Reactivation of context-specific brain regions during retrieval

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ABSTRACT

The neural correlates of recollection were examined using event-related functional MRI. We examined how the presence of different visual context information during encoding of target words influenced later recollection for the words presented alone at retrieval. Participants studied words presented with different pictures of faces or scrambled faces on each trial, and on a subsequent scanned recognition test made ‘remember’, ‘know’ or ‘new’ responses to words presented alone. Prior to the study phase, participants performed a localization task, in which the fusiform face area (FFA) was identified. We compared brain activation patterns for remember and know responses given to words studied with faces as compared to scrambled faces. Though behaviourally participants showed no difference in memory performance depending on encoding trial type, both a group- and individual-based region-of-interest analysis showed increased activation in the functionally-defined FFA for remember responses given to words studied with faces compared to scrambled faces. A regression analysis additionally showed that activation in the right fusiform gyrus increased as the relative recollection benefit for words studied with meaningful (face) compared to non-meaningful (scrambled face) context information increased. Results suggest that context-specific brain regions implicated during encoding are recruited during retrieval, and that the degree to which participants activate context-specific brain regions during retrieval is related to a behavioural benefit in later recollection for target information presented alone.

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Dual process theories of memory suggest that there are two ways in which we recognize items in our environment. Recollection occurs when we recognize an item and retrieve detailed contextual information about the learning episode, whereas familiarity is the nonspecific sense that an item has been previously encountered (Gardiner, 1988; Yonelinas, 2002). Research has shown that recollection and familiarity can be dissociated at both the cognitive and neural level. For example, divided attention at encoding, levels of processing, and speeded responding show larger effects on recollection than familiarity (Yonelinas, 2002). In addition, whereas damage to the hippocampus has been demonstrated to impair recollection and spare familiarity, damage to the surrounding temporal lobe has been shown to impair familiarity and spare recollection (Bowles et al., 2007; Yonelinas et al., 2002). Neuroimaging data provide converging evidence of this double dissociation (Montaldi, Spencer, Roberts, & Mayes, 2006), and suggest that recollection and familiarity also differ in the frontal and parietal brain regions recruited (Skinner & Fernandes, 2007; Vilberg & Rugg, 2008).

One method used to explore recollection and familiarity empirically is the remember-know paradigm (Gardiner, 1988; Tulving, 1985). In this procedure, participants study a list of items and, during a recognition test, are asked to state whether they ‘remember’ the item if they can recall specific details (e.g., contextual information) about it from the study episode, whether they ‘know’ an item was on the study list if it is familiar but lacks specific details from the study episode, or whether they deem the item to be ‘new’, and not from the study list. Remember responses align with recollective memory processes, whereas know responses support familiarity-based recognition (Yonelinas, 2001). One advantage of the remember-know paradigm is that it provides a more inclusive measure of recollection than other paradigms (e.g., it is not limited by what context the experimenter wants the participant to recall, as in the process dissociation procedure). As well, behavioural results using the remember-know paradigm converge with those using other methods (receiver operating characteristic curves and the process dissociation procedure) to measure recollection and familiarity (Yonelinas, 2001). While the paradigm is widely used, recent research suggests that the method may not measure separate psychological processes (Rotello & Zeng, 2008; Starns & Ratcliff,
2008). For example, Wais, Mikes, and Wixted (2008) found that source recognition for know responses was significantly above chance, indicating that know responses are not devoid of contextual detail, and suggested that the remember-know procedure probes ‘degrees of recollection’, rather than separate memory processes.

The current study is novel in that we sought to compare the behavioural effect of, and brain activation patterns for, two different types of remember responses: those given to items studied with and without meaningful visual context information. Such a comparison allowed us to identify the neural regions needed to retrieve specific context information, enabling context-specific recollection. We also considered whether our context manipulation selectively influenced remember responses, or affected both remember and know responses similarly.

Studies using functional neuroimaging have found that some of the cortical regions active during encoding are active again during retrieval, supporting models of memory which suggest that remembering episodes from one’s past involves the reinstatement of the representations active during initial learning (Nyberg, Habib, McIntosh, & Tulving, 2000; Nyberg et al., 2001; Wheeler & Buckner, 2003; Woodruff, Johnson, Uncapher, & Rugg, 2005). Wheeler and Buckner (2004) hypothesized that if it is recollection, and not familiarity, that involves the subsequent retrieval of contextual detail, only recollection should be associated with the reactivation of sensory-specific brain regions during a recognition test. In their study, participants studied words with accompanying related pictures (e.g., the word dog was presented visually along with a picture of a dog), and on a later scanned recognition test using event-related fMRI, made remember, know, or new responses to the words presented alone. They found that activity in a region of the left inferior temporal cortex, known to be activated during the perception of visual information based on a previous experiment (Maccotta & Buckner, 2002), was higher for remember than know responses. This finding has subsequently received support from Johnson and Rugg (2007), who showed that activation during remember, as compared to know, responses overlapped the brain regions used to originally encode the context information.

The current study examined how the provision of different visual context information (a face or scrambled face), at study, affected brain activation during later remember and know responses for target words encoded within this context. In our recent behavioural work, we examined whether the provision of contextual information at encoding, but absent at retrieval, increased subsequent recollection for target words similarly in younger and older adults (Skinner & Fernandes, 2009). In that study, we hypothesized that presenting context information rich in meaning would increase word context binding, improving subsequent recollection. Younger and older adult participants studied words presented with either a picture of a face (rich-context condition) or a rectangle (weak-context condition), and performed a subsequent remember-know recognition test for the words presented alone. The younger, but not older, adult participants showed better memory for words studied with faces than words studied with rectangles, and this benefit was specific to remember responses. We suggested that younger participants spontaneously engaged in elaborative processes at study that linked the item and face contexts into a cohesive memory trace, enabling subsequent recollection. Older adults did not initiate this elaborative process at encoding; however, when explicitly told to make an arbitrary link between the context and target study word, they did show an increase in recollection performance.

In the current study, we used this paradigm to examine whether the type of context information presented at study affects the brain regions sub-serving recollection. Whereas previous work has examined how sensory-specific reactivation of encoding context differs for remember and know responses, the current study compared activation for two different types of remember (or know) responses: those given to words studied with faces and those with scrambled faces. Such a comparison can identify the neural regions needed to retrieve specific context information, facilitating recollection. In addition, because the current study used faces as the context information, which consistently activates the fusiform gyrus bilaterally, known as the fusiform face area (FFA; Haxby et al., 1994; Kanwisher, McDermott, & Chun, 1997; O’Craven & Kanwisher, 2000), we could define, a priori, the specific region of the brain that should be activated during recollection.

The current study was conducted in two phases. In phase I, a localizer task was used to identify the FFA in each participant, using a block design. To identify the FFA, activation during the viewing of faces was compared to that from the viewing of houses, as this contrast has been shown to isolate the FFA in other work (Yovel & Kanwisher, 2004). In phase II, participants studied words presented visually, accompanied by pictures of faces or pictures of scrambled faces on each trial (encoding was not scanned). In this way, we changed the meaning of the context information presented with the study word, while keeping the basic visual features (luminance and contrast) of the context constant. The subsequent recognition test, in which participants gave a remember, know, or new response to words presented alone, was scanned using event-related fMRI.

To examine the neural regions recruited for remember or know responses to these different word types, we contrasted activation for responses given to words studied with faces compared to scrambled faces, separately for each response type. We hypothesized that the brain regions used to retrieve information studied with different context information would differ only for remember responses. Specifically, if the face context is bound to the target word, and retrieved through recollective memory processes, activation in the FFA during word recollection should be higher for words studied with faces than scrambled faces. According to dual process theory, know responses are not influenced by availability of contextual detail; thus, there should be no significant effect of context on these responses, nor any differences in pattern of brain activation in the FFA for know responses to words studied with faces compared to scrambled faces.

We were additionally interested in whether activation in the fusiform gyrus was related to behavioural performance on the recognition memory task. In our other work, we hypothesized that when meaningful context information is provided at study, participants engage in elaborative processes that bind the item and context information in memory, improving subsequent recollection; we found that participants differ in their tendency to engage in such item-context binding at encoding (Skinner & Fernandes, 2009). Given these individual differences, it is possible that sensory-specific reactivation is related to the extent to which participants engage in the successful binding, and subsequent retrieval of, the word-face pairs. In the current study we hypothesized that activation in the fusiform gyrus would increase as the relative difference in recollection accuracy between words studied with intact faces compared to scrambled faces increased. Sensory-specific reactivation was thus expected to be related to recollection accuracy.

1. Methods

1.1. Participants

Fifteen normal healthy participants (8 female; 1 left-handed), from 19 to 29 years of age (M = 23.13, SD = 2.97), with a mean of 16.67 (SD = 1.84) years of education completed the study after giving informed consent. All procedures were approved by the ethics committee at the University of Waterloo and a joint ethics committee of the University of Toronto and Baycrest Centre for Geriatric Care. All participants spoke English fluently and were free from psychiatric or neurological disease.
of houses (O'Craven, Downing, & Kanwisher, 1999). The face and house stimuli were matched for size (11 cm × 9 cm). Two-hundred twenty-five medium to high frequency words were chosen from Celex, a lexical database available on CD-ROM (Baayen, Piepenbrock, & Gulikers, 1995) for the three study-test cycles of the memory task. For each cycle, the study list was comprised of 50 words: 25 were paired with pictures of faces (face trials) and 25 were paired with pictures of scrambled faces (scrambled trials). For the subsequent recognition test, a corresponding list was created, consisting of the 50 studied words plus 25 words not presented in the study phase (lures). Accordingly, across all three study-test cycles, 75 words were paired with pictures of faces, 75 with the picture of a scrambled face, and 75 served as lures. Three different study-test list combinations were created such that each word was paired with either a picture of a face, a scrambled face, or served as a lure across lists, counterbalanced across participants. The order of presentation of the word lists for the three study-test cycles was also counterbalanced across participants. All test lists were equated for word length (M = 6.31), and word frequency (M = 18.27 occurrences per million; Baayen et al., 1995). An additional 30-item word list was used in the practice phase, with the same characteristics as the words in the experimental session. Seventy-five faces with neutral expressions, 38 male and 37 female, were randomly chosen from the AR face database to serve as the face stimuli for the memory task. The face stimuli were randomly assigned to 25 words for each study list; thus, all study words were paired with a unique face. An additional 8 face stimuli were used in the practice session. The scrambled faces were created in Matlab 7.06 software by randomizing the pixels of the 75 face images chosen from the database (see Fig. 1 for sample stimuli). Thus, for each face stimulus there was a corresponding scrambled image. This randomization altered the spatial frequency, and meaningful content, of the images, while preserving luminance and contrast.

1.2. Behavioural task materials

Face stimuli for the localizer task were taken from the AR face database, which contains black and white photographs showing the frontal view of male and female faces (Martinez & Benavente, 1998). House stimuli were 20 black and white pictures of houses (O’Craven, Downing, & Kanwisher, 1999). The face and house stimuli were matched for size (11 cm × 9 cm). Two-hundred twenty-five medium to high frequency words were chosen from Celex, a lexical database available on CD-ROM (Baayen, Piepenbrock, & Gulikers, 1995) for the three study-test cycles of the memory task. For each cycle, the study list was comprised of 50 words: 25 were paired with pictures of faces (face trials) and 25 were paired with pictures of scrambled faces (scrambled trials). For the subsequent recognition test, a corresponding list was created, consisting of the 50 studied words plus 25 words not presented in the study phase (lures). Accordingly, across all three study-test cycles, 75 words were paired with pictures of faces, 75 with the picture of a scrambled face, and 75 served as lures. Three different study-test list combinations were created such that each word was paired with either a picture of a face, a scrambled face, or served as a lure across lists, counterbalanced across participants. The order of presentation of the word lists for the three study-test cycles was also counterbalanced across participants. All test lists were equated for word length (M = 6.31), and word frequency (M = 18.27 occurrences per million; Baayen et al., 1995). An additional 30-item word list was used in the practice phase, with the same characteristics as the words in the experimental session. Seventy-five faces with neutral expressions, 38 male and 37 female, were randomly chosen from the AR face database to serve as the face stimuli for the memory task. The face stimuli were randomly assigned to 25 words for each study list; thus, all study words were paired with a unique face. An additional 8 face stimuli were used in the practice session. The scrambled faces were created in Matlab 7.06 software by randomizing the pixels of the 75 face images chosen from the database (see Fig. 1 for sample stimuli). Thus, for each face stimulus there was a corresponding scrambled image. This randomization altered the spatial frequency, and meaningful content, of the images, while preserving luminance and contrast.

1.3. Procedure

Stimulus presentation and response recording were controlled by an IBM PC, using E-prime v.1.1 software (Psychology Software Tools Inc., Pittsburgh, PA). Participants were tested individually, and completed the experiment in approximately 2 h. The experiment began with a practice session, outside of the scanner, consisting of a block of the localizer and a block of the memory task, using the same timings and procedure as in the experimental trials. This was done to ensure that all participants understood the experimental tasks before entering the scanner. Participants first viewed 10 face and 10 house stimuli for the practice localizer task, followed by the practice study session, in which 16 study trials (8 face-word and 8 scrambled-word) were presented visually, in random order. Subsequently, ‘remember-know’ test response instructions were given and 15 recognition trials consisting of 4 words studied with faces, 4 words studied with scrambled faces, and 7 new words, were presented in random order.

The instructions for the remember-know test were as follows: participants were told that they would see some words that were from the study list, and other words that were not. If they believed the word was not from the study list, participants were instructed to respond ‘N’ for new by pressing the ‘2’ key with their ring finger on a computer keypad. If they thought the word was from the study list, they had two options, ‘R’ or ‘K’. They were told to report ‘R’ for remember by pressing the ‘1’ key with their index finger if the word was ‘old’ and they could recall specific details associating that word with the study episode. They were given examples of such details: They may remember an image, thought, or feeling they had associated with the word during study, or the temporal order of the words. These contextual details meant they had a specific recollection of that word. If however, they believed the word to be ‘old’ but they did not recall a specific study detail associated with the word, they were asked to report ‘K’ for know by pressing the ‘2’ key with their middle finger. To clarify the ‘K’ memory response, participants were also given the example of meeting someone on the street that they knew they had met before, but not being able to determine the specific instance in which they had met them. Participants were then asked if they understood the distinction between ‘R’ and ‘K’ responses and, after the practice session, participants were asked to give the details of the context accompanying an ‘R’ response to the experimenter, to ensure that they understood the difference between ‘R’ and ‘K’, and were not simply responding on the basis of response confidence.

Following practice, participants entered the scanner and the anatomical scan was obtained. For the subsequent localizer task, a block design was used. Participants viewed 19 blocks of 20 images; 10 blocks contained images of faces and 9 blocks contained images of houses, with blocks presented in alternating sequence. The images remained on the screen for 1000 ms, followed by a 500 ms fixation cross presented centrally. In each of the three study phases, 50 trials were presented (25 face-word and 25 scrambled-word), with trial type randomized. Within each study phase, the 25 scrambled images were the scrambled versions of the 25 face images presented in the face trials. Participants were asked to memorize the words for an upcoming memory test. To ensure that participants associated faces (or scrambled faces) during study, participants were also asked to manually identify, for each study trial, the picture presented with each word as either a face or a scrambled face by making a button press using their index or middle finger on a button box (the Identification task). Participants used their dominant hand to make their responses. Each trial was completed in 3500 ms (timings noted above), and participants were asked to make their classification response during this time. After each study phase, participants counted backwards by threes for 30 s before beginning the remember-know recognition test. The test phase of each study-test cycle was scanned using a fast event-related design. Each run consisted of 75 words (25 studied with faces, 25 studied with scrambled faces, and 25 lures) and 25 central fixation crosses presented in a pseudo-random order. During each non-fixation trial, the word was presented in the centre of the screen in the same font and size as at study. As described above, participants were asked to make a remember, know, or new response by pressing one of three buttons on a button box with their dominant hand. The word/fixed cross remained on the screen for 4000 ms, followed by a central fixation cross for 250 ms; thus, for the fixation trials, the fixation cross remained on the screen for 4250 ms. Participants could make their response anytime within the 4250 ms of each recognition trial.

1.4. fMRI data acquisition

Visual displays were presented on a screen which participants viewed using a mirror attached to the head coil. Headphones and foam pillows were used to dampen scanner noise and minimize head movement. Participants responded by pressing one of three buttons on a ORF bimanual 8-button fiber optic response box positioned under their dominant hand, which rested on the scanner bed (Current Designs Inc., Philadelphia, PA). Data were acquired with a whole-body 3.0Tesla MRI scanner (Siemens Tim Trio, Erlangen, Germany) with a standard head coil. Axial anatomical images were acquired using a three-dimensional T1-weighted fast spoiled gradient echo image (TR = 2000 ms; TE = 30 ms; flip angle = 70 degrees; acquisition matrix = 256 × 192; FOV = 250 mm; 160 axial images; slice thickness = 1 mm). Functional imaging was performed to measure brain activation by means of the blood oxygenation level-dependent (BOLD) effect (Ogawa, Lee, Kay, & Tanaka, 1990). Functional scans for the localizer and memory tasks were acquired with a single-shot T2*-weighted pulse sequence with echo planar imaging (EPI) acquisition (TR = 2000 ms; TE = 30 ms; flip...
1.5. fMRI data analysis

Processing and analysis were performed using the Analysis of Functional
Images (AFNI, version 2007_05_20_1644) software package (Cox & Hyde, 1997). The first 5 data points in all fMRI time series, corresponding to presentation of a blank screen in our paradigm, were omitted from analysis to ensure magnetization
had reached steady state. For the event-related (memory retrieval) runs, between-

slice timing differences caused by slice acquisition order were adjusted and time series were spatially co-registered to a reference scan to correct for head motion
using a 3D Fourier transform interpolation, using a functional volume that mini-
imized the amount of head motion to <2 mm. One participant was removed from the behavioural and fMRI analysis due to excessive head motion (>3 mm). Localizer
and memory retrieval data were then converted to units of percent change and the memory retrieval runs were concatenated using the 3dcalc and 3dTcat commands in
AFNI.

Individual participant data were analyzed using the 3DDeconvolve program in
AFNI. For the Localizer data, General Linear Tests (GLTs), using a block response function, were used to distinguish different regions of BOLD signal change for the FACE
and HOUSE trials. The response was modeled with one regressor, with the HOUSE
trials serving as the baseline. For the memory retrieval (event-related) runs, par-
ticipants were divided into the following response types: (1) REM FACE: words studied with a face and correctly identified with a remember response, (2) REM SCR: words studied with a scrambled face and correctly identified with a remember response, (3) KNOW FACE: words studied with a face and correctly identified with a know response, (4) KNOW SCR: words studied with a scrambled face and correct response, and (5) FIX: baseline fixation crosses. GLTs were used to contrast the selected memory responses to baseline (FXY). New items
given remember and know responses (false alarms), misses, and correct rejections
were also identified, but were not used in the analyses. A tent function was used
to model the data, with the function estimated at 7 time points. Events of interest
were time-locked to the stimulus onset. Each participant’s data were extracted and trans-
formed into a common space based on the Talairach and Tournoux (1988) atlas and
spatial smoothing was performed using an isotropic Gaussian blur with a full width
at half maximum (FWHM) of 6 mm to increase the signal-to-noise ratio. Original
3 × 3 × 3 mm voxels were resampled to 2 × 2 × 2 mm prior to group analysis.

A voxel-wise, two-factor ANOVAs, using FIX as baseline, with Response Type (FACE and SCR) as a fixed factor and participants as a random factor, were conducted to compare activ-
ation for (1) REM FACE to REM SCR, and (2) KNOW FACE to KNOW SCR responses. We used the Talairach atlas (Talairach & Tournoux, 1988) in AFNI and the auto-
mated Talairach Daemon (Lancaster et al., 2000) to define Brodmann Areas for the
regions of activation identified by the analyses. To address the issue of multiple com-
parisons, a Monte Carlo simulation was completed using the Alphashim program in
AFNI to determine a threshold and cluster size combination with a low false positive
discovery rate. We used a threshold of p < .001 and a cluster size of 30 resampled
voxels, which yielded a false positive rate of < .05.

Next, two-region-of-interest (ROI) analyses were performed in both analyses.
Data from the localizer task were used to define the fusiform face area (FFA). Thus, the analyses used a functional localizer, or fROI, approach (Saxe, Brett, & Kanwisher, 2006). The first ROI analysis defined the FFA using the averaged group data. A voxel-
by-voxel t-test, using the activation during HOUSE trials as a baseline, was used to
distinguish the brain regions in which percentage change in activation for FACE trials
was significantly different from zero. These maps were averaged across participants,
and the Group FFA was defined by identifying the 100 most significant voxels active
in either the left or right fusiform gyrus using the 3dmerge program in AFNI.

Since there is considerable variability in the location of the FFA across partici-
pants, we also performed a ROI analysis using individual participant data. The GLTs
from the localizer data were used to distinguish different regions of BOLD signal
change for the FACE and HOUSE trials. Individual FFA were defined by identifying
the 100 most significant voxels active in either the left or right fusiform gyrus, for
their individual contrast, using the 3dmerge program in AFNI. For both the Group
ROI and Individual ROI analyses, we performed two repeated measure ANOVAs on
the data. First, we compared the mean activation in the FFA for REM FACE and
REM SCR responses, extracted for each participant using the 3dROIStats program in
AFNI. We then performed a similar analysis for KNOW FACE and KNOW SCR
responses.

A regression analysis was additionally performed to identify regions of acti-
vation in the REM FACE > REM SCR contrast that correlated significantly with
behavioural performance on the recognition memory task. For the analysis, memory
performance was measured as a difference score: remember accuracy for words studied with faces minus remember accuracy for words studied with
scrambled faces. This difference score shows the relative recollection advantage
( or disadvantage) for words studied with faces as compared to scrambled
faces, for each participant. The 3dRegAna program in AFNI was used for this analysis.

2. Results

2.1. Behavioural data

2.1.1. Localizer task

Behavioural data from the localizer task were analyzed using repeated measure ANOVAs. Mean accuracy (measured as hit rate false alarm rate) on the one-back localizer task was .88 (SD = .11) for faces and .81 (SD = .20) for houses, which did not differ significantly, F (1, 13) = 1.83, p < .05. Mean response time (RT) in milliseconds to correct responses was 583 ms (SD = 53) for faces and 590 ms (SD = 76) for houses, which also did not differ significantly, F (1, 13) = .22, p > .05.

2.1.2. Identification task

Mean accuracy on the identification task, performed during the study phase, was .94 (SD = .05) for faces, and .94 (SD = .04) for scrambled faces, which did not differ significantly, F (1, 13) = 0.32, p > .05. Mean RT in milliseconds to correct identifications was 1322 ms (SD = 577) for faces and 1227 ms (SD = 583) for scrambled faces, which differed significantly, F (1, 13) = 11.64, p < .05.

2.2. Recognition memory task

Data from the recognition memory task were analyzed in a within-participant (word context: word studied with a face or scrambled face) ANOVA. Table 1 shows the means for each memory measure and trial type, collapsed across the three recognition tests. Overall recognition accuracy was measured as number of hits out of 75 number of false alarms out of 75, for each word type. The effect of word context was not significant, F (1, 13) = .75, p > .05.

We then analyzed proportion of remember responses (number of correct remember responses out of 75 number of false remember responses out of 75) and proportion of know responses (number of correct know responses out of 75 number of false know responses out of 75) for each word type. There was no effect of word context for remember, F (1, 13) = 0.01, or know, F (1, 13) = 1.75, responses, nor for independent measures of familiarity, F (1, 13) = .290, p > .05. Comparisons of Response Time showed no effect of context for either remember, F (1, 13) = 3.67, know, F (1, 13) = .46, responses, p > .05.

2.3. fMRI data for recognition memory

2.3.1. Whole-brain analysis

Using a significance threshold of p < .001 and a cluster size of 30 or more contiguous interpolated voxels, direct comparisons of REM

Note: RT = response time in milliseconds. Standard deviations are shown in parentheses.

Table 1

<table>
<thead>
<tr>
<th>Measure</th>
<th>Face</th>
<th>Scrambled face</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall memory</td>
<td>.46 (.16)</td>
<td>.48 (.14)</td>
</tr>
<tr>
<td>Remember accuracy</td>
<td>.35 (.15)</td>
<td>.34 (.12)</td>
</tr>
<tr>
<td>Know accuracy</td>
<td>.11 (.10)</td>
<td>.14 (.11)</td>
</tr>
<tr>
<td>Familiarity</td>
<td>.26 (.14)</td>
<td>.31 (.15)</td>
</tr>
<tr>
<td>RT remember responses</td>
<td>1496 (205)</td>
<td>1581 (246)</td>
</tr>
<tr>
<td>RT know responses</td>
<td>1906 (292)</td>
<td>1942 (312)</td>
</tr>
</tbody>
</table>

Mean memory performance and response time in milliseconds for words studied
with different contexts.
The Talairach coordinates represent the peak for the given region, for the face and REM SCR conditions showed that remember responses given to words studied with faces were associated with increased activity in the right posterior cingulate, right middle temporal, left superior temporal, left middle occipital, right cuneus, thalamus, and left cerebellar gyri (see Table 2). The analysis also showed increased activation for REM FACE than REM SCR responses in the right hippocampus (see Fig. 2). A region in the left fusiform gyrus was also identified when the threshold was lowered to p < .005 (see Fig. 2); a Monte Carlo analysis showed that the false positive rate for this region was α < .005 (Alphasim, AFNI). This region of the fusiform gyrus (peak activation (x, y, z) = −36, −39, −11) is similar to the region identified as the Group FFA in the localizer analysis (peak activation (x, y, z) = −40, −46, −12; see below). The analysis did not identify any regions of increased activation for REM SCR as compared to REM FACE responses.

The general linear model (GLM) analysis comparing activation during KNOW FACE and KNOW SCR responses showed no differences in brain activation between the two trial types. Importantly, the analysis did not show differential activation in the fusiform gyrus, even when the threshold was lowered to p < .01.

2.3.2 Region-of-interest analysis

We performed both a group and individual participant region-of-interest analysis. Analysis of the group localizer data identified a region in the left fusiform gyrus (peak region of activation (x, y, z) = −40, −46, −12) as the Group FFA. A repeated measures ANOVA with word context as the within-participant variable showed that, for the group analysis, percent signal change was higher in the Group FFA for REM FACE than REM SCR responses, F(1, 13) = 14.02, MSE = 2.08, p < .005 (see Fig. 3). There was no difference in activation in the FFA for the KNOW FACE (M = .51, SD = .65) versus KNOW SCR (M = .36, SD = .51) contrast, F(1, 13) = .44, p > .05.

We additionally extracted each individual’s FFA from the localizer data. Nine participants showed peak activation in the right fusiform gyrus and 5 showed peak activation in the left fusiform gyrus. A repeated measures ANOVA showed that percent signal change was higher in Individual FFAs for REM FACE than REM SCR responses, F(1, 13) = 7.24, p < .05 (see Fig. 3). As in the group analysis, there was no difference in activation in individual participant FFAs for the KNOW FACE (M = .33, SD = .65) compared to KNOW SCR (M = .19, SD = .69) contrast, F(1, 13) = .24, p > .05.

2.3.3 Regression analysis

A regression analysis was used to identify regions for which the level of activation across participants in the REM FACE > REM SCR contrast correlated significantly with behavioural performance on the recognition task, as measured by the difference in remember accuracy for words studied with faces as compared to scrambled faces. As in the whole-brain analysis, we used a threshold of p < .001 and a cluster size of 30 or more contiguous interpolated voxels. The regions identified in the analysis were the left middle frontal gyrus, bilateral superior temporal gyr, and importantly, the right fusiform gyrus (see Table 3 and Fig. 4). To depict this correlation graphically, we extracted each individual’s average percent signal change for the REM FACE versus REM SCR contrast in this right fusiform region and plotted this against their recollection performance (measured

Table 2

Coordinates and t-statistics of brain regions showing differences in activation for REM FACE responses compared to REM SCR responses.

<table>
<thead>
<tr>
<th>Brain region (BA)</th>
<th>Coordinates</th>
<th>t-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>REM FACE &gt; REM SCR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right posterior cingulate (30)</td>
<td>20 −62 7</td>
<td>4.35</td>
</tr>
<tr>
<td>Right hippocampus</td>
<td>31 −11 −15</td>
<td>4.68</td>
</tr>
<tr>
<td>Right middle temporal (37)</td>
<td>40 −55 −1</td>
<td>4.75</td>
</tr>
<tr>
<td>Left superior temporal (38)</td>
<td>−48 7 −14</td>
<td>4.68</td>
</tr>
<tr>
<td>Left middle occipital (19)</td>
<td>−29 −89 9</td>
<td>4.75</td>
</tr>
<tr>
<td>Left middle occipital (37)</td>
<td>−39 −67 2</td>
<td>4.61</td>
</tr>
<tr>
<td>Right cuneus (18)</td>
<td>6 −81 14</td>
<td>4.42</td>
</tr>
<tr>
<td>Left thalamus</td>
<td>−27 −29 1</td>
<td>4.46</td>
</tr>
<tr>
<td>Left cerebellum</td>
<td>−9 −58 −2</td>
<td>4.76</td>
</tr>
<tr>
<td>Left cerebellum</td>
<td>−35 −62 −45</td>
<td>4.47</td>
</tr>
</tbody>
</table>

Note: The Talairach coordinates represent the peak for the given region, for the t-statistic positive values represent greater activation for REM FACE than REM SCR; BA = Brodmann’s area according to the atlas of Talairach and Tournoux (1988).

Fig. 2. Brain areas with differences in activity for remember responses given to words studied with faces and words studied with scrambled faces on averaged anatomical scans. Areas in orange represent regions with higher activity for REM FACE than REM SCR responses. (A) An axial slice at z = −15 mm showing increased right hippocampal activity, p < .001. (B) An axial slice at z = −11 mm from the AC–PC line showing increased left fusiform activity, p < .005. (B) The analysis did not identify any regions of increased activation for REM SCR versus REM FACE responses. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)
Fig. 3. Functionally-defined FFA, identified in the localizer task, and percent signal change in the left FFA for remember responses given to words studied with pictures of faces or scrambled faces for the Group FFA (Panel A) and Individual FFA (Panel B) fROI analysis. Error bars show the standard error of the mean. Peak region of activation in the Group FFA was \((x, y, z) = -40, -46, -12\) and is presented on an averaged anatomical scan.

Fig. 4. Right fusiform activity, which increased in activation in the REM FACE > REM SCR contrast as the relative recollection benefit for words studied with faces increased across participants on an averaged anatomical scans at axial slice at \(z = -10\) from the AC-PC line. Areas in orange represent significantly positive correlations, \(p < .001\). The scatter plot depicts the correlation graphically; note that this scatter plot does not represent a new analysis. The correlation was \(r = .81, p < .001\), though this may be larger than the true \(r\) value given the small sample size of the study (cf. Yarkoni et al. (2009)).

### Table 3

Coordinates and \(t\)-statistics of brain regions showing increased activation across participants in the REM FACE > REM SCR contrast as the recollection benefit for words studied with faces increased.

<table>
<thead>
<tr>
<th>Brain region (BA)</th>
<th>Coordinates</th>
<th>(t)-statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left middle frontal (46)</td>
<td>-38 33 18</td>
<td>4.66</td>
</tr>
<tr>
<td>Right fusiform (37)</td>
<td>36 -41 -6</td>
<td>5.05</td>
</tr>
<tr>
<td>Right superior temporal (38)</td>
<td>28 12 -33</td>
<td>4.47</td>
</tr>
<tr>
<td>Left superior temporal (42)</td>
<td>-72 -25 8</td>
<td>4.85</td>
</tr>
</tbody>
</table>

Note: The Talairach coordinates represent the peak for the given region, for the \(t\)-statistic positive values represent greater activation for REM FACE than REM SCR with increasing behavioural performance (see Section 1); BA = Brodmann’s area according to the atlas of Talairach and Tournoux (1988).

3. Discussion

We examined how changing the type of visual context information present during encoding of target words influenced later recollection for the words presented alone at retrieval. Unlike our previous behavioural work (Skinner & Fernandes, 2009), we did not find a recollection benefit for words studied with meaningful context information; however, we still showed differences in brain activation for words studied with and without meaningful context information. Whole-brain analysis of fMRI data showed that activation for remember responses given to words studied with faces compared to scrambled faces was higher in the fusiform gyrus and hippocampus. The same pattern was observed in both a group and individual fROI analysis: there was increased activation in the functionally-defined FFA for remember responses given to words studied with faces compared to scrambled faces. No such context as remember accuracy for words studied with faces minus remember accuracy for words studied with scrambled faces; see Fig. 4). It is important to note that this was performed for graphical purposes only and does not represent a new analysis.

\footnote{We additionally examined whether each individual’s average percent signal change for the REM FACE versus REM SCR contrast in the localizer-identified FFA correlated with recollection performance (remember accuracy for words studied with faces minus remember accuracy for words studied with scrambled faces) for both the group and individual FFAs. The Group FFA analysis showed a correlation of \(r = .33, p = .13\). The individual FFA analysis showed a correlation of \(r = .13, p = .35\); there was, however, an outlier in this analysis and once removed the correlation increased to \(r = .45, p = .07\). Although failing to reach a significance level of \(p < .05\), these correlations are in the direction to suggest that activation in the FFA increases as the recollection benefit for words studied with faces increases, supporting the findings of our voxel-by-voxel regression analysis.}
effect was present at the neural level for know responses. In addition, activation in the right fusiform gyrus was found to correlate with behavioural performance on the memory task: activation in this region increased as the recollection benefit for words studied with faces, as compared to scrambled faces, increased.

3.1. Sensory-specific reactivation

To examine sensory-specific reactivation in an a priori defined brain region, we used a localizer task to identify the region of the fusiform gyrus most highly activated during the viewing of faces in our participants. Using an fROI approach (Saxe et al., 2006), we were then able to contrast activity for remember and know responses given to words studied with intact and scrambled faces in this brain region. The localizer task showed higher activation during the viewing of faces, as compared to houses, in a region in the left fusiform gyrus on averaged group data, which we called the Group fFA. Although the FFA is often found in the right fusiform gyrus (Kanwisher et al., 1997), other studies show bilateral (Bernstein, Beig, Siegenthaler, & Grady, 2002; Haxby et al., 1994) and left (Lobmaier, Klaver, Loenneker, Martin, & Mast, 2008) fusiform activity during face processing. We also identified each participant’s individual FFA. The analysis showed high variability in the location of the FFA across participants: nine participants showed peak activation during the viewing of faces, as compared to houses, in the right fusiform gyrus and five showed peak activation in the left. These individual FFAs were used for the Individual fROI analysis.

Importantly, in both the Group and Individual fROI analyses, activation in the FFA, defined by the localizer task, was higher when participants recollected words studied with faces as compared to scrambled faces. This occurred despite the fact that the faces were not re-presented at retrieval, indicating that the recollection of words studied with faces activated the same brain region implicated during the study phase. The whole-brain analysis additionally showed activation in the left fusiform gyrus; although this region was found at a lowered threshold, Monte Carlo simulations showed a low false positive rate for this region of activation. This region is notably close to the region identified as the Group FFA in the localizer task, garnering support that this represents sensory-specific reactivation of a face processing region. Our results are consistent with those that show the FFA is active when participants imagine faces (Ishai, Ungerleider, & Haxby, 2000; O’Craighan & Kanwisher, 2000).

Notably, we did not find a significant increase in FFA activity when know responses given to words studied with faces or with scrambled faces were contrasted, even at a lowered threshold, supporting the hypothesis that sensory-specific reactivation is specific to recollection (Johnson & Rugg, 2004; Wheeler & Buckner, 2004). However, as in most remember-know tests, participants correctly endorsed more items as remembered (M = 54.86, SD = 17.35) than known (M = 42.79, SD = 14.03). Thus, due to the smaller number of trials contributing to mean brain activation, as well as the increased variability in FFA activation for know than remember responses (see Section 2), this result should be interpreted with some caution.

A regression analysis was additionally used to identify the brain regions that increased in activation as the recollection benefit for words studied with faces increased across participants. This analysis identified a region of the right fusiform gyrus. Our results suggest that the degree to which participants recruit context-specific brain regions during retrieval is related to a behavioural benefit, in later recollection, for words studied with meaningful context information. Although this right-lateralized brain region differs from the left fusiform region identified in the whole-brain analysis, our individual fROI analysis showed that the lateralization of the fusiform face area varied across participants; nine participants showed peak activation in the right and 5 showed peak activation in the left fusiform gyrus, likely accounting for this difference across methods of analysis.

Other research suggests that the extent to which participants show sensory-specific reactivation, and subsequent recollection benefits, may depend on the extent to which they engage in processes at encoding that bind item and context information, or the degree to which the item and context can be bound. For example, Nyberg et al. (2001) showed a trend towards higher sensory-specific reactivation in left primary auditory cortex when word–sound pairs were strong associates, as compared to weak associates, suggesting that sensory-specific reactivation may be a function of ‘integratability’, or the binding, of context and item information. We have hypothesized that participants who engage in processes that bind item and context information at encoding will show a later recollection benefit for words studied with meaningful context information (Skinner & Fernandes, 2009).

The results of the current study suggest that this recollection benefit increases as activation in sensory-specific brain regions increases.

This study represents a single, rather than double dissociation, of context-specific reactivation. Other work in the field has observed double dissociations of sensory-specific reactivation (Kahn, Davachi & Wagner, 2004; Johnson & Rugg, 2007; Woodruff et al., 2005). While the observation of a double dissociation would provide additional evidence of sensory-specific reactivation, the major strength of this study is that, unlike previous work, we used a well-defined, highly selective brain region in which to test context-specific retrieval effects. The functional selectivity of the FFA suggests that the effects found in this study are indeed related to the reactivation of face (context) information at retrieval. Most importantly, we were able to demonstrate that individual differences in memory performance were related to activation in the fusiform gyrus, providing further evidence that the activation found in this study reflects context-specific reactivation. We believe that, in future research, a double dissociation of context-specific reactivation observed using the fROI approach of this paper would provide further supporting evidence that recollection of context information involves the reactivation of the sensory-specific brain regions originally used to process that context information.

3.2. Medial temporal lobe activation

The whole-brain analysis showed that activation in a region in the right hippocampus was higher for remember responses given to words studied with faces compared to scrambled faces. Multiple studies have found results consistent with the notion that hippocampal activation is selective to recollection. For example, Montaldi et al. (2006) showed bilateral hippocampal activation when scenes that were recollected were compared to scenes given high confidence familiarity ratings and Eldridge, Knowlton, Furmanski, Bookheimer, and Engel (2000) showed significantly higher activation in the left hippocampus for remember versus know responses. Our study differs from those previously reported, however, in that we did not contrast remember and know responses, but rather contrasted remember responses for words studied with different types of context. Thus, the difference in activation found in our study cannot relate to the experience of recollection per se, but rather reflects a difference in the content of what is recollected. For example, remember responses for words studied with faces may have been associated with the retrieval of additional context information relative to remember responses given to words studied with scrambled faces (cf. Dodson, Holland, & Shimamura, 1998), and the hippocampus indexed this increased source retrieval. One study, which manipulated the amount of source information retrieved, showed that hippocampal activation was related to source retrieval regardless of the amount of con-
textual information retrieved and that a region of the posterior parahippocampus increased in activation as the amount of contextual information retrieved increased (Tendolkar et al., 2008; also see Vilberg & Rugg, 2007), who found increased activation in a region adjacent/within the hippocampus when ‘strong’ recollection was contrasted with know responses, and a statistically weaker trend in this direction when ‘weak’ recollection was compared with know response). It is thus possible that the medial temporal lobe is involved in two aspects of the mnemonic experience: one that indexes the subjective experience of recollection and another that indexes the amount of contextual information retrieved. While this explanation is speculative and is in need of further testing, our data do suggest a role for the hippocampus beyond the distinction between remember and know responses. Specifically, we showed that the pattern of activation in the hippocampus differed during recollection of words studied with and without meaningful context information, suggesting that remember responses can differ in the extent to which they recruit the hippocampus.

3.3. Activation in additional brain regions

In the whole-brain analysis, participants showed significantly higher activation in right middle and left superior regions of the temporal lobe for remember responses given to words encoded with faces compared to scrambled faces. Research shows that semantic processing of verbal information recruits anterior (Noppeney & Price, 2002) and lateral posterior (Vandenberghe, Price, Wise, Josephs, & Frackowiak, 1996) regions of the temporal lobe. We suggest that when participants bound the meaningful face context and word information, they increased the semantic processing performed on the word, which was reactivated at retrieval. The regression analysis additionally showed that activation in the superior temporal lobe increased with behavioural performance, suggesting that semantic processing at retrieval is related to recollection benefits for words studied with meaningful context information.

The regression analysis also showed that activation in the dorsolateral prefrontal cortex increased as the recollection benefit for words studied with meaningful context information increased. Fletcher and Henson (2001) attribute activation in this region to the selection, manipulation, and monitoring of information. As this region did not show differential activity in the whole-brain analysis, the results suggest that, although the selection/manipulation/monitoring demands did not differ for the recollection of words presented with different context information, this region supported the recollection of words studied with meaningful (face) context information.

The whole-brain analysis did not identify any brain regions preferentially active for remember responses given to words studied with scrambled faces versus words studied with faces. This result suggests that there are no additional neural processes required to recollect words studied with non-meaningful contexts as compared to those studied with meaningful context information.

3.4. Behavioural performance

Based on previous behavioural work (Skinner & Fernandes, 2009), we expected memory performance to be higher for words studied with faces (meaningful context information) than words studied with scrambled faces. In the current study, however, memory performance was equal for words studied with faces and scrambled faces. It is possible that the scanner environment interfered with strategy-use in some participants, and our other work shows that this can directly influence recognition performance. We found that recollection benefits do not depend on what context is presented at study per se, but on the cognitive operations performed on that context, with higher recollection resulting from conditions that direct the use of a particular strategy—linking/binding item and context information (Skinner & Fernandes, 2009). In the current study, the use of a linking/binding strategy may not have been consistent across participants, resulting in variable recollection benefits for the face versus scrambled face trials. When we took advantage of that variability in the regression analysis, we showed that activation in the right fusiform gyrus increased as the recollection benefit for words studied with meaningful context information increased. This suggests that recollection benefits for words studied with meaningful contexts increase as activation in sensory-specific brain regions increase, supporting the notion that sensory-specific reactivation at retrieval is a function of the ‘integratability’, or the binding of item and context and information at study (Nyberg et al., 2001).

4. Conclusions

The study presents two novel findings. First, when meaningful context (face) information was presented at study, activation in the fusiform gyrus increased during the subsequent recollection of words presented alone. In particular, activation in the right fusiform gyrus increased as the recollection benefit for words studied with faces increased across participants, indicating that the degree to which participants recruit context-specific brain regions during retrieval is related to recollection performance. Second, there was higher activation in a region of the right hippocampus for remember responses given to words studied with meaningful (face), as compared to non-meaningful (scrambled face), context information. We suggest that the medial temporal lobe may be involved in indexing mnemonic aspects beyond the distinction between remembering and knowing. Patterns of brain activation at retrieval thus depend on the type of context information presented at study and recollection performance is related to the extent that context information is reactivated at retrieval.

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References


