

The nature of memory related activity in early visual areas

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Abstract

Memory for visual items can evoke activity in visual processing regions, which is typically assumed to reflect conscious remembering. However, based on previous findings, we hypothesized that such activity in early visual areas (BA17, BA18) may reflect priming, a form of nonconscious memory. We tested this hypothesis in two fMRI experiments with similar stimulus protocols, but explicit or implicit task instructions. During initial runs, abstract shapes were presented to either side of fixation, filled with parallel lines of random orientation and color. In subsequent runs, old and new shapes (plus related shapes in Experiment 2) were presented at fixation. In Experiment 1, participants were instructed to remember each shape and its spatial location during initial runs; during subsequent runs they classified each shape as old and on the “left”, old and on the “right”, or “new”. A right fusiform gyrus region (BA18) and a left lingual gyrus region (BA18) were preferentially associated with shapes previously presented on the left and right, respectively. In support of our hypothesis, this early visual area activity was independent of response accuracy for spatial location. In Experiment 2, for each shape, participants identified parallel line orientation relative to horizontal. Consistent with our hypothesis, specific neural activity was observed in early visual regions (BA17, BA18, extending into BA19), with old activity greater than related and new activity (likely reflecting priming). The results of these experiments provide convergent evidence that memory related early visual area activity (BA17, BA18) can reflect nonconscious processing.

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Human visual item localization has been associated with dorsal cortical processing, including the occipital and parietal cortex, while visual item identification has been associated with ventral cortical processing, including the occipital and temporal cortex (Köhler, Kapur, Moscovitch, Winocur, & Houle, 1995). Consistent with this functional-anatomic organization, memory for visual item identity has been associated with activity in ventral occipitotemporal cortex (Burgess, Maguire, Spiers, & O’Keefe, 2001; Katanoda, Yoshikawa, & Sugishita, 2000; Moscovitch, Kapur, Köhler, & Houle, 1995; O’Craven & Kanwisher, 2000; Schacter et al., 1995, 1997; Slotnick, Moo, Segal, & Hart, 2003; Slotnick & Schacter, 2004; Vaidya, Zhao, Desmond, & Gabrieli, 2002; Wheeler & Buckner, 2003; Wheeler, Petersen, & Buckner, 2000; for a review, see Slotnick, 2004). Although it is generally assumed that visual memory

related activity underlies subjective visual experience during conscious remembering, the nature of such activity is in fact a question for empirical determination (cf., Slotnick & Schacter, *in press*).

For instance, in a previous recognition memory functional magnetic resonance imaging (fMRI) study using abstract shapes (Slotnick & Schacter, 2004), we found converging evidence suggesting that recognition related activity in early visual regions (BA17, BA18) reflects nonconscious memory. In the main experiment, participants studied sets of abstract shapes; each set was related to a nonstudied prototype. During a subsequent recognition test, subjects made old/new recognition decisions about old shapes, related nonstudied shapes, and unrelated new shapes. The first piece of evidence relates to the common and disparate neural activity associated with true recognition (“old” responses to studied/old shapes, i.e. old-hits) and false recognition (“old” responses to related nonstudied shapes, i.e. related-false alarms). True and false recognition, relative to new shape correct rejections (“new” responses to novel shapes), were associated with common activity in ventral occipitotemporal cortex (BA17,

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BA18, BA19, and BA37); however, true recognition was associated with greater activity than false recognition in striate (BA17) and early extrastriate cortex (BA18). The high false alarm rate in that study led us to hypothesize that the differential true greater than false recognition related early visual area activity reflected nonconscious memory (or participants should have capitalized on this differential activity to reduce their level of false recognition to related items). The second piece evidence, stemming from a standard old/new recognition follow-up experiment, was consistent with this hypothesis. In late visual regions (BA19, BA37), we found greater activity associated with old-hits than old-misses (“old” and “new” responses to old shapes, respectively). Because this activity tracked the behavioral response, we argued that it was associated with conscious memory of old shapes. By contrast, activity in early visual regions (BA17, BA18) was similarly increased for old-hits and old-misses relative to new-correct rejections, that is, independent of the behavioral response. This evidence is also suggestive that early visual area activity reflects nonconscious memory.

The primary aim of the present investigation was to test our hypothesis, in two separate fMRI experiments, that visual memory related activity in early visual regions does indeed reflect nonconscious processing. In the first experiment, we used an explicit memory task as in Slotnick and Schacter (2004; referring here and subsequently to the main experiment, unless otherwise noted), but stimuli only included old and new shapes (Fig. 1). Shapes at study/encoding were presented to the left or right of fixation and during test/retrieval these shapes along with new shapes were presented at fixation. Participants responded whether each shape had been previously presented on the “left”, on the “right”, or was “new”. Given the known retinotopic organization of posterior visual processing regions (see Sereno et al., 1995; Slotnick & Moo, 2003), we expected that memory for shapes on the left would evoke activity in right visual areas while memory for shapes on the right would evoke activity in left visual areas (i.e., contralateral memory effects). In a previous event-related potential (ERP) spatial memory study by Gratton, Corballis, and Jain (1997) that used line patterns as stimuli, memory effects at test contralateral to the spatial location of items from study were observed, most markedly at temporal scalp electrodes. Furthermore, in a behavioral follow-up experiment, these investigators found that participants responded at chance as to the hemifield of initial presentation (i.e., the effects did not depend on response accuracy), suggesting that the associated contralateral activity was not associated with conscious memory. Given these findings, if our hypothesis is correct that early visual areas (BA17, BA18) are associated with nonconscious memory, we should observe contralateral memory effects within these regions and they should not depend on response accuracy. A secondary aim of this experiment deals with evidence of *feature specific* memory reactivation (e.g., activity associated with color or spatial location processing within the visual modality; see Slotnick, 2004). While the previously described evidence is suggestive, ERPs have inherently poor spatial resolution. Direct evidence for feature specific memory reactivation has not, to our knowledge, been reported.

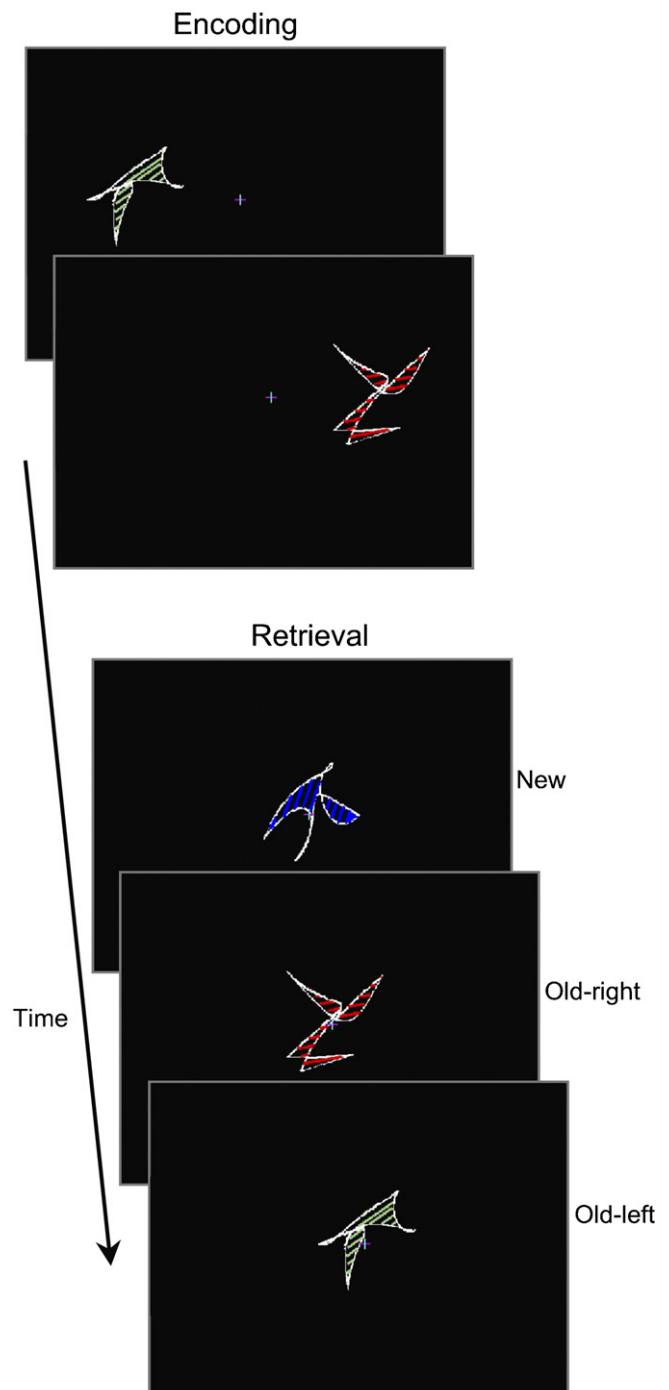


Fig. 1. Behavioral protocol for Experiment 1. During encoding, shapes were presented to the left of fixation (encoding-left) or right of fixation (encoding-right). During retrieval, shapes that had been presented in the left hemifield during encoding (old-left), shapes that had been presented in the right hemifield during encoding (old-right), and new shapes were presented at fixation (correct responses are shown to the right of each shape).

In the second experiment, we used the identical stimulus protocol as in Slotnick and Schacter (2004) but employed a task that does not require explicit or conscious memory. If our hypothesis is correct, there should be greater activity for old shapes as compared to related shapes in early visual areas (BA17, BA18), corresponding to the true recognition (old-hits)

greater than false recognition (related-false alarms) activity in these areas observed by Slotnick and Schacter (2004). Such differential activity may reflect repetition priming (as might differential activity between old and related shapes as compared to new shapes), a possibility that is evaluated more fully in Section 3.

1. Experiment 1

1.1. Materials and methods

1.1.1. Participants

Sixteen participants with normal or corrected-to-normal vision took part in the study. The experimental protocol was approved by the Massachusetts General Hospital Internal Review Board, and informed consent was obtained from each participant. Four of the participants did not complete the experiment; as such, the analysis was restricted to the remaining 12 participants (seven females; mean age 21 ± 2.6 S.D.).

1.1.2. Stimulus and task

All participants completed one study-test session for training immediately followed by six study-test sessions during fMRI. During each study phase, 32 unrelated shapes were sequentially presented every 3 s (duration 2.5 s), with pseudo-random assignment of spatial location equally often to the left or right hemifield (with each shape's closest point 3° of visual angle from fixation). Shapes were generated using custom software written in MATLAB (The Math-Works Inc.), and were comprised of four pseudo-randomly generated Bezier curves each with end-points on adjacent sides of a bounding square that had an edge length of 5.5° of visual angle. Each shape was filled with lines of a randomly generated color and orientation (Fig. 1; for additional details, see stimulus construction details of follow-up experiment, Slotnick & Schacter, 2004).

While maintaining fixation on a central cross, participants were instructed to remember each shape and the side of the screen it was on. During each test phase, the 32 shapes from the corresponding study phase in addition to 16 new shapes were sequentially presented at fixation every 4–12 s (duration 2.5 s). Shapes were never repeated (except for old shapes in the test phase), while line color and orientation were repeated across runs, but never within a run (except for old shapes in the test phase). During central fixation, participants made a dual-response with their left hand regarding whether each shape was: (1) old and on the “left”, old and on the “right”, or “new” (i.e. a recognition/source memory judgment), and (2) whether they were “sure” or “unsure” of this response. The latter confidence response was not considered in the present manuscript based in part on previous abstract shape memory analyses showing little modulation of extrastriate activity as a function of confidence (Slotnick & Schacter, 2004), but critically to ensure there were a sufficient number of responses to conduct the present analysis. Participants were instructed that response speed and accuracy were equally important. For a given participant, shapes were never repeated. Old-left, old-right, and new lists of shapes were counterbalanced across participants using a Latin square design.

1.1.3. Imaging data acquisition and pre-processing

Imaging was conducted using a 3 T Siemens Allegra scanner with a standard head coil. Anatomic images were acquired using a multiplanar rapidly acquired gradient echo (MP-RAGE) sequence (TR = 30, TE = 3.3 ms, slices = 128, resolution = $1 \text{ mm} \times 1 \text{ mm} \times 1.33 \text{ mm}$). Functional images were acquired using an echo planar imaging (EPI) sequence (TR = 2 s, TE = 30 ms, acquisition matrix = 64×64 , slices = 30, resolution = 4.5 mm isotropic).

Unless otherwise stated, imaging analysis was conducted using SPM99 (Wellcome Department of Cognitive Neurology). Functional data preprocessing began with slice-time correction and motion correction (i.e., alignment to the first functional volume for each participant), with voxel re-sampling at 3 mm isotropic resolution. Further preprocessing, conducted using custom software written in MATLAB, included high-pass filtering (via removal of linear, quadratic, cubic, and quartic components) followed by concatenation of all runs for each participant. No spatial smoothing was conducted.

1.1.4. Event-related fMRI analysis

The initial analysis was conducted using a general linear model approach. That is, on an individual participant basis, a canonical hemodynamic response function was convolved with the protocol of each event – modeled as a series of square waves defined by each event onset and the subsequent behavioral response – to produce that event's hemodynamic response model. On an individual voxel basis, a general linear model was then used to fit all event hemodynamic response models to each voxel's activation timecourse resulting in the best-fit event model amplitudes (i.e. beta-weights). For a given statistical contrast (e.g., encoding-left > encoding-right), voxels were deemed active when the difference between the associated beta-weights was significantly positive (using a one-tailed paired *t*-test, where variance was estimated using between participant variability; i.e., a random-effect analysis). One-tailed (rather than two-tailed) *t*-test were employed because positive fMRI activity has been shown to reflect positive neural activity (Logothetis, Pauls, Augath, Trinath, & Oeltermann, 2001). Hence, the direction of the statistical test (i.e., positive, rather than either positive or negative) was determined a priori, as it was in all cases where one-tailed tests are subsequently employed. Events included encoding of shapes and locations (encoding-left, encoding-right), successful retrieval of shapes and previous locations (old-left-hit-hit, old-right-hit-hit), successful retrieval of shapes but not locations (old-left-hit-miss, old-right-hit-miss), unsuccessful retrieval of shapes (old-left-miss, old-right-miss), false memory of new shapes (new-left-false alarm, new-right-false alarm), correct rejection of new shapes (new-correct rejection), failures to respond, and a constant. Encoding and no response trials were assumed to be 2.5 s in duration while other durations were measured from stimulus onset until the behavioral response. Each event's beta-weight reflected the degree to which that event reflected activity within a given voxel.

To investigate memory traces within retinotopically organized cortical areas, right hemisphere encoding-related retinotopic regions-of-interest (ROIs) were identified by contrasting encoding-left versus encoding-right, and left hemisphere encoding-related retinotopic ROIs were identified by contrasting encoding-right versus encoding-left. To restrict these regions to only those areas with robust retinotopic activity, a cluster extent threshold was enforced to correct for multiple comparisons (Forman et al., 1995; Ledberg, Åkerman, & Roland, 1998; Poline & Mazoyer, 1993; Roland, Levin, Kawashima, & Åkerman, 1993). Specifically, an individual voxel statistical threshold of $p < 0.01$ was enforced, cluster extent threshold corrected for multiple comparisons to $p < 0.001$ (i.e., relatively strict thresholds were enforced). Correction for multiple comparisons required a minimum cluster extent of 61 re-sampled voxels, a value computed via a Monte Carlo simulation with 1000 iterations where activity in each voxel was modeled with a normally distributed random number (mean of zero and unit variance) and type I error was assumed to be equal to the individual voxel threshold in a volume defined by the functional acquisition dimensions. Spatial correlation was simulated by smoothing with a 6.2 mm FWHM Gaussian; this value was estimated using the *t*-statistic maps associated with the contrasts of interest (i.e., encoding-left versus encoding-right and vice versa) where the spatial autocorrelation of each slice was computed and the corresponding FWHM values were calculated (yielding a FWHM value of 6.17 ± 0.21 mm, mean \pm one standard error; similar procedures have been used previously to estimate fMRI spatial correlation, e.g., see Katanoda, Matsuda, & Sugishita, 2002; Zarahn, Aguirre, & D'Esposito, 1997). The probability of observing successively larger cluster sizes was computed (based on the Monte Carlo maximal cluster size distribution), and the cluster extent threshold was selected such that the probability of observing that or larger clusters was less than the desired corrected *p*-value. Furthermore, only encoding-related activity within classically retinotopic regions were considered (i.e. BA17, BA18, BA19; see Sereno et al., 1995; Slotnick & Moo, 2003). For the encoding-left > encoding-right contrast, a single contiguous cluster was observed in retinotopic regions of the right (contralateral) hemisphere, while the encoding-right > encoding-left contrast also yielded a contiguous cluster in contralateral regions (and no retinotopic activity in ipsilateral retinotopic regions) along with more anterior activation foci (which will not be considered further as these foci do not pertain to the hypothesis under investigation). To aid in viewing activity, cortical segmentation and reconstruction of a representative participant were conducted using BrainVoyager (Brain Innovation, Maastricht, The Netherlands) and then activity was projected onto the cortical surface reconstruction (for details, see Slotnick, 2005). It is important to note that activity projected onto an individual participant should only be

considered a reflection of the group results; precise activation coordinates are listed in the tables.

To assess retinotopic effects at retrieval, for each participant, the mean retrieval-related beta-weights were extracted from voxels in a 6 mm sphere at the center of each identifiable BA/gyrus intersection within encoding-related activity (using custom software written in MATLAB). Note that in this ROI analysis, beta-weights were extracted, while it is more typical for timecourses to be extracted. While ROI timecourse analysis was initially conducted in this experiment (using the procedure described in Experiment 2), it did not yield any significant effects. By comparison, an ROI beta-weight analysis did produce significant effects (see Section 1.2). These differential outcomes suggest that, in this instance, ROI beta-weight analysis is more sensitive than ROI timecourse analysis. Why would timecourse analysis yield null results while beta-weight analysis produce significant results (or vice versa)? The differential sensitivity of these methods depends in large part on how well the assumed hemodynamic response model characterizes fMRI activity. If the model characterizes activity well, beta-weight analysis (which depends on the model) may prove more sensitive than timecourse analysis (which does not depend on the model). This appears to be the case in the present experiment and likely reflects the fact that the hemodynamic response model accurately characterizes activity in early visual areas. By contrast, in other regions of the brain, like the prefrontal cortex, where activity is not well characterized by the hemodynamic response model, time-course analysis has been shown to be more sensitive than beta-weight analysis (cf., Slotnick, 2005).

For the right hemisphere ROIs, beta-weights associated with all shapes previously presented on the left (old-left-hit-hit, old-left-hit-miss, old-left-miss) were compared to all shapes previously presented on the right, and vice versa for the left hemisphere ROIs. This analysis procedure was designed such that if increases in retrieval-related activity were in the contralateral posterior visual areas, the difference in beta-weights should be positive in magnitude, regardless of the encoding defined ROI hemisphere. To assess the significance of the effect within each ROI, this difference was compared to a value of zero with a one-tailed *t*-test, using between participant variability to estimate variance. Similarly, to assess significance of the effect across ROIs, a one-tailed *t*-test was employed using between region variability to estimate variance. As mentioned in the introduction, Slotnick and Schacter (2004) reported memory related activity within posterior visual regions (BA17, BA18) that did not depend on accuracy (i.e., activity was associated with both old-hits and old-misses to a greater degree than new-correct rejections); as such, we conducted the initial analysis without regard to accuracy in an effort to increase statistical power.

Given that effects were assessed in multiple ROIs it was necessary to correct for multiple statistical comparisons (to avoid type I error). The probability within each hemisphere of observing at least 1 significant activation across *n* ROIs was computed using the equation

$$p = 1 - (1 - \alpha)^n \quad (1)$$

where α (the type I error rate) was assumed to be 0.05. The product of these probabilities gives the joint probability of observing such activity in both hemispheres. Finally, this joint probability was multiplied by the probability of observing a given pattern of activity (i.e., as we found one activation in the left hemisphere and one in the right hemisphere, see Section 1.2, the magnitude of activity across hemispheres could be positive–positive, positive–negative, negative–positive, or negative–negative, with a given pattern corresponding to a probability of 0.25). If the overall probability is less than $p = 0.05$, the results are corrected for multiple comparisons.

To investigate the hypothesis under investigation, in ROIs with significant retrieval-related contralateral effects, a subsequent analysis was conducted to determine the degree to which response accuracy may have been a factor using a two-factor within participant ANOVA to test for a significant interaction, with accuracy at retrieval and spatial location at encoding as factors (for elaboration on the logic of using this statistic, see Section 1.2). To complement this analysis, an assessment of accuracy on contralateral memory effects was also investigated via planned comparisons using one-tailed *t*-test. Specifically, in ROIs with significant retrieval-related contralateral effects, the degree to which accurate memory for spatial location was a factor was assessed (e.g., in the right hemisphere, old-left-hit-hit versus old-left-hit-miss) as was the degree to which recognition memory accuracy was a factor (e.g., in the right hemisphere,

old-left-hit-hit and old-left-hit-miss were collapsed/averaged yielding ‘old-left-hit’ which was compared to old-left-miss). For the behavioral response time and response number analysis, a two-factor within participant ANOVA was also conducted to determine the effect of spatial location at encoding to test for significant main effects.

1.2. Results

1.2.1. Behavioral results

Participants were able to remember studied shapes and correctly reject new shapes to a reasonable degree, independent of spatial location accuracy ($67.2 \pm 1.6\%$ correct; chance = 50%; computed from hit rate $\times p$ (old item) + $(1 - \text{false alarm rate}) \times p$ (new item), cf. Macmillan & Creelman, 1991, where hit rate = $70.2 \pm 2.6\%$, false alarm rate = $38.9 \pm 3.3\%$). For those items correctly remembered from the study phase, participants also showed relatively accurate memory for spatial location ($70.0 \pm 2.0\%$ correct; chance = 50%). Of relevance to the fMRI analysis, the response time to old shapes that had been previously presented to the left (2414 ± 86 ms) was comparable to the response time to old shapes that had been previously presented to the right (2402 ± 83 ; $F(1,11) < 1$), indicating ‘time on task’ differences were not a concern. There were also no differences in number of responses to old shapes previously presented to the left or right ($F(1,11) = 1.55$, $MS_{\text{error}} = 0.44$, $p > 0.20$), and there were a sufficient number of responses of each event type to conduct the analysis (old-left-hit-hit = 48.2 ± 2.1 , old-left-hit-miss = 20.0 ± 1.6 , old-left-miss = 24.9 ± 2.3 , old-right-hit-hit = 43.3 ± 3.4 , old-right-hit-miss = 18.4 ± 1.2 , old-right-miss = 30.8 ± 3.1).

1.2.2. fMRI results

Thirteen encoding-related ROIs (six in the right hemisphere and seven in the left hemisphere) were identified. One ROI – in the left cuneus (BA19, coordinates, $x = -11$, $y = -92$, $z = 27$) – was associated with a decrease in activity associated with contralateral (old-right) retrieval events ($t(35) = 4.53$, $p < 0.001$, post hoc one-tailed *t*-test; McKiernan, Kaufman, Kucera-Thompson, & Binder, 2003, also reported deactivations within this region, and discuss possible interpretations of such activity). Given that increases in neural activity have been shown to correlate with increases in fMRI activity (Logothetis et al., 2001) and the left cuneus decrease in activity was in the opposite direction as that predicted based on known contralateral increases in neural activity, the pattern of activity within this region was not considered further. As would be expected, contralateral increases in activity were observed in the remaining 12 ROIs (i.e. old-left events were associated with increases in activity in right ROIs and old-right events were associated with increases in activity in left ROIs) to a marginally significant (right lingual gyrus, BA17, $t(35) = 1.49$, $p = 0.072$, and left lingual gyrus, BA18, $t(35) = 1.42$, $p = 0.083$) or significant degree (left lingual gyrus, BA17, $t(35) = 2.06$, $p < 0.05$, and the remaining nine *t*-values > 4 , $p < 0.001$). Retrieval-related effects within each of these ROIs are shown in Table 1.

As expected, the difference in contralateral versus ipsilateral activity (old-left $>$ old-right in right hemisphere ROIs and old-right $>$ old-left in left hemisphere ROIs) was typically positive in value (Table 1, column 4, even though most individual ROI activation differences did not reach significance, columns 5 and 6). Across all 12 ROIs, this contralateral memory effect proved to be significant ($t(11) = 2.49$, $p < 0.05$), although the effect within each hemisphere alone was only marginally significant (right hemisphere, $t(5) = 1.59$, $p = 0.086$, and left hemisphere, $t(5) = 1.94$, $p < 0.055$). Critically, these contralateral memory effects reached significance in the right fusiform gyrus (BA18) and left lingual gyrus (BA18). Fig. 2 shows the event-related activity (beta-weights) associated with old-left and old-right event types within these regions—in the right hemisphere, there was greater activity associated with shapes previously presented on the left (old-left) than those previously presented on the right (old-right), with the opposite pattern of activity in the left hemisphere. As mentioned previously, it was necessary to compute the probability of observing this pattern of activity (i.e., one significant activation in each hemisphere) to ensure that our findings were not due to type I error associated with multiple statistical comparisons. The probability of observing this pattern of activity was $p < 0.05$ (see Section 1.1); therefore, these results survived correction for multiple comparisons.

Of direct relevance to our hypothesis, subsequent analyses were conducted to determine the degree to which the significant effects within the

Table 1
Degree memory retrieval-related contralateral activity in posterior visual areas

Right ROIs	BA	<i>x, y, z</i>	(L–R) _{beta-weight}	<i>t</i> (11)	<i>p</i>
Lingual gyrus	17	16, –84, 3	$-8.1 \pm 25.1 \times 10^{-4}$	<1	>0.2
Lingual gyrus	18	26, –69, –8	$16.6 \pm 19.9 \times 10^{-4}$	<1	>0.2
Fusiform gyrus	18	27, –87, –12	$104.1 \pm 55.9 \times 10^{-4}$	1.86	<0.05
IOG	18	39, –83, –7	$18.7 \pm 12.3 \times 10^{-4}$	1.52	0.079
Fusiform gyrus	19	38, –78, –11	$4.0 \pm 21.3 \times 10^{-4}$	<1	>0.2
MOG	19	48, –72, 2	$20.1 \pm 29.6 \times 10^{-4}$	<1	>0.2
Left ROIs	BA	<i>x, y, z</i>	(R–L) _{beta-weight}	<i>t</i> (11)	<i>p</i>
Lingual gyrus	17	–5, –91, 1	$23.5 \pm 25.0 \times 10^{-4}$	<1	0.18
Lingual gyrus	18	–10, –81, –13	$52.9 \pm 28.6 \times 10^{-4}$	1.85	<0.05
Fusiform gyrus	18	–29, –90, –11	$47.1 \pm 41.0 \times 10^{-4}$	1.15	0.14
Lingual gyrus	19	–25, –69, –3	$-5.0 \pm 31.1 \times 10^{-4}$	<1	>0.2
Fusiform gyrus	19	–31, –67, –13	$-1.2 \pm 52.5 \times 10^{-4}$	<1	>0.2
MOG	19	–42, –85, 5	$2.9 \pm 18.2 \times 10^{-4}$	<1	>0.2

BA refers to Brodmann area and Talairach coordinates (*x, y, z*) refer to center of each encoding defined ROI (IOG: inferior occipital gyrus; MOG: middle occipital gyrus). Mean beta-weight difference \pm one standard error (i.e. beta-weights associated with studied shapes that had been presented on the left minus studied shapes that had been presented on the right (L–R) for right hemisphere ROIs, and vice versa for left hemisphere ROIs) were computed such that positive values reflect increases in retrieval-related contralateral activity within both right and left hemisphere ROIs.

right fusiform gyrus (BA18) and left lingual gyrus (BA18) depended on response accuracy. If accuracy was a principle factor, for instance, we would expect greater contralateral versus ipsilateral activation difference for correct as compared to incorrect responses (e.g., in the right hemisphere, the difference between old-left-hit-hit versus old-right-hit-hit would be greater than the difference between old-left-hit-miss versus old-right-hit-miss). However, there was no significant effect of response accuracy (hit-hit, hit-miss, and miss) as a function of event type (old-left and old-right) for either ROI (right fusiform, $F_{\text{accuracy} \times \text{event}}(2,22) = 1.99$, $MS_{\text{error}} = 3.73 \times 10^{-5}$, $p = 0.16$; left lingual, $F_{\text{accuracy} \times \text{event}}(2,22) = 1.86$, $MS_{\text{error}} = 2.03 \times 10^{-5}$, $p = 0.18$), suggesting

that the retrieval-related contralateral effects did not depend, to a significant degree, on accurate retrieval of previously studied shapes (it is also notable that there was no effect of response accuracy after averaging activity across all 12 ROIs, $F_{\text{accuracy} \times \text{event}}(2,22) < 1$). Still, accepting any null finding, such as these non-significant interactions, is always tenuous. A complementary analysis was conducted to further investigate whether contralateral memory effects might depend in some way on response accuracy. That is, we examined whether contralateral activity depended on accurate memory for spatial location and also whether this activity depended on accurate recognition memory (see Section 1.1). In the right fusiform gyrus (BA18), contralateral

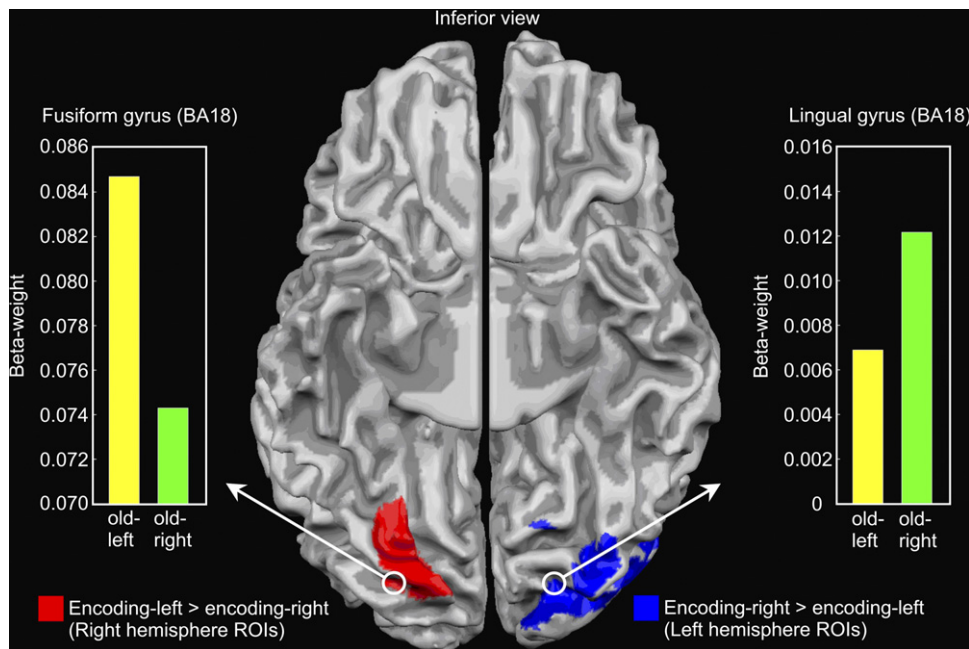


Fig. 2. Encoding-related retinotopic ROIs with selected retrieval-related contralateral effects. The cortical surface is viewed from below, with the occipital pole at the bottom and the right hemisphere to the left (gyri and sulci are shown in light and dark gray, respectively). Right hemisphere ROIs are shown in red and left hemisphere ROIs are shown in blue. Retrieval-related beta-weights (which quantify the magnitude of event-related activity) were extracted from a right hemisphere ROI (the fusiform gyrus, BA18) and a left hemisphere ROI (the lingual gyrus, BA18), both of which manifested significant contralateral effects (see bar graphs to left and right where old-left-related activity is shown in yellow and old-right-related activity is shown in green; see also Table 1). Note that the right hemisphere bar graph ordinate begins at 0.070, but the scale of both graphs is identical (such that the difference in activity – which is of primary interest – can easily be compared). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

activity did not depend on either accurate memory for spatial location or recognition memory accuracy (old-left-hit-hit versus old-left-hit-miss, $t(11) < 1$; old-left-hit versus old-left-miss, $t(11) < 1$). In the left lingual gyrus (BA18), contralateral activity did not depend on accurate memory for spatial location (old-right-hit-hit versus old-right-hit-miss, $t(11) < 1$), although it did depend on recognition memory accuracy (old-right-hit versus old-right-miss, $t(11) = 2.34$, $p < 0.05$). Furthermore, consistent with the findings of Slotnick and Schacter (2004), contralateral activity was independent of recognition memory accuracy in both regions when it was evaluated without regard for spatial location (i.e., old-hit versus old-miss; right fusiform gyrus, $t(11) < 1$; left lingual gyrus, $t(11) = 1.10$). Of particular importance, in both regions, there was no evidence that contralateral memory effects depended on accurate memory for spatial location.

Given that the foregoing findings hinge on null results, it is important to consider factors that can be taken as evidence against the possibility of type II error. The methods overall can be considered sensitive given that a significant effect of recognition memory accuracy was observed. Furthermore, in the right fusiform gyrus there was a lower magnitude of contralateral activity associated with accurate as compared to inaccurate memory for spatial location (i.e., 0.028 versus 0.029, anti-correlated with accuracy) and while the reverse pattern was observed in the left fusiform gyrus (i.e., 0.0053 versus 0.0049) the magnitude of activity was nearly identical within each region as a function of spatial location accuracy. Thus, the overall pattern of results indicates that contralateral activity does not depend on accurate memory for spatial location and instead reflects nonconscious memory.

2. Experiment 2

2.1. Materials and methods

2.1.1. Participants

Twelve participants took part in the study (11 females, mean age 23 ± 3.6 S.D.). All participants were right handed and had normal or corrected-to-normal visual acuity. The protocol was approved by the Massachusetts General Hospital Institutional Review Board, and written informed consent was obtained before the study commenced.

2.1.2. Stimuli and task

Given that the stimuli and experimental protocol were identical to those used by Slotnick and Schacter (2004) details will be limited to those relevant to the present investigation. As in Experiment 1, hundreds of distinct prototype shapes were generated. Each of these shapes was then spatially distorted to produce 10 unique exemplars of that prototype (where a set of shapes was comprised of a prototype and its corresponding exemplars), and each set of shapes was filled with lines of the same randomly generated color and orientation.

There were six phase I–II pairs of runs. During phase I, 16 sets of 9 exemplars alternated between the left and right of fixation, being sequentially presented every 3 s for a 2.5 s duration (Fig. 3). During phase II, 32 old shapes (2 exemplars from each phase I set), 32 related shapes (1 prototype and 1 nonstudied exemplar from each phase I set), and 32 new shapes were presented every 4–12 s for a 2.5 s duration. For both phases I and II, participants were instructed to respond whether each shape's internal lines sloped downward or upward relative to the horizontal using the middle or index finger of their left hand, respectively. Participants were told that response speed and accuracy were of equal importance.

2.1.3. Imaging acquisition and analysis

Data acquisition and pre-processing was identical to that described in Experiment 1.

For the beta-weight analysis, events included those in phase I (shapes on the left or right) and phase II (corresponding to old shapes, related shapes, new shapes, and failures to respond). As in Experiment 1, encoding and no response trials were assumed to be 2.5 s in duration while other durations were measured from stimulus onset until the behavioral response. Also as before, a random effect analysis was conducted to ensure activations were consistent across participants (with a one-tailed t -test, using between participant variability to estimate vari-

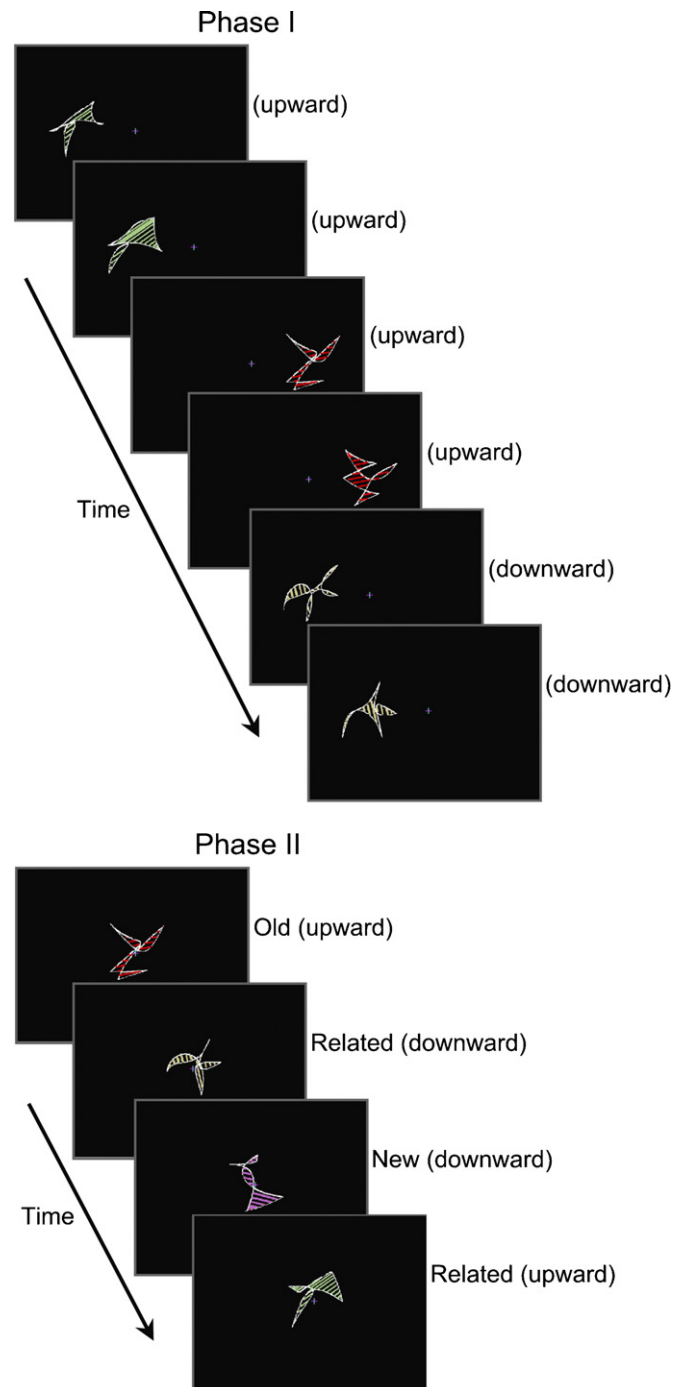


Fig. 3. Behavioral protocol for Experiment 2. During phase I, sets of similar shapes – with the same internal line orientation and color – alternated in presented to the left and right of fixation (two shapes/set shown, nine shapes/set actually used). During phase II, three classes of shapes were presented at fixation: (1) old shapes from phase I, (2) related shapes that were similar (but not identical) to shapes from phase I, and (3) new shapes. During both phases, participants responded whether the internal line orientation of each shape sloped upward or downward (correct responses are shown to the right of each shape, in parentheses).

ance). Reproducing the statistical thresholds employed by Slotnick and Schacter (2004), an individual voxel threshold of $p < 0.05$, corrected for multiple comparisons to $p < 0.01$, was used for all contrasts (maintaining these thresholds allowed us to directly compare the results of the present study with those of Slotnick & Schacter, 2004, without introducing a potential confound). It

should be noted that these thresholds are relatively more lenient than those used in Experiment 1, as encoding-related activity (as was assessed previously) reflects stimulus perception which is inherently more robust (i.e., associated with amplitudes an order of magnitude greater) than activity associated with retrieval-related activity (e.g., perception-related effects, see Liu, Slotnick, & Yantis, 2004; Tootell et al., 1998; retrieval-related effects, see Slotnick et al., 2003; Slotnick & Moo, 2006). The corrected p -value was enforced by requiring that clusters of activity were comprised of at least 31 contiguous re-sampled voxels, a value computed via 1000 Monte Carlo simulations (in this experiment, spatial correlation was ignored; for additional details, see Slotnick & Schacter, 2004). In an effort to avoid type I error, we only considered activity in brain regions that were relevant to the hypothesis under investigation—BA17, BA18, BA19 (including and ventral to the middle occipital gyrus, in accordance with the activity reported by Slotnick & Schacter, 2004, Table 2), and BA37. A statistical conjunction (\cap) was used to identify regions of common activity associated with two contrasts. Our conjunction operation identified voxels that were significantly active for *both* contrasts of interest (as described by Caplan & Moo, 2004) which is conceptually similar but differed in instantiation from the conjunction operation described by Friston, Holmes, Price, Buchel, and Worsley (1999; cf., Nichols, Brett, Andersson, Wager, & Poline, 2005). To conduct our conjunction analysis, the individual voxel threshold of each contrast was set to $p < 0.05$ (following Nichols et al., 2005). As in Experiment 1, activity was projected onto the cortical surface reconstruction of a representative participant.

For the ROI analysis, as in Experiment 1, event-related beta-weights were extracted from voxels in a 6 mm sphere centered at the coordinates of early visual area activity defined by the old-hits greater than related-false alarms contrast in Slotnick and Schacter (2004; Table 2). To complement this analysis, event-related timecourses were also extracted from these ROIs to allow for direct comparison with the timecourse analysis results of Slotnick and Schacter (2004). An event's timecourse was computed using the average voxel activity within a given ROI, where all trial onsets (associated with that event) were aligned and then activity was averaged (from -2 to 18 s after onset). This procedure is similar to event-related potential analysis, with no correction for overlapping responses (which does reduce sensitivity to some degree). Activation timecourses were baseline corrected such that the mean activity from -2 to 0 s after event onset was equal to 0% signal change and linear drift corrected. As the largest differential effects in Slotnick and Schacter (2004) occurred 8 s after event onset, this timepoint was selected *a priori* to conduct the main statistical assessment. Selecting a single timepoint has the advantage of avoiding the statistical problems associated with temporal autocorrelation, while having the potential disadvantage of increasing type II error. Regarding the latter point, if significant effects are observed, the results can be considered even that much more robust. Still, given that convolution of our event duration with a canonical hemodynamic response function was expected to evoke a maximal response between 6 and 8 s after event onset, additional analyses were conducted on activity at 6 s and the average activity from 6 to 8 s after event onset. For both event-related beta-weights and timecourses, the joint probability of observing differential activity across n independent ROIs was computed using the chi-square value given by

the equation:

$$\chi^2 = -2 \ln \prod_{i=1}^n p_i \quad (2)$$

with $2n$ degrees of freedom (Fisher, 1973).

2.2. Results

2.2.1. Behavioral results

Fig. 4 shows the reaction times for old, related, and new shapes in phase II. Reaction times to both old shapes (944.5 ± 16.4 ms) and related shapes (936.1 ± 13.6 ms) were faster than to new shapes (977.2 ± 15.1 ms; old versus new, $t = 2.0$, $p < 0.05$; related versus new, $t = 3.0$, $p < 0.01$). These behavioral effects may reflect priming for old and related shapes, and their similar magnitude (old versus related, $t < 1$, ns) indicates that behavioral priming was not specific to the exact shape presented at study (the nature of this non-specific priming will be more fully considered in Section 3). In addition, orientation discrimination accuracy was very high ($96.8 \pm 1.1\%$) indicating the fMRI results were not confounded by differential task difficulty between item types.

2.2.2. fMRI results

Fig. 5 (left) and Table 2 (top) illustrate the regions of activity associated with old greater than related shapes. Event-related beta-weights were extracted from the left striate cortex (BA17; Fig. 5, right), with old shapes evoking an increase in activity (all subsequent results were similarly associated with event-related increases in activity). This old greater than related shape early visual area activity (BA17, BA18) corresponds to the regions previously associated with nonconscious processing by Slotnick and Schacter (2004). It is also notable that one cluster of activity, although predominantly in BA18, extended into BA19, suggesting this region can also show increased activity on tasks that do not require conscious memory. Still, the almost complete absence of activity in later visual areas (more anterior BA19 and BA37) during an implicit memory task, in combination with their robust activation during a recognition task in our previous study, accords well with our previous conjecture that these regions are associated with conscious memory (Slotnick & Schacter, 2004).

Table 2
Regions within BA 17–19, and 37 associated with old > related shapes

Region	BA	x	y	z
Old > related (beta-weight analysis)				
Lingual gyrus (R)	18/19	15	-68	-2
Lingual gyrus (L)	18	-15	-79	-7
Striate cortex (L)	17	-5	-95	0
Old > related (ROI analysis)				
Fusiform gyrus (L)	18	-19	-85	-13
Lingual gyrus (L)	18	-16	-88	-13
Lingual gyrus (R)	18	9	-75	7
Cuneus (R)	18	9	-78	14
Striate cortex (R)	17	11	-76	11

Regions, Brodmann areas (BAs) and Talairach coordinates (x, y, z) refer to the center of each contiguous cluster of activity (R: right; L: left).

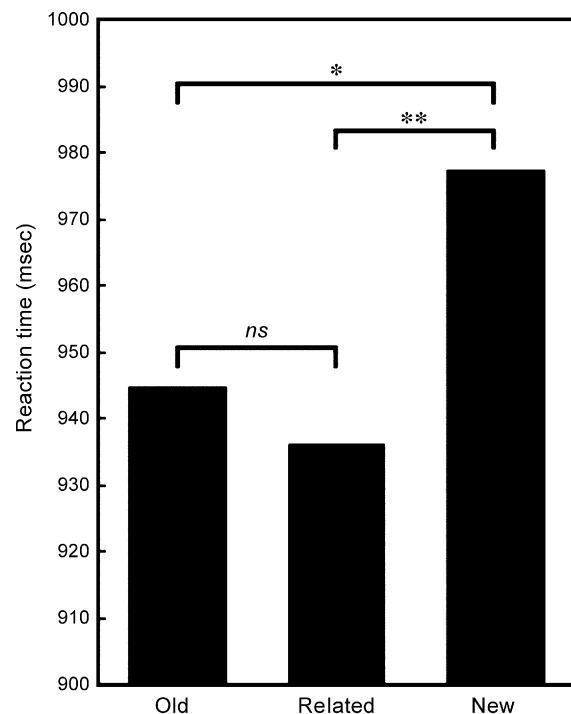


Fig. 4. Phase II reaction times for old, related, and new shapes. Asterisks demarcate statistically significant reaction time differences (* $p < 0.05$; ** $p < 0.01$).

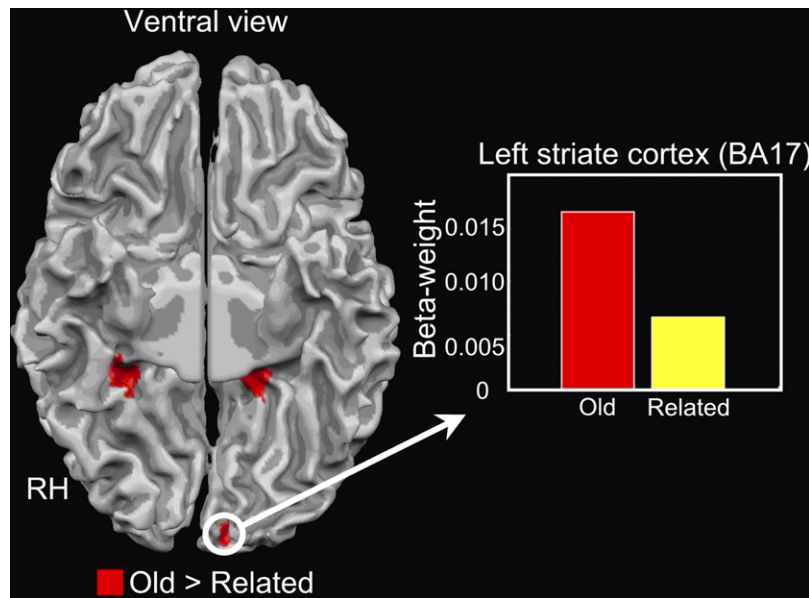


Fig. 5. To the left, activity associated with old > related shapes (in red) projected onto the ventral cortical surface of a representative participant (RH: right hemisphere). To the right, event-related beta-weights extracted from the left striate cortex region of activity (BA17; see color key to lower right). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

To obtain additional evidence relating to our primary aim, the old-hits greater than related-false alarm contrast of Slotnick and Schacter (2004) defined five early visual area ROIs (Table 2, bottom) from which event-related beta-weights were extracted (Fig. 6). All of these regions were associated with greater old than related shape activity. The differential activity in two of these regions reached significance (p -values < 0.05; left fusiform gyrus, BA18, $t = 1.9$; right lingual gyrus, BA18, $t = 1.9$) and was marginally significant in

the three other regions ($p < 0.10$; left lingual gyrus, BA18, $t = 1.5$; right striate cortex, BA17, $t = 1.4$; right cuneus, BA19, $t = 1.4$). Critically, the joint probability of observing old greater than related activity across these five regions was also significant ($p < 0.01$). The identical pattern of results was observed when event-related timecourses were assessed at 8 s after event onset, 6 s after event onset, and the average activity 6 and 8 s after event onset (all joint p -values < 0.01).

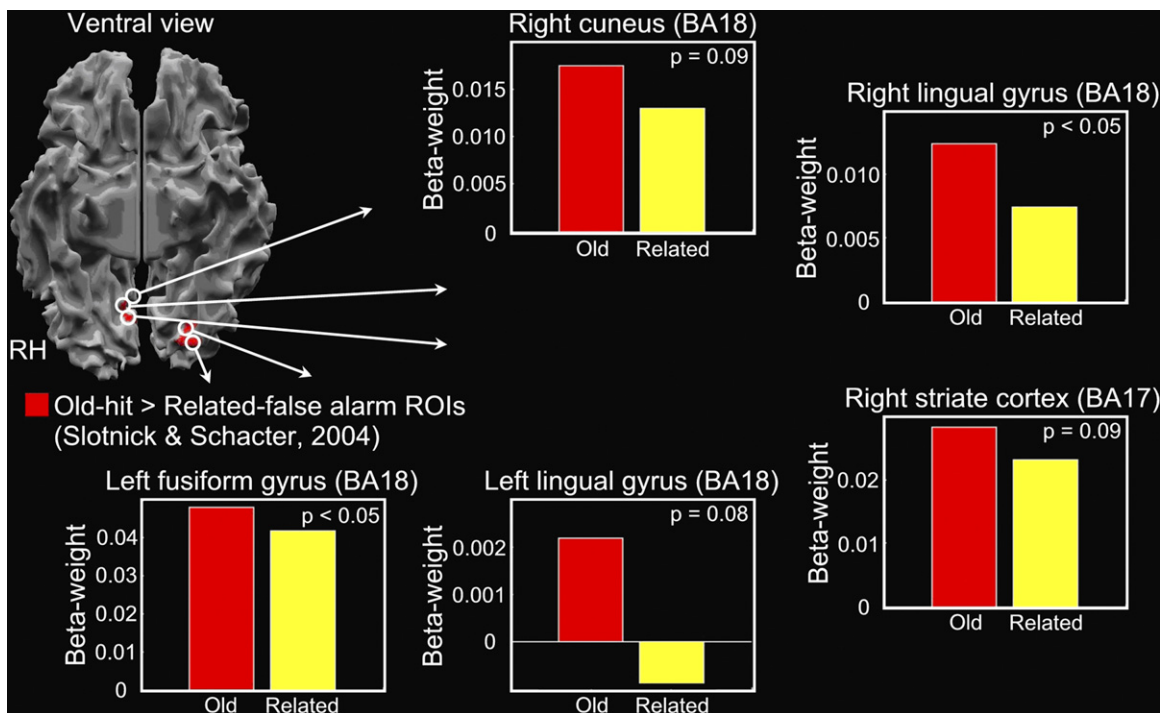


Fig. 6. To the upper left, BA17 and BA18 activity associated with old-hits > related-false alarms (in red) from Slotnick and Schacter (2004) that defined five ROIs. For each ROI, arrows indicate the respective event-related beta-weights associated with old and related shapes from the present study. The degree to which old shapes evoked greater activity than related shapes is reflected by the p -values shown in white. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

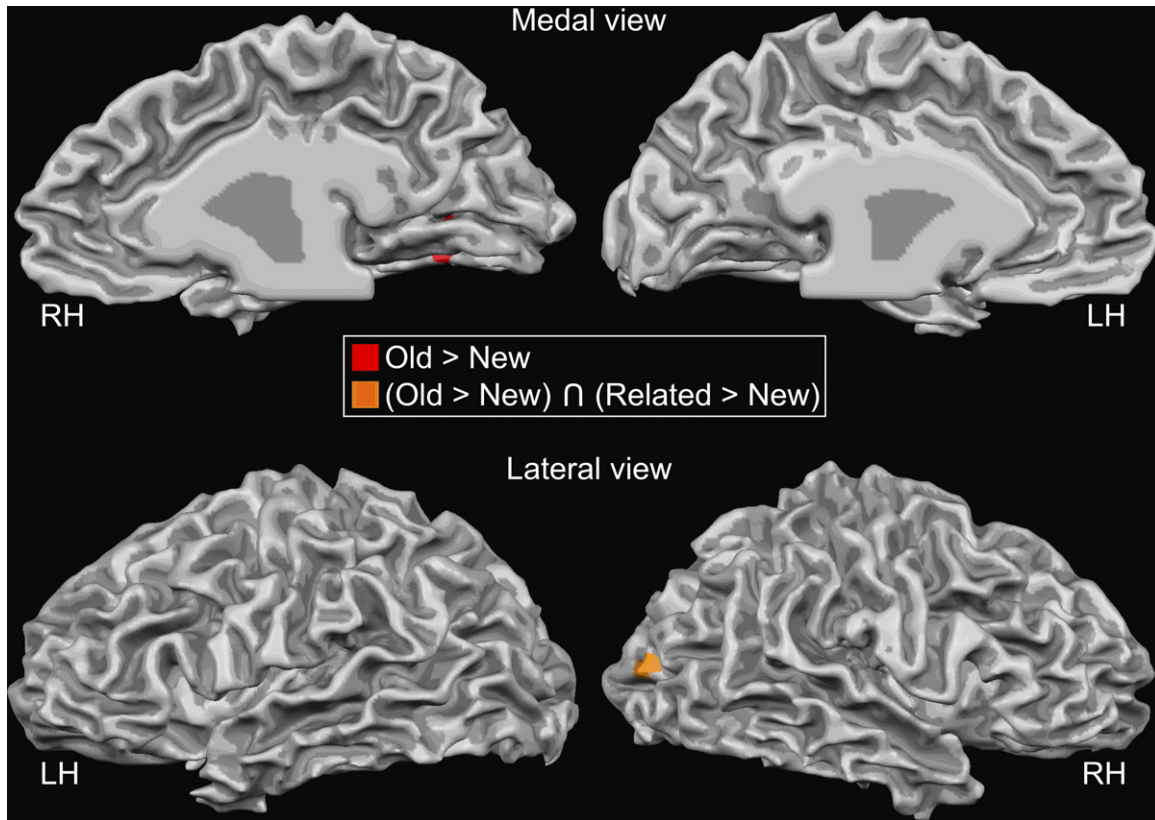


Fig. 7. Activity associated with old > new shapes (in red) and the conjunction (\cap) of old > new and related > new shapes (in orange; see color key at center) projected onto the medial and lateral surfaces of a representative participant (RH: right hemisphere; LH: left hemisphere). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Relating to the possibility that these effects reflect priming (for old and related shapes), Fig. 7 and Table 3 illustrate the regions associated with old greater than new shapes (reflecting specific neural priming) and a right middle occipital gyrus (BA18/BA19) region associated with the conjunction of old greater than new shapes and related greater than new shapes (reflecting non-specific neural priming). While the old greater than new contrast was associated with activity in early visual regions (BA17, BA18), the related greater than new contrast was not associated with any unique regions of activity. Additional evidence supporting this pattern of results was obtained by probing the event-related beta-weights extracted from the ROIs used above (Table 2, bottom). Across these ROIs, old shapes elicited greater activity than new shapes (joint $p < 0.05$), while there was no significant difference in activity between related and new shapes (the identical pattern of results was obtained by assessing event-related timecourse activity at 8, 6 s, and the average of 6 and 8 s after event onset). Event-related beta-weights were also extracted from the right middle occipital gyri region (BA18/BA19) corresponding to non-specific neural priming. As expected, old shapes and related shapes were both associated with greater activ-

ity than new shapes (old versus new, $t = 2.8$, $p < 0.01$; related versus new, $t = 2.32$, $p < 0.05$), and there was no difference in activity between old and related shapes ($t < 1$, ns).

3. General discussion

In the first experiment, we obtained evidence that retrieval of hemifield lateralized shapes is associated with reactivation of encoding defined contralateral posterior visual regions. These spatially specific contralateral memory effects reached significance within the right fusiform gyrus (BA18) and the left lingual gyrus (BA18), revealing spatially specific memory effects within individual visual regions (i.e., a double dissociation of beta-weights across hemispheres; see Fig. 2). The neural basis of memory has been construed as a constructive process, where the regions associated with processing an event or object during memory encoding are reactivated during retrieval (Schacter, Norman, & Koutstaal, 1998; Squire, 1992). There are a number of human neuroimaging findings consistent with this view (for a review, see Slotnick, 2004), including reactivation of visual processing regions during memory for visual items (Slotnick et al., 2003; Slotnick & Schacter, 2004; Vaidya et al., 2002; Wheeler & Buckner, 2003; Wheeler et al., 2000), reactivation of auditory processing regions during memory for spoken words or sounds (Nyberg, Habib, McIntosh, & Tulving, 2000; Schacter et al., 1996; Wheeler et al., 2000), reactivation of motor processing regions during memory for actions (Nyberg et al.,

Table 3
Regions within BA 17–19, and 37 associated with old > new shapes and the conjunction of old > new and related > new shapes

Region	BA	x	y	z
Old > new				
Lingual gyrus (R)	18	16	-71	-4
Striate cortex (R)	17	11	-70	6
(Old > new) \cap (related > new)				
Middle occipital gyrus (R)	18/19	27	-87	12

Regions, Brodmann areas (BAs) and Talairach coordinates (x, y, z) refer to the center of each contiguous cluster of activity (R: right; L: left).

2001), and reactivation of olfactory cortex during memory for odors (Gottfried, Smith, Rugg, & Dolan, 2004). These studies provide compelling evidence that retrieval can evoke reactivation of cortex associated with the appropriate sensory or motor modality, presumably reflecting the retrieval of modality specific encoding-related sensory processing details. Our contralateral memory effects (reflecting memory for spatial location) provide the first direct evidence, to our knowledge, of feature specific memory, and support the view that memory is a constructive process that operates by reactivating the individual features of an event or object to create a unified memory.

In support of the hypothesis under investigation, analyses of the contralateral memory related activity within the right fusiform gyrus (BA18) and left lingual gyrus (BA18) revealed that these memory effects did not depend on response accuracy for spatial location. It might be expected that retrieval-related contralateral reactivation would be greater for accurate judgments of spatial location, if such activity were associated with conscious memory (i.e. explicit visualization of the previously studied hemifield lateralized shapes). However, the fact that this contralateral activity did not depend on spatial location accuracy suggests that activity within BA18 is associated with nonconscious memory.

In the second experiment, we observed old greater than related shape activity in early visual regions (predominantly BA17 and BA18) during a line judgment task that did not require conscious/explicit memory for previously studied shapes. Although this activity extended into BA19, it was largely absent from more anterior BA19 and BA37. Overall, these results complement our previous findings – which used the same stimuli and experimental protocol but with explicit (recognition) memory instructions – that suggested late visual regions (BA19, BA37) are associated with conscious memory while early visual regions (BA17, BA18) are associated with nonconscious memory (Slotnick & Schacter, 2004). The present results are also consistent with previous findings of distinct neural processing associated with explicit and implicit memory (e.g., Donaldson, Petersen, & Buckner, 2001; Henson, Shallice, Gorno-Tempini, & Dolan, 2002; Schott et al., 2005).

The early visual region effects in this experiment may have reflected repetition priming. Priming refers to a facilitation or change in the processing of an item produced by a prior encounter with an identical or related item (Schacter, Dobbins, & Schnyer, 2004). Priming effects are most typically observed on implicit or indirect memory tasks that do not require explicit memory for previously studied items. It is important to consider that priming is typically defined in terms of *familiar* object processing and is manifested by a *decrease* in ventral occipitotemporal activity relative to new objects (Buckner et al., 1998; Eger, Henson, Driver, & Dolan, 2004; Henson, Rylands, Ross, Vuilleumier, & Rugg, 2004; Koutstaal et al., 2001; Simons, Koutstaal, Prince, Wagner, & Schacter, 2003; van Turennout, Bielarowics, & Martin, 2003; Vuilleumier, Henson, Driver, & Dolan, 2002; this corresponds to the classic posterior cortical activity priming related decreases with words, for a review, see Schacter & Buckner, 1998). However, repetition priming can also refer to processing of *unfamiliar* shapes or objects that can

elicit *increases* in ventral occipitotemporal activity relative to new objects (Henson, Shallice, & Dolan, 2000; Schacter et al., 1995; Uecker et al., 1997; priming related activity increases also occur for pseudowords, Fiebach, Gruber, & Supp, 2005, which can be considered unfamiliar words). Because our stimuli consist of abstract shapes that had not been encountered by participants prior to the experiment, repetition priming should have been manifested primarily by an increase in visual area activity for old shapes relative to related shapes and to new shapes, as was observed. Such priming effects are of theoretical importance, as they shed light on how activity in different neural regions can reflect either specific or non-specific representations of encoded items. Although there have been similar studies conducted for objects and words, this is the first time, to our knowledge, that priming effects for old and related shapes, relative to new shapes, have been evaluated.

It is important to note, however, that even though the line judgment task used here did not require conscious/explicit memory, we cannot rule out the possibility that performance of the task was influenced by some type of explicit memory process. It has long been known that performance on memory tasks is often not “process pure”, i.e., explicit/conscious memory can influence performance on nominally implicit or indirect tasks, and implicit/nonconscious memory can influence performance on nominally explicit or direct tasks (Jacoby, 1991; Schacter, Bowers, & Booker, 1989). Although there is no reason to believe that explicit memory processes contributed to priming on our line judgment task, further research using appropriate behavioral manipulations, or patient populations with explicit memory deficits, will be necessary to more formally evaluate this possibility. Nonetheless, this study takes a step forward from previous results by showing that early visual areas show increased activity on a task that does not require explicit memory, thereby providing evidence in support of our hypothesis that these regions support a nonconscious form of memory.

It is notable that our behavioral results showed the same amount of priming for old and related shapes on the line judgment task. The fMRI results showed a similar pattern of activity in a right middle occipital gyrus region (BA18/19), where old and related shapes both elicited greater activity than new shapes. These effects can be described as non-specific, given they were comparable for old and related items. By contrast, early visual region activity (BA17, BA18 extending into BA19) was specific to old shapes compared with either related or new shapes (where related and new shape activity was equivalent).

Our non-specific behavioral priming effects may at first seem at odds with previous object priming studies that have reported graded behavioral priming effects, where reaction time for old items was faster than for related items which was faster than for new items (Koutstaal et al., 2001; Simons et al., 2003; Vuilleumier et al., 2002). However, our abstract shapes are far less distinct than common objects. Furthermore, the line orientation task requires participants to focus on features of the shapes that are shared by old and related items (i.e., internal line orientation is identical for both old and related shapes derived from the same prototype). Thus, old and related shapes may have had equivalent representations for the purpose of perform-

ing the line orientation task (for examples of task dependent priming effects, see Bowers, Vigliocco, & Haan, 1998; Dobbins, Schnyer, Verfaellie, & Schacter, 2004; Wagner, Koutstaal, Maril, Schacter, & Buckner, 2000; Xiong, Franks, & Logan, 2003; for further discussion of specificity effects in priming, see Schacter et al., 2004). These non-specific behavioral priming effects were reflected in the right middle occipital gyrus (BA18/19), which suggests neural processing within this region subserves the behavioral effect. However, we also observed specific neural priming effects in early visual regions (predominantly BA17, BA18). Such dissociations between behavioral priming effects and neural priming effects are not uncommon in studies with old and related items. For instance, in two studies employing objects (Koutstaal et al., 2001; Simons et al., 2003), graded behavioral priming effects (reaction time for old < related < new) were reflected in the left fusiform gyrus (activity for old < related < new), while specific neural priming was observed in the right fusiform gyrus (activity for old < related = new). Furthermore, in a masked word priming study (with results paralleling the present study), non-specific behavioral priming (reaction time for old = related < new) was reflected by non-specific neural priming in the left fusiform gyrus (activity for old = related < new), while specific neural priming was observed in the right extrastriate cortex (activity for old < related = new; Dahanne et al., 2001). Why might behavioral priming effects only be reflected in activity within certain neural regions? Behavioral effects are a composite of many underlying neural processing stages, and are highly stimulus and task dependent. Thus, a behavioral effect may only reflect activity in one or a limited number of neural processing regions, even though distinct types of processing are occurring in other neural regions (cf., Dahanne et al., 2004).

As a case in point, our specific neural priming effects in early visual areas (activity for old > related = new) did not reflect our non-specific behavioral priming effects (reaction time for old = related < new). With regard to the source of this specific neural priming, it is important to consider that old and related shapes consisted of identical internal line color and orientation (such that orientation or color differences could not have driven the differential early visual area effects). Only the shape outline/contours differed between old and related shapes (and also differed between old and new shapes). Therefore, specific repetition priming in early visual areas can likely be attributed to priming of old shape contours, which differed from both related and new shapes. The high degree of specificity of this effect may be due to the precise retinotopic stimulus representation in striate and early extrastriate cortex (see Sereno et al., 1995; Slotnick & Moo, 2003), which should only be primed with repetition of the precise contours delineating old shapes. It should be possible to find behavioral evidence corresponding to such an effect by using a task that requires participants to focus on or detect the features that distinguish old from related shapes. Our imaging results can therefore serve the useful function of generating hypotheses that can be tested in future behavioral studies.

The results of the present experiments provide convergent support for our hypothesis that memory related activity in early visual areas (BA17, BA18) reflects nonconscious processing. In

the first experiment the same explicit task and a similar stimulus protocol as in our previous study was used (Slotnick & Schacter, 2004), but an additional analysis was carried out to assess contralateral memory effects. The results of the present study replicated our previously reported nonconscious memory effects with explicit memory instructions. In the second experiment the same stimulus protocol as in our previous study was used (Slotnick & Schacter, 2004), but with implicit rather than explicit task instructions. In this way, nonconscious memory effects associated with stimulus priming were isolated. Overall, the results indicate that memory related activity, even that associated with explicit memory tasks, should not be assumed to reflect conscious processing. Rather, memory related activity can reflect either conscious or nonconscious processing and determining the nature of this activity requires the appropriate analysis.

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