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SHORT COMMUNICATION
Temporal characterization of memory retrieval processes: an fMRI study of the 'tip of the tongue' phenomenon

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Abstract

'Tip of the tongue' (TOT) is a natural phenomenon in which people cannot retrieve a target word immediately, even though they feel confident that they know the target. This provides us an opportunity to understand the human memory system, because cognitive components of memory retrieval such as retrieval effort and successful retrieval are temporally dissociated from each other during the TOT states. The purpose of the present study was to reveal the neural correlates of the cognitive components of the retrieval process by separating cognitive phases of the TOT phenomenon using event-related functional magnetic resonance imaging with multiple regression analysis. We demonstrated that the left dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex were activated at the time of successful retrieval, and the left DLPFC also showed activation when the subjects successfully retrieved the target names as compared to when they gave up. This result suggests that the left DLPFC is specific to the successful retrieval process. During the TOT state, a number of regions were activated, and this suggests that widely distributed brain regions are engaged when people make a hard effort to retrieve a proper name in the TOT state. Our new approach employing temporal resolution of the TOT phenomenon may contribute to the understanding of the mechanisms of the human memory system.

Introduction

People often experience difficulty in retrieving a proper name, though they can vividly remember the face and clothes of the person in question. They have confidence that they know the target name, and sometimes can access the first letter of the missing name, often with a feeling of being just within reach of retrieving it (i.e. feeling of imminence). This is known as the 'tip of the tongue' (TOT) state (James, 1893; Burke *et al*., 1988). In ordinary life, TOT states occur sporadically, which makes it difficult to study TOT in the laboratory. Brown & McNeill (1966) first succeeded in studying TOT under controlled conditions using rare words. In the TOT states, people cannot retrieve a target word immediately, despite a hard effort at retrieval. The recovery of the missing target often occurs later. In this TOT phenomenon, a cognitive component such as successful retrieval is temporally dissociated with retrieval effort. We thought therefore that the TOT phenomenon would give us a good opportunity to examine the components of the retrieval processes.

Investigating the neural correlates of memory retrieval processes has been one of the fundamental themes among neuroimaging studies. Previous block-designed functional magnetic resonance imaging (fMRI) and positron emission tomography studies attempted to distinguish between retrieval effort and success (Kapur *et al*., 1995; Nyberg *et al*., 1995; Rugg *et al*., 1996; Buckner *et al*., 1998b; Wagner *et al*., 1998), but the interpretation of the results has been debated. Recent event-related fMRI studies reported that frontal and parietal regions were important for retrieval success (Henson *et al*., 1999; Konishi *et al*., 2000; McDermott *et al*., 2000). Those studies identified regions associated with retrieval success by comparing between trials with and without retrieval success. Their method of comparison is, however, based on the assumption that cognitive components other than retrieval success, such as retrieval effort, were balanced between the two trials compared (Konishi *et al*., 2000).

The purpose of the present study is to determine the neural correlates for components of the retrieval processes by temporally separating the cognitive phases of the TOT phenomenon. Based on the method of Brown & McNeill (1966), we developed a TOT task with proper names that appeared in a major Japanese newspaper and were controlled in frequency. The task successfully induced TOT states in a high percentage of cases. For data analysis, we first sorted fMRI data according to the subjects' responses. Second, we temporally separated the cognitive phases of the TOT phenomenon with multiple regression analysis (Worsley & Friston, 1995; Courtney *et al*., 1997). This became possible because the retrieval effort and the retrieval success are temporally separated from each other in the TOT phenomenon. Finally, we compared the activities related to successful retrieval and giving up of retrieval with random-effects models (Holmes & Friston, 1998).

Materials and methods

Subjects

Fourteen volunteers (12 males and 2 females, aged 20–35 years) participated in the experiment. They had all received college- or

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graduate-level education, and were strongly right-handed (Edinburgh Inventory scores of all subjects were 100; Oldfield, 1971). We excluded five subjects' data from analysis due to poor behavioural performance (proportion of correct responses < 50%) or excessive head motion. Written informed consent was obtained from each subject in accordance with the declaration of Helsinki, and the protocol was approved by the University of Tokyo School of Medicine.

Materials

Questions to identify a specific person's name were crafted to effectively induce prolonged memory retrieval. First, we collected proper names from the Asahi newspaper database (http://www.asahi.com/information/webdb.html), names which appeared fewer than 1000 times from 1985 to 1999. The collected names included the names of company founders, scientists, politicians etc. Then we created questions based on the newspaper articles. Finally, we selected the questions that induced TOT phenomena with a high frequency in pilot studies with another group of subjects, whose age and educational background matched the scanned subjects. In the experimental scans, the questions were presented in Japanese and subtended less than ≈ 5° of visual angle. A question was presented for 2 s using LabVIEW software (National Instrument, Inc., Austin, TX, USA) and a colour LCD projector (Sharp 2000, Osaka, Japan). Subjects were required to respond by pressing buttons made of optical fibres.

TOT task

The subjects were required to retrieve the target name as quickly and accurately as possible. When they retrieved the target name, they were required to press button 1 with their right hand. After 8–10 s from the button press, the correct answer was presented and they reported whether their answer was correct or not by pressing the button again (Fig. 1). When they did not know or gave up retrieving the target, they were required to press button 2, also with the right hand. During retrieval, they were instructed to fixate on a central point on the screen. The durations of the retrieval phase were variable for each trial, and the intertrial interval was 10–12 s. The total number of questions differed among subjects because the length of each trial depended on the subject's responses.

MRI procedures

Functional images were obtained with a 1.5 T scanner system (Hitachi, Tokyo, Japan) and gradient echo echo-planar imaging with BOLD contrasts [TR 2 s, TE 20 ms (half scan), flip angle 90°, 3×3 mm^2 in-plane resolution, 8 slices, 7 mm thickness]. One session consisted of 59 scans for each slice, lasted 119 s, and a total of 24 sessions per subject were obtained. To maintain the same head position, we used cushions which were designed for each subject. We also took structural images every four runs to check for head movement based on anatomical landmarks, and rejected data with > 3 mm of movement in any direction. The range of the scans was around z = 4–60 mm in the coordinates of Talairach and Tournoux (1988), avoiding susceptibility artifacts of the nasal sinuses. For each subject, conventional T1-weighted structural images were collected to provide anatomic information.

Data analysis

After discarding the initial five volumes of each session to avoid the nonequilibrium effects of magnetization, functional images were realigned with AIR software (Woods *et al.*, 1992) to compensate the head movement, and spatially smoothed with a Gaussian filter (6 mm full width, half-maximum). Signal intensity was normalized within-trial to remove baseline fluctuation, and temporal high frequency noise was removed (cut off 4 s). To compensate for the different sampling timings of different slices, voxel values were interpolated in a time series.

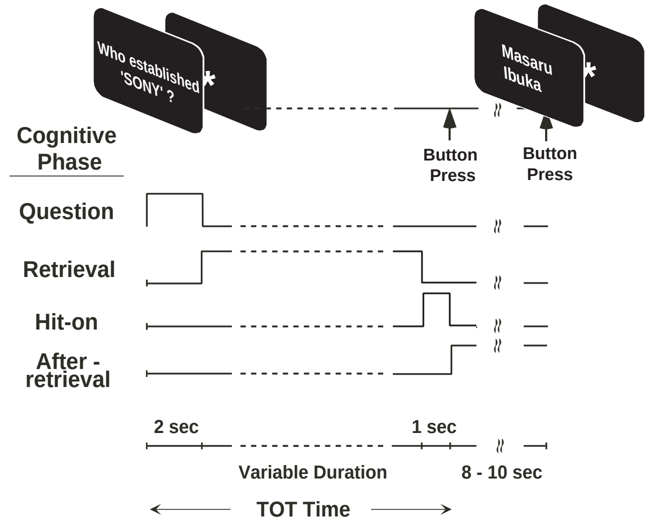


FIG. 1. A schematic representation of a 'tip of the tongue' (TOT) task and contrasts used for multiple regression analysis. In the TOT task, a question was presented for 2 s and a subject was required to retrieve the target name as quickly and accurately as possible. When they retrieved the target, they responded by a button press, and the answer was verified later also by button pressing. We defined the following four cognitive phases for a trial that induced a successful but prolonged retrieval: 'Question', 'Retrieval', 'Hit-on' and 'After-retrieval'. We applied four contrasts for each phase. Multiple regression analysis was performed with those contrasts convolved with the haemodynamic response function.

We analysed the trials in which prolonged retrieval was induced, that is, when it took > 6 s until the subjects responded that they had retrieved the targets (Hit-on trials) or that they had given up (Give-up trials). In this study, we used multiple regression analysis to differentiate transient from sustained activity. We defined four cognitive phases for a Hit-on trial: 'Question', 'Retrieval', 'Hit-on' and 'After-retrieval' phases. The phases were defined as follows: (i) the Question phase extended for 2 s during presentation of a question; (ii) the Retrieval phase followed the Question phase, and continued until 1 s before the subjects' responses signifying target retrieval; (iii) the Hit-on phase extended for 1 s just before the subjects' responses; and (iv) the After-retrieval phase was defined as following the Hit-on phase until the presentation of a correct answer. The contrast corresponding to each cognitive phase (Fig. 1) was convolved with the modelled haemodynamic response function to create the regressor. In the Give-up trials, we used another set of four regressors in the same way as in the Hit-on trials, and we termed the phase corresponding to the Hit-on phase in the Hit-on trials as the Give-up phase. We defined the After-retrieval phase so that the haemodynamic responses of the Hit-on phase were not contaminated by those of phase after the button press. A multiple regression analysis based on the general linear model (Worsley & Friston, 1995; Courtney *et al.*, 1997) was performed for the Hit-on and Give-up trials, by in-house software programmed with MATLAB (MathWorks, Natick, MA, USA).

Group analysis was performed between the Hit-on and Give-up phases (Fig. 2) based on random-effects models (Holmes & Friston, 1998). The functional images were smoothed with a Gaussian filter of

TABLE 1. Activated regions in each phase of the Hit-on trials

Phase Region (Brodmann Area)	R/L	N	Volume (cm^3)	Coordinates x	y	z
Question phase						
Dorsolateral prefrontal cortex (BA 9/44/6)	R	6	1.1 ± 0.6	38	16	34
	L	8	1.1 ± 0.6	–35	20	32
Inferior frontal gyrus (BA 44/6)	L	9	2.6 ± 0.8	–46	4	26
Superior temporal gyrus (BA 22/42)	L	7	3.2 ± 0.8	–60	–30	12
Retrieval phase						
Dorsolateral prefrontal cortex (BA 9/44/6)	L	8	2.3 ± 0.9	–38	18	32
Middle frontal gyrus (BA 9)	R	6	3.5 ± 0.8	34	30	32
	L	5	2.6 ± 1.1	–36	26	35
Middle frontal gyrus (BA 10)	R	5	2.3 ± 0.4	30	50	8
	L	5	2.1 ± 0.7	–34	48	10
Inferior frontal gyrus (BA 44/6)	L	9	2.0 ± 1.1	–43	4	24
Inferior frontal gyrus (BA 45/47)/insula	R	6	3.0 ± 0.9	40	21	11
	L	6	3.1 ± 1.3	–37	18	11
Premotor cortex (BA 6)	R	7	1.0 ± 0.5	30	–10	55
	L	8	1.4 ± 0.5	–35	–5	50
Lateral parietal cortex (BA 7)	R	6	1.6 ± 0.8	37	–59	46
	L	6	1.2 ± 1.0	–30	–65	42
Supramarginal gyrus (BA 40/39)	R	6	1.5 ± 0.5	40	–38	38
	L	6	1.5 ± 0.5	–35	–35	40
Superior temporal gyrus (BA 22/42)	R	7	1.7 ± 0.5	55	–35	10
	L	8	2.0 ± 0.6	–50	–26	12
Anterior cingulate cortex (BA 32/24)	R/L	8	2.2 ± 0.7	3	25	36
Precentral gyrus/Postcentral gyrus (BA 4/3/1/2)	L	7	2.2 ± 1.2	–35	–20	49
Hit-on phase						
Dorsolateral prefrontal cortex (BA 9/44/6)	L	6	2.0 ± 0.9	–40	22	35
Anterior cingulate cortex (BA 32/24)	R/L	6	1.5 ± 0.4	0.3	20	31
Middle frontal gyrus (BA 9)	R	5	1.2 ± 0.2	34	32	35
Lateral parietal cortex (BA 7)	L	5	1.8 ± 0.6	–34	–65	44
Precentral gyrus/Postcentral gyrus (BA 4/3/1/2)	L	5	1.8 ± 0.8	–38	–22	48

Activated regions in each phase of the Hit-on trials detected in more than five subjects. *N*, the number of subjects whose corresponding regions showed activation; R, right; L, left. Stereotaxic coordinates of each region were averaged among the subjects according to the atlas of Talairach and Tournoux (1988), and the approximate Brodmann areas are based on the atlas coordinates. All volumes are indicated as mean ± SD.

12 mm, linearly transformed into the Talairach & Tournoux (1988) space with translation, rotation and stretching in the three dimensions with in-house software on MATLAB, and second-level inferences were performed. We delineated activated regions with five or more contiguous voxels above $P < 0.001$ (uncorrected) (Buckner *et al.*, 1998a). The time course of the activated regions determined as above was calculated by averaging magnetic resonance signals in the activated voxels with a lower threshold ($P < 0.005$, uncorrected) in the grouped data. To ensure the validity of our multiple regression model, we also calculated fitted response functions (Courtney *et al.*, 1997) by multiplying each regressor coefficient with the time series of the corresponding regressor, and by summing up the total contribution from the regressors.

For single-subject analysis, we regarded the activated regions as five or more contiguous voxels above $P < 0.001$ (Fig. 3). We identified the regions among subjects based on anatomical landmarks (Grachev et al., 1999), and the locations of activated regions among subjects were within 15 mm of each other. The respective peaks of these regions were indicated based on the coordinates of Talairach & Tournoux (1988).

Results

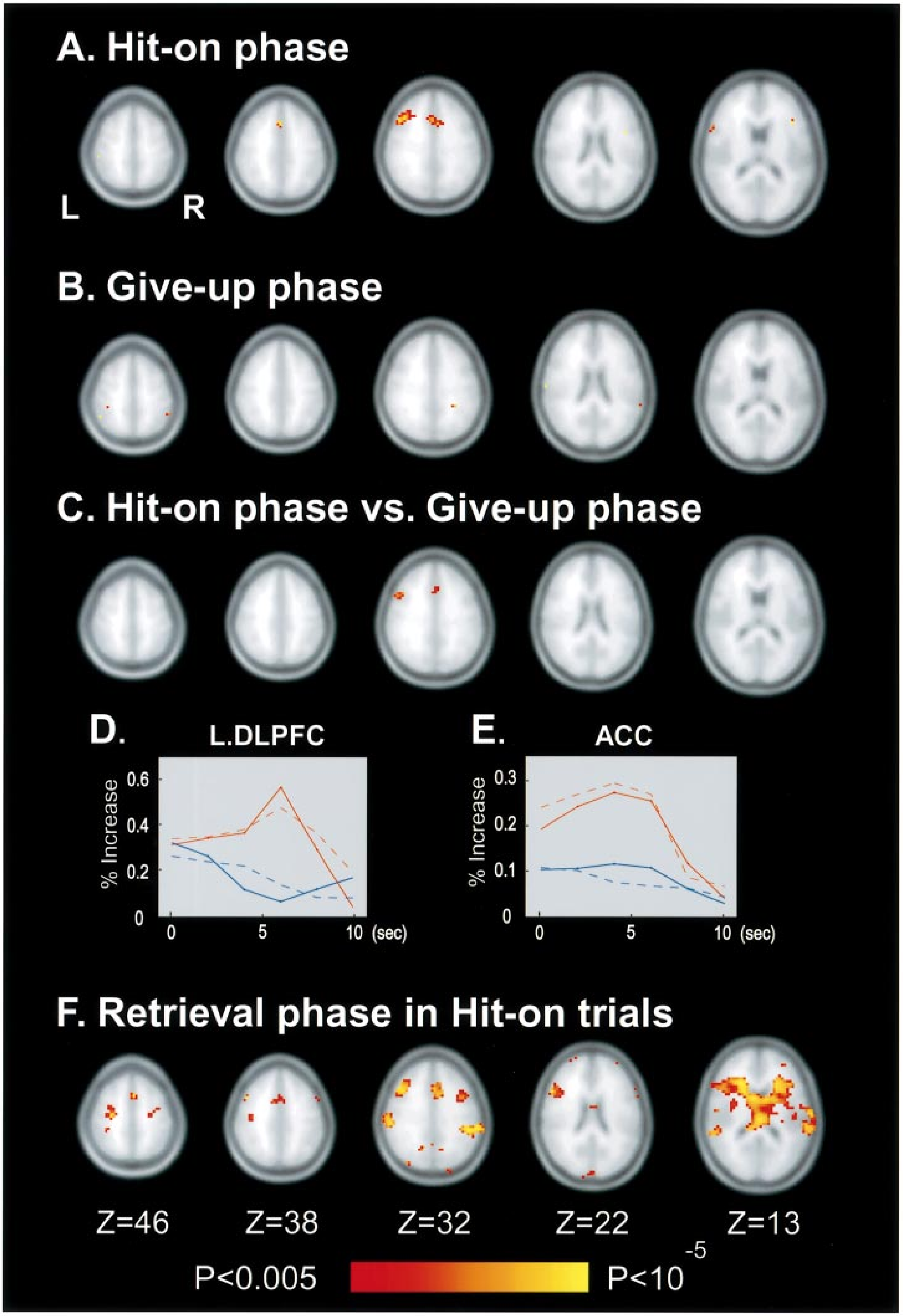
Behavioural results

The number of questions for each subject was 72.0 ± 8.1 (mean ± SD). The numbers of Hit-on and Give-up trials were 21.7 ± 4.1 and 13.8 ± 8.6, respectively. The mean response latency (TOT time in Fig. 1) was 10.5 ± 1.7 s in the Hit-on trials and 12.6 ± 3.3 s in the Give-up trials. The percentage of correct in Hit-on trials, which was the ratio of the number of correctly answered Hit-on trials to the sum of correctly and wrongly answered Hit-on trials, was 75.0 ± 14.0%. After the functional scan sessions, subjects very often reported that they experienced a feeling of imminence in the Hit-on trials, which is one of the characteristic features of the TOT state (Brown, 1991).

FMRI results

First, we applied multiple regression analysis with random-effects models to the fMRI data from nine subjects. The left dorsolateral prefrontal cortex (DLPFC; –40, 25, 33) and anterior cingulate cortex (ACC; –1, 25, 34) showed activation ($P < 0.001$) in the Hit-on phase of the Hit-on trials (Fig. 2A), whilst neither region showed activation ($P > 0.1$) in the Give-up phase of the Give-up trials (Fig. 2B). Moreover, the left DLPFC (–45, 18, 32) showed activation ($P < 0.001$) when it was compared between Hit-on and Give-up phases. In this comparison, the ACC was subthreshold at $P < 0.001$, but some activity was observed at $P < 0.005$ (Fig. 2C).

The time courses of the regions are shown in Fig. 2D and E. Their magnetic resonance signals were already elevated before the time of response (0 s) and transiently increased, time-locked with the response that the subjects had retrieved the targets.


A. Hit-on phase
L
R
B. Give-up phase
C. Hit-on phase vs. Give-up phase
D.
L.DLPFC
% Increase
0.6
0.4
0.2
0
0
5
10 (sec)
E.
ACC
% Increase
0.3
0.2
0.1
0
0
5
10 (sec)
F. Retrieval phase in Hit-on trials
Z=46
Z=38
Z=32
Z=22
Z=13
P<0.005
P<10 -5

We also confirmed in the single-subject analyses that the two regions showed activation ($P < 0.001$) in six out of nine subjects during the Hit-on phase (upper part of Fig. 3), but did not show activation in the Give-up phase even at a lower threshold ($P > 0.01$) (lower part of Fig. 3). In the single-subject analyses, we identified activations in the right prefrontal, left parietal and left motor/sensory regions during the Hit-on phase in five subjects (Table 1), but these activations were subthreshold in the random-effects analysis.

Figure 2F showed the results of group analysis during the Retrieval phase in the Hit-on trials. Bilateral activations were found in the DLPFC [Brodmann area (BA) 9/44/6], inferior frontal gyrus (BA 45/47/insula), supmarginal gyrus (BA 40/39) and superior temporal gyrus (BA 22/42), as well as supplementary motor area (BA 6) and ACC. We also observed left side activation in the inferior frontal gyrus (BA 44/6) and motor/sensory area (BA 4/3/1/2). Regions in which more than five subjects showed activation during the Question, Retrieval and Hit-on phase are listed in Table 1.

Discussion

We investigated the neural correlates of the retrieval processes by separating the cognitive phases of the 'tip of the tongue' (TOT) phenomenon. The fMRI data were analysed based on the random-effects models with multiple regression methods. We demonstrated that the left DLPFC and ACC were activated at the time of successful retrieval, and neither region showed activation in the Give-up phase in the Give-up trials. Especially, the left DLPFC showed activation when the subjects successfully retrieved the target names as compared to when they gave up.

Previous event-related fMRI studies (Henson *et al*., 1999; Konishi *et al*., 2000; McDermott *et al*., 2000) reported that the frontal and parietal regions were important for retrieval success. The left DLPFC activation found in our study (–45, 18, 32) is close to the region reported by Henson *et al*. (1999) and Konishi *et al*. (2000).

However, we should be careful in interpreting the results, because there are four major differences between these three previous studies and ours. (i) Previous studies detected regions responsible for retrieval success by comparing between trials with and without retrieval success in event-related fMRI. This comparison is based on the assumption that other cognitive components, such as retrieval effort, were balanced between trials with and without retrieval success (Konishi *et al*., 2000). In contrast, the method used in this study separated cognitive states within-trial by exploiting the temporal resolution of the TOT phenomenon without such an assumption. (ii) Previous studies used recognition tasks in episodic memory, whilst the TOT task required recall from semantic memory. (iii) The TOT task required subjects to retrieve targets from several years ago, whilst the recognition tasks required retrieval from at most a few hours previously. (iv) Previous studies compared between hit (correct recognition of a target encoded previously) and correct rejection (correct recognition of a target not encoded previously) trials, whilst we compared between Hit-on and Give-up phases. Despite these differences, the left DLPFC was commonly detected in association with retrieval success, suggesting that the region is important regardless of the type of memory.

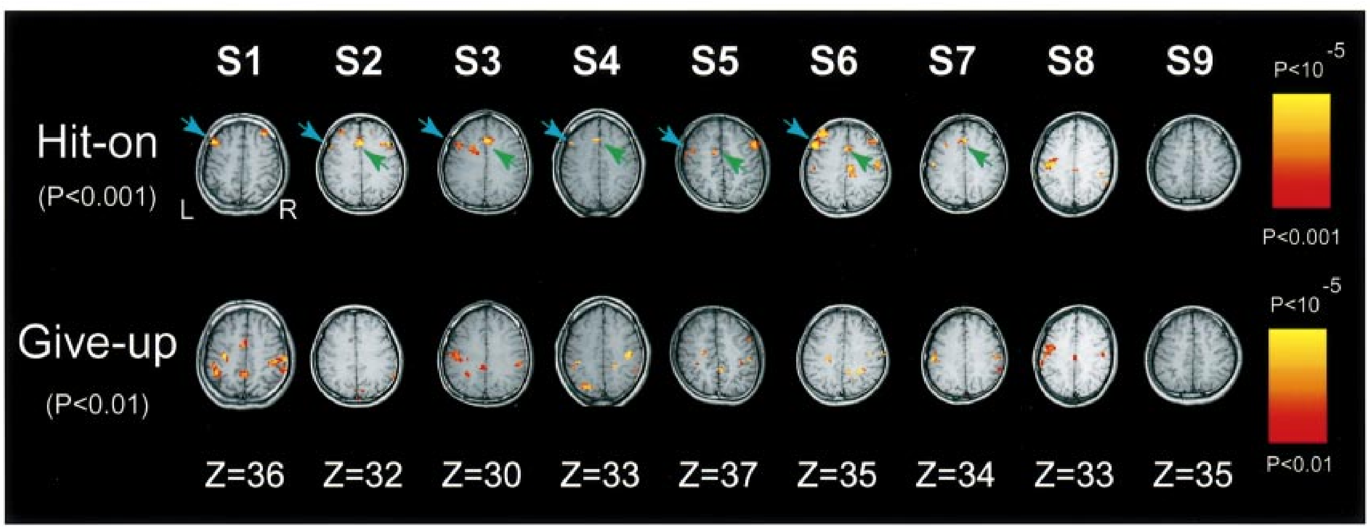


FIG. 3. Activation in the left dorsolateral prefrontal cortex (blue arrows) and anterior cingulate cortex (green arrows) of each subject during the Hit-on phase (upper panel) and the Give-up phase (lower panel). The right side of the images corresponds to the right side of the brain, and the stereotaxic coordinates based on the atlas of Talairach and Tournoux (1988) are indicated below. Both regions showed activation ($P < 0.001$) in six out of nine subjects, whilst there were no activations in these regions during the Give-up phase even at a lower threshold ($P < 0.01$).

FIG. 2. Statistical maps of grouped analysis during the Hit-on and Give-up phases. (A) Hit-on phase. (B) Give-up phase. (C) Hit-on phase vs. Give-up phase. The stereotaxic coordinates based on the atlas of Talairach and Tournoux (1988) are indicated below. (D and E) Time courses in (D) the left dorsolateral prefrontal cortex and (E) the anterior cingulate cortex. The red solid lines indicate the percentage changes of magnetic resonance signals as compared with the signals at the presentation of a question. The time point zero (0 s) was at the subjects' responses that they successfully retrieved the target or gave up. The red broken lines show the corresponding fitted response functions. Blue solid lines indicate the signal changes in the Give-up trials and blue broken lines represent their fitted functions. (F) The statistical maps of group analysis in the Retrieval phase in the Hit-on trials.

We demonstrated that a number of regions were activated in the Retrieval phase, including all the retrieval mode sites (Lepage *et al*., 2000), which were previously reported for episodic retrieval and/or working memory (Wagner, 1999; Smith & Jonides, 1999). Above all, the left prefrontal regions were continuously activated from dorsal to ventral, it is consistent with the notion that these regions serve as rehearsal circuits (Smith & Jonides, 1999). The left superior temporal cortex has been discussed in relation to the phonological processing (Demonet *et al*., 1992). These results support the idea that the regions might play a phonological role in the TOT states (James & Burke 2000), and the activations were emphasized in comparison with the recognition tasks, because the TOT task required longer and harder effort of recall than did recognition tasks. We observed activations in the middle frontal gyrus (BA 10) in the single-subject analysis during the Retrieval phase, but not in the group analysis. We suppose this is because the distortion due to susceptibility artifacts caused difficulties in the transformation among subjects. These results suggest that widely distributed brain regions are engaged when people make a hard effort to retrieve a proper name in the TOT states.

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Abbreviations

ACC, anterior cingulate cortex; BA, Brodmann area; DLPFC, dorsolateral prefrontal cortex; fMRI, functional magnetic resonance imaging; TOT, 'tip of the tongue'.

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