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Content-specific source encoding in human medial temporal lobe

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Abstract

While the medial temporal lobe (MTL) is known to be essential for episodic encoding, the contributions of individual MTL subregions remain unclear. Data from recognition memory studies have provided evidence that the hippocampus supports relational encoding important for later episodic recollection, while perirhinal cortex has been linked with encoding that supports later item familiarity. However, extant data also strongly implicate perirhinal cortex in object processing and encoding, suggesting that perirhinal processes may contribute to later episodic recollection of object source details. To investigate this possibility, we examined encoding activation in MTL subregions based on subsequent memory outcome while participants processed novel scenes paired with one of six repeating objects. Specifically, we analyzed BOLD encoding activation correlating with later successful scene recognition memory and source recollection for the object paired with the scene during encoding. In contrast to studies reporting a link between perirhinal cortex and item familiarity, we find that encoding activation in right perirhinal cortex correlates with successful recollection of the paired object. Furthermore, other MTL subregions also exhibit content-specific source encoding patterns of activation, suggesting that MTL subsequent memory effects are sensitive to stimulus category.

Keywords

fMRI; Perirhinal Cortex; Domain Specificity; Recollection; Medial temporal lobe

Introduction

It is said that, “A moment lasts all of a second, but the memory lives on forever,” (Anonymous). Yet, the landmark case of patient H.M. revealed that new memories only outlast moments if the medial temporal lobe (MTL) is intact. The severe anterograde amnesia H.M. suffered after bilateral MTL resection revealed the necessity of this region for the formation of new episodic memories (Scoville & Milner, 1957) and has led researchers to explore how the MTL supports episodic encoding. Recent focus is on the relative contributions of distinct MTL subregions, including the hippocampus, perirhinal cortex and parahippocampal cortex to episodic memory formation (for reviews, see Davachi, 2006; Eichenbaum et al., 2007; Mayes, 2007; Squire, 2004).

It has been posited that at least two distinct processes support episodic recognition memory, recollection and familiarity (Jacoby, 1991; Mandler, 1980; Tulving, 1985; see Yonelinas, 2002 for a review). Familiarity has been defined as recognition memory for a given stimulus in the absence of memory for additional episodic details of the initial encounter. Recollection

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is defined as the recovery of episodic source details surrounding the initial encounter. In a classic example highlighting these two processes, one encounters a person and can recognize that this individual has been previously encountered, but cannot recall any details of the circumstances of that event. This subjective experience, i.e. “I know *that* I know you, just not *how* I know you, ”nicely illustrates the process of familiarity. By contrast, during recollection, one is able to bring back to mind specific episodic source details of the previous encounter, such as spatial and temporal contexts bound to the memory for the individual (Johnson et al., 1993). The accessibility of these details can drive the subjective memory experience (Johnson & Raye, 1981). Thus, memory quality at retrieval is dependent, at least in part, on binding operations at encoding.

One technique that has widely been used to explore neural encoding operations is the subsequent memory paradigm. Brain data are collected during the study (encoding) phase and later sorted into memory encoding conditions based on each participant's performance on a subsequent memory retrieval test (Sandquist et al., 1980; Paller & Wagner, 2002). The nature of the memory test can be altered to allow examination of a number of different forms of memory encoding. For example, one can examine encoding activation correlated with objective measures of recollection through adoption of what have been referred to as source paradigms (e.g. Johnson & Raye, 1981; Johnson et al., 1993). During encoding, study items are presented within experimenter-manipulated contexts that later serve as the “source”, the episodic contextual detail upon which later recollection is assessed. At test, participants are typically asked to make old/new recognition judgments for the item itself and, additionally, to identify the source with which the item was paired during study.

Using this approach, much recent data have provided evidence that item recognition and source recollection are supported by distinct encoding operations. Specifically, a large body of work that links hippocampal encoding operations with recollection and perirhinal encoding with item recognition (Davachi et al., 2003; Dougal et al., 2007; Henson et al., 1999; Jackson & Schacter, 2004; Kensinger & Schacter, 2006; Kirwan & Stark, 2004; Ranganath et al, 2004; Sperling et al., 2003; Uncapher & Rugg, 2005; Uncapher et al., 2006). Interestingly, parahippocampal encoding activity has less consistently been associated with either item recognition or recollection. While many groups report encoding activation correlated with later source recollection (Davachi et al., 2003; Kensinger & Schacter, 2006; Ranganath et al., 2004; Schon et al., 2004), there is also evidence that parahippocampal encoding activation may correlate with item recognition (Gold et al., 2006; Kirwan & Stark, 2004). Importantly however, trials for which participants exhibit successful item recognition without source recollection, have, in some cases, been treated as trials in which participants only have item familiarity, without recollection (for review see Eichenbaum, 2007). It is unknown whether successful item recognition, in some cases, may arise not only from item familiarity but also from recollection of object level details (Staresina & Davachi, 2006).

While the aforementioned studies provide evidence in favor of differential contributions of MTL subregions to distinct *forms* of memory, other work has shown that MTL regions may differentially contribute to the *content* of memory. Consideration of anatomical inputs to the MTL reveals that perirhinal cortex receives the largest percentage of its input from higher level object processing areas in the ventral visual stream, while parahippocampal cortex is the only MTL region that receives input from the spatial processing regions of the dorsal visual stream (Suzuki & Amaral, 1994). This differential cortical input suggests that perirhinal and parahippocampal encoding support might be content-specific, i.e. differentially important in the processing specific types of features or aspects of complex events. Supporting this view, perirhinal cortex has been implicated in the processing of objects, both in tasks that appear primarily perceptual (Buckley et al., 2001; Buckley & Gaffan, 2006; Bussey et al., 2003; Lee et al., 2005; Litman et al., submitted) and in those that directly measure memory (Kohler et al., 2005; Murray et al., 2000; Norman & Eacott, 2005; Pihlajamaki et al., 2004; Staresina & Davachi, 2006). Likewise, a region in posterior parahippocampal cortex has been shown in humans to be differentially sensitive to the spatial relationships inherent in scene stimuli (see Epstein & Kanwisher, 1998) and to items strongly associated with spatial contexts (Aminoff & Bar, 2007; Bar & Aminoff, 2003; Janzen & van Turennout, 2004). Furthermore, two recent animal studies provide evidence for a double dissociation between anterior and posterior MTL cortical regions with the perirhinal cortex supporting object memory and parahippocampal cortex, spatial memory (Alvarado & Bachevalier, 2005, Norman & Eacott, 2005). Taken together, these data strongly demonstrate that the MTL cortical regions, including the perirhinal and parahippocampal cortices, are sensitive to particular categories of stimuli or event features.

Given this category specificity, it is interesting to note that the majority of memory studies have not systematically manipulated the kinds of stimuli that have served as study items and those that have served as source details. While experimentally it is often useful to simplify source to a single, experimenter controlled dimension, in the real world source is more complex and can encompass multiple pieces of information (Johnson & Raye, 1981; Johnson et al., 1993). In the example of a chance encounter with a familiar individual, memory for the spatial context of the initial episode could provide source information in support of recollection. Indeed, this situation often prompts the question, “Where do I know you from?” However, spatial context is not the only potentially available source detail. In fact, recollection could be supported by information from many different stimulus categories (see Johnson et al., 1988). A memory of an associated person, (e.g. the individual's spouse), the presence of a specific object (e.g. cake), or a verbal label (e.g. the individual's name) bound to the representation of the individual would each provide valuable source information. For this reason, it is important to resist conflating the terms “item” and “source” with specific stimulus categories to prevent misinterpreting differential category effects as differential memory effects (Chalfonte & Johnson, 1996). The source monitoring framework proposes that memories for multiple feature categories can potentially support the experience of remembering, or recollection, when bound in an event (Johnson & Raye, 1981). It follows then that if MTL regions are tuned to respond to different stimulus categories, they may in turn differentially contribute to memory formation through their processing of available event features. While the encoding effects seen in perirhinal cortex could be interpreted as evidence for a selective role in later familiarity, these findings may simply reflect the fact that, in those studies, item recognition, but not source recollection, was operationalized on recovery of a stimulus that is preferentially processed in perirhinal cortex. Given that perirhinal cortex is implicated in object processing, one might speculate that testing *object* source recollection would reveal perirhinal encoding activation consistent with later source recollection.

The present study directly tests this hypothesis. During a scanned encoding session, participants are presented with a series of unique scene pictures that serve as study items. Each is paired with one of the six repeating objects that serve as the basis for later source recollection decisions. At retrieval, we first assess old/new recognition memory for each scene. In addition, participants subjectively judge the scenes as “Remember”or “Familiar” to differentiate scene recognition with and without recollection of *scene* details. Each recognized scene (regardless of subjective memory judgment) is immediately followed by a source recollection test where participants attempt to indicate which object was paired with the scene during study.

Using this design, we find evidence that encoding activation in perirhinal cortex does indeed correlate with later source recollection. Specifically, increased activation was seen in perirhinal cortex during encoding trials for which the item (scenes) is later recognized and the the correct accompanying source detail (object) are recollected compared to trials for which the item was recognized without object source recollection. This is in contrast to numerous studies reporting perirhinal encoding activation that selectively correlates with item recognition. Interestingly, this object-specific source effect was seen in perirhinal cortex but not in any other MTL region. When participants could not recall the associated object, activation in perirhinal cortex did not differentiate between scenes subjectively rated “Remember” and “Familiar”. Additionally, whereas perirhinal cortex was the only MTL region that showed increased activation specific to object source recollection, parahippocampal cortex and posterior hippocampus appeared to exhibit scene-preferential encoding activation while anterior hippocampus displayed content-general relational encoding.

Methods

Participants

Fifteen right-handed, native English speakers participated in the fMRI study (6 female). Informed consent was obtained in writing under a protocol approved by the Institutional Review Board of New York University. All participants reported themselves to have normal vision and to be without neurological and psychiatric histories. We removed two subjects from inclusion in all analyses for insufficient number of trials in which they had correct source recollection (less than 10). Furthermore, we removed an additional three subjects from region of interest (ROI) analyses because their responses to the remember/familiar judgment did not lead to the criterion number of at least 10 trials for all conditions.

Stimuli

During the encoding stage, we presented 192 full color photographs of scenes (96 indoor and 96 outdoor). At test, we presented these studied scenes and a set of 192 novel scenes (96 indoor and 96 outdoor). We culled scene images from various sources including photo collections (IMSI MasterClips© and MasterPhotos™ Premium Image Collection, 1895□ Fransisco Blvd., East, San Rafael, CA 94901-5506, USA). The six objects were full color photographs depicting common items (toothbrush, hammer, cup, stapler, cellular phone, shoe). These images were found using an online image search engine (http://images.google.com). For a single participant, each object was paired with 32 different scenes. We counterbalanced the object-scene pairings such that across different participants, each scene was paired with each of the six objects. Scenes were grouped into four sets of 48 scenes that corresponded to each of the functional scans. The presentation order of these sets was also counterbalanced across participants.

Encoding Task

The experiment consisted of an incidental encoding task performed in the MRI scanner, followed by a three-step, unscanned, surprise memory test that assessed: 1) scene recognition, 2) subjective recollective assessments for recognized scenes (see below for details) and 3) object source recollection. At encoding, each trial consisted of a 4750 ms presentation of a composite image that contained a centrally presented novel scene and a smaller image of one of six objects in the upper left corner of the scene image (Figure 1). For each trial, participants were instructed to imagine using the presented object in the associated scene. Participants were prompted with a response screen to report whether they were successful or not (two choice) at coming up with a vivid image via a button press on a hand held response box. During the response screen, a green fixation cross appeared (250 ms after the offset of the scene-object stimulus) and remained visible for 1000 ms. The complete trial duration was 6000 ms. Trials were presented in a rapid event related design. In between trials, participants fixated on a white cross. Inter-trial fixation intervals ranged from 0 – 24 s in duration, and were jittered according to parameters determined by OptSeq (Dale, 1999). Importantly, trials in which subjects were unsuccessful or failed to report success were removed from subsequent analyses. A practice version of the task was administered to each participant outside the scanner to ensure they understood the task and the necessary response timing. Encoding trials were presented across four functional scans that were each 9 minutes and 36 seconds long (288 TRs).

A self-paced memory test was administered on the computer *after* we removed participants from the scanner (approximately a 20 minute study-test interval). During this test, they were presented with all the previously viewed scenes (192 total) and an equal number of novel scenes. Each test trial consisted of presentation of a scene, to which participants were first asked to make an old/new judgment. If they judged a scene old, they were then prompted to judge whether they recollected the scene or if it was only familiar by labeling scenes "Remember" or "Familiar" respectively (Jacoby, 1991; Mandler, 1980; Tulving, 1985; Yonelinas, 2002). Regardless of this answer, participants were next prompted to either choose the object (out of the six) that was paired with the scene during study or to respond that they did not know (this option was given to minimize guessing). All seven options appeared underneath the scene, labeled numerically (1–7) to indicate the corresponding keystroke. Prior to testing, participants received detailed instructions that explained each judgment they would have to make, with particular care given to explain the distinction between recollection and familiarity using a clear example to illustrate the two memory conditions. Furthermore, in reference to the specific judgments of the experiment, they were instructed:

> For some of the events, you might recognize the scenes and simply have a feeling of **familiarity** with them, without being able to specifically recollect anything about how they were presented. For other events you might recollect details such as what object was paired with the scene or something else about your previous encounter with the items. This might include remembering the appearance of the picture on the screen, recalling the action you imagined, remembering thoughts you were having or that were triggered by the presentation of the images, and so on. This kind of memory we classify as **recollection**. … If you make a judgment of **NEW** (press "N"), you will immediately proceed to the next scene. However, if you make a judgment of **OLD** (press "O", you will be asked to indicate whether the scene was familiar, or whether you recollected the scene.
>
> You should press:
>
> - ***1*** = if you find the scene FAMILIAR but cannot recall any specific details associated with it.
> - ***2*** = if you REMEMBER your encounter with the scene; whether the presentation of the scene, the action you imagined, or any other specific recollection of Part I.

Additionally, we administered a practice test session to ensure that participants understood the test format and the necessary responses.

Imaging Parameters

Imaging data were collected with a 3 Tesla Siemens Allegra scanner. We acquired functional data across four scans each containing 288 TRs (TR = 2000 ms, TE = 30 ms, flip angle = 80, 36 slices 3 × 3 × 3 mm voxels). Slices were coronal and angled perpendicular to the long axis of the hippocampus for optimal coverage of the medial temporal lobe. A high resolution, T1-weighted, full brain, anatomical scan (magnetization-prepared rapid-acquisition gradient echo) was also collected for visualization.

Data analysis

Behavioral Procedures

Trials for which participants failed to report success at the imagery task were removed from further analysis (mean = 21%). For the remaining, "successful" encoding trials, we used the results from the recognition memory test to conditionalize the encoding events with regard to subsequent memory. We first binned trials into three main conditions based on memory for components of the initial presentation: Miss (*M* –Scene was not recognized), Scene Only (*S* – Scene was recognized, but the paired object was not correctly identified) and Scene and Object (*S*+*O* – Scene was recognized and the paired object was correctly identified). The *S* condition encompasses both trials with incorrect source judgments and trials in which at the source judgment, participants responded that they "do not remember". This set of conditions allows for objective assessment of memory for an item only (*S*) compared to memory for an item with additional source information (*S*+*O*). It is important to note that in this paradigm, the objective marker of recollection for a trial is memory for the associated object. However, it is possible for participants to have a *subjective* sense of recollecting the scene itself based on the recovery of scene-based details even without corresponding object source recollection. For this reason, we collected subjective recollection judgments for the scene stimuli for each recognized scene, prior to the assessment of object recollection. Thus, within the *S* and *S*+*O* conditions, we subdivided trials based on the *subjective* Remember/Familiar scene judgments, creating four conditions: Scene Only Remember (*SR*), Scene Only Familiar (*SF*), Scene Remember and Object correctly identified (*SR*+*O*). The use of subjective Remember/Familiar ratings allow us to distinguish between object source recollection and recollection driven by other event features. We used these conditions (plus *M* or Misses) for subsequent analyses of imaging data. Across participants, there were too few trials for which the object was correctly paired with a scene that was judged familiar (*SF*+*O*) to further analyze this condition.

Imaging

For preprocessing and analysis of fMRI data, we used SPM2 (http://www.fil.ion.ucl.ac.uk/spm), a MATLAB-based analysis package (http://www.mathworks.com). Regions of interest (ROIs) were defined using both anatomical markers and functional activation arising from statistical parametric maps created through linear contrasts of activation during different conditions (see below). We extracted and compared ROI timecourse data utilizing the MarsBaR (http://marsbar.sourceforge.net) software package. We performed further statistical analyses using customized MATLAB based scripts and SPSS (SPSS for Windows, Release 14, 2005. Chicago: SPSS Inc).

Volumes were corrected for different times of slice acquisition, and were realigned correcting for subject movement and scanner drift. Data were next normalized to a Montreal Neurological Institute reference brain (MNI; Montreal Neurological Institute, Montreal, Canada). Data were then smoothed with an isotropic 6 mm full width half-maximum Gaussian kernel.

Data analysis was performed using the general linear model implemented in SPM2. Encoding trials were sorted according to the subsequent memory conditions described above and modeled using a canonical hemodynamic response function and its temporal derivative. Participant inclusion in each analysis was dependent on reaching a criterion number of at least 10 trials in each condition being examined. Statistical parametric maps (SPMs) were first computed at the individual subject level. Participant-specific estimates for task-related activation were entered into a second-level random-effects analysis (one-sample T-test). Regions consisting of at least five contiguous voxels that exceeded an uncorrected threshold of $p < 0.001$ were considered reliable.

At the group level, we performed a whole brain linear contrast of Task > Fixation (N = 13) to identify brain regions engaged during task performance. At the threshold $p < .001$, a large area of the MTL was activated; hence, the significantly activated voxels were spatially contiguous and spanned across the borders of MTL subregions of interest. In order to select discrete MTL regions of interest (ROIs), we anatomically constrained the functional voxels emerging from this contrast. First, utilizing MarsBar, 6 mm spherical ROIs centered within each MTL subregion were created according to anatomical markers on the normalized, mean, high-resolution full brain (see Amaral, 1999; Insausti et al, 1998). These anatomical spheres were then used to provide an `outline' of which voxels emerging from the functional contrast should be included in each MTL subregion. In other words, the overlap of the anatomical and functional data were used to create functional ROIs containing only voxels that showed significant activation during the encoding task but which are also constrained to different anatomical regions (anterior and posterior hippocampus, perirhinal cortex and parahippocampal cortex). It is important to note that while the voxels in these ROIs all showed significantly greater activation compared to fixation during the encoding task, they were unbiased with regard to subsequent memory.

BOLD activation for the conditions *SR+O*, *SR*, *SF*, and *M* in different MTL regions was then examined. Data from each ROI was analyzed in a repeated measures design, with planned comparisons made across memory conditions on the peak of the BOLD response (N=10). Percent signal change for each condition was calculated against the mean signal of each ROI. For these analyses, we determined the `peak' in each ROI by averaging across all conditions and participants and determining the point of maximal magnitude of activation. Since the hemodynamic response in MTL regions, particularly hippocampus, may not contain a single clear peak, we characterized the peak response *within* a region by statistically comparing the numerical peak time point to adjacent time points using a one tailed t-test ($p = .05$). In regions where the numerical peak activation was not significantly greater than that of an adjacent time point, the arithmetic mean of the neighboring time points was used as the peak for within ROI planned comparisons. It is important to point out that whichever peak was used in any given region, the same peak was used for all across-condition comparisons. A separate ANOVA was performed specifically to examine interactions across peak activations for the *SR+O* and *SR* conditions across selected MTL regions. When across-region comparisons were made, the numerical peak was used for all regions and conditions.

Results

Behavioral

For trials in which participants reported success during study, 54.3% of items (scenes) were correctly recognized while 45.7% were missed or forgotten (Table 1). The false alarm rate to novel scenes was 5.6%. Comparison of Hit and False alarm rates finds significant recognition memory ($p < .001$). Of the correctly recognized scenes, participants correctly recollected the associated object 47.2% of the time, picked the wrong object 22.6% of the time and chose the “do not remember” option 30.3% of the time.

Analysis of subjective remember/familiar judgments for the scenes revealed that 87% of scenes correctly paired with objects (*S+O*) were also judged remembered, indicating that correctly identified object pairings are strongly indicative of subjective scene recollection as well. However, of the scenes that were recognized without memory for the corresponding object (*S*), 50.3 % were still judged recollected.

Imaging

A contrast of all encoding trials compared to baseline (Task > Fixation) revealed activation in a large expanse of the MTL including voxels in right anterior hippocampus, bilateral posterior hippocampus, bilateral perirhinal cortex, and bilateral parahippocampal cortex, as well as extensive activation in bilateral occipital and prefrontal cortices. For the purposes of the present hypotheses, we focus this report on data from within the MTL.

A critical question was whether perirhinal cortex, a region previously associated with object processing, would show encoding activation consistent with the encoding of source details later supporting recollection. In our paradigm, the objective measure of this would be increased activation for *S+O* trials compared to *S* only trials. Consistent with our hypotheses, we found that encoding activation in right perirhinal cortex (y = −21) was significantly greater for *S+O* trials than that for both *S only* (*p* = .05) and *M* (*p = .003*) trials with *S* and *M* trials not significantly differing from each other (*p* = .3) (Figure 2b top panel).

Critically, this same pattern was not evident in parahippocampal cortex. Trials for which the object was later recollected did not differ from those for which the scene only was recognized. The statistical comparisons in left parahippocampal cortex (y = −34) did not reveal any significant differences: *S* did not differ from *S+O* (*p* = .6), nor from *M* (*p* = .23), but *S+O* did show a weak trend towards greater activation compare to *M* (*p* = .13) (Figure 2b bottom panel). These results suggest that the perirhinal cortex was differentially important for encoding object stimuli that serve as the basis for subsequent correct source recollection while the parahippocampal region did not appear to show a similar pattern.

We further probed the differences between conditions for which participants subjectively reported `Remember' or Familiar' for the individual scenes. We re-examined activation in the same ROIs, now splitting the *S+O* and *S only* conditions based on these subjective judgments, creating conditions *SR+O, SR* and *SF*. *SF+O* (familiar scenes with recollected object source) trials were rare and thus, could not be analyzed.

Importantly, activity in the same right perirhinal ROI continued to show an advantage for encoding object source compared to encoding of the scene only, even when the scene was judged remembered (Figure 2c top panel). Specifically, significantly greater activation was seen for *SR+O* trials compared to all other trial types [*SR* (*p* = .03), *SF* (*p* = .001) and *M* (*p* = .0001)] indicating increased encoding activation during trials for which the *object* source details were later recollected compared when scene details were later recollected. Moreover, *SR* did not differ significantly from either *SF* (*p* = .3) or *M* (p = .1), further suggesting that perirhinal cortex does not support all forms of later recollection.

A similar analysis in the left parahippocampal ROI revealed a different pattern across these memory conditions. Activation was numerically greatest during trials with scenes recollected *without* the associated object source. While comparison of *SR* activation with that of *SR+O* did not reach statistical significance (*p* = .3), *SR* activation was significantly greater than that of *SF* (*p* = .02) and *M* (*p* = .007) (Figure 2c bottom panel). Additionally, in the parahippocampal ROI, *SR+O* also differed from *M* (*p* = .04) (Figure 2c bottom panel). Interestingly, in comparison to the perirhinal region, this parahippocampal region showed numerically less activation during trials when object source details were subsequently recollected as compared to when scene details were remembered, suggesting that the encoding of different source attributes is distributed across MTL cortex.

Analyses of hippocampal regions also revealed interesting dissociations (Figure 3a). On the one hand, anterior hippocampus exhibited similar activation levels for all trials later recollected, regardless of the episodic content supporting recollection. On the other hand, posterior hippocampus showed a benefit for scenes recollected without object source details compared to those recollected with object information, similar to the pattern seen in posterior parahippocampal cortex. Specifically, in right anterior hippocampus (y = −10), encoding activation for the *SR* condition was significantly greater than that for *M* (*p* = .02); this was paralleled with *SR+O* trending towards being greater than *M* (*p* = .099). Here, *SR+O* and *SR* did not significantly differ from each other (*p* = .48). By contrast, in right posterior hippocampus (y = −31), *SR* activation was significantly greater than *SR+O* (*p* = .002), *M* (*p* = .004), and *SF* (p = .02). *SR+O* did not differ significantly from *SF* (*p* = .4), or *M* (*p* = .2) (Figure 3b).

Together the results from both hippocampus and neocortical MTL regions perirhinal and parahippocampal cortices, suggest distinctions along the anterior-posterior axis of MTL. In order to statistically examine these distinctions, we performed two-way repeated measures ANOVAs with the factors REGION (perirhinal and parahippocampal cortices) and CONTENT of recollection (SR+O, SR) to assess differences between responses during *SR+O* and *SR* conditions across these MTL regions (Figure 4A). We found a main effect of REGION (F (1,9) = 5.607, p = .04), but not of CONTENT (F (1,9) = .286, p = .6). Importantly, a significant interaction between REGION and CONTENT (F (1,9) = 8.139, p = .02) was seen, highlighting that perirhinal activation was greater when objects were later recollected while parahippocampal activation was greater when scenes were later recollected.

A similar two-way ANOVA was conducted for the hippocampal regions with REGION (anterior and posterior hippocampus) and CONTENT (*SR+O*, *SR*) as factors (Figure 4B). There were no main effects of REGION (F (1,9) = .540 p = .5), nor of CONTENT (F (1,9) =3.36 p = .1). However, a marginal interaction was seen, (F (1,9) =4.44, p = .06) driven by the result that activation in anterior hippocampus was not differentiated by memory content, whereas activity in posterior hippocampus was less for scenes recollected with associated object source compared to scenes recollected without.

Discussion

The present study provides evidence for distinct patterns of encoding activation in MTL subregions related to the type of event content later recollected. Our design enabled identification of three different subsequent memory components for each individual encoding trial: 1) old/new recognition memory for scenes 2) participant's subjective recollective experience for recognized scenes (“Remember” or “Familiar”) and 3) object source recollection, or remembering which of six objects were paired with the scene during encoding. Comparison of the encoding activation linked to these mnemonic measures revealed that activation in parahippocampal cortex and posterior hippocampus correlated best with scene encoding while activation in right perirhinal cortex was greatest when the presented object was successfully bound to the scene stimulus. Furthermore, a region in the right anterior hippocampus exhibited activation that, consistent with a content-general relational binding mechanism, did not differentiate between the different stimulus categories of recollected content. Taken together, these results provide evidence for content-dependent distinctions between the contributions of perirhinal and parahippocampal cortices to source encoding and also suggest important divergent contributions of different hippocampal regions to binding operations.

Data from single unit and human functional imaging experiments have suggested that perirhinal operations are selectively important for item, but not source, or relational, encoding (Davachi et al., 2003; Kensinger & Schacter, 2006; Kirwan & Stark, 2004; Ranganath et al., 2004; Uncapher et al., 2006; for review see also Brown & Aggleton, 2001). In the majority of paradigms used, however, source recollection has predominantly been indexed using memory for a spatial or cognitive context (Davachi et al., 2003; Kensinger & Schacter, 2006; Ranganath et al., 2004; Uncapher et al., 2006; but see Kirwan & Stark, 2004). The current experiment indexed recollection on successful source memory for a previously presented object in each event as well as on subjective measures of scene recollection. In this case, perirhinal activation showed a pattern consistent with successful object source encoding, i.e. when objects were bound to scenes. Specifically, activation in right perirhinal was greater during encoding of scenes later recollected *with* the presented object (*SR +O*) than when scenes were recollected, but the presented objects were not (*SR*). Furthermore, perirhinal activation did not statistically differentiate between scenes later judged recollected (*SR*) and scenes subsequently judged familiar (*SF*) or forgotten (*M*). Finally, this object-selective pattern of activation was seen only in right perirhinal cortex; no other MTL examined region showed this effect.

It is important to note this finding in and of itself is not inconsistent with the notion that perirhinal mechanisms are important in encoding processes that support later familiarity. Indeed, from that perspective, the enhancement from the *SR* condition to the *SR+O* condition may be seen because the *SR+O* condition elicits, on average, greater subsequent episodic familiarity. However, as stated above, the pattern seen across the other memory conditions is not consistent with the notion that MTL cortex solely supports later gradations in familiarity that is independent from stimulus content. Specifically, the lack of a graded effect from *SR* to *SF*, and from *SF* to *M*, argues against a general familiarity mechanism. Instead, the overall pattern suggests that perirhinal encoding processes are important for object encoding and, hence, may contribute to not only familiarity, but also recollection of object details. Recently, a few studies have also reported findings broadly consistent with this notion, showing that perirhinal encoding activation correlates with intra-item associative binding (Staresina & Davachi, 2006; 2008; Tendolkar et al., 2007) but not item-context binding (Staresina & Davachi, 2008). Furthermore, these data are in accord with cognitive models (e.g. Johnson et al., 1993) and models of MTL organization that explicitly take episodic content into account (Davachi, 2006; Mayes, 2007).

One critical consideration is whether the increased activation seen in perirhinal cortex is *sufficient* to support later recollection. We think this is unlikely given overwhelming evidence that patients with selective hippocampal damage appear to be grossly impaired in recollecting specific features of events (Manns et al., 2003 Wixted & Squire, 2004; Yonelinas et al., 2002). Instead, we propose that perirhinal processes may be important in item encoding both in the service of later familiarity and, perhaps in concert with hippocampal operations, in the service of binding object features in support of later recollection. It remains to be seen to what extent perirhinal and hippocampal encoding operations cooperate or act independently during episodic encoding.

Further examination is needed to address whether the enhanced activity in right perirhinal could be a direct consequence of low-level operations, such as foveation on the presented object, which may also be related to memory encoding. According to this account, the correlation between perirhinal BOLD activation and object source recollection may be indirect and mediated by a direct relationship between perirhinal activation and object viewing which may also relate, albeit indirectly, to later memory. Specifically, it is possible that differential foveation on the presented object across trials may modulate perirhinal activation and that longer foveation trials are also trials for which subjects are more likely to later remember the paired object. Inherent in this account is the assumption that perirhinal cortex is sensitive to the mere presence of a stimulus in the visual world of the observer. There is evidence that perirhinal neurons show stimulus specificity for objects (Miller et al., 1991; Sakai & Miyashita, 1991), and while much lesion work supports the notion that perception is intact with MTL damage (Buffalo et al., 1998; Hampton & Murray, 2002; Holdstock et al., 2000), a series of recent studies propose that perirhinal cortex may be critical for object perception (Buckley et al., 2001; Buckley & Gaffan, 2006; Bussey et al., 2002; 2003; Eacott & Gaffan, 2005). However, much of the neuropsychological work linking perirhinal cortical damage with perceptual deficits includes patients that, in addition to perirhinal damage, also have measurable lateral temporal damage, greatly limiting what can be concluded about perirhinal cortex and perception from those studies (Shrager et al., 2006). Additionally, it has been posited that the perceptual tasks used in these experiments are themselves dependent on learning and memory (Hampton, 2005). Nonetheless, it will be important for future studies to closely monitor viewing behavior to examine this possibility.

In contrast with perirhinal cortex that did not exhibit a pattern consistent with scene encoding, parahippocampal cortex and posterior hippocampus showed significantly greater activation for scenes reported as being subjectively recollected compared to those reported as simply familiar. Interestingly, parahippocampal cortex and posterior hippocampus actually show *less* activation when object information was accurately recollected compared to when the scene was recollected alone. The decreased activation in these regions when it would appear that more information was being encoded (*SR+O*) leads us to speculate that successful binding of the scene with the object may have reduced the attentional resources available to bind other features such as those within scenes or between scenes and participants' pre-existing experiences. In any event, this pattern of results suggests the possibility that no single MTL brain region should be used as an indicator of how much information is being encoded. Instead, these data suggest that the pattern across MTL regions may be a better measure of memory content. Although the exact mechanisms behind such a pattern are unknown, one possibility is that during any given event, attentional resources are limited; hence gating of these resources leads to differential activation distributed across MTL brain regions depending on the target(s) of attentional focus. In terms of the present data, if perirhinal and parahippocampal cortices differentially support the encoding of objects and scenes, respectively, the BOLD data might reflect the `sum of activation' volleying between the two regions and, hence, may also correlate with the overall content of the subsequent memory as we see in our data. Another factor that could contribute to such a pattern is that the *SR* condition may not reflect a condition where there is overall less source detail recollected than in the *SR+O* condition, but rather one where *qualitatively different* source detail is recollected. While participants are explicitly tested on source recollection for the presented object, presumably other, non-experimenter manipulated source details can drive “Remember” judgments (e.g. Johnson et al., 1988). Thus the two “Remember” conditions may not necessarily reflect a difference in the amount of recollected detail, but the content.

We also found that activation along the hippocampal anterior-posterior axis yields both similarities and differences. One similarity between the anterior and posterior hippocampus is that both regions displayed increased encoding activation for subsequently recollected scenes compared to those that were later judged familiar or new, replicating prior studies showing a strong correlation between the hippocampus and relational binding (Chua et al., 2007; Davachi et al., 2003; Dougal et al., 2007; Henson et al., 1999; Jackson & Schacter, 2004; Kensinger & Schacter, 2006; Kirwan & Stark, 2004; Prince et al., 2005; Ranganath et al, 2004; Sperling et al., 2003; Staresina & Davachi, 2006; 2008; Uncapher & Rugg, 2005; Uncapher et al., 2006; see Cohen & Eichenbaum, 1993), but contrasting with work suggesting that anterior, but not posterior hippocampus relational processes differentially contribute to subsequent memory (Chua et al., 2007). Interestingly, consideration of stimulus category yields a potential dissociation in the current data. Anterior hippocampus displayed activation consistent with a content-general relational binding process with a similar magnitude of encoding activation for recollected scenes regardless of correct object source identification. Consistent with this, other recent reports have provided evidence for content-general relational encoding and retrieval in anterior hippocampus (Prince et al., 2005) as well as shown evidence that anterior hippocampus appears to distinguish, not between the *type* of source information subsequently recollected, but the *amount* (Staresina & Davachi, 2008). By contrast, posterior hippocampus appears preferentially responsive to the encoding of the scene stimuli as discussed above. In right posterior hippocampus, scenes recollected *without* the object source showed greater activation than all other memory conditions, including recollected scenes that also included object source information. These findings are redolent of evidence suggesting posterior hippocampus may be preferentially engaged in spatial processing (Moser & Moser, 1998; Pihlajamaki et al., 2004). While further work will focus on understanding the functional architecture of the hippocampus, extant data in the rodent suggests that parahippocampal-hippocampal inputs preferentially project to the dorsal hippocampus (Hargreaves et al., 2005), a region thought to correspond to posterior hippocampus in humans. Thus, one can speculate that posterior hippocampus mechanisms may be operating on input from spatial information processing parahippocampal regions, rendering it more sensitive to spatial information encoding. However, this same logic cannot simply explain the anterior hippocampus effects that did not show any preferential encoding effects based on event content, but instead appear selective to memory quality only.

In conclusion, these data shed light on the differential role of MTL cortical regions in object and scene encoding and provide initial evidence for an anterior-posterior distinction along the hippocampus. More broadly, however, the current results support the notion that episodic memory quality is derived from differential processing of specific source features (e.g. Johnson et al., 1993) and that such content is an important organizing principle of the MTL (Davachi, 2006). Given this, it follows that *all* differential encoding activation patterns across MTL subregions seen in previous studies (Davachi et al., 2003; Henson et al., 1999; Jackson & Schacter, 2004; Kensinger & Schacter, 2006; Kirwan & Stark, 2004; Ranganath et al., 2004; Staresina & Davachi, 2006; Uncapher & Rugg, 2005; 2006) are likely influenced by the categories of stimuli used in those paradigms. Hence consideration of potential stimulus category effects should inform future studies of episodic encoding.

Citations

Alvarado MC, Bachevalier J. Comparison of the effects of damage to the perirhinal and parahippocampal cortex on transverse patterning and location memory in rhesus macaques. Journal of Neuroscience 2005;25:1599–1609. [PubMed: 15703414]

Amaral DG. Introduction: What is Where in the Medial Temporal Lobe? Hippocampus 1999;9:1–6. [PubMed: 10088895]

Aminoff E, Gronau N, Bar M. The parahippocampal cortex mediates spatial and non-spatial associations. Cerebral Cortex 2007;27:1493–1503. [PubMed: 16990438]

Bar M, Aminoff E. Cortical analysis of visual context. Neuron 2003;38:347–358. [PubMed: 12718867]

Brown MW, Aggleton JP. Recognition memory: what are the roles of the perirhinal cortex and hippocampus? Nature Reviews Neuroscience 2001;2:51–61.

Buffalo EA, Reber PJ, Squire LR. The human perirhinal cortex and recognition memory. Hippocampus 1998;8:330–339. [PubMed: 9744420]

Buckley MJ, Booth MCA, Rolls ET, Gaffan D. Selective Perceptual Impairments After Perirhinal Cortex Ablation. Journal of Neuroscience 2001;21:9824–9836. [PubMed: 11739590]

Buckley MJ, Gaffan D. Perirhinal cortical contributions to object perception. Trends in Cognitive Sciences 2006;10:100–107. [PubMed: 16469525]

Bussey TJ, Saksida LM. The organization of visual object representations: A connectionist model of effects of lesions in perirhinal cortex. European Journal of Neuroscience 2002;15:355–364. [PubMed: 11849301]

Bussey TJ, Saksida LM, Murray EA. Impairments in visual discrimination after perirhinal cortex lesions: testing `declarative' vs. `perceptual mnemonic' views of perirhinal cortex. European Journal of Neuroscience 2003;17:649–660. [PubMed: 12581183]

Chalfonte BL, Johnson MK. Feature memory and binding in young and older adults. Memory & Cognition 1996;24:403–416.

Chua EF, Schacter DL, Rand-Giovannetti E, Sperling RA. Evidence for a Specific Role of the Anterior Hippocampal region in Successful Associative Encoding. Hippocampus 2007;17:1071–1080. [PubMed: 17604351]

Cohen, NJ.; Eichenbaum, H. Memory, amnesia, and the hippocampal system. MIT Press; Cambridge, MA: 1993.

Dale AM. Optimal experimental design for event-related fMRI. Human Brain Mapping 1999;8:109–114. [PubMed: 10524601]

Davachi L, Mitchell JP, Wagner AD. Multiple routes to memory: distinct medial temporal lobe processes build item and source memories. Proceedings of the National Academy of Science USA 2003;100:2157–2162.

Davachi L. Item, context and relational episodic encoding in humans. Current Opinion in Neurobiology 2006;16:693–700. [PubMed: 17097284]

Dougal S, Phelps EA, Davachi L. The role of medial temporal lobe in item recognition and source recollection of emotional stimuli. Cognitive, Affective, and Behavioral Neuroscience. 2007 In Press.

Eacott MJ, Gaffan EA. The roles of perirhinal cortex, postrhinal cortex and the fornix in memory for objects, contexts and events in the rat. Quarterly Journal of Experimental Psychology 2005;58:202–217. [PubMed: 16194965]

Eichenbaum H, Yonelinas AP, Ranganath C. The medial temporal lobe and recognition memory. Annual Review of Neuroscience 2007;30:123–152.

Epstein R, Kanwisher N. A cortical representation of the local visual environment. Nature 1998;39:598–601. [PubMed: 9560155]

Gold JJ, Smith CN, Bayley PJ, Shrager Y, Brewer JB, Stark CEL, Hopkins RO, Squire LR. Item memory, source memory, and the medial temporal lobe: Concordant findings from fMRI and memory-impaired patients. Proceedings of the National Academy of Science USA 2006;103:9351–9356.

Hampton RR, Murray EA. Stimulus representations in rhesus monkeys with perirhinal cortex lesions. Behavioural Neuroscience 2002;116:363–377.

Hampton RR. Monkey perirhinal cortex is critical for visual memory, but not for visual perception: Reexamination of the behavioural evidence from monkeys. Quarterly Journal of Experimental Psychology 2005;58:283–299. [PubMed: 16194970]

Hargreaves EL, Rao G, Lee I, Knierim JJ. Major Dissociation Between Medial and Lateral Entorhinal Input to Dorsal Hippocampus. Science 2005;308:1792–1794. [PubMed: 15961670]

Henson RNA, Rugg MD, Shalice T, Josephs O, Dolan RJ. Recollection and familiarity in recognition memory: an event-related functional magnetic resonance imaging study. Journal of Neuroscience 1999;19:3962–3972. [PubMed: 10234026]

Holdstock JS, Mayes AR, Cezayirli E, Isaac CL, Aggleton JP, Roberts JN. A comparison of egocentric and allocentric spatial memory in a patient with selective hippocampal damage. Neuropsychologia 2000;38:410–425. [PubMed: 10683392]

Insausti R, Juottonen K, Soininen H, Insausti AM, Partanen K, Vaino P, Laakso MP, Pitkanen A. MR volumetric analysis of the human entorhinal, perirhinal, and temporopolar cortices. American Journal of neuroradiology 1998;19:659–671. [PubMed: 9576651]

Jackson O, Schacter DL. Encoding activity in anterior medial temporal lobe supports subsequent associative recognition. Neuroimage 2004;21:456–462. [PubMed: 14741683]

Jacoby LL. A process dissociation framework: separating automatic from intentional uses of memory. Journal of Memory and Language 1991;30:513–541.

Janzen G, Turennout MV. Selective neural representation of objects relevant for navigation. Nature Neuroscience 2004;7:673–677.

Johnson MK, Raye CL. Reality monitoring. Psychological Review 1981;88:67–85.

Johnson MK, Foley MA, Suengas AG, Raye CL. Phenomenal characteristics of memories for perceived and imagined autobiographical events. Journal of Experimental Psychology: General 1988;117:371–376. [PubMed: 2974863]

Johnson MK, Hashtroudi S, Lindsay DS. Source Monitoring. Psychological Bulletin 1993;114:3–28. [PubMed: 8346328]

Kensinger EA, Schacter DL. Amygdala activity is associated with the successful encoding of item, but not source, information for positive and negative stimuli. Journal of Neuroscience 2006;26:2564–2570. [PubMed: 16510734]

Kirwan CB, Stark CE. Medial temporal lobe activation during encoding and retrieval of novel face-name pairs. Hippocampus 2004;14:919–930. [PubMed: 15382260]

Kohler S, Danckert S, Gati JS, Menon RS. Novelty responses to relational and non-relational information in the hippocampus and the parahippocampal region: A comparison based on event-related fMRI. Hippocampus 2005;15:763–774. [PubMed: 15999342]

Lee ACH, Buckley MJ, Pegman SJ, Spiers H, Scahill VL, Gaffan D, Bussey TJ, Davies RR, Kapur N, Hodges JR, Graham KS. Specialization in the Medial Temporal Lobe for Processing of Objects and Scenes. Hippocampus 2005;15:782–797. [PubMed: 16010661]

Litman, L.; Awipi, T.; Davachi, L. Representational gradient in the human medial temporal lobe. 2007. In submission

Mandler G. Recognizing: the judgment of previous occurrence. Psychological Review 1980;87:252–271.

Manns JR, Hopkins RO, Reed JM, Kitchener EG, Squire LR. Recognition memory and the human hippocampus. Neuron 2003;37:171–180. [PubMed: 12526782]

Mayes A, Montaldi D, Migo E. Associative memory and the medial temporal lobes. Trends in Cognitive Sciences 2007;11:126–135. [PubMed: 17270487]

Miller EK, Li L, Desimone R. A Neural Mechanism for Working and Recognition Memory in Inferior Temporal Cortex. Science 1991;254:1377–1379. [PubMed: 1962197]

Moser MB, Moser EI. Distributed Encoding and Retrieval of Spatial Memory in the Hippocampus. Journal of Neuroscience 1998;18:7535–7542. [PubMed: 9736671]

Murray, EA.; Bussey, TJ.; Hampton, RR.; Saksida, LM. The parahippocampal region and object identification. In: Scharfman, HE.; Witter, MP.; Schwarcz, R., editors. The Parahippocampal region. Implications for neurological and psychiatric diseases. New York Academy of Sciences; New York: 2000. p. 166-174.

Norman G, Eacott MJ. Dissociable effects of lesions to the perirhinal cortex and the postrhinal cortex on memory for context and objects in rats Behavioral. Neuroscience 2005;119:557–566.

Paller KA, Wagner AD. Observing the transformation of experience into memory. Trends in Cognitive Science 2002;6:93–102.

Pihlajamaki M, Tanila H, Kononen M, Hannigen T, Mikkonen M, Hamalainen A, Soininen H, Aronen HJ. Visual Presentation of novel objects and new spatial arrangements of objects differentially activates the medial temporal lobe subareas in humans. European Journal of Neuroscience 2004;19:1939–1949. [PubMed: 15078568]

Prince SE, Daselaar SM, Cabeza R. Neural correlates of relational memory: successful encoding and retrieval of semantic and perceptual associations. Journal of Neuroscience 2005;25:1203–1210. [PubMed: 15689557]

Ranganath C, Yonelinas AP, Cohen MX, Dy CJ, Tom SM, D'Esposito M. Dissociable correlates of recollection and familiarity within the medial temporal lobes. Neuropsychologia 2004;42

Sakai K, Miyashita Y. Neural organization for the long term memory of paired associates. Nature 1991;354:152–155. [PubMed: 1944594]

Sandquist TF, Rohrbaugh JW, Syndulko K, Lindsley DB. Electrophysiological signs of levels of processing: perceptual analysis and recognition memory. Psychophysiology 1980;17:568–576. [PubMed: 7443924]

Schon K, Hasselmo ME, LoPresti ML, Tricarico MD, Stern CE. Persistence of parahippocampal representation in the absence of stimulus input enhances long-term encoding: A functional magnetic resonance imaging study of subsequent memory after a delayed match-to-sample task. Journal of Neuroscience 2004;24:11088–11097. [PubMed: 15590925]

Scoville WB, Milner B. Neylan TC. Loss of recent memory after bilateral hippocampal lesions. Memory and the Medial Temporal Lobe *Journal of Neuropsychiatry Clinical Neuroscience* 1957;12(1):103–113. 2000 Winter.

Shrager Y, Gold JJ, Hopkins RO, Squire LR. Intact visual perception in memory-impaired patients with medial temporal lobe lesions. Journal of Neuroscience 2006;26:2235–2240. [PubMed: 16495450]

Sperling R, Chua E, Cocchiarella A, Rand-Giovannetti E, Poldrack R, Schacter DL, Albert M. Putting names to faces: Successful encoding of associative memories activates the anterior hippocampal formation. NeuroImage 2003;20:1400–1410. [PubMed: 14568509]

Squire LR. Memory systems of the brain: A brief history and current perspective. Neurobiology of Learning and Memory 2004;82:171–177. [PubMed: 15464402]

Staresina B, Davachi L. Functional Dissociation in the Human Medial Temporal Lobe for Item Specific and Domain General Associative Encoding. Journal of Cognitive Neuroscience 2008;20(8) in press.

Staresina B, Davachi L. Differential Encoding Mechanisms for Subsequent Associative Recognition and Free Recall. Journal of Neuroscience 2006;26:9162–9172. [PubMed: 16957073]

Suzuki WA, Amaral DG. Perirhinal and parahippocampal cortices of the macaque monkey: Cortical afferents. Journal of Comparative Neurology 1994;350:497–533. [PubMed: 7890828]

Tendolkar I, Arnold J, Petersson KM, Weis S, Brockhaus-Dumke A, Eijndhoven P, Buitelaar J, Fernández G. Probing the neural correlatets of associative memory formation: A parametrically analyzed event-related functional MRI study. Brain Research 2007;1142:159–168. [PubMed: 17306237]

Tulving E. How many memory systems are there? American Psychologist 1985;40:385–398.

Uncapher MR, Rugg MD. Effects of divided attention on fMRI correlates of memory encoding. Journal of cognitive neuroscience 2005;17(12):1923–1935. [PubMed: 16356329]

Uncapher MR, Otten LJ, Rugg MD. Episodic encoding is more than the sum of its parts: an fMRI investigation of multifeatural contextual encoding. Neuron 2006;52:547–556. [PubMed: 17088219]

Wixted JT, Squire LT. Recall and recognition are equally impaired in patients with selective hippocampal damage. Cognitive, Affective, and Behavioral Neuroscience 2004;4:58–66.

Yonelinas AP. The Nature of Recollection and Familiarity: A Review of 30 Years of Research. Journal of Memory and Language 2002;46:41–517.

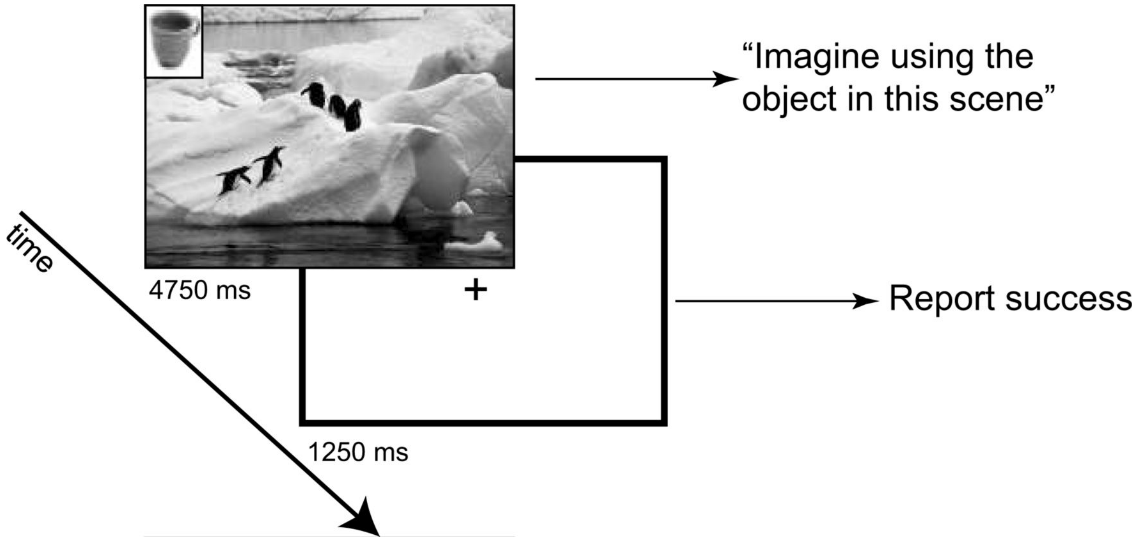

Figure 1.
Schematic of a single encoding trial. A full-color, trial-unique scene is presented in the center of the screen with one of six objects, here a cup, presented in the upper left corner of the scene image. This composite image is presented for 4750 ms. Participants are instructed to imagine using the object in the scene during this time. After a 250 ms pause, a response screen with a green fixation cross appears for 1000 ms. During this time, participants are instructed to indicate whether or not they were successful at the encoding task.

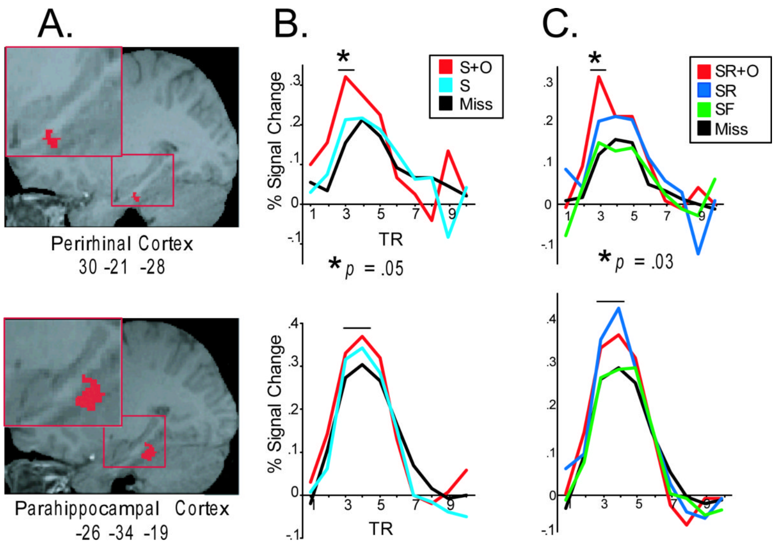

Figure 2.

BOLD responses in cortical regions along the parahippocampal gyrus. A) Brain regions of interest: top: perirhinal cortex; bottom: parahippocampal cortex. B) Comparisons of Scene + Object (*S*+*O*), Scene only (*S*) and Forgotten items (*M*). In perirhinal cortex, *S*+*O* differs from *S* (*p* = .05), no significant differences are seen in parahippocampal cortex. C) Comparisons in the same regions separating scene memory conditions into those subjectively reported as “Remember” (recollected) or ”Familiar”. In perirhinal cortex, Scene Remember + Object (*SR*+*O*) is significantly greater than Scene Remember only *(SR)*, despite the fact that both scenes are judged remembered. This trend appears inverted in parahippocampal cortex with *SR* numerically greater than *SR*+*O*. (Abbreviations: *S*+*O* = Scene + Object; *S* = Scene Only; *M* = Forgotten items (Miss); *SR*+*O* = Scene Remember + Object; *SR* = Scene Remember Only; *SF* = Scene Familiar Only)

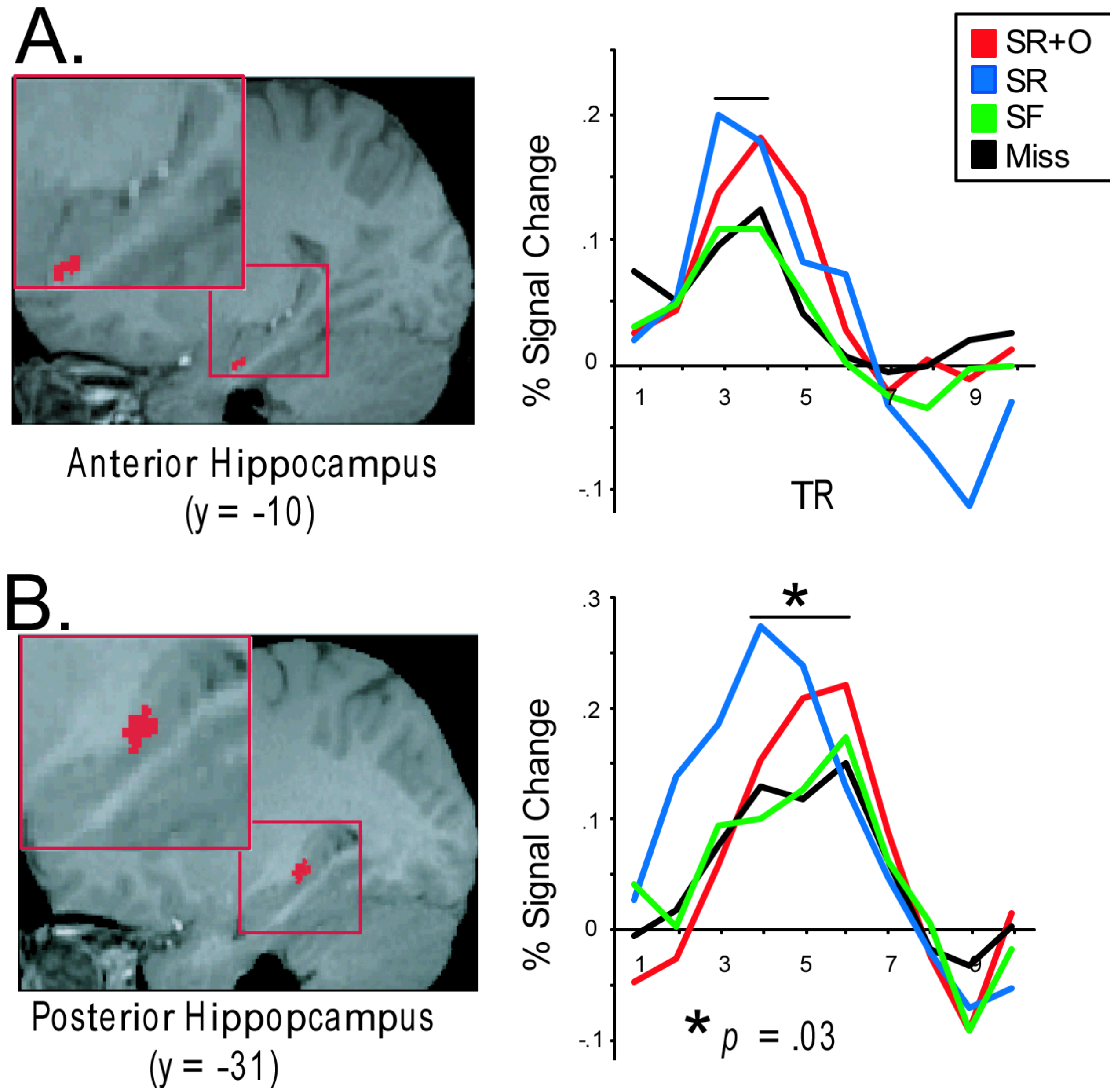

Figure 3.
BOLD responses in Hippocampus. Plots show hemodynamic responses for four conditions (*SR+O*, *SR*, *SF*, and *M*). A) ROI in anterior hippocampus shows comparable activation for *SR* and *SR+O* suggesting content-general recollective effects. B) ROI in posterior hippocampus: *SR* shows significantly greater activation compared to all other conditions including *SR+O*. (Abbreviations: *SR+O* = Scene Remember + Object; *SR* = Scene Remember Only; *SF* = Scene Familiar Only; *M* = Forgotten items (Miss))

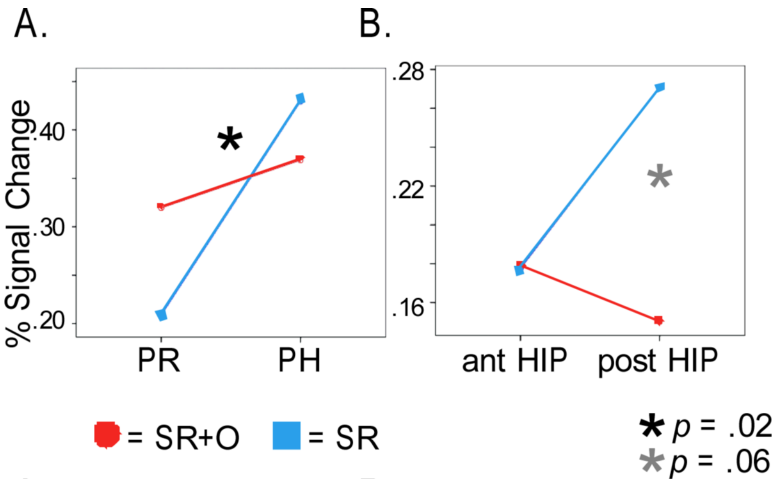

Figure 4.

Region by condition interactions. Activation for *SR+O* and *SR*, remembered conditions that differ on subsequent object source recollection, were compared across different MTL regions. A) Comparison of perirhinal and parahippocampal cortices reveals a significant REGION by CONTENT interaction for *SR+O* and *SR* across the anterior perirhinal region and in the posterior parahippocampal region. B). Comparison of the same conditions in anterior hippocampus and posterior hippocampus reveals an interaction that trends towards significance (*p* = .06). (Abbreviations: *SR+O* = Scene Remember + Object; *SR* = Scene Remember Only; PR = perirhinal cortex; PH = parahippocampal cortex; HIP = hippocampus; Ant = anterior; Post = posterior)

Table 1

Behavioral data across memory conditions

Table shows mean percentages and standard errors of the means (in parentheses) across subjects for various memory conditions. Conditions reflect subsequent memory for each item, or scene as a function of subjective reports of recollection and familiarity. Additionally, within each of those conditions, the proportion of trials for which subjects were able to correctly identify object source (object source recollection) is reported such that: Correct Source = During test, participants select correct object source paired with the item during encoding; Incorrect Source = participants select incorrect object source; No Source = when prompted to select the object source, participants respond "do not remember"

Condition		**Remember**	**Familiar**	**Total**
Scene Hits		*36.7%*	*17.6%*	*54.3%*
	Correct Source	22.3% (3.7%)	3.3% (1.5%)	25.6%
	Incorrect Source	9.4% (1.6%)	2.8% (.8%)	12.3%
	No Source	5.0% (1.5%)	11.4% (2.8%)	16.4%
Scene Miss		N.A.	N.A.	45.7% (4.1%)
False Alarm		1.5% (.5%)	4.2% (.9%)	5.6%