

Left posterior parietal cortex participates in both task preparation and episodic retrieval

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ABSTRACT

Optimal memory retrieval depends not only on the fidelity of stored information, but also on the attentional state of the subject. Factors such as mental preparedness to engage in stimulus processing can facilitate or hinder memory retrieval. The current study used functional magnetic resonance imaging (fMRI) to distinguish preparatory brain activity before episodic and semantic retrieval tasks from activity associated with retrieval itself. A catch-trial imaging paradigm permitted separation of neural responses to preparatory task cues and memory probes. Episodic and semantic task preparation engaged a common set of brain regions, including the bilateral intraparietal sulcus (IPS), left fusiform gyrus (FG), and the pre-supplementary motor area (pre-SMA). In the subsequent retrieval phase, the left IPS was among a set of frontoparietal regions that responded differently to old and new stimuli. In contrast, the right IPS responded to preparatory cues with little modulation during memory retrieval. The findings support a strong left-lateralization of retrieval success effects in left parietal cortex, and further indicate that left IPS performs operations that are common to both task preparation and memory retrieval. Such operations may be related to attentional control, monitoring of stimulus relevance, or retrieval.

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Previous memory research has demonstrated that a person's attentional state during memory retrieval can affect the success and efficiency of retrieval. Attentional states conducive to episodic retrieval in general, or to specific retrieval conditions, have been referred to as *retrieval mode* and *retrieval orientations*, respectively (Nyberg et al., 1995; 2000). Neuroimaging findings suggest that preparatory cues indicating the nature of retrieval operations to be performed can facilitate the adoption of a retrieval mode or appropriate retrieval orientations (Herron and Wilding, 2004; Rugg and Wilding, 2000; Woodruff et al., 2006). Preparation for retrieval can be interpreted in terms of task-level rules and strategies: when cues provide no information about specific retrieval targets, subjects can prepare by bringing to mind the decision criteria required by the task, response options, and useful criteria for filtering information in memory. Task-level control processes can be difficult to dissociate from stimulus-level retrieval processing, since the two occur in conjunction.

Much of the neuroimaging evidence supporting task-level preparation for memory retrieval comes from studies of event-related potentials (ERPs). These studies have demonstrated that cues signaling episodic and semantic retrieval tasks produce differential

patterns of brain activity (Duzel et al., 1999; Herron and Wilding, 2004; Morcom and Rugg, 2002), supporting the hypothesis that subjects adopt an appropriate retrieval mode prior to an act of retrieval. Preparatory brain activity not only differs between episodic and semantic retrieval, but also between different episodic retrieval tasks (Dobbins and Han, 2006; Herron and Wilding, 2006; Werkle-Bergner et al., 2005).

To date, the number of functional magnetic resonance imaging (fMRI) studies investigating preparatory processes in episodic retrieval has been relatively small. While studies using fMRI and positron emission tomography (PET) have linked sustained brain activity during episodic retrieval with the concept of a retrieval mode (Buckner et al., 1998b; Duzel et al., 1999; Lepage et al., 2000; Nyberg et al., 1995; Velanova et al., 2003), these studies have not distinguished initial preparation for retrieval from the effects of repeated task performance. Other fMRI investigations (e.g., Dobbins and Han, 2006) have distinguished between early preparation and later retrieval phase processing in episodic retrieval. The current study thus investigates brain activity associated with preparation for episodic vs. non-episodic retrieval tasks, in order to identify neural mechanisms which may be involved in the initial adoption of an attentional state appropriate to episodic retrieval.

In the current paradigm, we used a catch-trial fMRI design (Ollinger et al., 2001a; Ollinger et al., 2001b; Shulman et al., 1999;

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Wheeler et al., 2006) to temporally dissociate brain activity related to task vs. memory retrieval. During scanning, participants alternated semi-randomly between old/new recognition memory trials (episodic retrieval) and living/non-living decision trials (semantic retrieval). Preparatory phase brain activity was associated with the presentation of task cues which provided no information about upcoming memory probes, but which communicated task-level information about response options and decision criteria (Fig. 1). In contrast, retrieval phase brain activity was associated with the presentation of memory probes and the subsequent behavioral response. Processing during this period is likely to include brain activity directly related to memory retrieval, as well as general attentional control processes involved in goal maintenance, decision making, and response selection and execution.

We reasoned that attentional control regions involved in task preparation should exhibit robust responses to preparatory cues. We hypothesized that preparation would modulate activity in parietal and posterior temporal areas that have been found to be responsive during preparation to retrieve sensory-specific information (Wheeler et al., 2006) and to make sensory discriminations (Shulman et al., 1999). Additionally, we sought to separate retrieval phase activity related to attentional control vs. memory retrieval by its sensitivity to old/new stimulus differences. Regions involved in putative retrieval processing should be sensitive to the study history of stimuli (Donaldson et al., 2001a) and should exhibit differential responses to previously studied and new items. In contrast, regions involved in post-stimulus attentional control processes would be insensitive to study history.

Materials and methods

Participants

Participants were nineteen right-handed native English speakers with normal or corrected-to-normal vision (10 female, mean age 25 years). All participants underwent screening for conditions which would preclude behavioral participation or present a hazard for participation in an MRI experiment. Four participants were excluded due to excessive head motion (greater than 3 mm), failure to complete the study, or scripting errors. Three additional participants were excluded due to chance-level performance in the old/new recognition task. All remaining participants ($n = 12$) provided 8–10 runs of data, depending upon available time. The participants gave informed consent as required by the Institutional Review

Board of the University of Pittsburgh and were paid \$75 for their participation.

Materials

Stimuli were 480 English nouns obtained from the MRC Psycholinguistic Database (http://www.psy.uwa.edu.au/mrcdatabase/uwa_mrc.htm). Stimuli were between 4 and 8 letters in length, with Kucera–Francis written frequencies (Kucera and Francis, 1982) from 1 to 787 instances per million. The stimulus set was divided into 240 words representing living things (mean frequency = 34 instances/million) and 240 words representing non-living things (mean frequency = 48 instances/million). For each participant, we created a study list of 192 words, randomly selected in equal proportions from the “living” and “non-living” lists. These words were considered old items during the scanned retrieval tests. A second list of 192 randomly selected words, also comprising equal numbers of living and non-living items, formed the set of new items. In both the episodic and semantic tasks, equal proportions of old and new items were presented. The proportion of living vs. non-living items was likewise balanced in each task. Order of stimulus presentation was randomly determined. Words were displayed in capital letters in 12-point black Helvetica font on a white background.

Experimental paradigm

The scanned test phase used a fast event-related task-cueing paradigm in which the participants engaged in pseudorandomly ordered trials of episodic (old/new recognition memory) and semantic (living/non-living) retrieval tasks. For each subject, 10 runs of 177 image acquisitions each were prepared. The factors of task (episodic or semantic judgment), animacy (living or non-living word), and study history (old or new word) were orthogonally manipulated to yield 4 trials per run of each combination of factors. In all experimental trials, the participants saw a centrally-presented task cue (“OLD OR NEW” or “LIVING OR NON”) for 500 ms, followed by 1500 ms of central fixation before the appearance of the probe word (Fig. 1). Each probe word appeared on screen for 500 ms, followed by 3500 ms of fixation, during which subjects were to respond. At the end of this period, the fixation cross turned red for 500 ms to indicate the end of the trial. These “compound” (preparatory cue + memory probe) trials comprised 80% of experimental trials. Compound trials were pseudorandomly intermixed with “catch” trials (Fig. 1), in which a task

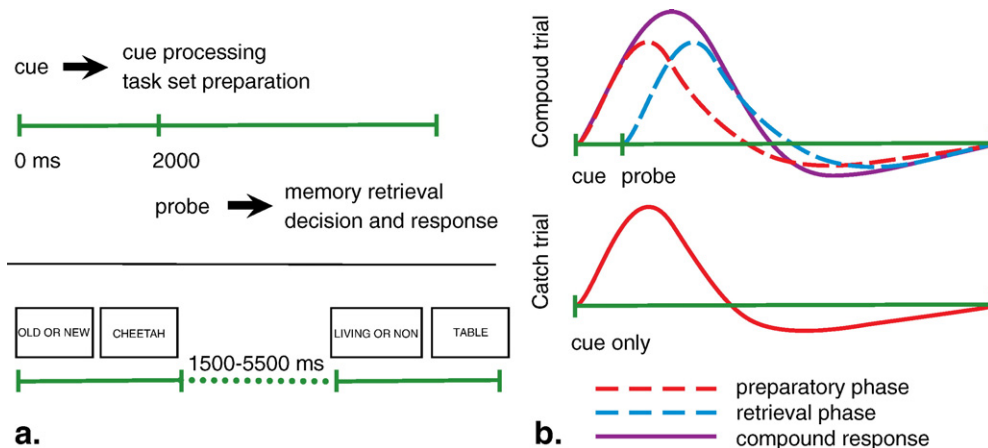


Fig. 1. Top: Overview of trial structure and hypothesized cognitive processes engaged by task preparation and performance. In the preparatory phase, the participants were shown either an episodic (“OLD or NEW”) or semantic (“LIVING or NON”) task preparatory cue for 500 ms, followed by a constant fixation interval of 1500 ms. Preparatory activity is thought to reflect cue processing and task-level preparation, including self-reminding of task goals, decision criteria, and response options. Retrieval phase activity is associated with search of and retrieval from declarative memory, as well as decision making and response processes. Bottom: Neural responses to preparatory cues and memory probes were independently modeled using a catch-trial design. Compound trials (preparatory cue + memory probe) comprise 80% of trials; catch trials (cue only) comprise 20%. Inclusion of catch trials allows sufficient variability to separate cue and probe responses in GLM analysis (Ollinger et al., 2001a, b; Shulman et al., 1999; Wheeler et al., 2006).

cue was followed by 1500 ms of fixation and the trial-end signal (red fixation cross), without the intervening presentation of a test item. Catch trials allowed separation of hemodynamic responses associated with preparatory and retrieval phases of experimental trials (Ollinger et al., 2001a,b; Shulman et al., 1999; Wheeler et al., 2006). Four episodic-cue and four semantic-cue catch trials were included in each run. This proportion is within the range recommended by Ollinger and colleagues (2001a). The pseudorandom ordering of conditions was determined using an automated algorithm which ensured that a given trial type was equally likely to be preceded by all other trial types (Buckner et al., 1998a). To allow deconvolution of the hemodynamic response, randomly distributed inter-trial intervals (ITIs) of 1500, 3500, and 5500 ms were used; the distribution of these ITIs was exponential, with more ITIs of shorter duration (Dale, 1999).

Image acquisition

All images were acquired on a 3-Tesla Siemens Allegra magnet at the University of Pittsburgh's Brain Imaging Research Center. Prior to functional imaging, a T1-weighted high-resolution magnetization prepared rapid gradient echo (MP-RAGE) image (192 parasagittal slices; 1 mm³ voxels; repetition time (TR) = 1540 ms; echo time (TE) = 3.04 ms; flip angle = 8°; inversion time = 800 ms) and a T2-weighted in-plane anatomical image (35 oblique axial slices parallel to the anterior–posterior commissure (AC–PC) line; in-plane resolution = 0.8 mm × 0.8 mm; slice thickness = 3.2 mm; TR = 5780 ms; TE = 73 ms; flip angle = 150°) were acquired. Functional images were collected with a T2*-weighted echo-planar pulse sequence sensitive to blood oxygenation level-dependent (BOLD) contrast (Kwong et al., 1992; Ogawa et al., 1992) in the same orientation as anatomical images (in-plane resolution = 3.2 × 3.2 mm; slice thickness = 3.2 mm; TR = 2000 ms; TE = 30 ms; flip angle = 79°). The first five image acquisitions per run were discarded to allow net magnetization to reach steady state. No trials were performed during the last nine image acquisitions of each run, allowing time for the BOLD response to return to baseline.

Procedure

Prior to the scanning session, the participants studied a list of 192 words, which they were instructed to remember for an upcoming memory test. Words were presented serially on a computer monitor for 3 s each, and the participants were told that they would not be asked to recall the order of presentation, only whether a word had been studied or not. After each word disappeared from the screen, the participants pressed the space bar to advance to the next word. Following the study session, a full explanation of the episodic and semantic tasks was given, and the participants performed a brief practice block using words from outside the experimental set. In the practice session, the participants were instructed to pay attention to the task cue on each trial and to respond by making one of two keypresses (old/living or new/non-living). The participants were informed beforehand of the occurrence of catch trials and the reason for their inclusion.

Scanning began approximately 45 min after study and instruction phases. Stimuli were presented using PsyScope X (Cohen et al., 1993; <http://psy.ck.sissa.it>) on a Macintosh PowerBook G4, and were projected from the rear of the scanner to a mirror positioned above the participants' eyes. The participants held a button stick in either their left or right hand and were instructed to respond by pressing the index or middle finger buttons. Response hand was counterbalanced across the participants. In all cases, the index-finger button corresponded to living and old responses, while the middle-finger button corresponded to non-living and new responses. Old and new items were sampled in a 1:1 ratio. The factor of study history was thus controlled during semantic retrieval, and the participants had the opportunity to make the same number of hits and correct rejections in

the episodic task. Data were scored for accuracy and assigned to separate conditions based on study history (old, new), task (episodic, semantic), and accuracy (correct, incorrect). Trials with RTs < 300 ms were discarded from behavioral analysis.

Functional MRI data analysis

The participants' imaging data were corrected for head motion within and across runs using a rigid-body algorithm with 3 translational and 3 rotational parameters (Snyder, 1996). Whole-brain adjustment normalized the modal voxel value for all the participants to a value of 1000 to facilitate comparison between datasets (Ojemann et al., 1997). A sinc interpolation corrected for between-slice differences in acquisition time, re-aligning all slices to the first slice. Data were resampled into 2 mm isotropic voxels and transformed to the Talairach and Tournoux (1988) reference space.

Data were analyzed at the voxel level using a general linear model (GLM) (Friston et al., 1994; Miezin et al., 2000). Analysis was performed using the FIDL software package, developed at Washington University, St. Louis (Miezin et al., 2000; Ollinger et al., 2001a). GLMs for each participant were smoothed with a 4 mm Gaussian filter. For each run, a trend term was used to regress out the influence of scanner signal drift over each term, while a constant term modeled the baseline signal. Timecourses for each condition of interest were estimated by a deconvolution analysis, which makes no assumptions regarding the shape of the hemodynamic response.

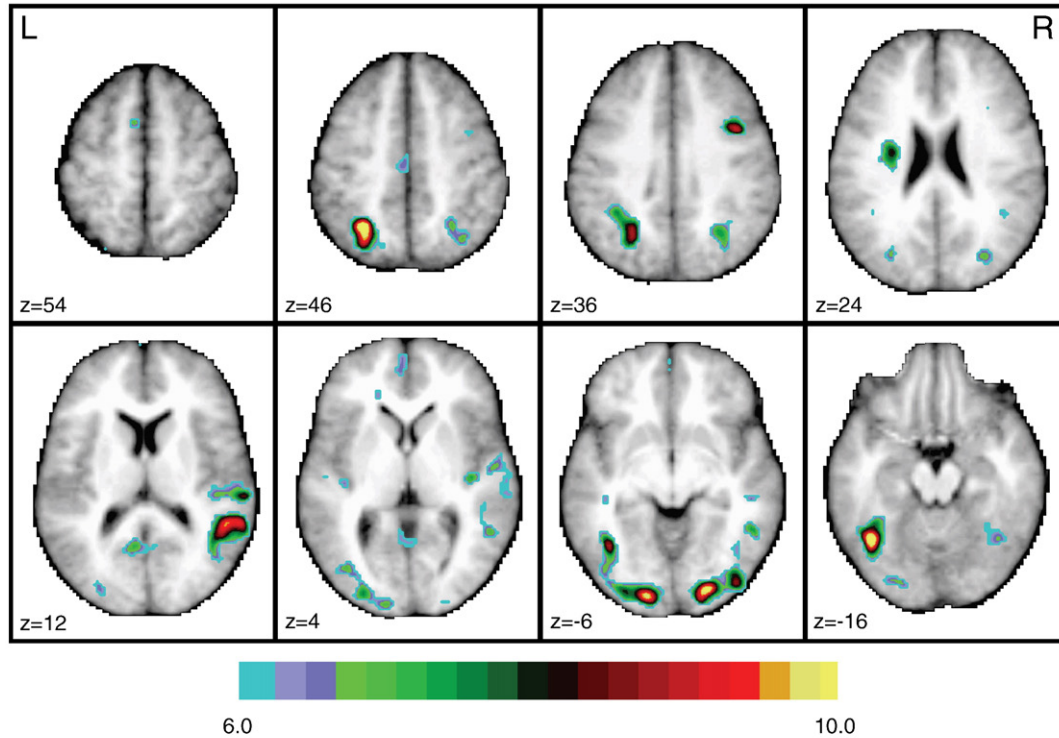
BOLD responses to preparatory cues and memory probes (Fig. 2) were modeled separately using the method described by Wheeler et al. (2006). Preparatory responses were time-locked to the onset of task cues and coded into the GLM design matrix with a series of 10 delta functions, one for each functional volume collected in the 20 s following onset of the preparatory cue. To obtain an estimate of the preparatory phase response, catch-trial cues were coded together with cues occurring in compound trials. Retrieval phase responses were time-locked to the onset of memory probes and were coded with a series of 9 delta functions, comprising 9 functional volumes (18 s) after the onset of test words. On compound trials, in which preparatory cues were followed by memory probes with a stimulus-onset asynchrony of 2 s, modeling of the preparatory phase response thus began 1 TR before modeling of the retrieval phase response.

While the cue-probe interval was held constant, between-trial intervals varied between 1500 and 5500 ms (Fig. 1). By jointly including catch trials and jittering inter-trial intervals, we created sufficient variability to allow independent estimation of preparatory and retrieval phase responses. GLM coding distinguished episodic and semantic preparatory cue responses; retrieval phase responses were sorted by retrieval task, study history of memory probes (old vs. new), animacy of the probe's referent (living vs. non-living), and response accuracy (correct vs. incorrect).

Analysis of preparatory phase timecourses

Analysis of preparatory phase conditions aimed to identify regions involved in task preparation. Data from the preparatory phase were entered into a 2 × 10 voxelwise repeated measures ANOVA, with two levels of cue type (episodic, semantic) and 10 levels of time. Subject was treated as a random effect. This analysis produced a main effect of time image, identifying voxels in which brain activity significantly changed from baseline, independently of cue type, over the ten volumes of the preparatory phase timecourse. The analysis also produced an interaction of cue type by time image, which identifies voxels in which activity differs over time as a function of cue type. To identify voxels involved in task preparation, independently of task, we examined regions of interest (ROIs) from the preparatory phase main effect of time map. Because the main effect of time image was associated with a large number of highly reliable voxels, we defined

a. Preparatory phase



b. Retrieval phase

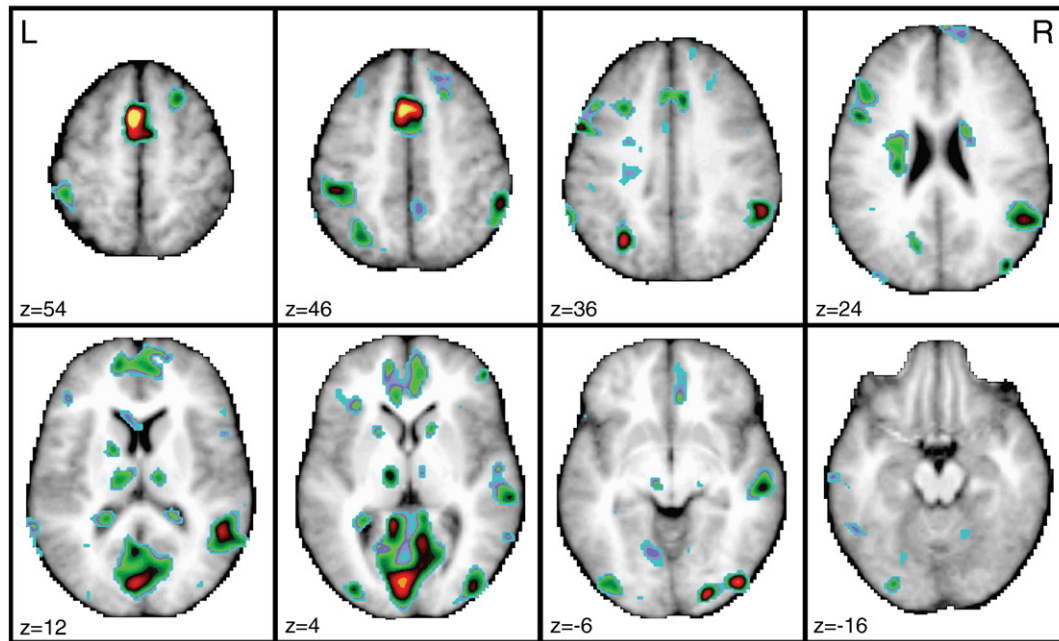


Fig. 2. Main effect of time maps from preparatory (top) and retrieval (bottom) phases of experimental trials, indicating regions in which activity significantly changed from baseline. Maps shown are uncorrected for multiple comparisons and thresholded at $z > 6.0$. Regions of interest were defined by masking the uncorrected main effect of time maps with Monte Carlo-corrected, sphericity-adjusted versions of same to exclude peaks which did not meet a corrected alpha level of 0.05.

ROIs by applying a conservative threshold of $z > 6.0$ and masking out voxels that did not surpass sphericity and multiple comparisons corrections. The more conservative threshold was helpful because it reduced the number of regions to a manageable level. The multiple comparisons correction employed a minimum cluster extent of 45 voxels to achieve an adjusted alpha level of $p < 0.05$, based on previous Monte Carlo simulations conducted by McAvoy et al. (2001). An automated algorithm was used to define ROIs around local maxima.

Peaks separated by less than 10 mm were consolidated into the same region of interest. ROIs included voxels which fell within a 10 mm radius of a peak. Region coordinates are listed in Table 4.

Given past observations of both memory-related effects and attentional modulations in posterior parietal cortex (Astafiev et al., 2003; Cabeza et al., 2008; Corbetta et al., 2000; Corbetta and Shulman, 2002; Henson et al., 1999; Konishi et al., 2000; Wagner et al., 2005; Wheeler and Buckner, 2003, 2004; Woodruff et al.,

2005; Yonelinas et al., 2005), we selected 4 regions in bilateral intraparietal sulcus (IPS) for further analysis: in the left hemisphere, preparatory cues significantly modulated activity in the anterior ($x = -34, y = -47, z = 37$; BA 7/40) and middle ($x = -27, y = -58, z = 43$; BA 7/40) IPS; in the right hemisphere, robust responses were observed in the middle ($x = 29, y = -62, z = 37$; BA 7/19) and posterior IPS ($x = 32, y = -64, z = 47$; BA 7). Because sensitivity to the cued task would suggest candidate regions supporting task set preparation and implementation, we identified additional regions of interest from the main effect of time image that were differentially modulated by episodic and semantic preparatory cues. For each region, preparatory cue differences were assessed over volumes at timepoints 4–6 (8–12 s from preparatory cue onset), corresponding to the estimated peak of the hemodynamic response across all conditions. Statistical significance was tested using a single-factor ANOVA and an alpha level of 0.05. Regions displaying significant cue type differences were selected for further analysis.

Analysis of retrieval phase timecourses

We additionally aimed to identify regions which were engaged by episodic and semantic retrieval. We reasoned that brain areas which were sensitive to the content of episodic memory would exhibit differential responses to old and new memory probes. To generate maps, a $2 \times 2 \times 9$ voxelwise repeated measures ANOVA was performed on task phase data, with two levels of task (episodic, semantic), two levels of study history (correct old, correct new) and 9 levels of the repeated measure time. This analysis produced a set of main effect and interaction images. We used the main effect of time image to identify regions (see *Materials and methods* in previous section) which responded only during the retrieval phase, and which were thus unaddressed by analysis of preparatory phase timecourses. In selecting preparatory and retrieval phase ROIs for further analysis and presentation, we compared voxel overlap between the two sets of regions by computing a union mask of preparatory and retrieval phase ROIs. Based on this qualitative assessment, preparatory and retrieval phase ROIs reported below did not spatially overlap with one another.

ROIs were submitted to a 2×2 ANOVA, including the factors of task (episodic/semantic) and stimulus study history (old/new). As in preparatory phase analysis, significance tests employed an alpha level of 0.05 and were performed on the average response over volumes 4–6 of retrieval phase timecourses (8–12 s from memory probe onset). Only correct trials were included in retrieval phase analysis, since error trials might correspond to periods of inattention, confusion about task demands, or motor error.

Results

Behavioral results

Relatively high accuracy rates in both episodic and semantic retrieval tasks (Table 1) indicate that subjects attended to preparatory cues, as required by the experimental paradigm. The participants performed near-ceiling in the living/non-living task: accuracy in all stimulus categories was greater than 90%, and an ANOVA including the factors of animacy (living, non-living) and study history (old, new) returned no significant effects. The few errors committed in semantic retrieval may reflect either uninten-

Table 1
Accuracy rates for episodic and semantic tasks.

	Episodic task		Semantic task	
	OLD	NEW	LIVING	NON-LIVING
Mean acc. (%)	81	72	96	94
Std. dev.	15	22	3	4

Table 2
Response times for episodic and semantic tasks.

	Episodic task				Semantic task (correct trials)			
	OLD		NEW		OLD		NEW	
	Correct	Inc.	Correct	Inc.	Living	Non	Living	Non
Mean RT (ms)	1516	1856	1775	1914	1334	1351	1318	1303
Std. dev.	282	324	408	538	252	205	280	226

Notes: Inc. = incorrect; Non = non-living.

tional button-presses or responses to ambiguous stimuli (e.g., body parts, or words which could indicate either animals or food products). In the episodic task, the participants reliably discriminated between old and new words in the episodic task, with a mean d' of 1.6. Overall, the participants recognized 81% of old words, while correctly rejecting 72% of new words. This apparent effect of study history was non-significant [$F(1,11) = 1.369, p < 0.3$]. The main effect of animacy [$F(1,11) = 4.608, p < 0.06$] and the interaction of animacy with study history [$F(1,11) = 3.572, p < 0.09$] were marginal but non-significant.

Mean response times for both tasks are shown in Table 2. Given the participants' near-ceiling performance in the semantic task, only RT data for correct trials were subsequently analyzed in this task. Neither old/new differences [$F(1,11) = 2.744, p < 0.1$] nor living/non-living differences [$F(1,11) = 0.001, p < 0.98$] had a significant main effect on semantic task response times. The interaction of study history and animacy approached, but did not achieve, statistical significance [$F(1,11) = 0.980, p < 0.1$]. Similarly, in episodic task RT data, no main effect of animacy and no interactions involving animacy were found. The factor of animacy was thus dropped from subsequent analysis. While accuracy data had revealed no significant effect of study history, RT data indicated that recognition decisions to old items were significantly faster than those to new items [$F(1,11) = 6.1, p < 0.05$]. A significant effect of response accuracy on RT was also found [$F(1,11) = 11.4, p < 0.01$], indicating that the participants responded more quickly on correct than incorrect trials. No interaction between the factors of study history and response accuracy was found [$F(1,11) = 3.2, p < 0.1$].

The maintenance of discrete task sets was partially corroborated by a response congruency analysis. This analysis tests for evidence of irrelevant stimulus processing by contrasting RTs for trials in which old/new and living/non-living decisions would elicit the same motor response with RTs for trials in which the two tasks would have required incongruent responses. The difference between congruent and incongruent trial RTs is interpreted as a measure of the degree to which the uncued task set intrudes upon performance of the cued task. When cued to perform old/new judgments, for example, the participants might respond more slowly to stimuli which were old (index finger response) and non-living (middle finger) than to stimuli which were old and living (i.e., when both features map to index finger response). Such RT differences would suggest that processing related to the irrelevant task had created interference in performance of the cued task.

Mean RTs for congruent and incongruent trials in each task are given in Table 3. An ANOVA indicated a significant main effect of congruency [$F(1,11) = 5.7, p < 0.05$], as well as a significant interaction of task and congruency [$F(1,11) = 5.7, p < 0.05$]. While congruent-response trials in both tasks produced shorter mean RTs than in

Table 3
Response congruency analysis of episodic and semantic task RTs.

	Episodic task		Semantic task	
	Congruent	Incongruent	Congruent	Incongruent
Mean RT (ms)	1655	1742	1351	1369
Std. dev.	301	388	230	240

incongruent-response trials, post-hoc *t*-tests indicated that congruency effects were non-significant in the semantic task [$t(11) = 1.1, p < 0.3$]. In contrast, this effect was larger (88 ms) in the episodic task and was statistically significant [$t(11) = 2.6, p < 0.05$]. This asymmetric finding indicates that subjects may have considered animacy-related characteristics of stimuli when cued to perform an old/new decision; however, they only performed old/new decisions when instructed to do so. Given the quickness of living/non-living decisions relative to old/new decisions, subjects may have had time to consider the animacy of the memory probe's referent prior to reaching a recognition memory decision. However, a null effect of congruency in semantic trial RTs suggests that when performing living/non-living decisions, the participants experienced no interference based on consideration of a memory probe's study history. Accordingly, the episodic task may not be 'process pure' because subjects may have also made semantic decisions on episodically cued trials.

Imaging results

Preparatory phase effects

The preparatory phase main effect of time map (Fig. 2) revealed widespread, bilateral modulation by preparatory cues. Table 4 lists the peak coordinates of 30 regions displaying the most robust preparatory responses. A full list of regions identified by the main effect of time analysis may be obtained from the authors. Activity encompassed multiple peaks in primary visual, extrastriate, and posterior parietal cortices, as well as midline frontal areas. Notably, several of these peaks correspond to putative loci of attentional or cognitive control, including bilateral intraparietal sulcus (IPS), pre-supplementary motor area (pre-SMA), fusiform gyrus (FFG), and anterior insula (AI). Remarkably similar patterns of activation are reported in Dosenbach et al.'s, (2007, 2006) investigations of dynamic and stable task set control, as well as Chein and Schneider's (2005) meta-analytic study of control networks modulated by learning. Preparatory cues

Table 4
Regions defined from preparatory phase main effect of time map.

Region	BA	x	y	z	Z-score	Cluster size
L fusiform gyrus	37	-39	-60	-15	11.1	472
L middle IPS	7/40	-27	-58	43	11	497
R inferior occipital gyrus	18	22	-88	-6	10.3	495
R superior temporal gyrus	22	51	-45	15	10.3	486
L inferior occipital gyrus	17	-16	-91	-9	10.2	439
R precentral gyrus	9	38	4	35	9	487
R inferior occipital gyrus	19	39	-82	-6	8.7	470
L inferior occipital gyrus	18	-29	-89	-9	8.5	411
R superior temporal gyrus	42	60	-29	12	8.4	418
L insula	13	-27	-13	23	8.3	460
R fusiform gyrus	37	40	-62	-11	7.9	437
R claustrum	13	38	-19	1	7.7	294
R middle IPS	7/19	29	-62	37	7.7	417
L middle occipital gyrus	18	-28	-85	6	7.6	438
L fusiform gyrus	37	-34	-49	-19	7.5	337
L ant. IPS	7/40	-34	-47	37	7.5	453
R middle temporal gyrus	37	49	-51	-6	7.4	398
R middle temporal gyrus	21	48	-32	-2	7.4	404
R middle temporal gyrus	19	41	-59	11	7.4	481
L post. cingulate	30	-6	-60	14	7.2	457
L inferior occipital gyrus	19	-39	-76	0	7.2	463
R superior temporal gyrus	22	58	-13	3	7	428
R precuneus	31	29	-74	25	7	377
L claustrum	13	-38	-23	2	6.9	287
L precuneus	31	-28	-73	24	6.9	336
R post. IPS	7	32	-64	47	6.9	352
R trans. temporal gyrus	41	44	-25	10	6.8	395
pre-SMA	6	-8	6	54	6.8	256
R cerebellum	*	32	-60	-20	6.6	399
L paracentral lobule	31	-2	-18	45	6.6	383

Notes: L = left; R = right; ant. = anterior; post. = posterior; IPS = intraparietal sulcus; trans. = transverse; x, y, z = Talairach atlas coordinates; cluster size in voxels ($2 \times 2 \times 2$).

signaling episodic and semantic retrieval thus appear to evoke activity in domain-general control areas.

Differential modulation by episodic and semantic preparatory cues was observed in pre-SMA, left anterior IPS, left FFG, and right precuneus (Fig. 3, top row; see Table 6 for statistical results), indicating that these regions were sensitive to the cued task. Preparatory responses in the right middle and posterior IPS (Fig. 3, bottom right) exhibited a similar response pattern, but in these regions preparatory cue differences were non-significant or marginally significant. Preparatory responses in left middle IPS (Fig. 3, bottom left) were robust but equivalent for both cue types. Surprisingly, in regions showing effects of cue type, semantic task cues elicited larger responses than episodic cues. This finding is counterintuitive, given the relative difficulty of episodic retrieval and the involvement of posterior parietal and medial frontal brain regions in prior studies of episodic retrieval. Nevertheless, episodic task cues produced robust modulation from baseline in all of the regions detailed in Fig. 3, suggesting their importance in episodic task preparation.

One possible explanation for our finding that semantic cues elicited more activity than episodic cues is that the analysis combined trials in which subjects have just performed the same task on the previous trial (stay trials) and trials in which they have just performed the other task (switch trials). There is evidence from ERP studies that preparatory effects take time to manifest in task-switching paradigms, appearing on stay but not on switch trials (Herron and Wilding, 2004; Morcom and Rugg, 2002). To test this possibility we performed the same analysis on stay trials only. In general, the overall pattern of findings in these ROIs was the same on stay trials, with greater activity following semantic than episodic cues (see supplementary text and figure). It is important to note that the paradigm was not optimized for detecting such effects, so we do not view this null result as a robust test of the stay-specific task set effects reported in the literature.

Retrieval phase activity in task preparation regions

We sought to further characterize regions identified through preparatory phase activity by examining their responses during episodic and semantic retrieval. The pre-SMA, left anterior IPS, and left fusiform gyrus (Fig. 3, top row), and left middle IPS (Fig. 3, bottom left) exhibited greater modulation during episodic than semantic retrieval. Because these regions are often reported as being more active in more effortful tasks, this finding is consistent with the premise that the old/new task required subjects to engage in more controlled processing than the living/non-living task. The right middle and posterior IPS also displayed task differences (Fig. 3, bottom right), although these should be interpreted with caution due to apparent baseline differences between timecourses in these regions (note first and last timepoints).

In addition to task differences, both the left anterior and middle IPS exhibited significantly greater responses to correct old than correct new items. Notably, these effects were significant in both episodic [left anterior IPS, $t(11) = 3.2, p < 0.01$; left middle IPS, $t(11) = 2.8, p < 0.05$] and semantic [left anterior IPS, $t(11) = 3.9, p < 0.005$; left middle IPS, $t(11) = 3.1, p < 0.01$] retrieval tasks. The right posterior IPS also displayed a main effect of study history; in this region, old/new differences in the episodic task were significant [$t(11) = 3.2, p < 0.05$], while they were not in the semantic task [$t(11) = 1.4, p < 0.2$]. However, baseline differences between timecourses in this region suggest that old/new effects should be treated with caution. Sensitivity to the study history of memory probes suggests that retrieval phase processing in posterior parietal regions incorporates information from episodic memory.

Although left and right IPS both exhibited positive BOLD modulations in response to preparatory cues, retrieval phase timecourses indicated a dissociation between these two regions. While left anterior and middle IPS exhibited robust increases in activity during

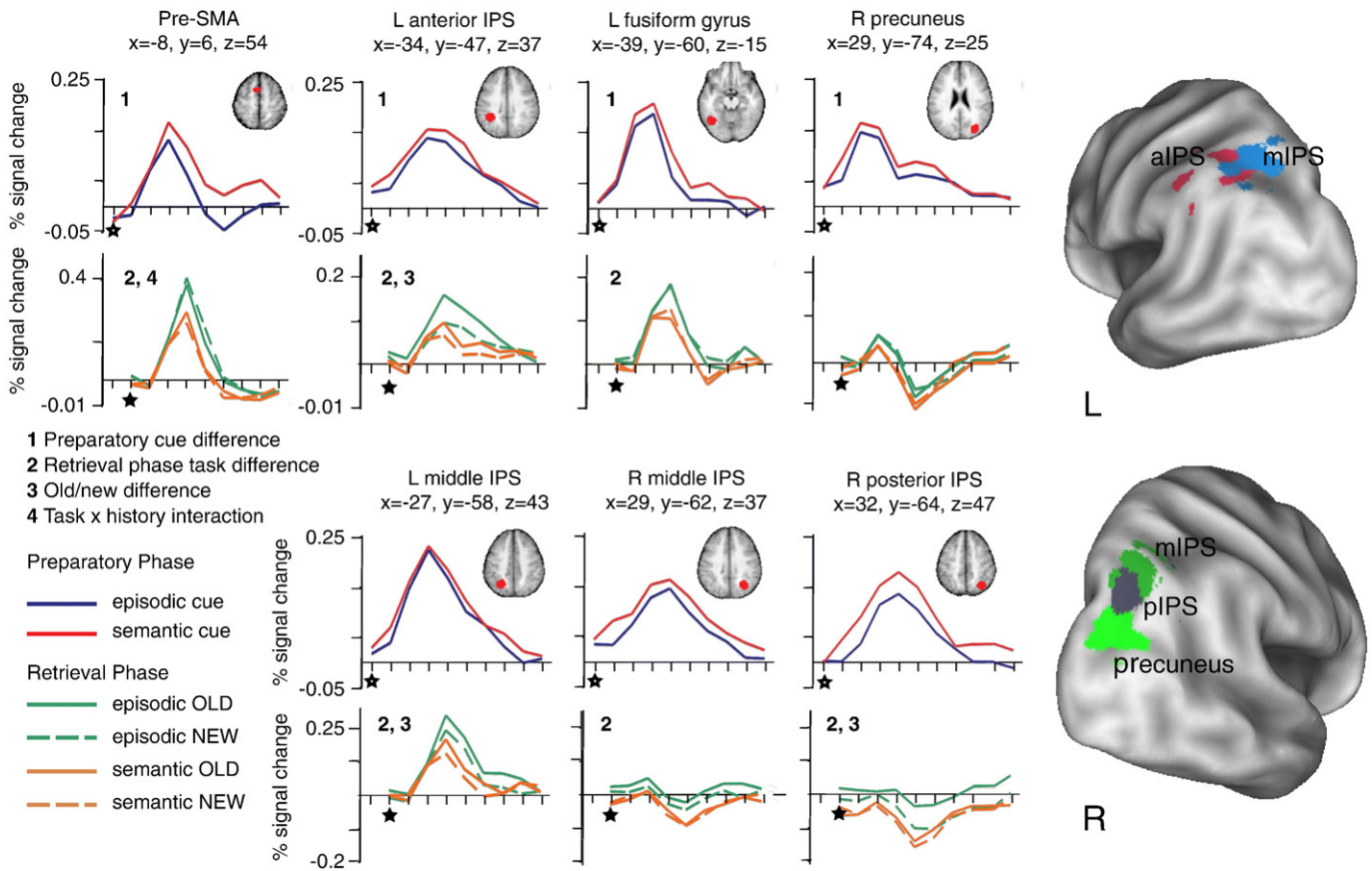


Fig. 3. Regions of interest defined from preparatory phase main effect of time map. Number labels on timecourse plots indicate the occurrence of statistically significant experimental effects (see legend). Top: significant cue type differences were observed in pre-SMA, left anterior IPS, left FFG, and right precuneus (Table 6). In the retrieval phase, pre-SMA, left anterior IPS, and left FFG displayed significant task differences. Left anterior IPS additionally exhibited old/new differences. Bottom: bilateral middle and right posterior IPS likewise displayed robust cue responses, although cue type differences were not statistically significant. All three regions exhibited retrieval phase task differences; additionally, old/new differences were observed in left middle IPS and right posterior IPS. Vertical axis: BOLD signal magnitude as percent change from baseline. Horizontal axis: timecourses extend from 0 to 20 s, beginning from preparatory cue onset; each tick mark corresponds to one 2 s volume of fMRI acquisition. Open stars indicate onset of preparatory cue; closed stars indicate onset of memory probes. Retrieval phase timecourses are based on correct trials only. For visualization purposes, the five parietal ROIs have been projected onto inflated cortical surfaces (Van Essen et al., 2001). Posterior views are displayed in the right panels. Note that contiguous ROIs can become separated in the warping and unfolding procedure. a = anterior, m = middle, p = posterior.

episodic and semantic retrieval, activity in both right IPS foci did not differ consistently from baseline. To obtain statistical confirmation of hemispheric differences in the IPS' retrieval phase response profile, we contrasted the combined response of the two left IPS clusters with the combined response of the two right IPS clusters. A $2 \times 2 \times 2 \times 3$ ANOVA, comprising factors of region (left/right IPS), task, study history, and time (volumes 4–6) yielded a main effect of region [$F(1,11) = 34.9, p < 0.0001$] and an interaction of region \times time [$F(2,22) = 7.1, p < 0.005$]. The heterogeneity of retrieval phase responses in approximate homotopic regions suggests that the role of right IPS in the current paradigm is limited to processing carried out during the preparatory phase of the trial, while left IPS is involved in both preparation and retrieval.

Brain regions responding specifically during retrieval

The retrieval phase main effect of time map (Fig. 2, bottom panel) revealed a spatial distribution of brain activity which partially overlapped with sites of preparatory phase modulation. Table 4 lists the peak coordinates of 30 regions unique to the retrieval phase map. (Lack of overlap with preparatory phase ROIs was initially determined by visual inspection and confirmed by overlaying ROI masks from the two trial phases.) Included are 20 regions displaying the most robust retrieval phase modulation, as well as additional frontoparietal, limbic, and subcortical regions selected on the basis of relevant significant experimental effects. A

full list of regions identified by the main effect of time analysis may be obtained from the authors. Retrieval phase modulation was observed in anterior and posterior precuneus activations near the midline, as well as more lateral activations in the inferior parietal lobule and supramarginal gyrus. Activity was also seen in a number of medial and lateral frontal lobe structures, including left dorsolateral prefrontal cortex (DLPFC) and anterior cingulate.

Effects of study history and task in retrieval phase regions

Old/new effects were observed in several left posterior parietal regions that were undetected by the preparatory phase voxelwise analysis, including ventral and dorsal regions with foci near the precuneus, as well as a region near the left inferior parietal lobule (IPL; see Fig. 4). In all of these regions, preparatory responses were statistically non-significant and insensitive to cue type (Table 6), providing evidence that the function of these regions is limited to processes beginning after onset of the memory probe. As in the left IPS, both precuneus regions exhibited a main effect of study history: old words were associated with significantly greater responses than new words, collapsing across episodic and semantic retrieval tasks (Table 6). Pairwise *t*-tests indicated that in both precuneus foci, old/new differences were significant only in the episodic task [left superior precuneus, $t(11) = 2.5, p < 0.05$; left inferior precuneus, $t(11) = 4.3, p < 0.01$]. In contrast, responses in the IPL were marked by sharp negative transient responses during the retrieval phase; old/new

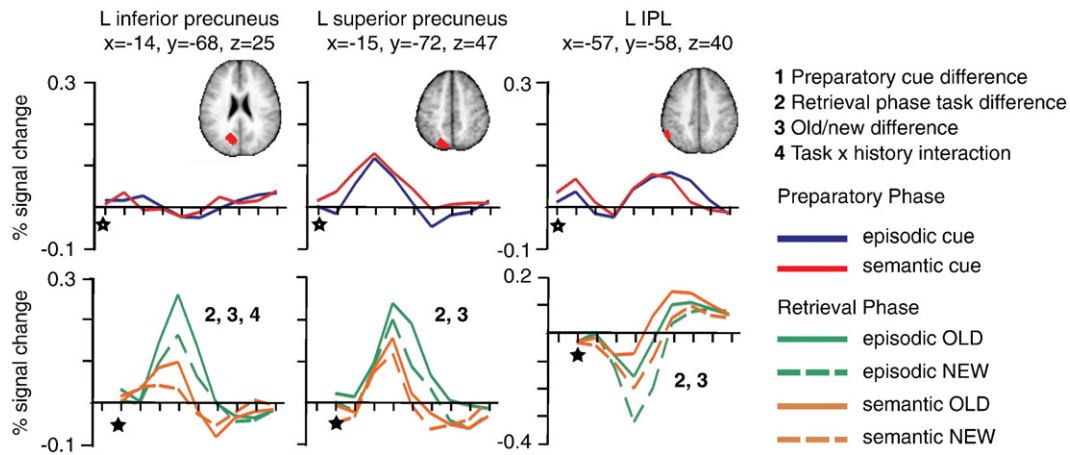


Fig. 4. Left parietal regions showing old/new differences, identified from retrieval phase main effect of time map. Number labels on timecourse plots indicate the occurrence of statistically significant experimental effects (see legend). Left inferior precuneus, superior precuneus, and IPL all exhibit significant effects of task and study history in the retrieval phase (Table 6). Vertical axis: BOLD signal magnitude as percent change from baseline. Horizontal axis: timecourses extend from 0 to 20 s, beginning from preparatory cue onset; each tick mark corresponds to one 2 s volume of fMRI acquisition. Open stars indicate onset of preparatory cue; closed stars indicate onset of memory probes. Retrieval phase timecourses are based on correct trials only.

differences in this region were significant in both episodic and semantic retrieval [$t(11) = 4.1, p < 0.01$; $t(11) = 4.6, p < 0.001$, respectively]. All three regions displayed significant retrieval phase task effects. In the precuneus, episodic retrieval was associated with larger positive responses than semantic retrieval. Conversely, greater negative

modulation was observed in left IPL during episodic than semantic retrieval. The absence of preparatory phase activity in these regions, coupled with robust effects of study history and task in the retrieval phase, suggests that their function is circumscribed to post-stimulus retrieval processes.

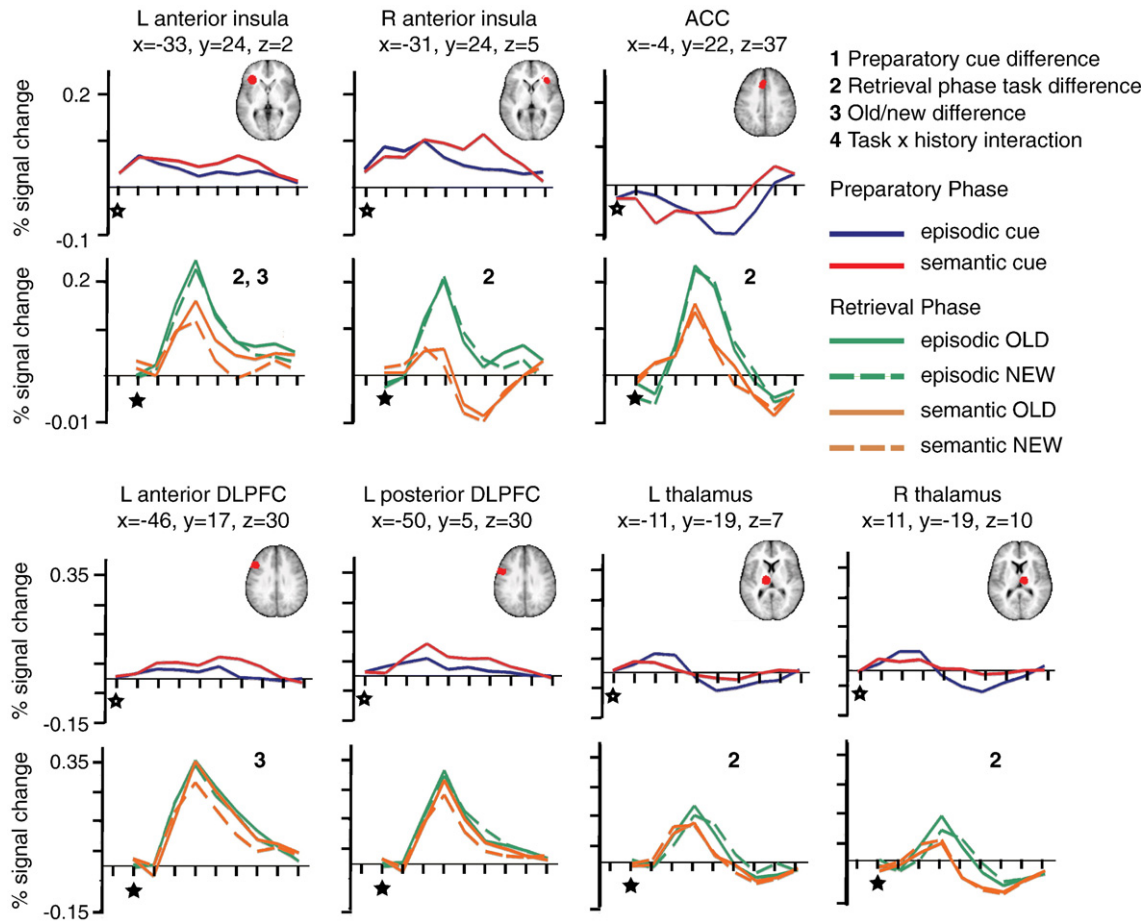


Fig. 5. Regions previously implicated in attentional control, identified from retrieval phase main effect of time map. Number labels on timecourse plots indicate the occurrence of statistically significant experimental effects (see legend). All regions except left anterior and posterior DLPFC exhibit significant retrieval phase task differences. Old/new differences occur in left AI and left anterior DLPFC; in all other regions, study history effects are non-significant. Vertical axis: BOLD signal magnitude as percent change from baseline. Horizontal axis: timecourses extend from 0 to 20 s, beginning from preparatory cue onset; each tick mark corresponds to one 2 s volume of fMRI acquisition. Open stars indicate onset of preparatory cue; closed stars indicate onset of memory probes. Retrieval phase timecourses are based on correct trials only.

Episodic and semantic retrieval was also associated with activity in anterior cingulate cortex (ACC), bilateral anterior insula (AI), left DLPFC, and bilateral thalamus (timecourses, Fig. 5; see Table 5 for statistical results). Preparatory responses were small and insensitive to cue type (Table 6), and even to the cues in general, suggesting that these regions are involved in cognitive operations beginning after onset of the memory probe. Retrieval phase responses in these regions and bilateral thalamus were greater for episodic than semantic retrieval, consistent with the exercise of controlled processing during episodic retrieval. Task effects were absent in both anterior and posterior left DLPFC foci (Fig. 5, bottom left panels). In contrast to the left parietal ROIs described above, activity in these regions was largely insensitive to stimulus study history. Exceptions to this pattern occurred in left AI and anterior DLPFC (Fig. 5, left panels). Both regions displayed a main effect of study history (old > new; Table 6). Post-hoc *t*-tests indicated that these differences were significant during semantic [insula, $t(11) = 3.3$, $p < 0.01$; DLPFC, $t(11) = 2.4$, $p < 0.05$] but not episodic ($p > 0.05$) retrieval.

Discussion

If attentional control processes are as integral to the processing of internal memory representations as they are to processing external perceptual representations (Griffin and Nobre, 2003; Nobre et al., 2004), a full model of episodic memory must specify the neural substrates of attentional processes engaged during retrieval. In the current study, separation of task preparation and memory retrieval trial components allowed the dissociation of brain activity related to task preparation from activity associated with episodic and semantic retrieval. The findings indicate that preparing to engage in episodic and semantic retrieval recruits brain areas associated with domain-general attentional control (Buckner, 2003; Buckner and Wheeler, 2001; Cole and Schneider, 2007; Dosenbach et al., 2008; Miller and Cohen, 2001; Wagner et al., 2001). A noteworthy result was that,

Table 5
Regions defined from retrieval phase main effect of time map.

Region	BA	x	y	z	Z-score	Cluster size
L superior frontal gyrus	6	-5	8	52	11.6	407
R cerebellum	*	32	-60	-27	10.1	492
L cuneus	17	-2	-82	8	10	478
L superior parietal lobule	7	-30	-60	41	9.7	515
R medial frontal gyrus	6	4	12	47	9.5	305
R inferior occipital gyrus	19	40	-83	-5	9.5	504
R inferior occipital gyrus	18	23	-90	-7	9.1	426
L cerebellum	*	-36	-56	-29	9.1	474
R superior temporal gyrus	22	50	-54	18	9	506
L anterior DLPFC	9	-46	17	30	8.8	444
R inferior parietal lobule	40	54	-46	37	8.8	515
R cuneus	23	7	-74	8	8.7	426
L parahippocampal gyrus	30	-10	-48	4	8.7	420
L inferior occipital gyrus	18	-29	-89	-12	8.6	458
R lingual gyrus	18	8	-61	5	8.6	446
L thalamus	*	-11	-19	7	8.5	464
L inferior parietal lobule	40	-45	-35	47	8.5	525
L posterior DLPFC	9	-50	5	30	8.5	441
R middle temporal gyrus	21	56	-24	-5	8.3	463
L posterior cingulate	30	-4	-62	11	8.2	418
R parahippocampal gyrus	30	9	-43	1	8.2	424
L supramarginal gyrus	40	-62	-47	37	7.8	225
R thalamus	*	11	-19	10	7.7	363
L inferior precuneus	31	-14	-68	25	7.6	431
R caudate head	*	13	9	2	7.4	277
Anterior cingulate	32	-4	22	37	7.3	393
L anterior insula	47	-33	24	2	6.9	465
L superior precuneus	7	-15	-72	47	6.1	332
L inferior parietal lobule	40	-57	-58	40	6.1	186
R anterior insula	45	31	24	5	6	257

Notes: L = left; R = right; * = not applicable; x, y, z = Talairach atlas coordinates; cluster size in voxels (2 × 2 × 2).

Table 6
Overview of preparatory and retrieval phase effects.

	Preparatory cue differences	Retrieval task differences	OLD/NEW differences
Regions identified from preparatory phase			
L anterior IPS	7.1*	7.1*	18.9*
Pre-SMA	20.7**	20.5**	0.1; task × history interaction, $F(1,11) = 10.1^*$
L FFG	7.9*	6.6*	1.2
R precuneus	7.0*	4.1	2.3
L middle IPS	1.3	9.4*	16.8*
R middle IPS	1.6	5.8*	3.6
R posterior IPS	3.4	19.1*	14.6*
Retrieval phase regions displaying OLD/NEW effects			
L inferior precuneus	0.1	39.4**	7.8*; task × history interaction, $F(1,11) = 5.1^*$
L superior precuneus	1.3	20.8**	4.9*
L IPL	0.0	11.3*	65.7**
Retrieval phase regions implicated in attentional control			
L anterior insula	1.0	18.4*	6.5*
R anterior insula	1.7	62.8**	0.1
ACC	0.9	14.3*	0.7
L anterior DLPFC	0.9	1.4	8.9*
L posterior DLPFC	4.1	2.2	1.5
L thalamus, MDN	0.0	6.7*	0.1
R thalamus, MDN	1.7	12.8*	0.1

*Reported values are *F*-statistics from ANOVAs of imaging data, all *df* = 1,11. Statistical significance is denoted by asterisks: * $p < 0.05$, ** $p < 0.001$.

while preparation to retrieve engaged areas in left and right parietal cortex, only the left parietal regions were active during episodic and semantic memory retrieval. Left IPS, portions of which have been separately implicated in attentional control and in episodic retrieval, displayed both preparatory effects and a sensitivity to stimulus study history. These findings indicate that left IPS is involved in operations that are engaged during both task preparation and memory retrieval.

Task preparation recruits domain-general attentional network

Preparing to perform either episodic or semantic retrieval involved activation of regions in or near bilateral posterior parietal, IPS, inferior temporal, and occipital lobes, as well as right frontal and right posterior superior temporal cortex (Fig. 2). These modulations are likely to include regions which are involved in low-level processing of cues, such as early visual processing stages, as well as regions which are sensitive to cue type and are engaged in preparing an appropriate task set.

Given our interest in task preparation, we focused on regions differentially modulated by episodic and semantic cues. Cue type effects were found in pre-SMA, left anterior IPS, left FFG, and right precuneus (Fig. 3); similar but non-significant trends were observed in right middle and posterior IPS. In previous fMRI studies of cognitive control, similar sets of brain regions have been associated with responses to task instructions (Dosenbach et al., 2007; Dosenbach et al., 2006) and with practice-related decreases through task learning (Chein and Schneider, 2005). The parietal preparatory effects are also consistent with fMRI results from Wheeler et al. (2006), who reported that preparatory cues signaling the modality (visual, auditory) of retrieval targets influenced activity in bilateral posterior parietal cortex located near typical retrieval success areas. In relation to previous ERP studies of episodic retrieval mode, the engagement of bilateral parietal cortex is most consistent with Morcom and Rugg (2002), who reported differential cue type responses over both centro-parietal and frontal electrode sites.

Regions which were differentially modulated by preparatory cues consistently and unexpectedly exhibited greater responses to seman-

tic than episodic task cues. This result was supported by both an initial analysis of cue type, and by a supplementary analysis which additionally categorized trials by switch/repeat status. It is possible that study instructions (to encode stimuli for a later memory test) biased the participants towards episodic task performance, resulting in the need for greater control during semantic task preparation. However, this interpretation must be considered in light of behavioral results, which suggest that the participants found the episodic task more difficult. Lower accuracy and higher RTs suggest a need for enhanced control during episodic task preparation, and would lead one to expect greater neural responses to episodic task cues. The absence of a response congruency effect in semantic task RTs is likewise inconsistent with the proposal that the participants were biased toward performing episodic retrieval, as RT data showed no evidence that the episodic task set intruded upon semantic retrieval decisions. An alternative explanation of cue type differences involves the degree of success which the participants might experience in preparing for both retrieval tasks. In anticipation of a living/non-living decision, the participants could readily shift attention to conceptual knowledge or mental imagery related to animacy; however, an old/new recognition memory decision might not offer an analogous opportunity to prepare before the presentation of a specific memory probe. This asymmetry in the participants' ability to prepare could give rise to the observed pattern of cue type effects.

Episodic and semantic old/new effects in parietal cortex

Retrieval phase effects of study history (correct old > new) implicate left IPS (Fig. 3) and adjacent subregions of left parietal cortex (Fig. 4) in an episodic retrieval network. Greater responses to old than new stimuli in left IPS and precuneus replicate similar findings in many fMRI investigations of recognition memory (Donaldson et al., 2001b; Habib and Lepage, 1999; Henson et al., 1999; Konishi et al., 2000; McDermott et al., 2000; Rugg et al., 2002; Velanova et al., 2003; Vilberg and Rugg, 2008; Wagner et al., 2005). Interestingly, the left anterior and middle IPS were also more active for old than new items in the semantic task (Fig. 3, bottom left; Fig. 4, bottom right) despite the fact that differentiating old and new items was unnecessary. While the congruency analysis suggests that subjects did not consistently attempt to also make explicit old/new decisions on semantic trials, it is nevertheless possible that studied words resulted in spontaneous memory retrieval, either in the form of spontaneous recollection or an automatic familiarity signal.

If the old/new modulations are present in the semantic task, why did they not influence behavior as indicated by the congruency analysis? We can only speculate, but it is possible that this signal could be inconsequential in the context of a semantic decision, and thus have little effect on overt behavior during the semantic task. In a decision making framework, one could view spontaneous old/new modulations as sources of evidence that are monitored or not depending upon the task demands (Gold and Shadlen, 2007; Hecker et al., 2008; Ploran et al., 2007; Wheeler et al., 2008).

Laterality differences in IPS during retrieval

Left and right IPS were both positively modulated by preparatory cues signaling episodic and semantic retrieval. However, the left and right regions responded differently during retrieval. The left anterior ($x = -34$, $y = -47$, $z = 37$) and middle IPS ($x = -27$, $y = -58$, $z = 43$) exhibited positive transient responses in the retrieval phase and were more active on correct old than new trials (Fig. 3). These regions are located near parietal areas that have been associated with successful retrieval in recognition memory studies (Buckner and Wheeler, 2001; Rugg and Wilding, 2000; Wagner et al., 2005). In contrast, activity in the right IPS did not modulate significantly during task performance. This retrieval phase dissociation of left and right IPS

is consistent with left-lateralization of retrieval success effects, which cannot be attributed to the use of linguistic stimuli (Sanefuji et al., 2007; Shannon and Buckner, 2004).

Left IPS participates in both preparatory and retrieval processes

Although several brain regions were positively modulated during both preparatory and retrieval phases, the left IPS was the only region sensitive to both cue type and study history (old > new). To take a component processing view (Moscovitch, 1992), this region may thus represent a point of overlap between sets of operations performed initially at task preparation and later during retrieval. The current findings do not identify the nature of that operation (or set of operations), which can conceivably include possibilities such as orienting of attention to internal representations, an assessment of stimulus relevance, or an oldness signal. For example, Ciaramelli et al. (2008) have proposed an 'attention to memory' (AtoM) hypothesis in which superior and inferior parietal areas are associated with distinct roles in allocating attention to internal representations. Cabeza (2008) has proposed a similar account, the dual attentional processes hypothesis (DAP). According to these accounts, superior parietal areas mediate the control of top-down attention while inferior parietal areas, including the supramarginal and angular gyri, mediate automatic detection of task-relevant information. In part, these accounts are supported by recognition studies using confidence assessments, which show that superior parietal areas near the IPS are more active for low than high confidence old and new items (Daselaar et al., 2006; Fleck et al., 2006; Kim and Cabeza, 2007).

An alternative explanation for our pattern of results in the parietal lobes is related to stimulus relevance. According to this view, the results of a retrieval attempt alter a representation of stimulus relevance that is computed or monitored in IPS, leading to the additional activation elicited on hit trials (compared to CR trials). This proposal draws an analogy between the current left IPS memory effects and visual attention studies in non-human primates which indicate that top-down and bottom-up influences converge in parietal cortex to form a spatial map of behaviorally relevant stimuli (Balan and Gottlieb, 2006; Colby and Goldberg, 1999). Memory signals—in particular, the knowledge that an item was previously encountered—frequently convey useful information about the behavioral relevance of a stimulus, and may influence left IPS activity. One complication with the stimulus relevance proposal is that parietal old/new effects persist even when subjects are instructed that the relevant stimuli are new items rather than old items (Shannon and Buckner, 2004). To be plausible, the relevance signal would need to be somewhat automatic, and relatively resistant to countermanding task goals.

Theoretical accounts of the role of parietal lobes in memory and attention should ultimately address a number of outstanding issues. First, the lateralization effects reported in the memory literature (left > right) tend to oppose those reported in the attention literature (bilateral or right > left) (Corbetta and Shulman, 2002; Hopfinger et al., 2000; Woldorff et al., 2004). Second, contrary to a predicted by a role in attentional control, the IPS does not consistently modulate according to retrieval difficulty. For example, Wheeler and Buckner (2003) found that IPS responses did not differ during source retrieval of items that were studied many times (easier retrieval) and those studied one time (harder retrieval). However, portions of posterior parietal cortex have been shown to modulate according to retrieval demands, increasing activity more during source recollection than mere item recognition (Dobbins et al., 2002; Dobbins et al., 2003). Third, the IPS is as active during 'know' judgments as 'remember' judgments in remember/know (RK) tasks (Henson et al., 1999; Wheeler and Buckner, 2004). This appears to be a particular challenge to an attention-to-memory account because, theoretically, familiarity (the basis for a 'know' judgment) is thought to be a fast and automatic signal while recollection (the basis for a 'remember' judgment) tends

to be more amenable to strategic processing (Jacoby, 1991). However, these RK tasks used relatively long response windows. Under this condition, a fast familiarity signal may evoke an effortful search for recollective details, with the goal of boosting confidence in the memory decision (Henson et al., 1999; Wheeler and Buckner, 2004). When this happens, 'know' responses could routinely be made after recollection fails, and may thus be associated with a robust strategic memory search (Wheeler et al., 2006). Differentiating among these possibilities will require methods that can identify the precise nature of retrieval under various circumstances.

More generally, the topographic relationship between memory and attention effects in the parietal lobes needs to be specified in greater detail. This need particularly applies to the IPS (Critchley, 1953), which is relatively large and functionally heterogeneous (Culham and Kanwisher, 2001). The IPS has been associated with both recollection and familiarity, and IPS activity has been shown to be greater on trials with an "old" response than on trials with a "new" response, independently of accuracy (Kahn et al., 2004; Wheeler and Buckner, 2003). This result suggests that information processed in the IPS reflects the outcome of memory decisions (Ploran et al., 2007). Perhaps relatedly, both the IPS (Montaldi et al., 2006) and supramarginal gyrus (Yonelinas et al., 2005) have been shown to be sensitive to recognition confidence, increasing activity more on high confidence recognition memory trials than on low confidence trials. This type of result is hard to reconcile with an AtoM account of IPS (Ciaramelli et al., 2008), which posits increases in activity with decreases in confidence (for an alternative result see Cabeza, 2008; Daselaar et al., 2006; Fleck et al., 2006; Kim and Cabeza, 2007). In contrast to the left IPS, the lateral surface near the supramarginal and angular gyri tends to be associated specifically with increased activity during recollection but not familiarity (Henson et al., 1999; Vilberg and Rugg, 2007; Wagner et al., 2005; Wheeler and Buckner, 2004; Yonelinas et al., 2005). Vilberg and Rugg (2007) found that increases in the quantity of retrieved information were associated with increased activity in voxels on the lateral surface of the left IPL near the angular and supramarginal gyri, but not in the IPS proper.

One final consideration pertains to the cue-phase responses in left IPS. We have generally framed this response as indicative of preparatory processing, perhaps related to orienting or to the setting of task parameters such as decision criteria and response options. However, there is a plausible memory-based explanation which can account for the sensitivity of left IPS to task cues. Having been learned prior to the test, the cues are certainly familiar and are each associated with a memory specifying different sets of task parameters. In order to prepare for a task, this information must be either held online continuously or retrieved as needed from long-term memory. Given the nature of the task, and the behavioral task-switch effects, it is unlikely that the task settings were maintained online continuously. If this is true, the cue-phase responses in parietal cortex may be inextricably linked to retrieval of task-relevant information (as well as setting of task-level variables).

Retrieval phase modulates activity in additional control areas

We additionally identified retrieval phase activity in a set of brain regions, including left DLPFC, bilateral AI, thalamus, and ACC (Fig. 5). In contrast to task preparation regions like the left FFG and bilateral IPS, these regions displayed negligible preparatory responses. Thus, they did not participate in anticipatory task-level processing such as the preparation of the appropriate task set. Despite robust responses during task performance, many regions of this set were insensitive to the study history of stimuli, suggesting that they are also not involved in retrieval-specific operations. Instead, they may perform control-related functions during retrieval, such as decision making or response selection and execution (Dosenbach et al., 2006). For example, the modulation of atten-

tional control during retrieval is supported by Dobbins et al. (2002), who reported activation in left DLPFC and left inferior prefrontal cortex during both source and item memory tasks. Dobbins et al. (2002) observed greater responses in these regions during the source memory task, which was hypothesized to require higher levels of executive control in cue specification and recollective monitoring.

Conclusion

Human beings benefit greatly from the ability to perform directed, voluntary memory retrieval. Neuroimaging studies of memory demonstrate that this ability depends upon complex interactions among multiple brain regions over time. Our results indicate that preparation for memory retrieval relies on frontal and parietal brain regions previously associated with attentional control, including bilateral parietal cortex. Retrieval itself was associated with the activation of additional regions that have been associated with attentional control, which in the present task may have participated in decision making and response processes. Retrieval also produced robust old/new effects in both episodic and semantic tasks in left, but not right, parietal cortex, particularly the IPS. The combination of preparatory effects and old/new differences in left IPS may be indicative of some aspect of attention, such as orienting to internal representations, or to a quantification of stimulus relevance. However, it is also plausible that IPS activity reflects memory processing because preparatory cues can initiate the retrieval of previously learned task parameters and decision criteria. Further research is needed to clarify the causes of, and functional topography of, parietal old/new and attention effects in controlled memory retrieval.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.neuroimage.2009.02.044.

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