

The Medial Temporal Lobes Distinguish Between Within-Item and Item-Context Relations During Autobiographical Memory Retrieval

Signy Sheldon^{1*} and Brian Levine^{2,3}

ABSTRACT: During autobiographical memory retrieval, the medial temporal lobes (MTL) relate together multiple event elements, including object (within-item relations) and context (item-context relations) information, to create a cohesive memory. There is consistent support for a functional specialization within the MTL according to these relational processes, much of which comes from recognition memory experiments. In this study, we compared brain activation patterns associated with retrieving within-item relations (i.e., associating conceptual and sensory-perceptual object features) and item-context relations (i.e., spatial relations among objects) with respect to naturalistic autobiographical retrieval. We developed a novel paradigm that cued participants to retrieve information about past autobiographical events, non-episodic within-item relations, and non-episodic item-context relations with the perceptuomotor aspects of retrieval equated across these conditions. We used multivariate analysis techniques to extract common and distinct patterns of activity among these conditions within the MTL and across the whole brain, both in terms of spatial and temporal patterns of activity. The anterior MTL (perirhinal cortex and anterior hippocampus) was preferentially recruited for generating within-item relations later in retrieval whereas the posterior MTL (posterior parahippocampal cortex and posterior hippocampus) was preferentially recruited for generating item-context relations across the retrieval phase. These findings provide novel evidence for functional specialization within the MTL with respect to naturalistic memory retrieval. © 2015 Wiley Periodicals, Inc.

KEY WORDS: episodic memory; medial temporal lobes; contextual memory; relational memory

INTRODUCTION

Recollecting autobiographical events involves retrieving many elements of an experience, including details about specific objects and the

context of the remembered event. It is clear that the medial temporal lobes (MTL), and the hippocampus more specifically, relates together these elements to support re-experiencing a past event (Tulving, 2002; Moscovitch et al., 2005; Schacter, 2012; Schacter et al., 2012), however it is less clear how the MTL supports different relational processes during autobiographical memory (AM). Deciphering MTL differentiation during AM is key for understanding the mechanisms of naturalistic memory.

Distinct structures of the MTL have distinct functional roles during memory retrieval; however there are differing views on the nature of this functional differentiation (Brown and Aggleton, 2001; Eichenbaum et al., 2007; Ranganath, 2010; Staresina et al., 2013). One possibility is that following the long axis of the hippocampus, the MTL supports different types of subjective remembering. The perirhinal cortex is involved in familiarity responses, which depends heavily on binding object information, and the parahippocampal cortex is involved in recollection responses, which requires recovering contextual associations (Brown and Aggleton, 2001; Montaldi and Mayes, 2011). Another view is that MTL specialization is based on information processing. Several neuroimaging studies have used recognition memory paradigms to suggest that anterior aspects of the MTL (anterior hippocampus and perirhinal cortex) support object or item recognition and posterior aspects of the MTL (posterior hippocampus and parahippocampal cortex) support scene recognition (Awipi and Davachi, 2008; Staresina and Davachi, 2008; Cowell et al., 2010; Preston et al., 2010; Staresina et al., 2011; LaRocque et al., 2013). Reports have also linked anterior and posterior aspects of the hippocampus proper to object and spatial processing, respectively (e.g., Pihlajamaki et al., 2004), corresponding to the ventral (object) and dorsal (spatial) visual streams (Farah et al., 1988; Goodale and Milner, 1992; Ungerleider et al., 1998) that terminate in the perirhinal and parahippocampal cortex and separately enter the hippocampus (Knierim et al., 2006).

While these findings suggest that aspects of the MTL play qualitatively different roles in memory, many of these investigations have relied upon recognition memory paradigms in which qualitatively distinct stimuli were used to assess different processes. Thus, the functional specialization of the MTL as promoted

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in the recognition memory literature has not been systematically assessed using naturalistic memory retrieval. Studies that have examined MTL functional specialization in naturalistic retrieval scenarios have tended to focus on examining the influence of variables such as the age of memory (Bonnici et al., 2013), spatial relations (Nadel et al., 2013) or vividness (Sheldon and Levine, 2013). In the present study, we assessed MTL functional specialization using AM stimuli to determine the correspondence to the MTL dissociations observed with recognition paradigms.

On the basis of the recognition memory literature, we predicted that anterior MTL structures, namely the perirhinal cortex and anterior hippocampus, would support retrieving object-based or within-item relations, such as those required for relating together concepts or features of objects from a past event. Posterior aspects of the MTL, including the posterior hippocampus and parahippocampal cortex would support item-context relations, such as those required for reinstating detailed spatial contexts from a past event (Poppenk et al., 2013, see also Komorowski et al., 2013; Nadel et al., 2013). There is indirect evidence for these predictions in the AM literature. For example, commonalities between retrieving AM and performing higher-order spatial navigation (Hassabis et al., 2007; Spreng et al., 2009) and spatial retrieval tasks (Greenberg et al., 2009; Hoscheidt et al., 2010; Sheldon and Moscovitch, 2012) are typically reported in posterior aspects of the MTL. Involvement of anterior aspects of the MTL, including the perirhinal cortex, is reported when retrieving intra-item elements or integrating the perceptual features of objects (Cabeza and St Jacques, 2007; Addis et al., 2011) and for basic imagery tasks that require integrating object features, such as imagining famous faces (Ishai et al., 2002) or complex objects (Huijbers et al., 2011).

In addition to examining the functional segregation of MTL subregions, we also considered functional distinctions of the MTL in terms of the profile of activity over time. Studies have found distinct temporal patterns of MTL activity for different types of memory retrieval scenarios, such as between direct and effortful AM retrieval (Addis et al., 2012), vivid and non-vivid AM retrieval (Sheldon and Levine, 2013), and episodic and semantic information retrieval (Burianova and Grady, 2007). In general, these studies reported that direct and vivid AM retrieval was associated with earlier MTL (hippocampal) peaks than more effortful or less vivid AM, yet it is unclear what component is being rapidly retrieved for these direct and vivid memories. We examined MTL time course activity to determine how regional support of within-item and item-context information is time-locked to AM.

To test our hypothesis that the MTL functionally differentiates between two relational mnemonic processes, within-item and item-context relational processing, along the long axis of the hippocampus during AM retrieval we developed a novel paradigm to reliably assess MTL activity without the influence of different stimuli or forms. This paradigm was used to exploit similarities and differences between patterns of brain activity associated with retrieving autobiographical events and

retrieving non-episodic within-item or item-context relations, with perceptuomotor complexity and specificity equated across tasks. This greatly reduced method variance in probing each process and permitted us to tease apart elements of AM retrieval while also determining the relation of neural activity to these component processes outside of event memory.

Participants were presented with pictured objects under three different cueing instructions. The first condition required participants to retrieve a past personal event associated with the presented object (event condition). The two other conditions required participants to retrieve non-episodic information related to within-item or item-context relations. In the within-item condition, participants generated details associated with the presented object (generating within object relations/associations). In the item-context condition, participants determined an appropriate spatial location for the presented object (generating item relations in space). We compared neural activity evoked by these three conditions within our region-of-interest (ROI), the MTL, and across the whole brain.

We used a multivariate neuroimage analysis method, spatio-temporal Partial Least Squares (PLS; McIntosh et al., 1996; McIntosh and Lobaugh, 2004; Krishnan et al., 2011; Abdi and Williams, 2013) to extract common and distinct functional patterns of neural activity over time associated with event retrieval, within-item and item-context relational processing. As described above, we hypothesized that within-item and item-context relational processing would recruit anterior and posterior regions of the MTL, respectively, both in isolation and with respect to event memory. We hypothesized that the time course of the activity in the posterior and anterior MTL regions would reflect the importance of spatial layouts in accessing and establishing AM representations (Hassabis and Maguire, 2007; Summerfield et al., 2010; Mullally et al., 2012) and in integrating conceptual or object feature information to create a flexible and diverse behavioural context later on in retrieval (Addis et al., 2007). Thus, we posited early onset of posterior MTL activity for the retrieval of item-context information and later onset of anterior MTL activity for the retrieval of within-item details. Finally, we hypothesized that the dissociations within the MTL represent dissociations of a larger neural network, thus we expected the differences in MTL activity across the conditions to remain when we examined whole brain activity.

METHODS AND MATERIALS

Participants

The participants in this study were 28 healthy adults (average age = 26.2 yr; years of education = 17.1; 16 female; 23 right-handed). All participants were free from significant physical or mental illnesses, gave informed consent in accordance with the Rotman Research Institute/Baycrest Health Sciences Centre ethical guidelines, and received compensation for their

participation. One subject was excluded because of failure to follow instructions.

Procedure

All participants completed a neuropsychological test battery on a separate day as part of a different study. On the day of the scan, prior to entering the scanner, participants were given detailed instructions of the task and completed a practice run containing two trials of each experimental condition while they were in a mock-scanner.

Stimuli

The stimuli consisted of 60 colored pictures of familiar objects chosen from a set of 480 visual stimuli from the bank of standardized stimuli (BOSS; <http://boss.smugmug.com/>). From this normative bank, we chose pictures of objects that had over 50% name agreement, had a familiarity rating between 3 and 4.5 out of 5 (removing objects that had high and low familiar ratings), and whose visual complexity rating was over 2 (out of 5). We further reduced our set to 60 by eliminating any pictured objects that could not be held (e.g., a couch) or had very few associated sensory details (e.g., a ruler). The pictures were distributed randomly across the three conditions.

Scan procedure

The experimental paradigm is displayed in Figure 1. Each trial began with a four second screen informing the participants of the upcoming trial (“autobiographical memory”: event condition; “object imagery”: within-item condition; “object location”: item-context condition; “odd/even”: baseline), followed by the pictured object for six seconds with a short reminder of the instructions for each task (see Fig. 1). For the event condition, they were to think of a past personal memory (something that happened to them excluding the past 2 days) that took place in a single time and place (e.g., “going out for Indian food with my sister”). They were instructed to press a button when they had that memory in mind, and to spend the remainder of the retrieval period elaborating on details of that event. For the within-item condition, they were instructed to thoroughly imagine holding the object, to press a button to indicate they had that image in mind, and to spend the rest of the retrieval period thinking about the sensory or perceptual features or details of the object—what the object looks, feels, tastes, or sounds like. For the item-context condition, they were instructed to think of a spatial location where the object may be present, to press a button when they had that environment in mind, and to think of other objects that could also be in that location while keeping the spatial layout in mind. For the within-item and item-context conditions, participants were asked to avoid thinking about past events. For all conditions, the stimuli disappeared after six seconds but the short instructions remained in view for another 18 s. Thus, each trial contained a 24 s retrieval period. After the 24 s period, participants were given six seconds to rate on a scale of 1 to 8 the vividness with which they retrieved the desired

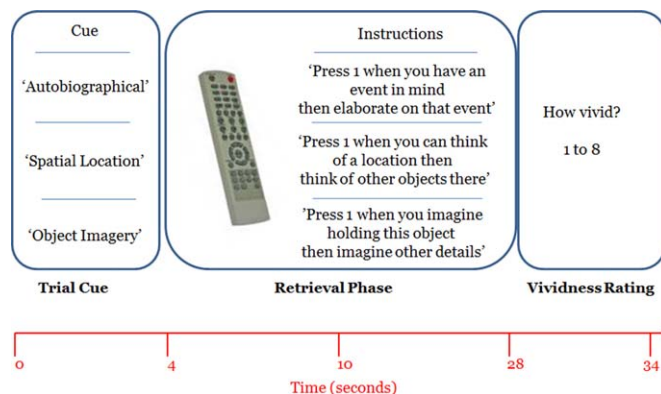


FIGURE 1. A depiction of the experimental paradigm. Each trial began with the presentation of a cue to alert the participants of the upcoming task (4 s). A randomly selected stimulus (pictured object) was presented along with the corresponding instructions for the cue task, indicating what information the participant was to retrieve using the stimulus to guide retrieval. While the stimulus remained on the screen for 6 s, the instructions, shown in the middle column for the event, item-context, and within-item conditions, remained on the screen for the length of the retrieval phase (24 s). For the purposes of the experiment, the three conditions were referred to as “autobiographical” (event), “spatial location” (item-context), and “object imagery” (within-item). Participants were instructed to press a response button (1) when they retrieved the required information (whether or not the stimulus was present). They were then to elaborate on that information for the remainder of the trial. After the retrieval phase, participants rated how vivid their recall was for that particular trial on a scale of 1 to 8. This ratings period lasted 6 seconds, followed by an additional 6 s prior to the next trial. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

information. There were six seconds of rest between each trial. For the baseline task (odd/even number detection), participants were shown a series of digits over the course of the 24 s retrieval period and silently judged if the digit was odd or even. As a manipulation check, they rated vividness after this task. A vividness rating for this baseline task indicates off-task thought (number detection does not require vivid thought, thus high vividness ratings indicates off-task thought) with the same scale used in the three experimental conditions.

Participants completed five functional runs. Each run contained four event, four item-context, four within-item, and two baseline task trials presented in random order. The functional runs were preceded by a T1-anatomical scan and a 6-min resting state scan.

Post-scan session

We conducted a post-scan interview as a manipulation check to ensure that the desired information was being retrieved during the scan session. For each object shown in the event condition, participants briefly described and dated the event they retrieved (to ensure they recalled a specific past personal memory), rated the event for emotion and personal significance on a scale of 1 to 6, and stated the perspective with which they recalled that memory (observer, field, or both). Trials from the

event condition in which general or extended events were recalled or those events that occurred in the past 48 h were excluded from analysis. To characterize the specificity of the memories retrieved in the event condition, for each event, we assigned one point each if a specific time, place or event was described (max = 3 points).

For objects shown in the within-item condition, participants stated the specific details they remembered generating in the scanner. They also indicated if they thought of a specific object from their own life (e.g., their own teddy bear versus the teddy bear shown or a generic teddy bear) and if they recalled an associated specific event during each trial. For objects shown in the item-context condition, participants stated the location for which they pressed the button and also listed the other objects they remembered generating in the scanner. They also indicated if they thought of a specific location from their own life (e.g., their own gym versus a general gym) and if they recalled an associated specific event during each trial. The number of details generated in the within-item condition and the number of objects generated in the item-context condition were tallied and averaged across trials and used as a measure of specificity for each condition. Trials from the item-context and within-item conditions that elicited recall of a specific event were excluded from subsequent analyses so that comparisons to the event condition would not be contaminated by event recall in these conditions.

Neuroimage Data Acquisition and Processing

Images were acquired on a 3 Tesla Siemens full-body MRI machine with a standard 12-channel array head coil located at the Rotman Research Institute/Baycrest Hospital. Anatomical scans were acquired via T1-weighted volumetric MRI (TR = 2,000 ms, TE = 2.63 ms, 160 axial slices, 1.0-mm-thick, FOV = 256 mm). For the functional images, 30.5-mm-thick axial slices with T2*—weighted EPI pulse sequence were obtained (TR = 2,000 ms, TE = 30 ms, flip angle = 70°, FOV = 200 mm) with no spacing.

All of the images were reconstructed and pre-processed using AFNI (Cox and Hyde, 1997). We discarded the first two images that were acquired for each functional run to allow brain magnetization to reach a steady state. Images were reconstructed, corrected for physiological movement due to heart rate and respiration, slice-time corrected to the first slice, and motion corrected using a 3D Fourier transform interpolation with a functional volume that minimized the amount of motion to ~1.5 mm. The data were transformed into voxels of $4 \times 4 \times 4 \text{ mm}^3$, normalized to a Talairach and Tournoux (TT) EPI template, and smoothed with an 8-mm isotropic Gaussian filter.

Neuroimage Data Analysis

The functional data were analyzed with Partial Least Squares (PLS; McIntosh et al., 1996; McIntosh and Lobaugh, 2004; Krishnan et al., 2011). PLS is a flexible multivariate technique that describes the relations between exogenous measures (e.g., experimental design or behavioural measures) and a set of

dependent measures (e.g., brain imaging data). PLS is similar to other data-driven multivariate techniques, such as principal component analysis, in that contrasts across conditions are not specified in advance. PLS begins with a covariance matrix between the experimental conditions (i.e., task conditions) and each voxel's signal at each lag (TR). The covariance matrix is then decomposed using singular value decomposition (SVD) to produce orthogonal latent variables (LVs) that optimally represent relations between brain voxels and the design (McIntosh et al., 1996; McIntosh and Lobaugh, 2004). The LVs are extracted in order of the amount of covariance explained. Each LV has a "singular value" that indicates the amount of covariance accounted for. The significance for each LV as a whole is determined via a permutation test whereby the order of conditions is reassigned for each participant without replacement for 500 samples. The number of times the permuted singular values exceed the observed singular values is calculated, providing exact probabilities for all LVs, and an objective means for determining the number of LVs to be retained. Because the decomposition of the data matrix is done in a single analytic step, correction for multiple comparisons is unnecessary. The reliability of the weights (saliency) for the brain voxels showing the pattern of condition contrasts identified by the LVs is determined via bootstrap estimation of the standard errors in which participants are randomly re-sampled 300 times with replacement. The saliency/standard error ratio (bootstrap ratio) is analogous to a *Z* score that is used for thresholding images and creating activation maps. We used a bootstrap ratio of 3.3 (corresponding to $P < 0.001$) for the whole brain analysis and 2.8 (corresponding to $P < 0.005$) for the ROI analysis as a threshold. Local maxima for the brain areas with reliable saliences on each LV were defined as the voxel with a bootstrap ratio higher than any other voxel in a cube centered on that voxel. Multiplication of each voxel's saliency by its BOLD signal intensity and summing across voxels for a given participant yielded a "brain score" that indicated the degree to which that participant expressed the activation pattern identified by the LV at each lag (TR).

Task PLS extracted common and distinct patterns of spatial and temporal activity across the conditions that were apparent when examining whole brain patterns of activity as well as those that appear within the MTL. We applied event-related task PLS to map changes in patterns of neural activity across the retrieval period, beginning with the onset of the stimuli to 24 s (12 TRs or lags). We report both mean-centered task PLS and non-rotated task PLS. Mean-centered PLS is a data-driven analysis that calculates the means for the tasks/conditions across participants for each voxel. The grand mean is calculated to generate LVs that best account for the observed contribution of conditions to the identified brain pattern. In non-rotated task PLS, *a priori* contrasts are used to restrict the patterns derived from PLS. We focused on mean-centered PLS analysis because we wanted to determine patterns of overlap that were driven by the data. These more agnostic analyses were supplemented with non-rotated task PLS analyses in which we pre-defined contrasts of interest to test predictions that may have been

overshadowed by the data-driven distinctions revealed by mean-centered PLS methods. The MTL ROI analyses incorporated a bilateral MTL mask (the hippocampus, perirhinal, entorhinal as well as the parahippocampal cortices) based on a Freesurfer average of five healthy young adult brains that were not involved in this study (mask dimensions: $45 \times 54 \times 45$ voxels). The mask was in TT space.

RESULTS

Behavioural Results

We removed event condition trials that were answered with extended events, general events, or those that happened to the participants in the past 48 h, which excluded 41 trials across all participants (7.5% of all responses). Trials from the within-item and item-context conditions that were answered with an associated specific event were also removed from analysis. This removed 20 responses (3.7% of all responses) from the within-item condition and 65 responses from the item-context condition (12% of all responses).

In-scanner behavioural responses

There was a significant effect of condition on the time taken to make a response (i.e., to press 1; $F(2, 52) = 8.519$, $P = 0.001$). The response time for the event condition (mean = 4.6 s, SD = 1.6 s) was slower than the average response time for the item-context (mean = 3.6 s, SD = 1.5 s; $t(26) = 6.172$, $P < 0.001$) and within-item condition (mean = 3.5 s, SD = 2.0 s; $t(26) = 2.865$, $P = 0.008$), but there was no difference in response time between the within-item and item-context conditions ($t(26) = 0.218$, $P = 0.829$). There was also a significant effect of condition on the vividness ratings ($F(2,52) = 3.862$, $P = 0.027$). The only significant difference was between the event (mean = 5.5, SD = 1.02) and within-item condition (mean = 5.9, SD = 1.12; $t(26) = 2.403$, $P = 0.024$) with no differences emerging between the item-context condition (mean = 5.8, SD = 1.1) and the event or within-item conditions ($t(26) = 1.608$; $P = 0.120$; $t(26) = 1.387$; $P = 0.177$, respectively). The mean vividness rating for the baseline odd-even number detection task was low (mean = 1.81, SD = 0.80). This task does not require vivid thought, thus this low rating confirms that the participants were not recalling task-irrelevant vivid images or details and were on-task.

Post-scan responses

During the post-scan interview, participants were asked if they thought of a specific object (i.e., my teddy bear versus a general teddy bear) or a specific environment (i.e., my kitchen versus a general kitchen) for the within-item and item-context condition trials, respectively. For the within-item condition, across all participants, a specific object was reported for 163

trials (30%) and a general object was reported for 313 trials (58%; for 2% of the trials, the participants could not remember specificity). For the item-context condition, across all participants, a specific location was reported for 332 trials (61%), and a general spatial location was reported for 85 trials (16%; for 23% of the trials, the participants could not remember specificity). As these specific or personal versus general trials were unbalanced across conditions, we contrasted these in an ancillary analysis to rule out differences in specificity as confounding our main results (see the supplementary material for the results of this analysis).

We also used the data collected from the post-scan interview to clarify the processes implemented during each condition. For the event condition, we rated the specificity of the recalled events on a three-point scale. Participants generated memories that were specific for at least two out of these three elements (1.9, SD = 0.4). For the item-context condition, we first determined the specificity of the location that was generated. Participants generated a specific room (e.g., basement) or a location within a room (e.g., under the stairs in a basement) 67.9% percent of the time and a general area (e.g., park) 23.2% of the time; 5.3% of responses were unclassifiable. We averaged the number of additional items participants recalled generating in the scanner for this task. Participants listed an average of 3.7 additional items for each spatial context (SD = 2; range 0 to 10 items). For the within-item condition, when thinking about object features, participants focused on one sensation on 45.4% of trials and integrated two or more sensations (e.g., touch, visual) on 53.7% of trials. The sensation that was most often described was touch. We averaged the number of features or details participants recalled generating in the scanner for this task. Participants listed an average of 3.3 details (SD = 1.5; range 0–10 features).

Medial Temporal Lobe Activity

A mean-centered PLS extracted two significant patterns (LVs). The first pattern (55.76% of the cross-block variance; $P < 0.001$) showed distinct MTL activity for the event and within-item conditions (Fig. 2, top panel; the item-context condition did not contribute to this LV). The event condition activated a distributed pattern along the length of the MTL, including the hippocampus bilaterally. The within-item condition was associated with a cluster that had peak activity in the left perirhinal cortex (anterior MTL) but also a cluster that extended into the left parahippocampal gyrus near the fusiform gyrus. The second LV (44.24% of the cross-block variance; $P = 0.014$) depicted a pattern of activity common to the event and within-item condition that consisted of early activity in the anterior right hippocampus and left parahippocampal gyrus (rhinal cortex), peaking at Lag 3 (6 s; Fig. 2, middle panel), and a distinct pattern for the item-context condition that centered on bilateral posterior hippocampal and parahippocampal regions (Fig. 2, middle panel). A non-rotated PLS was run to determine similar MTL activity patterns between the event and item-context conditions. A significant LV ($P < 0.001$) indicated

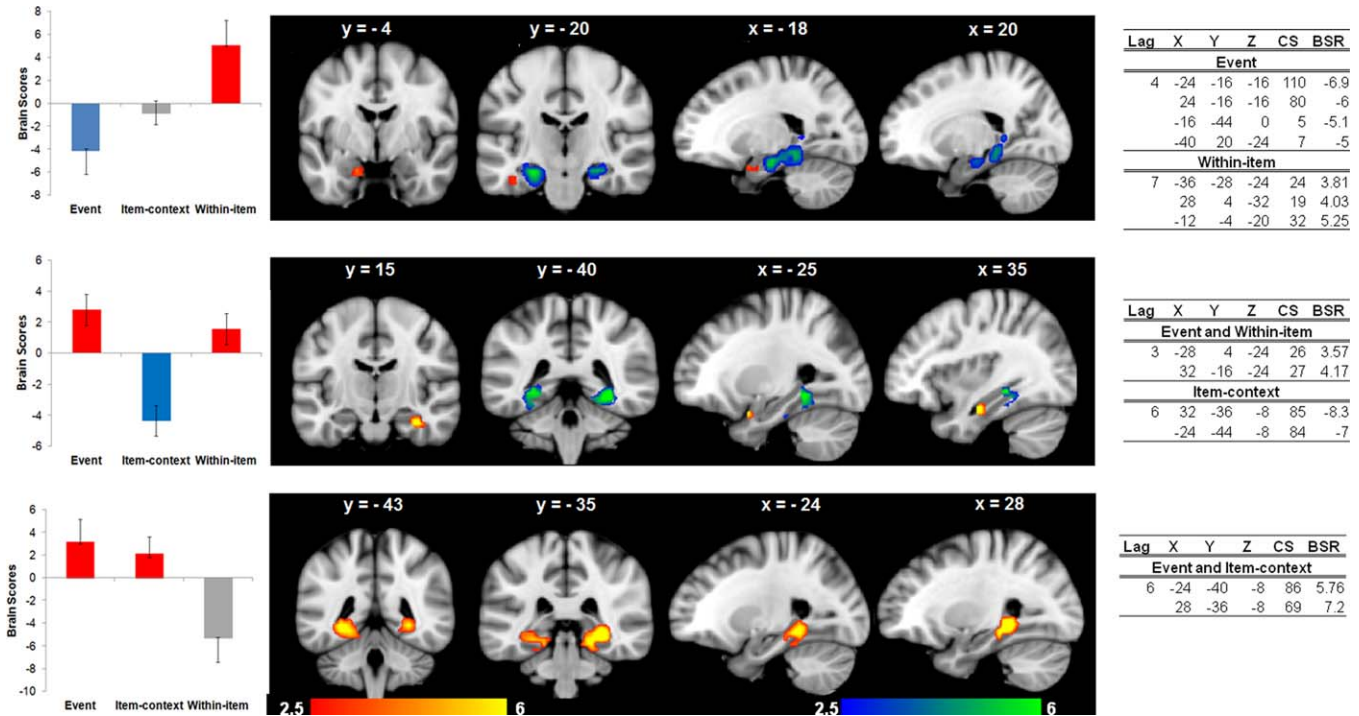


FIGURE 2. PLS results depicting MTL patterns of activity. For each pattern, the brain scores (with 95% confidence intervals) that depict the condition contrast are plotted on the left, the location of MTL activity associated with these contrasts is illustrated in the middle and the coordinates (TT coordinates) of the significant peak clusters and the associated lag (TR) for each contrast is shown on the right. Top Panel. The MTL pattern of activity from the first Latent Variable (LV) of the mean-centered task PLS. Warm colors are the areas that were distinctly activated for the within-item condition, activity depicted on the brain represents contributions from Lag 7. Cool colors are the areas that were distinctly activated for the event condition from Lag 4. Middle Panel. The MTL pattern of activity from LV2 of the mean-centered task PLS. Warm colors are the areas that were jointly activated for the event and within-item

conditions, activity depicted on the brain represents contributions from Lag 3. Cool colors are the areas that were distinctly activated for the item-context condition from Lag 6. Bottom Panel. The MTL pattern of activity from non-rotated task PLS contrasting the event and item-context conditions to the within-item condition. Warm colors are the areas that were jointly activated for the event and item-context conditions, activity depicted on the brain represents contributions from Lag 6. BSR = bootstrap ratio. CS = cluster size. Negative BSRs are associated with negative brain scores (see plots on left) and cool colors, and positive BSRs are associated with positive brain scores and warm colours. Brain patterns are superimposed on the template brain (voxels ≥ 5 , bootstrap ratio $\geq \pm 2.8$). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

that activity in the posterior hippocampal and parahippocampal regions in both hemispheres was common to the event and item-context conditions (Fig. 2, bottom panel).

A follow-up analysis assessed activity for the within-item and item-context conditions in relation to the event condition within the anterior and posterior hippocampus. For each participant, we created a 10 mm³ sphere around the peak voxel of activity in the left and right anterior and posterior hippocampus for the event condition (see Supporting Information Table S1 for subject-specific peaks; n.b. peaks were defined and extracted using anatomically defined left/right and anterior/posterior hippocampal masks) and extracted the mean signal from the item-context and within-item conditions, beginning at the time in which the required information was generated. A repeated-measures ANOVA was run on these values with laterality (left vs. right), hippocampal subregion (anterior vs. posterior) and condition (item-context vs. within-item condition). This analysis revealed a main effect of laterality

($F(1,25) = 9.74, P = 0.004$) and condition ($F(1,25) = 25.61, P < 0.001$). While there was no main effect of subregion, there was an interaction of subregion and condition ($F(1,25) = 37.50, P < 0.001$). This suggests that anterior versus posterior MTL activity was different for the within-item and item-context conditions, confirming our PLS MTL analysis.

We next examined the time course of the MTL activity across the retrieval period by extracting the signal change at each lag across the entire 24-s retrieval period. So not to bias temporal activity to one condition or another, we used anterior and posterior MTL seeds that were derived from the literature. A motivation for our study came from findings from the recognition memory literature, thus we identified two key regions from Staresina et al.'s (2011) recognition memory study that showed an object-preferential effect in the anterior MTL (perirhinal cortex) or a scene-preferential effect in the posterior MTL (parahippocampal cortex). We extracted mean activity in each condition from each of these voxels and the next closest

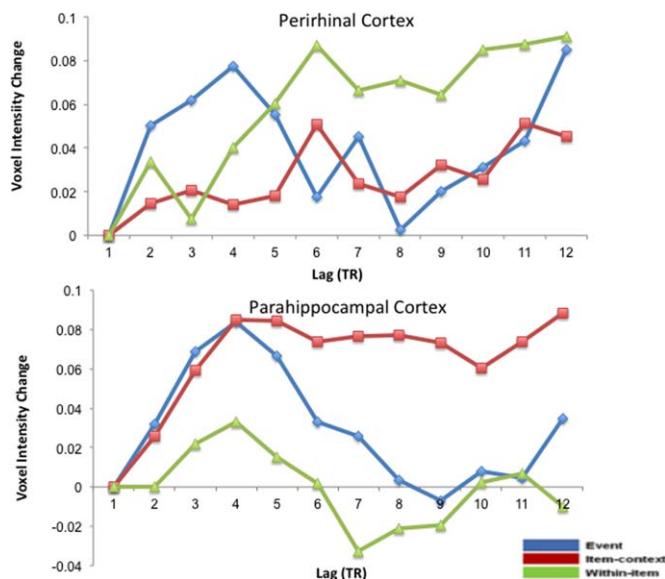


FIGURE 3. Time course of anterior MTL (perirhinal cortex; $x, y, z = 32, -9, -22$, coordinates converted from MNI to TT) and posterior MTL (parahippocampal cortex; $x, y, z = 26, -37, -3$, coordinates converted from MNI to TT) activity across conditions. Peaks in the respective regions were selected from Staresina et al. (2011), to reflect the engagement of object-based and scene-based processes associated with the anterior and posterior MTL, respectively. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

neighbour (27 voxels in each cluster) and plotted activity across conditions over the entire retrieval phase (Fig. 3). There was an interaction between condition and time (lag; $F(20,520) = 2.485, P < 0.005$) for perirhinal activity. Figure 3 illustrates that the perirhinal cortex showed early peak activity for the event condition with an additional later peak of activity, sustained and later activity for the within-item condition and lower level fluctuations across retrieval for the item-context condition. This was confirmed with a post hoc comparison of early (average activity during lag 3 and 4) versus later (average activity during lag 11 and 12) activity in each condition (event, $t(26) = 0.192, P = 0.849$; within-item $t(26) = 2.385, P = 0.025$; item-context $t(26) = 1.189, P = 0.245$). The posterior parahippocampal cortex also showed an interaction between condition and time (lag; $F(20,520) = 4.610, P < 0.005$), but showed early onset of activity for the event condition (and to a lesser extent the within-item condition), and early and sustained activity for the item-context condition, confirmed with a post hoc comparison of early (lag 3 and 4) versus later (lag 11 and 12) activity in each condition (event, $t(26) = 3.107, P = 0.005$; within-item $t(26) = 1.323, P = 0.197$; item-context $t(26) = 0.395, P = 0.696$). We confirmed this pattern by extracting activity from the peak MTL clusters that were associated distinctly with each condition from the mean-centered PLS analysis (Supporting Information Fig. 1). This analysis showed early onset for the event condition in its peak region, item-context peak MTL activation that had an early rise in activation and that was sustained through-

out the retrieval period and peak MTL activity for the within-item condition that was more robust at later time points in the retrieval period.

Whole Brain Activity

To determine commonalities among the three retrieval conditions compared to the odd-even number detection baseline task, a non-rotated task PLS was run that weighted the three conditions equally. A significant LV emerged ($P < 0.001$) revealing a common pattern of activity that included the posterior parahippocampus, lateral parietal, medial frontal, inferior temporal, and occipital cortical regions. This common activity was most robust in the first four lags of retrieval (8 s; Table 1).

A mean-centered (data-driven) PLS revealed distinct patterns of activity across the event, within-item and item-context conditions (Fig. 4; Tables 2 and 3). The first LV (78.63% of the cross-block variance; $P < 0.001$) showed patterns of activity that separated the event condition (the pattern associated with the negative brain scores; cool colors illustrated in the upper panel Fig. 4) from the within-item condition (the pattern associated with positive brain scores; warm colors illustrated in the upper panel Fig. 4); the item-context condition did not contribute to this pattern. Areas preferentially associated with the event condition included prominent regions of the default mode network, namely midline frontal and posterior regions, the parahippocampal gyri (including the hippocampus—encompassed by the cluster with peak activity in the fusiform gyrus), the middle temporal gyrus bilaterally, and the left angular gyrus. The within-item condition was associated with bilateral activity in the inferior and middle frontal gyri, precuneus, superior parietal lobule, inferolateral temporal cortex, middle occipital gyrus, and the pre- and post-central gyri (Table 2). The second LV (21.38% of the cross-block variance; $P < 0.001$) identified a pattern that was common to both the event and within-item conditions (associated with positive brain scores) that included the left inferior parietal lobule and left inferior frontal gyrus (warm colors illustrated in the bottom panel of Fig. 4). This LV also extracted a pattern distinct for the item-context condition that included the bilateral posterior parahippocampal cortex, the posterior cingulate cortex, and the precuneus (cool colors illustrated in the bottom panel of Fig. 4; Table 3).

DISCUSSION

While there is a general consensus for the critical role of the MTL in supporting relational mnemonic processing (Eichenbaum and Cohen, 2014), the precise intra-MTL functional specialization is underspecified, particularly with it comes to naturalistic memory retrieval. Here we used an AM retrieval experiment to test the functional roles of distinct MTL components as proposed by the recognition memory literature. This proposal suggests a divide between anterior and posterior MTL

TABLE 1.

Non-rotated Task PLS Results that Describe a Common Pattern for all Three Retrieval Conditions (Positive BSR) and Another Pattern That was Associated With the Baseline Task (Negative BSR) Across Retrieval (Even Lags Shown)

Lag	Lobe	Brain region	BA	X	Y	Z	CS	BSR
2	Frontal lobe	L middle frontal gyrus	9	-44	12	32	191	7.82
		R precentral gyrus	4	32	-24	52	40	6.73
		L precentral gyrus	6	-56	0	12	22	-7.89
	Sub-lobar	L thalamus	-	-8	-24	0	94	8.21
		R insula	13	44	-40	24	25	-5.87
	Temporal lobe	L fusiform gyrus	37	-32	-36	-12	1,530	12.84
Posterior lobe	L cerebellar tonsil	-	0	-52	-36	27	7.57	
4	Frontal lobe	L medial frontal gyrus	6	-4	12	44	746	9.64
		R middle frontal gyrus	6	28	-8	60	84	6.6
	Sub-lobar	L insula	13	-56	-36	20	44	-8.67
		L insula	13	-36	-28	24	25	-6.79
	Temporal lobe	L fusiform gyrus	30	-24	-32	-16	1,989	11.55
		L superior occipital gyrus	39	-32	-76	32	345	11
Posterior lobe	R cerebellar tonsil	-	16	-32	-44	49	7.89	
6	Frontal lobe	L middle frontal gyrus	6	-28	4	52	332	8.74
		L middle frontal gyrus	9	-52	20	28	132	7.39
		L middle frontal gyrus	47	-40	36	-8	36	6.53
	Sub-lobar	L insula	13	-52	-32	20	57	-8.48
		L parahippocampal gyrus	-	-24	-32	-20	96	9.56
	Lingual gyrus	-	-8	-44	0	45	7.11	
Parietal lobe	R precuneus	19	36	-76	36	26	6.91	
	R inferior parietal lobule	40	52	-28	24	69	-7.28	
	L angular gyrus	39	-36	-76	32	164	8.19	
Posterior lobe	R cerebellar tonsil	-	36	-60	-32	109	6.8	
8	Frontal lobe	L middle frontal gyrus	8	-24	24	44	258	8.08
		L middle frontal gyrus	9	-52	20	28	44	6.72
	Sub-lobar	L insula	13	-52	-36	20	31	-7.91
		L fusiform gyrus	20	-28	-36	-16	38	8.57
	Parietal lobe	L precuneus	7	-12	-68	48	111	8.37
	Occipital lobe	L inferior occipital gyrus	18	-36	-84	-8	58	-6.32
Posterior lobe	R cerebellar tonsil	-	32	-56	-32	27	6.39	
Temporal lobe	L fusiform gyrus	37	-28	-36	-12	32	9.3	
10	Frontal lobe	L middle frontal gyrus	6	-28	4	52	69	6.9
	Sub-lobar	L insula	13	-48	-36	16	39	-6.54
	Temporal lobe	L fusiform gyrus	20	-28	-36	-16	25	8.44
	Parietal lobe	L precuneus	7	-24	-76	44	31	7.01
		R inferior parietal lobule	40	52	-28	24	71	-6.93
Occipital lobe	L middle occipital gyrus	18	-40	-80	-8	115	-7.6	

Minimum cluster size was set to 10 voxels ($4 \times 4 \times 4 \text{ mm}^3$). BA = Brodmann Area; CS = cluster size; BSR = bootstrap ratio.

structures. Anterior MTL structures like the perirhinal cortex are involved in item specific relational retrieval and posterior MTL regions, namely the posterior parahippocampal cortex, are involved in source or item-context relational retrieval (Awipi and Davachi, 2008; Staresina and Davachi, 2008; Staresina et al., 2011; LaRocque et al., 2013). To measure this MTL functional specialization during naturalistic memory retrieval, we compared activity during event recollection to activity during non-episodic retrieval of within-item (intra-item) and item-context relations, taking three steps to ensure we were measuring these distinct relational processes. First, we

used the same retrieval cues across conditions, improving upon previous studies that have used different types of cues to probe within-item and item-context relational processes. Second, we ensured that the non-episodic relational conditions (within-item and item-context) were not contaminated by event recollection by removing trials in which an event was recalled as determined during a post-scan interview. Third, we used a powerful method of multivariate analysis, partial least squares (PLS), to show both common and distinct patterns of activity that supported retrieving within-item and item-context relations, both with respect to event and non-event retrieval. With

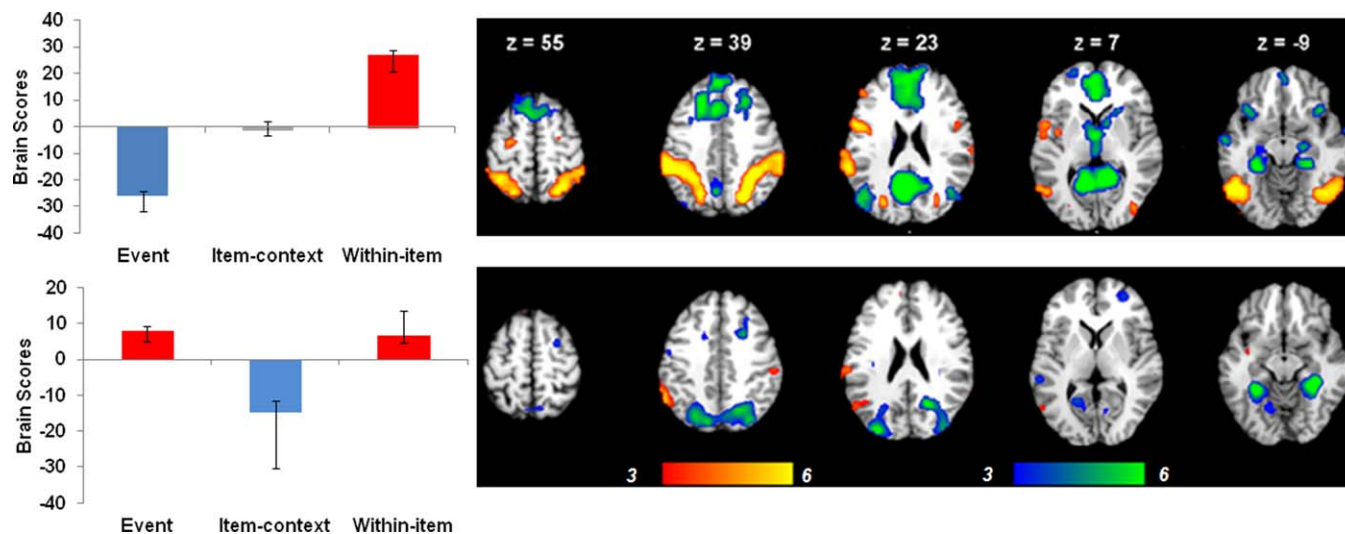


FIGURE 4. Mean-centered PLS results contrasting patterns of whole-brain activity across the three conditions. For each pattern, the brain scores (with 95% confidence intervals) that depict the condition contrast are plotted on the left. The patterns of brain activity associated with these contrasts are shown on the right. The full list of clusters is reported in Tables 2 and 3. Top: Brain scores and activity patterns from latent variable (LV) 1. The event condition was associated with negative brain scores (cool colors) whereas the within-item condition was associated with positive brain scores (warm colors). Brain activity patterns are displayed

for Lag 4, where conditions were maximally differentiated (see Table 2). Bottom: Brain scores and activity patterns from LV 2. The item-context condition was associated with negative brain scores (cool colors) whereas the event and within-item conditions were associated with positive brain scores (warm colors). Brain activity patterns are displayed for Lag 4, where conditions were maximally differentiated (see Table 3). Brain patterns are superimposed on the template brain (voxels ≥ 10 , bootstrap ratio $\geq \pm 3.3$). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

these steps taken, we provide insight into the dynamic interplay between the functionally discrete subregions of the MTL memory system.

MTL Functional Specialization Along the Hippocampal Long-Axis

We found common MTL activity between the event and two non-episodic retrieval conditions. From a broad standpoint, this challenges traditional views of the MTL, and the hippocampus more specifically, as being selectively engaged by episodic memory tasks. Our data instead support a contemporary view that assigns the MTL a role in a multitude of non-mnemonic retrieval scenarios (Suddendorf and Corballis, 2010; Sheldon et al., 2011; Schacter et al., 2012; Sheldon and Moscovitch, 2012; Gerlach et al., 2014).

Critically, we also found differential engagement of MTL subregions across the retrieval conditions. The precise pattern aligns with models of MTL functional segregation reported in the recognition memory literature (Staresina and Davachi, 2008; Staresina et al., 2011; LaRocque et al., 2013). Retrieving relations among elements of an object (within-item condition) disproportionately recruited very anterior MTL regions (rhinal cortex) compared to other regions of the MTL. Retrieving relations among objects in a spatial context (item-context condition) relied more heavily on posterior MTL regions (posterior parahippocampal cortex). This dissociation was also evident

when we restricted our analysis to participant-specific anterior and posterior hippocampal ROIs.

Although we report an anterior/posterior MTL dissociation, we also note that the activity in anterior and posterior MTL segments was asymmetric. There was greater activity (in terms of signal strength and cluster extent) in the posterior MTL in the item-context and event conditions compared to the anterior MTL in the within-item condition (Fig. 2). Although the within-item condition preferentially engaged the anterior versus the posterior MTL, the overall reduction in activity for the within-item versus other conditions could reflect underlying functional or structural differences between these MTL subregions (Strange et al., 2014).

Our findings contribute to theories of MTL functional specialization. The perirhinal cortex and posterior parahippocampal cortex relate to different functional cortical networks that interact with the hippocampus distinctly along the long axis (Poppenk and Moscovitch, 2011; Libby et al., 2012; Ranganath and Ritchey, 2012; Ritchey et al., 2014), which suggests that functional models of the hippocampus extend to extra-hippocampal MTL regions. One model of hippocampal specialization suggests that coarse coding of event information is supported by the anterior hippocampus and specific place coding is supported by the posterior hippocampus (Poppenk et al., 2013). This model has received support from studies focusing on environmental context (e.g., Evensmoen et al., 2013; Nadel et al., 2013). A related theory or interpretation of hippocampal

TABLE 2.

Mean-Centered Task PLS: Latent Variable (LV) 1, Contrasting the Within-item Condition (Positive BSR) to the Event Condition (Negative BSR; the Item-context Condition did not Contribute to this LV)

Lag	Lobe	Brain region	BA	X	Y	Z	CS	BSR	
2	Parietal lobe	R precuneus	7	24	-56	52	38	6.35	
		L inferior parietal lobule	40	-60	-40	32	59	6.01	
		L precuneus	7	-28	-48	48	20	5.05	
	Limbic lobe	L posterior cingulate	23	-8	-56	12	134	-7.03	
	Frontal lobe	L inferior frontal gyrus	9	-48	4	20	87	6.97	
4	Temporal lobe	R inferior temporal gyrus	37	56	-60	-4	126	7.1	
		L middle temporal gyrus	37	-52	-56	-8	168	8.37	
	Parietal lobe	L superior parietal lobule	7	-36	-52	60	512	7.99	
		R superior parietal lobule	7	28	-52	40	413	8.6	
	Frontal lobe	L medial frontal gyrus	10	0	52	-4	450	-7.24	
	Limbic lobe	R posterior cingulate	29	12	-48	8	418	-12.75	
	Sub-lobar	L insula	13	-32	16	-4	23	-7.34	
		L thalamus	-	0	-8	8	24	-6.55	
	Temporal lobe	L fusiform gyrus	37	-28	-36	-12	39	-6.8	
		R middle temporal gyrus	39	40	-68	28	21	-6.61	
	Parietal lobe	L angular gyrus	39	-44	-68	28	61	-6.72	
	6	Frontal lobe	L middle frontal gyrus	46	-48	40	20	33	5.93
Temporal lobe		R inferior temporal gyrus	37	56	-60	-4	108	6.8	
		L middle temporal gyrus	37	-48	-60	-4	160	7.84	
Sub-lobar		R insula	13	44	0	4	128	7.45	
		L insula	13	-44	-8	4	204	8.38	
Parietal lobe		R precuneus	7	24	-60	48	333	7.12	
		L inferior parietal lobule	40	-60	-32	32	481	8.68	
Limbic lobe		R posterior cingulate	30	8	-52	12	379	-8.76	
Frontal lobe		R superior frontal gyrus	8	20	24	48	49	-7.51	
		L medial frontal gyrus	10	0	56	0	127	-6.13	
Limbic lobe		R posterior cingulate	30	8	-52	12	379	-8.76	
Temporal lobe		L middle temporal gyrus	39	-44	-72	28	60	-6.27	
	R middle temporal gyrus	39	40	-68	28	31	-6.24		
8	Frontal lobe	R inferior frontal gyrus	9	56	8	32	35	6.04	
		R middle frontal gyrus	10	44	44	12	35	7.42	
		L middle frontal gyrus	10	-40	40	12	137	8.14	
	Sub-lobar	R insula	13	40	0	0	127	6.76	
	Temporal lobe	R fusiform gyrus	37	48	-60	-12	116	6.94	
		L inferior temporal gyrus	37	-52	-60	-8	195	7.67	
	Parietal lobe	R postcentral gyrus	2	56	-28	40	400	7.54	
		L inferior parietal lobule	40	-48	-28	32	783	8.6	
	10	Frontal lobe	L inferior frontal gyrus	44	-56	8	20	189	8.56
			L inferior frontal gyrus	46	-44	40	12	94	7.54
			R inferior frontal gyrus	9	52	4	32	44	5.79
			R medial frontal gyrus	6	4	-4	60	22	5.4
		R precentral gyrus	4	40	-12	56	24	5.2	
Temporal lobe		L fusiform gyrus	37	-52	-60	-12	217	8.78	
	R inferior temporal gyrus	37	56	-60	-4	101	7.6		
	R superior temporal gyrus	22	56	8	4	70	6.17		
Parietal lobe	L inferior parietal lobule	40	-60	-32	36	384	7.88		
	R postcentral gyrus	2	56	-28	40	250	6.44		
	L postcentral gyrus	3	-20	-36	72	62	6.06		
Occipital lobe	L cuneus	17	-12	-88	8	168	7.17		
	R middle occipital gyrus	19	40	-80	4	24	5.89		
Limbic lobe	R posterior cingulate	30	16	-52	16	101	-6.9		

Minimum cluster size was set to 10 voxels ($4 \times 4 \times 4 \text{ mm}^3$). BA = Brodmann Area; CS = cluster size; BSR = bootstrap ratio.

TABLE 3.

Mean-centered Task PLS: Latent Variable (LV) 2, Contrasting the Event and Within-item Conditions (Positive BSR) to the Item-context Condition (Negative BSR)

Lag	Lobe	Brain region	BA	X	Y	Z	CS	BSR
2	Limbic lobe	R posterior cingulate	30	16	-56	16	20	-5.38
4	Frontal lobe	L inferior frontal gyrus	47	-24	16	-12	31	5.18
	Parietal lobe	L inferior parietal lobule	40	-52	-44	48	77	6.47
		L precuneus	19	-28	-72	36	52	-5.12
6	Limbic lobe	L parahippocampal gyrus	37	-24	-44	-8	27	-5.67
		L posterior cingulate	30	-20	-56	12	41	-6.23
		R posterior cingulate	30	16	-56	16	165	-8.35
	Parietal lobe	L inferior parietal lobule	40	-60	-24	28	174	6.68
	Frontal lobe	R middle frontal gyrus	8	24	16	40	31	-4.89
	Limbic lobe	L parahippocampal gyrus	37	-28	-44	-8	89	-8.96
8	Occipital lobe	R parahippocampal gyrus	37	32	-36	-8	78	-7.89
		L middle occipital gyrus	19	-36	-88	20	713	-8.54
	Frontal lobe	L inferior frontal gyrus	47	-36	24	-16	27	4.5
	Parietal lobe	L inferior parietal lobule	40	-52	-48	44	200	5.73
	Limbic lobe	R parahippocampal gyrus	37	32	-36	-8	927	-9.72
	Parietal lobe	L precuneus	7	-24	-68	36	151	-7.35
10	Frontal lobe	L inferior frontal gyrus	47	-36	24	-16	22	5.63
	Temporal lobe	L superior temporal gyrus	22	-64	-52	20	62	4.64
	Parietal lobe	L inferior parietal lobule	40	-56	-40	44	64	5.4
		L inferior parietal lobule	40	-60	-24	28	34	5.01
		Limbic lobe	L parahippocampal gyrus	37	-28	-44	-8	564
		R parahippocampal gyrus	37	32	-36	-8	59	-6.87
	R posterior cingulate	31	24	-60	20	74	-4.58	

Minimum cluster size was set to 10 voxels (4 × 4 × 4 mm³). BA = Brodmann Area; CS = cluster size; BSR = bootstrap ratio.

function that accounts for the breadth of information retrieved during AM is that the anterior hippocampus incorporates higher-order non-spatial (and spatial) information to flexibly link conceptual and episodic information (Giovanello et al., 2009) and the posterior hippocampus identifies and relates objects to location based on sensory or perceptual details (for some reviews of MTL functional specialization, see Davachi, 2006; Ranganath, 2010; Strange et al., 2014). By this view, the division in the MTL is based on diversity or complexity rather than the spatial granularity of information. A recent study reported that during spatial navigation the posterior hippocampus tracked an environment's spatial scale based on the physical environment and the anterior hippocampus tracked the environment based on route complexity (Baumann and Mattingley, 2013). Bonnici et al. (2013) reported that the anterior and not the posterior hippocampus could delineate recent from remote memories, suggesting that the anterior hippocampus is better able to recruit a rich behavioural context to distinguish between different memories. Our results fit well with this view of MTL specialization. In our study, anterior MTL regions were engaged during the construction of a conceptually specific context for retrieving within-item relations and the posterior regions were engaged by the construction of a spatial and perceptually specific context for retrieving the item-context relations (but see Diana et al., 2012). These results cannot be accounted for by overall

specificity, as both the within-item and item-context conditions were rated as equally vivid and attracted a similar number of details.

The time course differences found in anterior and posterior MTL regions across the three conditions also supports distinct roles for the MTL segments in retrieving a conceptual versus spatial context, although we interpret these time courses with caution because we cannot be sure that participants were on-task for the whole retrieval phase. The early onset of MTL activity, both anterior and posterior, for the event condition reflects the integration of conceptual and spatial information necessary to fully experience an AM. This requires relating together several disparate aspects of a memory to create a cohesive whole. Anterior activity peaked later and was sustained for the within-item conditions which we suggest reflects the anterior MTL integrating several disparate elements (e.g., smooth touch; shiny handle) or concepts to create the mental representation of a cohesive item (e.g., a spatula), a process attributed to the anterior MTL (Graham et al., 2010). The anterior MTL also peaked later in retrieval for the event condition, suggesting an additional role of anterior MTL components in binding features of a memory together at these later time-points. Finally, the early onset and temporally extended posterior MTL/hippocampal involvement for the item-context condition likely reflects the emphasis on selective and specific spatial relations

across the retrieval epoch, although an alternative account is that the posterior hippocampus supports different functions at different points in retrieval. Spatial context is critical for establishing a memory (Hassabis and Maguire, 2007, 2009; Mullally et al., 2012; Mullally and Maguire, 2013), possibly by serving as scaffolding for event details, fitting with the early peak for the event condition.

The more extensive MTL activity for the item-context and event conditions compared to the within-item condition could reflect the critical role of binding large-scale spatial relations throughout the time-course of event retrieval or that participants were more likely to recruit personal spatial layouts when thinking about item-context information. To test this, we ran a supplementary analysis (interpreted with caution given the limited number of trials with personalized objects in the within-item condition) that determined minimal differences between trials that used specific and general information for the non-event conditions, primarily showing only increased activity in the inferior frontal cortex and cingulate for using general versus specific instances for the within-item condition. The absence of differences between the specific and general instances for the item-context condition could also reflect the inherent use of personal space when recalling spatial environments. In a previous study, our group showed that the autobiographical significance of famous names (i.e., the degree to which the name was associated with personal event) modulated the late positive component (LPC) associated with episodic memory in a fame judgement task (Renoult et al., 2014). This suggests that the overlap between conceptual and autobiographical episodic information can be manipulated by adjusting the personal significance of the conceptual information (Renoult et al., 2012). It would be fruitful to promote the retrieval of specific, personally significant object exemplars to more closely align within-item and item-context conditions in terms of personal significance.

Finally, we note that the event condition recruited a distinct pattern of hippocampal activity along the length of the axis, possibly reflecting temporal contextual retrieval that is necessary for event recollection but that is not necessarily retrieved during the non-episodic tasks (Eichenbaum, 2013; Hsieh et al., 2014). An alternate possibility is that this recruitment along the length of the hippocampus reflects the addition of self-referential processing (Buckner and Carroll, 2007) and/or multimodal binding that is required to a greater extent for event recollection versus non-episodic retrieval.

Functional Specialization Across the Whole Brain

There was a high degree of overlap in whole brain activity across the three conditions during the first 6 s of retrieval in regions such as the left parahippocampus, bilateral fusiform gyrus, and bilateral precentral gyrus, likely reflecting the processing of the picture stimulus. Later common regions of activity were in the bilateral insula, left medial frontal gyrus, the right middle frontal gyrus, and the left caudate, a pattern that likely reflects the retrieval of salient and self-relevant information (insula activity; Craig, 2009; Menon and Uddin, 2010)

and contextually relevant information (right middle frontal cortical activity; Kaller et al., 2011). In addition to patterns of overlap, we also found dissociable patterns of whole brain activity. A data-driven mean-centered PLS extracted two patterns. The first pattern separated the event and within-item conditions. The event condition exclusively evoked the classic AM pattern (left posterior cingulate, left angular gyrus, left medial frontal gyrus, and bilateral middle temporal gyri) peaking early (8 s). The within-item condition evoked activity in lateral temporal-parietal regions, the inferior and middle frontal gyri, and regions of the motor cortex peaking later in retrieval (20 s). These distinct patterns reflect the dissociation between rapid integration of self-related episodic autobiographical information versus the processing of conceptual and visual information combined with motor imagery. The temporal difference across these two conditions also hints at the speed at which multimodal autobiographical details accumulate and iteratively stimulate further retrieval, whereas the more constrained within-item task entailed a slower constructive process, fitting with our theorizing of the MTL timescale (Sheldon and Levine, 2013).

The second pattern extracted common activity for the event and within-item conditions compared to a distinct pattern for the item-context condition. The event and within-item conditions recruited the left inferior frontal gyrus, the left inferior parietal lobule, and superior temporal gyrus, reflecting the integration and attention to sensory detail with conceptual representations (Jobard et al., 2003; Gitelman et al., 2005). This speaks to the dependence of aspects of event AM on retrieving rich perceptual object details, like those required by visual imagery (Greenberg and Rubin, 2003), and integrating them with conceptual information. Retrieving item-context relations recruited the precuneus and the bilateral parahippocampal gyri, supporting the view of a primary role of visuospatial construction skills to spatial imagery (Hassabis and Maguire, 2007, 2009).

CONCLUSIONS

The reported patterns of MTL activity associated with retrieving and relating within-item features and item-context information with respect to AM suggests that there are dissociable MTL-mediated functional networks that support particular relational processes when recalling a past event. The pattern of differentiation between the anterior and posterior MTL for within-item and item-context relations extends findings and formulations from the recognition memory literature to naturalistic AM conditions. Fitting with these formulations, our findings suggest a process-based hierarchical framework along the axis of the MTL that moves from flexibly integrating concepts and sensory elements within a global behavioural context (anterior MTL: Holdstock et al., 2009; Clarke and Tyler, 2014) to establishing relations of objects or entities in a

physical context (posterior MTL). More broadly, our results suggest that because we can dissociate these component processes of AM, what we recollect is a matter of retrieval processes rather than mental content.

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