Dissociated Pathways for Successful Memory Retrieval from the Human Parietal Cortex: Anatomical and Functional Connectivity Analyses

The parietal cortex has traditionally been implicated in spatial attention and eye-movement processes. Recent functional neuroimaging studies have found that activation in the parietal cortex is related to successful recognition memory. The activated regions consistently include the intraparietal sulcus in the lateral parietal cortex and the precuneus in the medial parietal cortex. However, little is known about the functional differences between lateral and medial parietal cortices in the memory retrieval process. In this study, we examined whether the human lateral and medial parietal lobes have differential anatomical and functional connectivity with the temporal lobe. To this end, we used functional magnetic resonance imaging to constrain the analysis of anatomical connectivity obtained by diffusion tensor imaging (DTI). Both DTI tractography and functional connectivity analysis showed that the lateral parietal region has anatomical and functional connections with the lateral temporal lobe, and the medial parietal region has connections with the medial temporal lobe. These results suggest the existence of segregated lateral and medial parieto-temporal pathways in successful memory retrieval.

Keywords: diffusion tensor imaging, functional connectivity, long-term memory, parietal cortex, temporal lobe

Introduction

The parietal cortex is thought to be involved in attention and eye-movement processes (Hyvarinen 1982; Corbetta 1998; Colby and Goldberg 1999; Mesulam 1999). In addition, recent functional neuroimaging studies have found activation in the parietal cortex during various memory tasks, especially those related to successful recognition memory (Henson et al. 1999; Donaldson et al. 2001; Konishi et al. 2001; Cansino et al. 2002; Dobbins et al. 2003; Rugg et al. 2003; Wheeler and Buckner 2003; Herron et al. 2004). Most studies have identified several regions in the parietal cortex that respond to “Hits” (when subjects correctly recognize previously studied old items) more than to “Correct rejections” (when they correctly identify new items). The regions in which this effect was identified consistently include intraparietal sulcus (IPS or Brodmann areas [BA] 7), medial parietal cortex (the precuneus [PCu] or medial BA 7, and posterior cingulate cortex or BA 23/31), and several prefrontal regions. Although the roles of the prefrontal cortex (PFC) in successful memory retrieval have been relatively well studied (Buckner, Koutstaal, Schacter, Dale, et al. 1998; Buckner, Koutstaal, Schacter, Wagner, et al. 1998; Henson et al. 1999, followed by many other studies), those of the parietal cortex are still poorly understood (Shannon and Buckner 2004; Nagnhi and Nyberg 2005; Wagner et al. 2005; Cavanna and Trimble 2006). Because it is well known that declarative memory relies on the medial temporal lobe (MTL) and lateral temporal cortex, a key strategy for studying successful memory retrieval in the parietal cortex is to study its relationship with the temporal lobe. Given the accumulating knowledge on the functionally dissociated roles of the temporal lobe in terms of memory, studying connectivity between IPS/PCu and the temporal lobe should be fundamental to understand the roles of the parietal regions in memory.

Neuropsychological studies suggest that different types of memory depend on separated cortical structures (Squire 1994; Takahashi and Miyashita 2002). For example, patients with left lateral temporal lobe damage have impaired memory for semantic knowledge (De Renzi et al. 1987; Snowden et al. 1989; Hart and Gordon 1990), but relatively preserved memory for episodic information (De Renzi et al. 1987; Snowden et al. 1994). Recent functional imaging studies also showed that lateral temporal cortex is activated by semantic memory retrieval or item-based memory, whereas the MTL is activated by episodic memory retrieval or relational memory (Wiggs et al. 1999; Lee et al. 2002; Konishi et al. 2006). Based on these functional dissociations between the MTL and lateral temporal cortex studies of the specific connections between these areas should provide insight into the process of memory retrieval in parietal cortex.

Diffusion tensor imaging (DTI) is a technique that measures the diffusion properties of water molecules from diffusion-weighted magnetic resonance images (Basser et al. 1994). Tractography algorithms are then applied to DTI data to reconstruct connections between various brain regions (Conturo et al. 1999; Jones et al. 1999; Mori et al. 1999). Many studies have used DTI to show anatomical connections in the human brain (Conturo et al. 1999; Bass et al. 2000; Stieltjes et al. 2001; Xu et al. 2002; Behrens et al. 2003; Lehericy et al. 2004; Powell et al. 2004), and recent studies have used DTI to assess connectivity between functionally defined regions of interest (ROIs) (e.g., Guye et al. 2003; Toosy et al. 2004; Dougherty et al. 2005; Kim et al. 2006; Takahashi et al. 2007). In this study, we use a boot-trac algorithm (Lazar and Alexander 2005; Takahashi et al. 2007) to create probabilistic maps of DTI tractography. We find that IPS is connected with a lateral temporal region, whereas PCu is connected with MTL. This result suggests that IPS has an important role in retrieval of items’ information stored in the lateral temporal cortex, and PCu interacts with MTL to recall relational memories.

Although DTI provides information about anatomical pathways in vivo, there is no functional interpretation in the reconstructed fibers themselves. We performed a whole-brain functional connectivity analysis, looking at the functional coupling between parietal ROIs. This analysis based upon the
functional magnetic resonance imaging (fMRI) data identified significant interactions with the temporal lobe that showed a regional specificity. We found that IPS was correlated with the lateral temporal cortex, and PCu was correlated with MTL. These results suggest that, with respect to successful memory retrieval, lateral and medial parieto-temporal pathways are anatomically and functionally dissociated.

Methods

Subjects

Twenty healthy normally sighted subjects were tested (8 males and 12 females, aged 21–39, mean age 25). All subjects reported themselves to be native speakers of English, right handed, with no neurological or psychiatric histories. Written informed consent in accordance with the Declaration of Helsinki was obtained from each subject after the nature and possible consequences of the studies were explained. The procedures were approved by Boston University School of Medicine.

Stimuli

Word stimuli consisted of a pool of 216 words (upper case, 3–7 letters in length, 1–200 occurrences per million; Kucera and Francis 1967). We also used nonword stimuli (alphabetical) for the encoding task and the number sign (####) for the retrieval task as control stimuli. The nonword stimuli contained both consonants and vowels, but the order of letters was randomized. Alphabetical stimuli were made using random sequences of letters having the same length as the word stimuli. All stimuli were presented on a tangential screen 1.1 m from the subjects. Words were white on a black background, occupied 3.10° × 1.30° to 7.30° × 1.30° of visual angle and appeared at the center of the screen. All stimuli were presented using presentation software (Neurobehavioral Systems, Inc., Albany, CA).

Procedure

The experiment consisted of 2 parts, an encoding phase and a retrieval phase. fMRI data were acquired during both the encoding and the retrieval phase. In the current study, only the data of the retrieval phase were used. The results of the encoding phase were reported previously (Takahashi et al. 2007). In the encoding phase, subjects were asked to perform 4 different "encoding" tasks: 1) make a living/nonliving judgment (deep encoding), 2) detect a given letter within a nonword letter sequence (shallow encoding), 3) press a random button, and 4) fixate on a central target. There were 48 blocks of 6 trials each in the encoding phase. Each trial lasted 4.0 s. At the beginning of each block, an instruction was shown that specified the type of encoding task to be performed. In the "living/nonliving" blocks, subjects decided whether each word was animate. In the "detection" blocks, they decided whether each word contained an "E." In both the "living/nonliving" and "detection" blocks, subjects reported their response by pressing 1 of 2 buttons held in the right hand. In the "random button press" (visuo-motor control) blocks, they looked at each nonword letter sequence and pressed 1 of the 2 buttons held in the right hand. In the fixation blocks, they looked at the fixation cross and did not press any buttons. Each word was presented only once throughout the encoding phase. The length, percentage of living words, and the percentage of words containing "E" were each balanced across all the living/nonliving and detection blocks. The ordering of living/nonliving and detection blocks, and stimuli used in both blocks were counterbalanced across subjects. The encoding phase lasted approximately 25 min.

The retrieval phase (4 runs) started about 20 min after the end of the encoding phase. During the interval between the encoding and the retrieval phases, subjects performed a distractor task (white circle detection out of 4 circles) to disengage various strategies for encoding. In the retrieval phase, subjects performed randomly intermixed retrieval trials, visuo-motor control trials, and fixation trials. Each run consisted of 72 trials. In the retrieval trials, subjects made yes/no recognition memory judgments for previously studied and new stimuli. Subjects reported their response by pressing 1 of the 2 buttons held in the right hand. Half of the words from the encoding phase were presented again (72 words: 36 words were deep-encoded, the other 36 words were shallow-encoded), along with new words (72 words). In the visuo-motor control trials, they looked at the number sign (####) and pressed the 3rd button that was specifically assigned for this trial type. In the fixation trials, they looked at the fixation cross and did not press any buttons. Each trial was 4.0 s long, and the 4 trial types occurred with equal probability across the experiment in pseudorandom sequence. The stimulus onsets were not jittered. The retrieval phase lasted approximately 20 min.

Mean percent correct in the deep and shallow conditions did not differ significantly during the encoding phase (P > 0.05; 2-tailed t-test) (Supplementary Table S1). Reaction times of the deep and shallow encoding, and visuo-motor control tasks were significantly different (F2,51 = 13.8, P < 10⁻⁴, 1-way ANOVA). In the post hoc Tukeys t-test, the visuo-motor reaction times were significantly different from both the deep and shallow encoding tasks (P < 0.05), but the deep and shallow encoding tasks were not significantly different (P > 0.05). In the retrieval phase, the percent correct for deeply encoded words was significantly higher than the percent correct for shallowly encoded words, thus confirming that the words were more deeply encoded during the living/nonliving judgment task than in the detection task. Reaction times were not significantly different between deeply encoded words and shallowly encoded words (P > 0.3; 2-tailed paired t-test). Correct retrieval judgments were made on 73.6% of trials for the studied words ("Hits") and 64.5% for new words ("correct rejections").

Image Acquisition

A 3-Tesla whole-body scanner (Intera, Philips) was used to acquire T1-weighted anatomical images, gradient-echo, echo-planar T2*-weighted blood oxygen level-dependent sensitive images, and spin-echo echo-planar imaging (SE-EPI) diffusion-weighted images (DWIs) for the DTI data sets. For each subject, 16 data sets were acquired (15 diffusion weighted + 1 nondiffusion weighted images). From these data, diffusion tensors were calculated for all image pixels. Functional data were taken in the identical field of view (FOV) with diffusion tensor images to simplify post hoc spatial registration. Subsequently, the foci of fMRI activations were used as seeding points for DTI fiber reconstruction algorithms.

Parameters for functional image acquisition were as follows: repetition time (TR) = 4.0 s; echo time (TE) = 35 ms; flip angle = 90°; in-plane resolution 1.8 × 1.8 mm²; FOV = 230 × 230 mm²; number of slices 56; slice thickness 4 mm. Slice orientation was axial, and the imaging volume was aligned to cover the whole brain. For each subject, conventional T1-weighted structural images were obtained to provide anatomical information. Each scanning run commenced with the acquisition of 2 dummy volumes, allowing tissue magnetization to achieve a steady state, after which functional volumes were acquired (85 volumes for each encoding run, and 73 volumes for each retrieval run).

DWIs were acquired using multislice SE-EPI. Parameters for DTI acquisition were as follows: TR = 17.1 s; TE = 80 ms, matrix size 128 × 128, FOV = 230 × 230 mm²; fat suppression, number of slices = 96, slice thickness = 1.5 mm, b = 1000 s/mm², 15 directions, gradient strength = 0.2 G/mm, P reduction = 2.0. A total of 4 signal averages were collected to ensure a sufficient signal-to-noise ratio for high-quality tensor mapping. In order to compensate for motion, each scan was acquired separately and then coregistered with the others before averaging. The sensitivity encoding technique (SENSE) was used, which is known to reduce susceptibility artifacts significantly (Jaermann et al. 2004).

fMRI Analyses

All functional images were analyzed with SPM99 (Wellcome Department of Neurology, UK). For each subject, the acquired images were realigned to the 1st volume to correct for head movement. Differences in acquisition timing between each slice were corrected for using sinc-interpolation. Each volume was spatially normalized to a standard EPI template of 2-mm cubic voxels in the Talairach and...
Tournoux space (Talairach and Tournoux 1988) using nonlinear basis functions. Each image was smoothed spatially with a Gaussian kernel of 8-mm full-width half-maximum (FWHM), and the time series was smoothed temporally with a 4-s FWHM Gaussian kernel. Slow signal drifts were removed by high-pass filtering using cut-off periods of 128 s. For each voxel, data were best fitted (least square) using a linear combination of regressors. The regressors were constructed to correspond to each trial type for each subject and then convolved with the standard hemodynamic response function (HRF). In the retrieval phase, we separated correct and incorrect trials ("Hit," "Correct Rejection," "Miss," and "False Alarm"), and made 5 regreessors, corresponding to these trial types and "visuo-motor control." Trials in which the subject did not report a response by pressing a button in the retrieval phase (9 trials) were explained by an extra regressor. Contrasts were 1st performed at the single subject level and then the resulting images were taken up to the group level using t-tests. The statistical threshold was set to $P < 0.001$ as an initial height threshold and to $P < 0.05$ corrected for whole-brain multiple comparisons at cluster level, according to the SPM99 standard procedures (Friston et al. 1994). The location of each cluster was indicated by peak voxels on the normalized structural images and labeled using the nomenclature of Talairach and Tournoux (1988).

**DTI Analyses**

DTI images were realigned using the diffusion toolbox in SPM2. The 1st images of each run were realigned to the 1st image of the 1st run. This procedure removed eddy current-induced distortions. Then all the images were averaged across the 4 runs. For each voxel, the diffusion tensor and fractional anisotropy (FA) were calculated using standard procedures (Basser et al. 1994). We removed voxels that had extremely large residuals after fitting the 15 DWIs by an ellipsoid tensor. When the residual exceeds 35% of the value of apparent diffusion constant averaged across the whole brain, those voxels were removed. Approximately, 20% of the voxels were removed and those voxels were distributed along the edge of the brain. Using the T maps generated by SPM99, which are the result of the random effect analysis of 20 subjects, we created starting points for DTI fiber tracking. We used the same statistical criteria ($P < 0.05$ corrected at the cluster level) as a criterion for identifying regions that were the reference or seed points. The starting points for fiber tracking were set in intervals of 1 mm in the foci of fMRI activation clusters. The coordinates of the activated clusters in Talairach coordinates were reverse normalized into each subject’s coordinates, and used as the basis for fiber tracking and determining the coordinates of the end points of the fibers. Then we normalized the end points’ coordinates, averaged the data across all the subjects, and superimposed the resulting maps onto the normalized T1-weighted images. The reverse normalization and normalization of the coordinates were performed in the following way. We took $T_1$ and DWI scans in the same FOV, and using SPM99, we transformed the end points coordinates of each subject into Talairach space, averaged the data across all the subjects, and superimposed the resulting maps onto the T1-weighted images in Talairach space. For each subject, we applied reverse conversion of normalization to the seed points, using in-house Matlab (The Mathworks, Inc., Natick, MA) programs. This approach is better than normalizing DWIs directly because the resolution of DWIs was reduced when we resample DWIs during normalization.

**DTI Tractography**

Diffusion tensors, FA, and fiber tracts were calculated using custom-made Matlab programs. We used a tractography algorithm based on the method described in Lazar et al. (2003). At every position along the fiber trajectory, a diffusion tensor is interpolated (linear) and eigenvectors are computed. The eigenvector associated with the greatest eigenvale indicates the principal direction of water diffusion. The fiber tract is propagated along this direction over a small distance (0.5 mm) to the next point where a new diffusion tensor is interpolated. Fiber tracking terminates when the angle between 2 consecutive eigenvectors is greater than a given threshold (60°), or when the FA value is smaller than a given threshold (0.14). The criteria of $FA < 0.14-0.15$ is reported to provide the best tradeoff between fewer erroneous tracts and penetration into the white matter (Thottakara et al. 2006). This tensor deflection algorithm is 1 of the tensorline approaches that was developed to overcome crossing fiber problem (Alexander et al. 2001) by using the entire tensor information instead of reducing it to a single eigenvector (Lazar et al. 2003).

**Group Study in DTI Tractography**

For Figure 1A, we performed DTI tractography from all voxels in each activated cluster. To establish a dissociation between the anatomical connectivity of the medial and lateral parietal areas, we used a heuristic algorithm that propagated streamlines from both regions. The termination points of the streamlines were assessed by evaluating the probability of an end point, from a particular seed region, falling within a voxel, over subjects. The resulting map was superimposed onto normalized T1-weighted anatomical images. The maps were reported as percentage of subjects in whom connections were found.

**Estimation of Tractography Error by the Bootstrap Method**

In this study, the dispersion errors in DTI tractography were estimated by a statistical nonparametric bootstrap method (Lazar and Alexander 2005; Takahashi et al. 2007) to ensure that the tractography was reliable by evaluating intra- and intersubject variability. For each gradient direction, 2 out of 4 data sets (volumes) were selected randomly and averaged. This comprised one 15-direction data set, and diffusion tensors and reconstructed fibers were calculated. We repeated this procedure 100 times, and created probabilistic maps that are based on how many times, out of 100, fibers passed each voxel in the brain. A probabilistic map from multiple seeds was obtained as follows. First, we performed fiber tracking from all the seed points, for each bootstrap sample. We defined a voxel, which was passed by at least 1 fiber as "1," and a voxel which was not passed by any fiber as "0." When more than 1 fiber passed a voxel, we defined it as "1." We performed these procedures for 100 bootstrap samples, obtained probabilities for each voxel to be "1," and defined this as a probabilistic map.

**Functional Connectivity Analyses**

Functional connectivity analysis was performed from the same ROIs with DTI fiber-tracking analyses. The fMRI signals were preprocessed for realignment, slice timing correction, normalization, and spatial smoothing, as the same way as described above (see fMRI Analyses). Then low-frequency drifts in the time course in each voxel were removed. We excluded the task-specific regressor and used 2 regressors, which are the time series from the 2 parietal regions, not convolved with the HRF. Because of the spatial smoothing of the fMRI data, a single voxel’s activity can be thought of as representing the activity of the region around the voxel. Peak voxels were used for functional connectivity analysis (Talairach coordinates -44, -66, 46 in left IPS and 24, -62, 22 in PCu). We obtained maps of correlation coefficients between residual time courses in the peak voxel (either IPS or PCu) and other voxels were calculated for individual subjects. To make inferences at the between-subject level about the functional connectivity encoded by these correlation coefficient maps, we transform them into summary statistics using Fisher’s $Z$ transform. These within-subject maps were then passed to a 2nd-level or between-subject 1-sample t-test to provide statistical parametric mapping (SPMs) in the usual way. The same analysis was previously used by other groups (Dosenbach et al. 2007). $T$ values were corrected for multiple comparisons for a whole brain at voxel level ($P < 0.05$), and superimposed onto normalized T1-weighted anatomical images. Mean $z$-values across all subjects were also calculated. To find areas that displayed a functional connectivity with both parietal regions, we show the voxels surviving an uncorrected threshold of $P = 0.001$ in both functional connectivity maps.

**Results**

**Subjects Performances and Functional MRI**

Twenty healthy normally sighted subjects were tested. Correct retrieval judgments were made on 73.6% of trials for the
studied words ("Hits") and 64.5% for new words ("Correct rejections"). In the comparison between Hits and Correct rejections, the following brain areas were activated: left IPS, right PCu, left superior temporal gyrus (STG), right middle temporal gyrus (MTG), left middle frontal gyrus, right inferior frontal gyrus, and cerebellum (Table 1).

**Group Study in DTI Tractography**

We used DTI tractography to reconstruct fibers originating from IPS and PCu. The distribution of fiber terminals from 20 subjects is shown in Figure 1A. Probabilistic maps were obtained by a statistical nonparametric bootstrap method (Lazar and Alexander 2005; Takahashi et al. 2007), and displayed in Figure 1B (note that only terminal points of the reconstructed fibers are displayed in Figure 1A, whereas the entire fibers are displayed in Fig. 1B). The IPS had connections with lateral temporal cortex (STG [BA 22], the MTG [BA 21], and the fusiform gyrus [FG, BA 37]) and bilateral superior colliculi (Fig. 1A, upper row). PCu had connections with MTL (hippocampus, parahippocampal gyrus, the occipital cortex [BA 17, 18, 19], and posterior cingulate cortex (Fig. 1A, lower row).

**Functional Connectivity**

Functional connectivity analysis was performed from the same ROIs with DTI fiber-tracking analyses. Regions with a significant functional correlation with an activated region in PCu (Talairach coordinates: x, y, z = 24, −62, 22) is shown in Figure 1C (upper row) and Figure 1D (yellow and green). Activity in bilateral hippocampi, parahippocampal gyri, occipital cortices (BA 17, 18, 19), posterior insula, anterior cingulate cortices (BA 32, 34), posterior cingulate cortices (BA 23, 31), PCu (BA 7), inferior parietal lobes (BA 39) was highly correlated with activity in PCu (P < 0.05, corrected for whole-brain multiple comparisons for whole-brain at the voxel level (P < 0.05). (D) A map of mean z value of correlation (z > 0.3) using activated regions in PCu and left IPS.
Functional Segregations of the Two Pathways in Anatomical and Functional Connectivity

The terminal points of reconstructed fibers from IPS and PCu exhibited very little overlap (11.0% compared with the total terminal points from IPS, or 3.3% compared with those from PCu; using a threshold of 5 subjects). Functional connectivity (at the threshold of $P < 0.05$, corrected for multiple comparisons for a whole brain at voxel level) also exhibited little overlap (5.68% compared with all the correlated areas of IPS, and 3.58% compared with those from PCu; using a threshold of $5$ subjects). The activity in bilateral frontal operculum (BA 47), IPS (BA 7), inferior parietal lobes (BA 39, 40), superior parietal lobes (BA 7), supplementary motor area (BA 8), PCu (BA 7), middle frontal gyrus (BA 8), left MTG (BA 21, 37), inferior frontal gyrus (BA 44), superior frontal gyrus (BA 6) was highly correlated with activity in the left IPS ($P < 0.05$, corrected for multiple comparisons at voxel level).

Table 1

<table>
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<th>Cluster size</th>
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<th>Coordinate (mm)</th>
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Note: Regions activated in the comparison “Hits versus Correct rejections.” Only clusters with a significant activity of $P < 0.05$ corrected for whole-brain multiple comparisons are reported. The coordinates and their $T$ values are at the peak voxels in each cluster, and the coordinates and approximate BA are indicated in the Talairach and Tournoux atlas space. 1 voxel = 8 mm$^3$.

Segregations of the Two Pathways in Anatomical and Functional Connectivity

The patterns of activity in the clusters in the left MTG and parahippocampal gyrus depend on the memory performance of the subjects (Hits, Misses, False alarms, and Correct rejections). These clusters were defined by functional connectivity analysis with the IPS and the PCu, respectively. For the MTG (Fig. 2C), $F_{1,05} = 4.66, P = 0.0018$, and there were significant differences between Misses and False alarms, and Misses and Correct rejections (Tukey’s $t$-test $P < 0.05$). For the parahippocampal gyrus (Fig. 2D), $F_{1,95} = 3.6, P = 0.009$, and there were significant differences between Misses and False alarms, and Misses and Correct rejections (Tukey’s $t$-test $P < 0.05$). Correlations between the $z$-scores for functional connectivity and success rates (Buchel et al. 1999; Hampson et al. 2006) were also examined across all the subjects ($n = 20$). The functional connectivity between IPS and MTG was positively correlated to success rates ($r = 0.63, P = 0.0028$) and that between PCu and MTL was negatively correlated to success rates ($r = -0.7167, P = 0.004$, see also Supplementary Fig. S1). Thus, the MTG and parahippocampal gyrus show a similar pattern of activity to the IPS and PCu, which suggests that the connections between the IPS and MTG and that between PCu and parahippocampal gyrus are involved in successful memory retrieval.

Discussion

The major goal of this study was to examine memory-related function of the parietal cortex and its connectivity with the temporal lobe. Using a combination of DTI tractography and functional connectivity analyses, we demonstrated that the lateral parietal region (IPS) is connected with the lateral temporal cortex (MTG), and the medial parietal region (PCu) is connected with the MTL (hippocampus/parahippocampal gyrus). The pattern of activity in memory retrieval conditions also showed a similar dissociation between the parietal and temporal cortices. The IPS region had more activity than PCu in the “Hit,” “Correct rejection,” and “False alarm” compared with “Control” conditions, but not in the “Miss” compared with “Control” condition. These differences were observed in all areas dissociated by the functional connectivity analyses. Our
results suggest that IPS and PCu regions contribute differentially to successful episodic memory retrieval through dissociated pathways.

Comparison with Previous Human and Animal Studies of Anatomical Connections

Intraparietal Sulcus
Nonhuman primate studies showed that the inferior bank of IPS has connections with the lateral temporal cortex, especially with the superior temporal sulcus (STS), inferior temporal (IT) cortex, and the surrounding areas (Neal et al. 1988; Cavada and Goldman-Rakic 1989; Neal et al. 1990). STS is a multimodal region in monkeys, and is thought to be a homolog to human lateral temporal regions (Pandya and Kuypers 1969; Seltzer and Goldman-Rakic 1989; Neal et al. 1990). These observations are in agreement with our current tractography results. Our results also showed anatomical connections between PCu and MTL. In nonhuman primates, some studies reported connections between PCu and MTL (Cavada and Goldman-Rakic 1989; Kobayashi and Amaral 2003). Our ROI in the PCu for the tractography analyses might have a small overlap with the posterior cingulate cortex (Fig. 1A).

Role of the Parietal Cortex in Episodic Memory Retrieval
In this study, we found anatomical connections and functional connectivity between IPS and a lateral temporal region, and between PCu and MTL. MTL has been implicated in recollection of past episodes (Aggleton and Brown 1999, Eldridge et al. 2000; Takahashi et al. 2002; Yonelinas 2002; Yonelinas et al. 2005) and relational processing (Cohen and Eichenbaum 1993; Squire 1994; Henke et al. 1999; Davachi and Wagner 2002; Giovanello et al. 2004; Preston et al. 2004; Prince et al. 2005; Konishi et al. 2006). On the other hand, the lateral temporal cortex has been implicated in nonrelational item-based memory (Wiggs et al. 1999; Lee et al. 2002; Konishi et al. 2006). Our results in the current study suggest that IPS is related to successful retrieval of items' information stored in the lateral temporal cortex, and PCu has interactions with MTL to recall relational information. Specific functional connectivity between prefrontal areas (DLPFC/VLPFC) and IPS reinforces the suggestion. We showed higher activity with successful memory performance in MTL and MTG. Furthermore, functional connectivity between IPS and MTG was positively correlated to success rates, whereas that between PCu and MTL was negatively correlated to success rates. The positive correlation of success rates to the functional connectivity between IPS and MTG may indicate that this connectivity is important to successfully recognize previously presented items. Interestingly, success rates were negatively correlated to the functional connectivity between PCu and MTL. This may suggest that relational memory is recruited when subjects were not confident about their judgments. In other words, when IPS failed to retrieve items' information stored in the lateral temporal cortex, PCu might try to retrieve relational memory stored in MTL. Although these results suggest the functional dissociation of the lateral and medial parietal lobes in episodic memory retrieval, further studies are needed to clarify the role of the parietal cortex in episodic memory retrieval.
memory retrieval, further direct evidence to show the detailed roles in these 2 regions remains for future challenges.

Supplementary Material
Supplementary material can be found at: http://www.cercor.oxfordjournals.org/

Funding
National Institutes of Health (NS44825); the Human Frontiers Science Program; and the Uehara Memorial Foundation (Japan) supported E.T.

Notes
We gratefully acknowledge Jeff Thompson, Robert Levy, and Szymon Mikulski for their helpful editorial comments. Conflict of Interest: None declared.

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