Dissociable Human Perirhinal, Hippocampal, and Parahippocampal Roles during Verbal Encoding

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The precise contribution of perirhinal cortex to human episodic memory is uncertain. Human intracranial recordings highlight a role in successful episodic memory encoding, but encoding-related perirhinal activation has not been observed with functional imaging. By adapting functional magnetic resonance imaging scanning parameters to maximize sensitivity to medial temporal lobe activity, we demonstrate that left perirhinal and hippocampal responses during word list encoding are greater for subsequently recalled than forgotten words. Although perirhinal responses predict memory for all words, successful encoding of initial words in a list, demonstrating a primacy effect, is associated with parahippocampal and anterior hippocampal activation. We conclude that perirhinal cortex and hippocampus participate in successful memory encoding. Encoding-related parahippocampal and anterior hippocampal responses for initial, remembered words most likely reflects enhanced attentional orienting to these positionally distinctive items.

Key words: perirhinal cortex; hippocampus; parahippocampal cortex; fMRI; episodic memory encoding; subsequent memory effect; primacy effect

Human electrophysiological and functional magnetic resonance imaging (fMRI) memory experiments have characterized medial temporal responses during episodic memory encoding that predict whether individual items are subsequently recalled or forgotten. For example, depth electrode recordings in human unilateral temporal lobe epilepsy patients indicate that during verbal encoding, greater responses in perirhinal cortex, as well as hippocampus, are evoked by words subsequently recalled than forgotten (Fernandez et al., 1999). This finding differs from event-related fMRI studies of the "subsequent memory effect", which demonstrated that responses in parahippocampal cortex (posterior to perirhinal cortex) to words (Wagner et al., 1998; Kirchoff et al., 2000) and pictures (Brewer et al., 1998; Kirchoff et al., 2000) predict whether items are subsequently recognized. In addition, a recent fMRI study demonstrated verbal encoding-related activation in left hippocampus predictive of subsequent recognition (Otten et al., 2001). Hence, fMRI studies, in contradistinction to the human intracranial recording data (Fernandez et al., 1999), fail to demonstrate differential encoding-related perirhinal responses to subsequently remembered versus forgotten words.

A critical issue raised by the apparent conflict between intracranial recordings and functional neuroimaging evidence is that epilepsy patients, subject to intracranial recordings, may display abnormal response profiles that reflect adaptive neuronal change to underlying core pathology, such as medial temporal sclerosis. Alternatively, fMRI may be relatively insensitive to activation in perirhinal cortex, which lies in anterior medial temporal lobe in the banks of the anterior extent of the collateral sulcus (Amaral, 1999). The medial temporal lobe, particularly its anterior extent, is subject to fMRI susceptibility artifacts and signal drop-out (Ojemann et al., 1997), yielding less signal-to-noise in anterior medial temporal structures compared with most other cortical regions.

The issue addressed by the current experiment was whether an absence of perirhinal activation in subsequent memory fMRI experiments reflects decreased sensitivity of fMRI in these anterior perirhinal regions. Hence, we used the paradigm of Fernandez et al. (1999), which demonstrated perirhinal responses during intracranial recordings, in the context of an event-related fMRI experiment (Fig. 1*a*). Critically, fMRI data acquisition parameters were manipulated to maximize sensitivity to anterior medial temporal responses (see Materials and Methods and Fig. 1*b*). Fourteen normal subjects were instructed to rote encode 12 words presented during scanning. After a distractor task, subjects freely recalled from the 12 words. This procedure was repeated 30 times for each subject. To test for encoding-related perirhinal responses, predictive of subsequent memory, encoding-related responses evoked by subsequently recalled words were compared with encoding responses to forgotten words.

MATERIALS AND METHODS

Subjects. Informed consent was obtained from 14 right-handed subjects (4 male, 10 female; age range, 19–32 years; mean age, 24.2; recruited by advertisement). Ethics approval was obtained from the National Hospital for Neurology and Neurosurgery Joints Ethics Committee.

Task. During fMRI scanning, words were presented in uppercase letters (white against black background), in central vision (horizontal visual angle 3.0°), and for a duration of 400 msec (randomized stimulus onset asynchrony; mean, 2.5 sec; range, 2.3–2.7 sec). All subjects were presented with the same words (4–11 letters in length, 15–175 occurrences per million as per the Kucera and Francis (1967) frequency count) with presentation randomized across subjects. In each scanning session, subjects were presented with 12 words and instructed to use a rote strategy to memorize each word. That is, it was emphasized that they were not to use mnemonics such as imagery or making sentences, stories,

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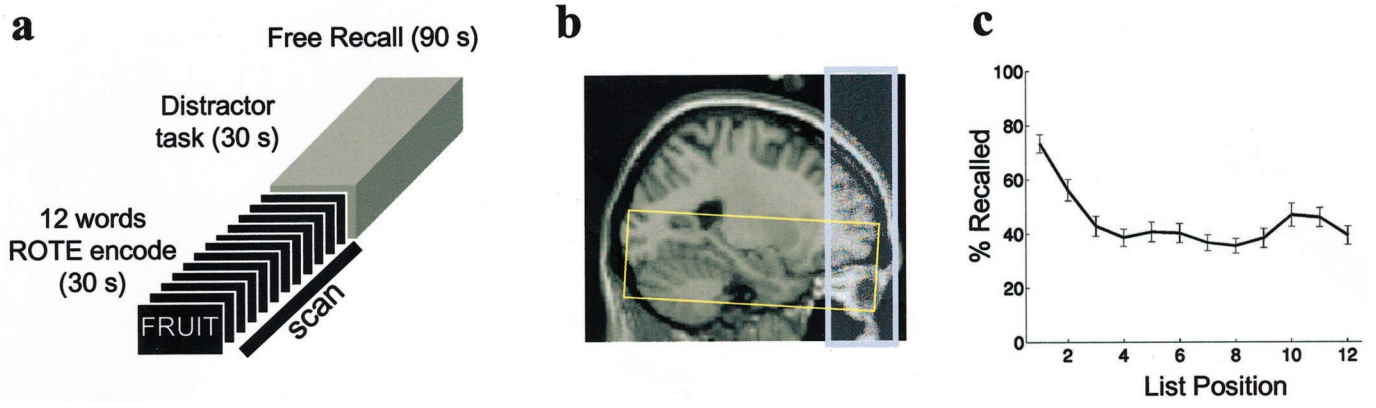

Figure 1. Experimental set up and behavioral results. *a,* Schematic of the experimental design. *b,* Sagittal section of the T1 MNI reference brain (Cocosco et al., 1997) demonstrating location of transverse functional image acquisition (*yellow*) and the position of the coronal saturation pulse (*blue*). *c,* Serial position curve for the 14 subjects. Recall performance (± 1 SE) has been collapsed across sessions within subjects and averaged across subjects.

or rows. The presentation of each list of 12 words was followed immediately by a 30 sec distraction task (not scanned) during which subjects were instructed to count backwards in threes (out loud), starting at a number between 81 and 99 displayed on the screen. The distractor task was followed immediately by the instructions, displayed on-screen, to free-recall the words presented in the preceding list in any order, for which subjects were allowed 90 sec (Fig. 1*a*). Immediately before scanning, the experimental procedure was explained to each subject, and two training blocks were completed outside of the scanner. The psychological task was therefore identical to that used by Fernandez et al. (1999), except that here 30 lists of words were presented as opposed to 20.

Data acquisition. A Siemens (Erlangen, Germany) VISION system, operating at 2 T, was used to acquire both T1-weighted anatomical images and gradient-echo echoplanar T2*-weighted MRI image volumes with blood oxygenation level dependent contrast. For each subject, data were acquired in 30 scanning sessions. In each scanning session, 22 volumes were acquired plus five "dummy" volumes, acquired at the start of each session and subsequently discarded, to allow for T1 equilibration effects. Volumes were acquired continuously every 1750 msec. Each volume comprised 24 2 mm axial slices, with an in-plane resolution of 2.5 × 2.5 mm and in-plane field of view of 160 mm, positioned to cover the perirhinal, entorhinal, and parahippocampal cortices and the hippocampus (used here to refer to dentate gyrus, CA subfields, and subiculum). Before the acquisition of each slice, a slab-selective saturation pulse was applied to a coronal section positioned to cover the eyes and frontal pole (thickness 60 mm) to minimize frontal-occipital wrap-around and Nyquist ghosting of the eyes. The scanned region and position of the saturation pulse are illustrated in Figure 1*b*. An echo time of 30 msec was used to minimize signal drop-out from the temporal lobes.

The imaging time series was realigned, slice-time corrected, normalized into a standard anatomical space (Talairach and Tournoux, 1988), and smoothed with a Gaussian kernel of 6 mm full width half maximum, as described previously (Friston et al., 1995a). Five sessions were discarded from one subject because of poor image quality.

Data analysis. Imaging data were analyzed using Statistical Parametric Mapping (SPM99). Two analyses were performed, both using an event-related model (Josephs et al., 1997) to compare encoding-related responses to individual words that were subsequently remembered versus words that were forgotten. Both were random effects analyses implemented using a two stage procedure.

The first analysis focused on the subsequent memory effect in the list body. The first two words in each list demonstrated a primacy effect (see Results), and hence were modeled separately from the remaining 10 words (the list body), to avoid confounding subsequent memory with the primacy effect. Four effects of interest were therefore specified for each session: the events corresponding to subsequently remembered and forgotten words in the initial and list body positions. Trial-specific responses were modeled by convolving a delta function (or "stick" function) that indicated each event onset with two basis functions to create regressors of interest. The basis functions used were a synthetic, canonical hemodynamic response function (HRF) and a delayed HRF shifted to onset 3.5 sec (i.e., two repetition times) later than the canonical HRF. The use of both an early and late response function followed suggestions that the time of maximal activation can be later for some brain regions (e.g., hippocampus) than the sensory regions on which the HRF is based (Otten et al., 2001). The covariates for the late HRF were orthogonalized with respect to those for the early HRF using a Gram–Schmidt procedure to give priority to the early covariate (Andrade et al., 1999), i.e., variance common to the early and late covariates is attributed to the early covariate.

Session-specific parameter estimates pertaining to the height of the HRF for each regressor of interest were calculated for each voxel (Friston et al., 1995b). A contrast of parameter estimates across sessions comparing subsequently remembered versus forgotten words in the list body was calculated in a voxel-wise manner to produce, for each subject, one contrast image for the subsequent memory effect in the list body. In the second stage of the random effects analysis, each subject's contrast image was entered into a one-sample *t* test across the 14 subjects. An identical procedure was used to test parameter estimates for words in the initial positions and for the delayed HRF modeling words in the list body.

The second analysis investigated the neuroanatomical correlates of the primacy effect and tested for an interaction between subsequently remembered versus forgotten items in the initial positions (positions 1 and 2) versus the body of the list. A single regressor was created to test this interaction, and the only basis function used was the canonical HRF. To create the interaction regressor, for each list the two initial words were modeled as well as two body words chosen at random. These two body words were selected to match recall performance for initial words. If, in a given list, both initial words were remembered, the interaction regressor modeled these two responses plus the event-related responses (multiplied by −1) for two recalled body words chosen at random. If both initial words were forgotten, their modeled responses were multiplied by −1, and the responses to two forgotten body words were multiplied by +1. If one initial word was remembered, the interaction regressor consisted of the remembered and forgotten initial word and a randomly selected remembered and forgotten body word (modeled responses multiplied by +1, −1, −1, and +1, respectively). The event-related responses to the remaining words in the body of each list were modeled as effects of no interest. The session-specific parameter estimates pertaining to the interaction were averaged across sessions, within subject, and the resulting contrast image was entered into a one-sample *t* test across the 14 subjects. To enable plotting of parameter estimates in Figure 3, a separate analysis was conducted that modeled the four components of the interaction separately, i.e., remembered and forgotten words in the initial positions and two remembered or forgotten words in the list body randomly selected under the same constraints as for the original primacy analysis.

Sessions in which no words were recalled from the list body were not included in either analysis, because these sessions may have reflected a failure at retrieval rather than at encoding. Ten sessions (of a total of 420 sessions across subjects) were thus excluded, with no particular subject displaying more than three zero recall sessions. In both analyses, movement parameters, determined during realignment, were entered as covariates of no interest to remove possible movement-related residual effects.

We report all medial temporal activations at a threshold of $p < 0.005$, uncorrected for multiple comparisons. This uncorrected threshold was adopted because of the low signal-to-noise ratio in anterior medial temporal lobe (Ojemann et al., 1997). Activation of posterior fusiform cortex in the primacy analysis survived this threshold and is also reported given that this region has previously been implicated in the subsequent memory effect (Brewer et al., 1998; Wagner et al., 1998; Kirchoff et al., 2000). All SPMs are superimposed on two T2* functional images. The first T2* image is the mean functional image (produced for each subject during realignment and then normalized) taken from one subject. The other T2* image is the normalized, mean functional image averaged across the 14 subjects. Voxel intensities in this image have been increased by a power of 5 to improve contrast and enable localization of the collateral sulcus. Color contrast of these T2* images has been inverted for illustration.

RESULTS

Behavior

The serial position recall curve averaged across all 14 subjects is shown in Figure 1*c*. A repeated measures ANOVA demonstrated a significant list position by performance interaction ($F_{(4.4, 57.5)} = 14.85$; $p < 0.001$; Greenhouse-Geisser corrected for non-sphericity). A *post hoc* Tukey's test (degrees of freedom corrected for non-sphericity) demonstrated a significant primacy effect but no significant recency effect. The recency effect, enhanced memory for the last presented items in a given list, is thought to be medial temporal lobe-independent (Baddeley and Warrington, 1970), dependent instead on short-term memory and hence removed by the distractor task (Baddeley, 1990).

Functional imaging

The scanning parameters used provided high spatial resolution T2* images of the medial temporal lobes, enabling different medial temporal structures to be discriminated. Our first event-related analysis compared encoding-related activation evoked by subsequently remembered versus forgotten words. This comparison was restricted to the list "body" (serial positions 3–12) to preclude responses specific to the primacy effect observed in the behavioral data. This subsequent memory analysis demonstrated a distinct left anterior medial temporal activation, located in perirhinal cortex (Fig. 2*a*). Left hippocampal activation, located in the body of left hippocampus and bordering adjacent entorhinal cortex (Amaral, 1999), was also found to predict subsequent memory (Fig. 2*b*). A weaker subsequent memory effect was also observed in right entorhinal cortex (Fig. 2*b*). The analysis testing for subsequent memory effects using a delayed HRF did not yield any significant differential medial temporal activations.

By contrast to the current behavioral data, medial temporal lobe epilepsy patients performing the same task do not demonstrate enhanced memory for initial list items (Fernandez et al., 1999), which is in line with previous observations of absent primacy in hippocampal-lesioned patients (Jones-Gotman, 1986; Hermann et al., 1996). Given that these patients have medial temporal damage, we hypothesized that the primacy effect may have a discrete neuronal substrate in the medial temporal lobe. Thus, our second analysis tested for an interaction between responses predictive of subsequent memory for the first two presented words in each list versus words presented later in the list body. In this analysis, significant effects were observed in right anterior hippocampus (Fig. 3*a*) and bilateral parahippocampal gyrus (Fig. 3*b*) in the medial temporal lobe, as well as in bilateral posterior fusiform cortex (Fig. 3*b*). The plots in Figure 3 show that these regions predict subsequent memory only for initial words. Greater responses were observed for remembered versus forgotten initial words, but not for words presented later in each list. No significant activation was observed for the reverse comparison testing for subsequent memory effects greater for the list body than for initial words.

Perirhinal responses, predictive of subsequent memory for words in the list body, did not, therefore, show further enhancement for initial remembered words. A remaining issue was whether perirhinal responses demonstrated any differential response to subsequently remembered versus forgotten words when examining the first two serial position words alone. Recall that in our first analysis, words in these primacy positions were modeled separately (see Materials and Methods). Critically, a test of encoding responses to subsequently remembered versus forgotten initial items alone revealed greater activation in left perirhinal cortex for remembered items (x, y, z coordinates $-24, -6, -34$, respectively; $Z = 2.72$; $p < 0.005$). This activation was in the same perirhinal region (within the spatial resolution of our analysis) as that demonstrating a subsequent memory effect for the list body ($-30, -4, -36$; $Z = 3.07$; $p < 0.005$) (Fig. 2*a*). There was, however, no evidence of a subsequent memory effect for these initial words in left hippocampal body, which may reflect less power because of fewer events. Thus, perirhinal responses predicted subsequent memory for words in all list positions, whereas right anterior hippocampal, bilateral parahippocampal, and fusiform responses predicted subsequent memory for initial words alone.

The fact that each subject underwent a study-test procedure 30 times raised the possibility that medial temporal encoding-related activation varied as a function of encoding session, perhaps reflecting subtle changes in subjects' strategies as they became increasingly practiced and familiar with the study-test procedure. We tested for this by comparing encoding-related responses in the first half of the experiment versus the second half. This was done for both the analysis of successful encoding in the list body and the analysis testing for the neuronal correlates of primacy. Neither of the ensuing one-sample t tests revealed any significant ($p < 0.05$ uncorrected) medial temporal activation, suggesting that reported responses do not vary as a function of practice. Furthermore, there was no effect of practice on performance. Paired t tests comparing performance in the first half of the experiment versus the second half did not yield significant differences for either mean performance on the first two serial positions ($p > 0.4$) or the list body ($p > 0.4$).

DISCUSSION

Human *in vivo* electrophysiological recordings (Fernandez et al., 1999) in epilepsy patients provide a clear prediction that encoding-related responses in perirhinal cortex should be greater for subsequently remembered versus forgotten words. One major qualification to this prediction is that perirhinal involvement was seen in the context of medial temporal pathology. However, the imaging data reported here confirm this prediction. We show that for verbal stimuli, encoding-related hemodynamic responses in left perirhinal cortex, measured with fMRI parameters that maximized sensitivity to anterior medial temporal activation, were significantly greater for remembered versus forgotten words.

The precise functional role of human perirhinal cortex in memory is not fully understood. Lesion studies and single-unit recordings in monkeys demonstrate a perirhinal role in processing contextual novelty (Brown and Aggleton, 2001) and in associative learning (Sakai and Miyashita, 1991; Erickson and Desimone, 1999). In the current experiment, although all words in each list were equally contextually novel, particular words may

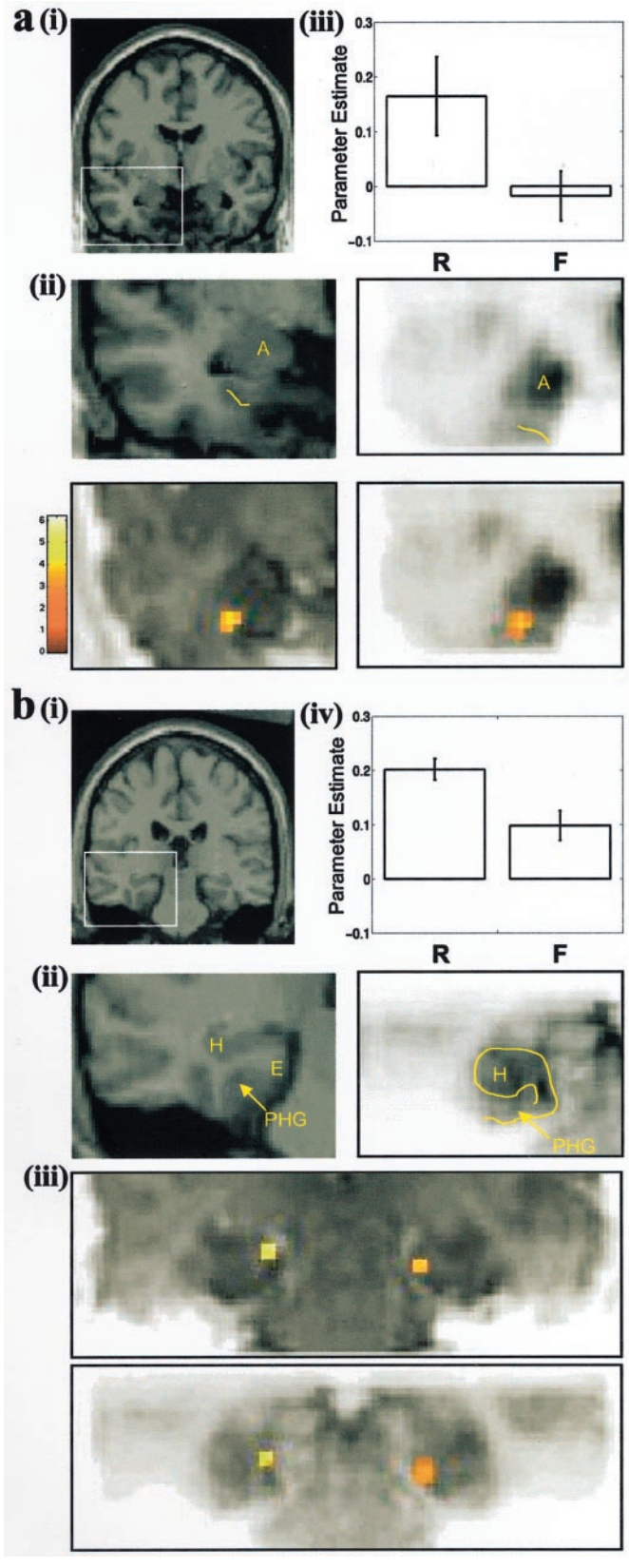

Figure 2. Medial temporal encoding-related activation predictive of subsequent memory. *a,* Greater activation in left perirhinal cortex (*x*, *y*, *z* coordinates, −30, −4, −36; $Z = 3.07$; $p < 0.005$) for subsequently remembered versus forgotten words. *ai,* Coronal section of the reference T1 image ($y = -4$) with the region displayed in *aii* indicated by the *white rectangle*. *aii*, *Top panel,* Coronal sections of left temporal lobe of (from left to right) the T1 reference image and the average functional image from the 14 subjects. The *yellow line* indicates the collateral sulcus. *A,* Amygdala. *Bottom panel,* The SPM (threshold $p < 0.01$), demonstrating perirhinal activation in the depths of the collateral sulcus, is superimposed on the mean functional image from a single subject and the average functional image from the 14 subjects. The *colored bar* indicates the T statistic of the activation. *aiii*, Parameter estimates (± 1 SE) for the height of the hemodynamic response in left perirhinal cortex for subsequently remembered (*R*) and forgotten (*F*) words (units are arbitrary). The parameter estimates, here and in Figure 3, have been collapsed across sessions within subjects, and averaged across subjects. *b,* Hippocampal–entorhinal responses predict subsequent memory. Activation in left hippocampus (−22, −26, −16; $Z = 3.74$; $p < 0.001$), bordering with left entorhinal cortex, was greater for remembered than forgotten words. *bi,* Coronal section of the reference T1 image ($y = -26$) with *white rectangle* depicting the region shown by the two coronal sections in *bii* below. *bii,* Coronal sections of left temporal lobe of the T1 reference image (*left panel*) and the average functional image from the 14 subjects (*right panel*). The outline of the hippocampus (*H*) is traced in *yellow*. *E,* Entorhinal cortex; *PHG,* parahippocampal gyrus. *biii,* The SPM (threshold $p < 0.01$) has been superimposed on a coronal section ($y = -26$) of the mean functional from a single subject (*top panel*) and the average functional image from the 14 subjects (*bottom panel*) to illustrate activation in left hippocampus. The coronal sections show that right entorhinal cortex (22, −26, −20; $Z = 2.78$; $p < 0.005$) was also predictive of subsequent memory. *biv,* Parameter estimates for responses in left hippocampus as for *a*.

have been subjectively perceived as novel and account for encoding-related perirhinal activation. Alternatively, enhanced perirhinal activation could reflect associative encoding of successive words during the rote encoding demanded by our task. A currently controversial issue is the role of perirhinal cortex in recognition memory (Aggleton and Shaw, 1996; Reed and Squire, 1997; Aggleton and Brown, 1999). Our findings, along with those of Fernandez et al. (1999), imply that regardless of its role in recognition, perirhinal cortex supports an encoding process contributing to subsequent free recall.

In further agreement with electrophysiological (Fernandez et al., 1999) and fMRI (Otten et al., 2001) data, hippocampal activation was also found to predict subsequent memory. This activation was located in left hippocampal body, a region previously implicated in verbal encoding (Kopelman et al., 1998) and retrieval (Lepage et al., 1998; Schacter and Wagner, 1999). Our data therefore raise the possibility that perirhinal cortex and hippocampal body operate on a functionally integrated basis. Alternatively, these regions may make independent contributions to verbal encoding. Future experiments seeking variables that independently influence encoding-related activity in perirhinal cortex and hippocampal body may allow their roles in episodic encoding to be dissociated.

The predominantly left-sided perirhinal and hippocampal activation in the subsequent memory analysis of the list body might be expected, given the dominant role of the left medial temporal lobe in verbal memory (Milner, 1972). Fernandez et al. (1999) did not, however, find evidence of laterality of perirhinal or hippocampal electrophysiological responses predictive of subsequent memory, which may have resulted from reorganization of function to contralateral medial temporal lobe structures secondary to unilateral sclerosis.

The observation of a primacy effect in our behavioral data, in the face of absent primacy in patients with medial temporal damage performing the same task (Fernandez et al., 1999), motivated an analysis of neuronal responses predictive of subsequent memory for initial words in each list. The analysis demonstrated right anterior hippocampal, bilateral parahippocampal, and pos-

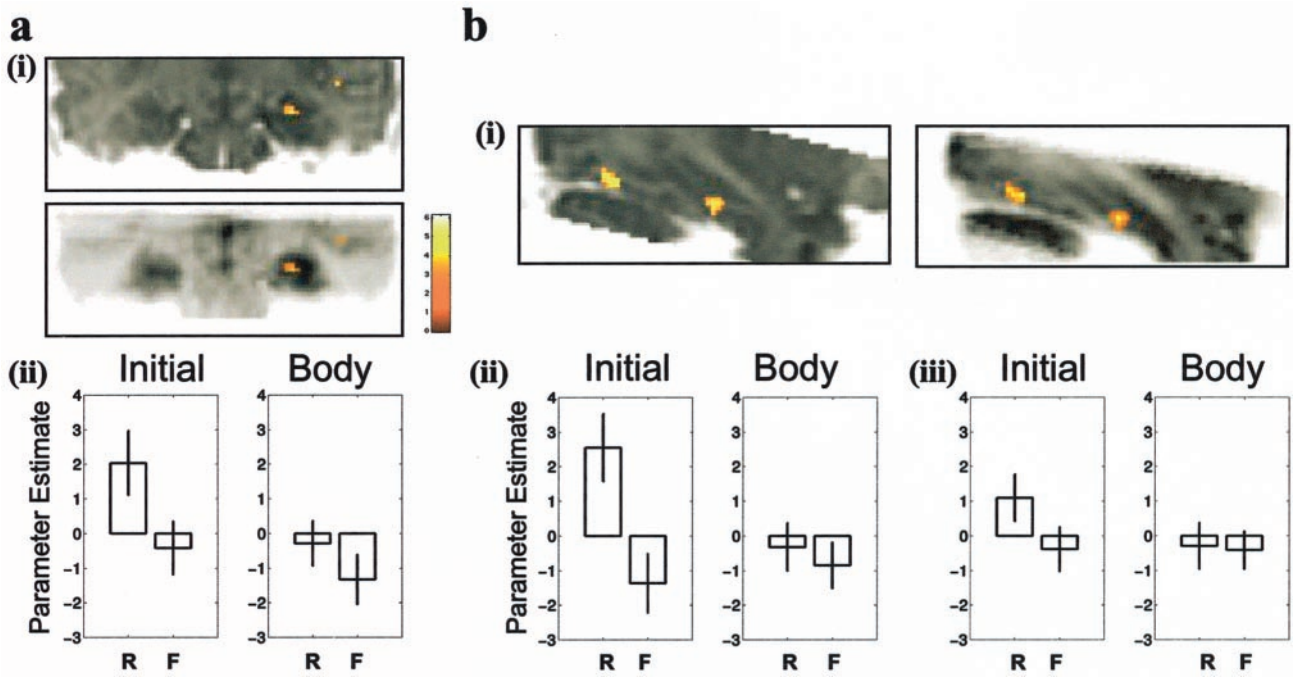

Figure 3. Neuronal correlates of the primacy effect. *a,* A significant interaction between subsequent memory and list position (initial versus body) was observed in right anterior hippocampus (28, −16, −22; $Z = 3.09$; $p < 0.001$). *ai,* The SPM (threshold $p < 0.01$) is superimposed on a coronal section ($y = -16$) of the mean functional from a single subject (*top panel*) and the average functional image from the 14 subjects (*bottom panel*). *aii,* Parameter estimates (± 1 SE) for the height of the hemodynamic response in right anterior hippocampus for remembered (*R*) and forgotten (*F*) words in the initial and list body positions. *b,* Posterior fusiform and parahippocampal activation predicts subsequent memory for initial words only. *bi,* The SPM ($p < 0.01$) is superimposed on a sagittal section ($x = 36$) of the mean functional from a single subject (*left*) and the average functional image from the 14 subjects (*right*) to demonstrate right posterior fusiform (38, −68, −14; $Z = 3.91$; $p < 0.001$) and right parahippocampal (36, −24, −24; $Z = 3.25$; $p < 0.001$) activation. A significant interaction was also observed in left posterior fusiform cortex (−42, −58, −12; $Z = 3.79$; $p < 0.001$) and left parahippocampal gyrus (−32, −26, −22; $Z = 3.04$; $p < 0.005$). Parameter estimates for responses in right posterior fusiform (*bii*) and right parahippocampal gyrus (*biii*) are plotted below.

terior fusiform activation that predicted subsequent memory for the initial two words of each list but not for later presented words. The fact that anterior hippocampal primacy activation was right lateralized may reflect sensitivity to the visual characteristics of situationally novel items. Critically, left perirhinal and hippocampal body activation, predictive of subsequent memory for words in the list body, did not show further enhancement for remembered initial words. Hence, successful encoding of initial words engaged regions additional to those demonstrated for the list body.

The primacy effect has been attributed to greater rehearsal of initial items (Rundus, 1971) or, alternatively, to enhanced encoding of initial items because of their relative distinctiveness (Murdoch, 1960). Neuroimaging studies have demonstrated responses in anterior hippocampus (Tulving et al., 1996; Strange et al., 1999; Strange and Dolan, 2001), parahippocampal gyrus (Stern et al., 1996; Gabrieli et al., 1997), and posterior fusiform cortex (Schacter and Buckner, 1998; Strange et al., 2000) to contextually novel or distinctive stimuli. In addition, intracranial recordings demonstrate that focusing attention on words evokes focal field potentials in posterior fusiform cortex (Nobre et al., 1998) and that rare target and distractor stimuli evoke parahippocampal and fusiform responses thought to reflect orienting (Halgren et al., 1995). The finding that regions where activity predicted subsequent memory for initial words are the same as those implicated in the processing of novelty and distinctiveness suggests that primacy effects reflect distinctiveness in addition to any benefit from greater rehearsal.

Previous fMRI studies have demonstrated fusiform and parahippocampal encoding responses predictive of subsequent memory (Brewer et al., 1998; Wagner et al., 1998; Kirchoff et al., 2000). These responses were recorded, however, in the context of long stimulus lists, precluding the possibility that these activations were specifically caused by primacy. Interestingly, the previous studies of subsequent memory that demonstrate parahippocampal and fusiform activation have included either a long (13 sec) interstimulus interval (Brewer et al., 1998) or null events, during which a fixation cross is presented instead of a stimulus (Wagner et al., 1998; Kirchoff et al., 2000). A stimulus after a long or unpredictable stimulus onset asynchrony could be defined, in principle, as situationally novel, capable of evoking an orienting response. Fusiform and parahippocampal responses mediating successful encoding may consequently reflect attentional orienting, either to situationally distinctive stimuli, as suggested by the current data, or to an item within a long list rendered distinctive by virtue of its temporal unpredictability. It should also be noted that previous studies of subsequent memory used incidental encoding strategies (Brewer et al., 1998; Wagner et al., 1998; Kirchoff et al., 2000), whereas in the current study, subjects deliberately engaged in episodic encoding. This could have contributed to the differences in activations observed between this and previous studies.

The current scanning parameters enabled an investigation of human perirhinal responses without the limitation of decreased sensitivity to hemodynamic responses in anterior medial temporal lobe. Distinct patterns of responses for subsequently remembered compared with forgotten items means that fMRI tech-

niques can now be used to address the precise functional role of this region in human memory. The data suggest that the role of perirhinal cortex in episodic encoding can be dissociated from that of other medial temporal structures. Responses in perirhinal cortex predict subsequent memory for all list words, whereas parahippocampal and anterior hippocampal roles in successful encoding may be limited to items that, for one reason or another, are treated as distinctive.

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