleus and the medial thalamus were connected with the LIFG for Rn. The LIFG connections were significantly stronger for Nn than Rn in the mSFG, the bilateral MFG, the left IPL, the caudate nucleus, and the medial thalamus (also see Table I). By contrast, the LMTG network showed similar patterns for the new and the real nouns (Fig. 1B). For both Nn and Rn, the LMTG interacted with the SMA, the anterior cingulate cortex (ACC), the middle/posterior cingulate cortex (MCC/PCC), the bilateral MFG, the bilateral IPL, the precuneus, and the left thalamus. The LMTG connection was not significantly different between Nn and Rn in these areas except the left precuneus and the right IPL (also see Table I). This pattern was replicated with data from another experiment [Mestres-Missé et al., 2009] using a similar design but different materials and participants (Supp. Info., Fig. S2).

Figure 2 shows the patterns of the LIFG and the LMTG networks changed from the first to the second presentation of a new word. For 1Nn, the LIFG strongly interacted with the mSFG/SMA, the bilateral MFG, the right IPL, the caudate nucleus, and the medial thalamus. Although the LIFG interacted with the same areas for 2Nn, the LIFG connections were significantly weakened from 1Nn to 2Nn in the SMA/MCC, the right MFG, and the caudate nucleus (Fig. 2A and Table II). For 1Nn, the LMTG interacted with the SMA, the MCC/PCC, the bilateral MFG, the bilateral IPL, the precuneus, the caudate nucleus, and the thalamus. Among these areas, only the left MFG and the precuneus were connected with the LMTG for 2Nn. The LMTG connections were significantly weakened from 1Nn to 2Nn in

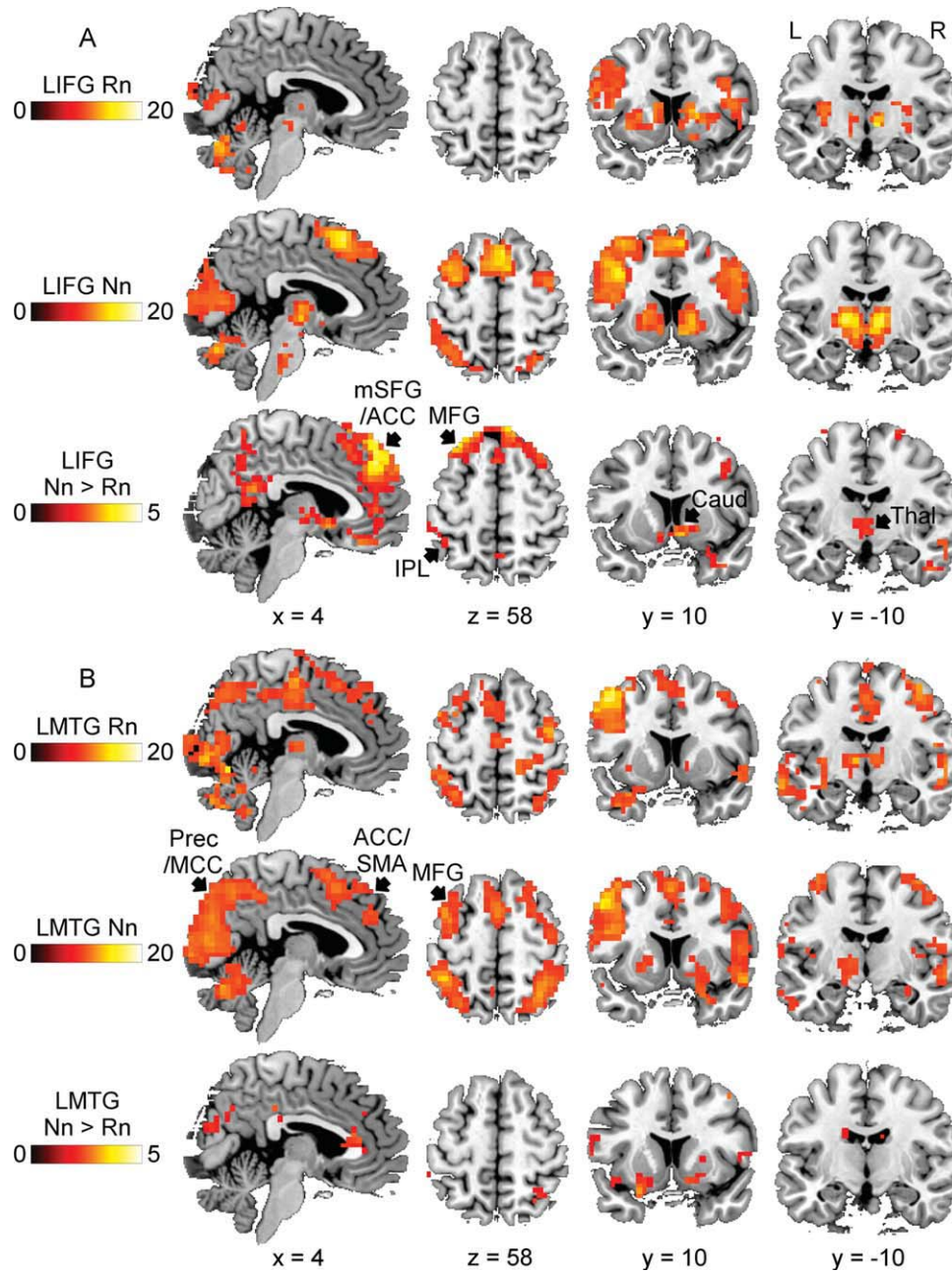


Figure 1.

Interregional interactions for the new noun (Nn) and for the real noun (Rn). **A**, Regions functionally connected with the LIFG for Rn and for Nn, and LIFG connections stronger for Nn than Rn ($Nn > Rn$). **B**, Regions functionally connected with the LMTG for Rn and for Nn, and LMTG connections stronger for Nn than Rn ($Nn > Rn$). mSFG, medial superior frontal gyrus;

SMA, supplementary motor area; ACC, anterior cingulate cortex; MCC, middle cingulate cortex; MFG, middle frontal gyrus; IPL, inferior parietal lobule; Prec, precuneus; Caud, caudate nucleus; Thal, thalamus; L, left; R, right. Coordinates in MNI. Color scales indicate *t* values.

TABLE I. LIFG connections and LMTG connections stronger for Nn than Rn

Region	BA	H	x	y	z	t	Size
LIFG connections							
Medial superior frontal gyrus	9	L/R	8	44	56	4.53	399
Middle frontal gyrus	9/8	L	-36	28	56	2.99	81
		R	24	28	56	2.85	70
Inferior frontal gyrus	45	L	-52	20	20	2.46	19
	47	R	40	32	-12	3.43	88
Inferior parietal lobule	40	L	-52	-32	56	2.30	12
Precuneus	30	R	4	-48	20	2.90	163
Middle occipital gyrus/angular gyrus	19/39	L	-44	-72	36	2.30	11
		R	40	-76	32	3.07	121
Inferior temporal gyrus	20	L	-44	-4	-24	2.18	20
		R	40	4	-36	2.63	26
Fusiform gyrus	37	L	-28	-44	-16	2.66	11
		R	44	-16	-32	2.79	42
Caudate nucleus		L/R	8	8	-8	3.27	20
Thalamus		L/R	0	-4	4	2.89	8
LMTG connections							
Superior frontal gyrus	8	R	20	32	56	2.34	18
Inferior frontal gyrus (orbital)	47	L	-56	24	-4	3.71	382
		R	44	16	-20	3.63	148
Superior parietal lobule	7	R	28	-60	60	2.24	24
Inferior parietal lobule	40	R	52	-56	52	2.33	10
Precuneus	30	L	-12	-56	16	3.32	103
Angular gyrus	39	L	-48	-72	24	2.68	26
Inferior occipital gyrus	18	L	-28	-84	-16	3.24	12
Fusiform gyrus	37	L	-28	-36	-16	2.42	20

BA, Brodmann Area; H, hemisphere; L, left; R, right; coordinates in MNI; *t*, statistic values; size in number of voxels.

the SMA, the right MFG, and the caudate nucleus (Fig. 2B and Table II).

DISCUSSION

With the connectivity approach, we observed two neural networks during the mapping of meaning. One network connected the LIFG with the mSFG/SMA, MFG, IPL, caudate nucleus, and medial thalamus. The other network connected the LMTG with MFG, ACC, and PCC. The LIFG network showed stronger interregional interactions for the new than the real words, whereas the LMTG network showed similar connectivity patterns for the new and the real words. These two networks therefore appear to support different functions during our simulated word learning task and, by extension, in natural word learning. A new word in a sentence with low contextual constraint (as in the 1Nn condition) may activate a large set of candidate concepts. Further semantic constraints imposed by the second sentence allow to home in on the most appropriate meaning and to map the novel word to an existing concept. The connectivity dynamics of the LIFG network fit with this, as connectivity was much stronger for the first exposure of the new word than for the second exposure. Also, the LIFG network did not show up when connectivity was analyzed for real words. Here, no mapping

of meaning has to take place because the concept-word correspondence has been firmly established in semantic memory and it is unnecessary to select a meaning from competing alternatives. We therefore propose that the LIFG network is supporting the actual mapping process. By contrast, the LMTG network showed very different connectivity dynamics as it was similarly recruited for new and real words. Regardless of whether the sentence terminal stimulus was a word or a new word, it has to be integrated into the sentential context. We therefore suggest that the LMTG network is related to semantic integration during sentence reading. It is noteworthy that both, LIFG and LMTG networks share a common node, i.e. the MFG. This structure has been identified with working memory processes [e.g., McCarthy et al., 1994, 1996; Tsukiura et al., 2001] suggesting that LIFG and LMTG networks contribute information to a common workspace in working memory (see illustration in Fig. 3).

LIFG Network

Within the LIFG network, the LIFG (especially pars triangularis, BA45) has been associated to control semantic retrieval and/or selection processes which operate on simultaneously activated representations to bias toward one particular lexical item during word comprehension

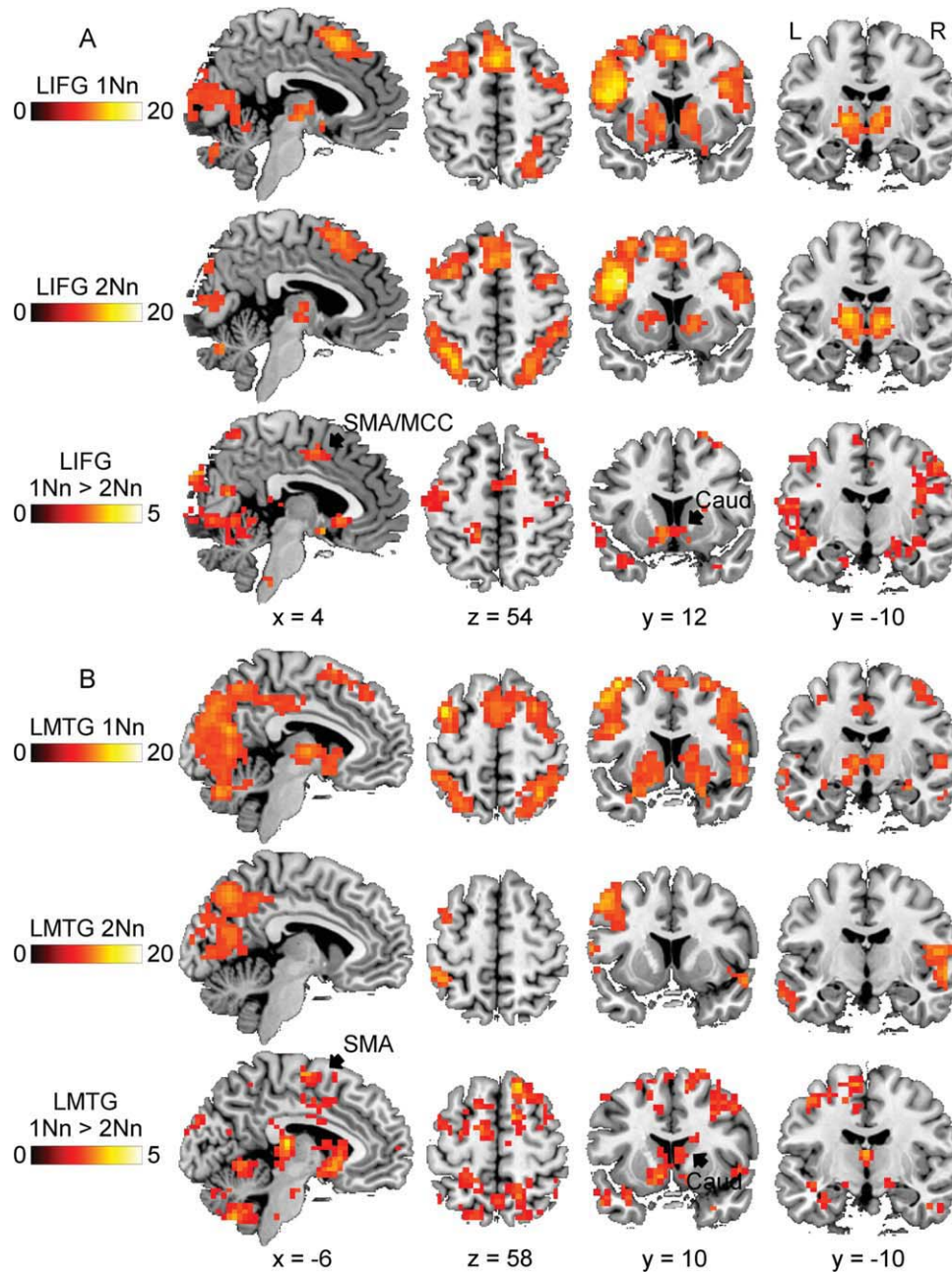


Figure 2.

Interregional interactions for the new noun in the first sentence (1Nn) and that in the second sentence (2Nn). **A**, Regions functionally connected with the LIFG for 1Nn and for 2Nn, and LIFG connections stronger for 1Nn than 2Nn (1Nn > 2Nn). **B**, Regions functionally connected with the LMTG for 1Nn and for

2Nn, and LMTG connections stronger for 1Nn than 2Nn (1Nn > 2Nn). SMA, supplementary motor area; MCC, middle cingulate cortex; IPL, inferior parietal lobule; Caud, caudate nucleus; L, left; R, right. Coordinates in MNI. Color scales indicate t values.

and production [Badre and Wagner, 2007; Badre et al., 2005; Thompson-Schill et al., 1997]. The dorsal mSFG is assumed to maintain task goals and to monitor and adjust cognitive processes in sensory, memory and motor sys-

tems [Botvinick et al., 2001; Carter et al., 1998; Dosenbach et al., 2007]. The IPL may play a role in binding a concept with a particular sign or sound during word learning [Breitenstein et al., 2005] or in binding a new label with a

TABLE II. LIFG connections and LMTG connections stronger for 1Nn than 2Nn

Region	BA	H	x	y	z	t	Size
LIFG connections							
Supplementary motor area	6	L/R	4	0	48	3.01	57
Middle frontal gyrus	46	R	36	32	48	2.95	93
Rolandic operculum		L	-44	-24	24	3.23	354
Precentral gyrus	6	L	-60	4	24	3.06	111
Postcentral gyrus	2	L	-20	-40	56	2.75	59
		R	20	-28	56	2.87	12
Superior temporal pole	38	R	52	8	-16	2.32	5
Superior parietal lobule	7	L	-24	-72	60	2.93	5
		R	24	-68	64	3.11	25
Superior occipital gyrus	18	L	-24	-92	20	3.88	40
		R	28	-92	30	4.33	74
Lingual gyrus	18	L	-20	-80	-8	4.39	88
		R	28	-80	-8	3.61	138
Caudate nucleus		L/R	-8	16	-4	3.06	37
Cerebellum		L	-24	-40	-48	3.39	43
LMTG connections							
Supplementary motor area	6	L/R	-8	-12	64	3.09	99
Superior frontal gyrus	8	L	-16	8	56	2.30	22
		R	16	24	56	3.58	133
Middle frontal gyrus	46	R	44	28	12	4.60	305
Inferior frontal gyrus (orbital)	47	L	-48	40	-12	2.78	14
Rolandic operculum		L	-36	-28	20	2.57	18
Superior parietal lobule	7	L	-20	-72	60	2.41	17
		R	20	-32	52	3.14	185
Precuneus	7	R	8	-64	40	2.18	12
Superior temporal pole	38	L	-32	8	-24	2.59	24
Middle temporal pole	21	L	-52	8	-28	2.66	19
Middle occipital gyrus	19	R	44	-76	32	2.82	18
Caudate nucleus		L/R	-8	8	-8	3.04	78
Thalamus		L	-4	-24	12	4.39	42
Cerebellum		L	-8	-64	-44	3.13	1,112
		R	20	-18	-52	5.05	

BA, Brodmann Area; H, hemisphere; L, left; R, right; coordinates in MNI; *t*, statistic values; size in number of voxels.

novel object during object naming [Cornelissen et al., 2004]. The current connectivity analysis demonstrated that these cortical regions are linked to subcortical structures, i.e. the basal ganglia and the thalamus. Animal work has shown that the caudate nucleus and the putamen receive cortical projections and project back to cortical regions via the thalamus, forming parallel [Middleton and Strick, 2002] and integrative [Bar-Gad and Bergman, 2001] circuits in support of motor, cognitive, and emotional processes.

The loops passing through the caudate nucleus and the medial thalamus seem to play a role in the learning and usage of conceptual and lexical knowledge [Ullman, 2006]. On the one hand, the caudate nucleus has been proposed to mediate a form of learning in which the stimulus-response association is incrementally acquired [Knowlton et al., 1996; Packard and Knowlton, 2002]. On the other hand, the thalamus has been stressed in the processing of lexical-semantic and syntactic information [Nadeau and Crosson, 1997; Wahl et al., 2008]. Mestres-Missé et al. [2008] further suggested that this loop can maintain a

processing bias because the thalamus receives inhibitory projections from the basal ganglia. Once the most appropriate item is selected, the inhibition of the thalamus will be released by the excitation of the caudate nucleus via

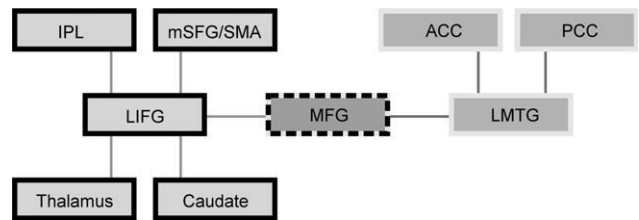


Figure 3.

Two neural networks underlying meaning acquisition. LIFG, left inferior frontal gyrus; LMTG, left middle temporal gyrus; MFG, middle frontal gyrus; mSFG/SMA, medial superior frontal gyrus/supplementary motor area; IPL, inferior parietal lobule; ACC, anterior cingulate cortex; PCC, posterior cingulate cortex.

the inhibition of the globus pallidus, giving rise to the excitation of related cortical regions [Crosson et al., 2003].

LMTG Network

The involvement of the LMTG may reflect the activation of stored semantic information because the regions are proposed to be a supramodal structure involved in the long-term storage of conceptual knowledge which is segregated from word-form representations [Martin and Chao, 2001; Patterson et al., 2007; Vandenberghe et al., 1996]. A prominent node of the LMTG network is the ACC, which is called upon whenever cognitive control processes are needed and attentional resources need to be assigned [Botvinick et al., 2001; Gitelman et al., 1999]. Other nodes including the PCC and adjacent precuneus have been linked with the encoding and retrieval of episodic memory [Valenstein et al., 1987; Vogt et al., 1992] as well as the monitoring and evaluation of sensory events [Raichle et al., 2001]. In the language domain, the ACC and the LMTG have been shown to be more activated for nonwords than words and for irregular than regular words during word production [Binder et al., 2005]. The PCC and the angular gyrus have been found more activated for words than nonwords during word recognition [Binder et al., 2003]. These findings suggest that the ACC corresponds to the difficulty of lexical/semantic processes and the PCC corresponds to the access of lexical items.

Although the LMTG network did not show differences between the new and the real words, connectivity within this network was weaker for the second than the first presentation of a new word. The same pattern was obtained for real words: the interregional connectivity was stronger for the first than the second presentation of a real word (Supp. Info., Fig. S1). The changes in the connectivity pattern might be explained by strategic factors. Since participants knew that the second sentence of a pair always had the same terminal word as the first sentence, it was easier for them to access and integrate that word. First and second sentences of a pair also differed in contextual constraint. Since the first sentence had the weaker contextual constraint, the stronger connections between LMTG and related regions may reflect a more effortful integration process. Alternatively, it might be considered that the decrease in connectivity strength from the first to the second presentation might result from repetition suppression. Repetition suppression is a phenomenon in which the BOLD response in neuronal populations sensitive to a stimulus is reduced after repetition of that stimulus [Grill-Spector et al., 2006; Kregelberg et al., 2006]. The distinction of these two possibilities, ease of contextual integration versus stimulus repetition, could be done by including a condition that repeats the novel word but in two sentential context that do not allow the extraction of a coherent meaning. If repetition was driving connectivity patterns,

connectivity should still decrease from the first to the second presentation of a word. If ease of contextual integration was crucial, connectivity should not decrease. Indeed, we have used such a condition in prior work with the human simulation paradigm in conjunction with event-related brain potentials [Mestres-Missé et al., 2007] and fMRI [Mestres-Missé et al., 2008]. Unfortunately, the timing of events in the latter study did not allow to apply connectivity analysis to this data set. Thus, a new study should be run, to clarify this point.

It is interesting to try to relate the current findings regarding the LIFG network to existing models of language processing. The functions that have been assigned to the LIFG are quite diverse. For example, Hagoort [2005] in his memory-unification-control (MUC) model proposed the LIFG to be an active workspace unifying word information retrieved from memory at the semantic, syntactic, and phonological levels. The LIFG, as the core of the unification component, is thought to interact with the memory component, situated in left temporal cortex, and the control component, located in dorsolateral prefrontal cortex and the anterior cingulate cortex. The MUC framework does not specify functions of subcortical structures. The current data suggest that the LIFG and MTG networks are dissociable and it would thus be interesting to apply connectivity analysis more formally to test the predictions of the MUC-model.

A proposal put forward by Friederici [2002] specifies the functions of the frontal and temporal brain regions on the basis of fMRI and ERP data. In her view, frontal regions support the formation of relationships with a specialization of BA 44 and the frontal opercular cortex for syntactic relationships, and BA 45/47 for semantic relationships. By contrast, temporal regions support identification processes, again with a specialization for semantic (left MTG) and syntactic (left anterior STG) processes. In Friederici's [2002] model, building of relationships and identification are partially independent processes. It is interesting to speculate whether the dissociation of the LIFG and LMTG network in the current study corresponds to Friederici's model. Clearly, connectivity analyses might be used to test predictions of Friederici's [2002] and Hagoort's [2005] (model), as well as those made by other recent neuroanatomical models of language processing [Caplan, 2001, 2006; Hickok and Poeppel, 2000, 2007; Poeppel and Hickok, 2004].

In conclusion, we found two neural networks involved in a task requiring the mapping of meaning to a novel word. One network, involving the LIFG, MFG, mSFG/SMA, caudate nucleus, thalamus, and IPL, supports the selection of the most appropriate meaning over competing candidates and to map the selected meaning onto the new word. The second network, comprising MTG, MFG, ACC, and PCC, is recruited to integrate the incoming word into the sentential context, no matter whether the word is pre-existing in semantic memory. A common node shared by both networks is the MFG which serves as a neural hub

for working memory. Thus, the two networks may communicate in working memory to work together during word learning.

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