Rapid Communication

Understanding metamemory: Neural correlates of the cognitive process and subjective level of confidence in recognition memory

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An essential feature of human memory is the capacity to assess confidence in one's own memory performance, but the neural mechanisms underlying the process of determining confidence in memory performance have not yet been isolated. Using functional magnetic resonance imaging, we examined both the process of confidence assessment and the subjective level of high or low confidence expressed during this process. The comparison of confidence assessment to recognition showed greater relative activation during confidence assessment in medial and lateral parietal regions, which typically deactivate during cognitive tasks, previously described as part of the "default network". Furthermore, comparisons of high versus low confidence judgments revealed modulation of neural activity in the hippocampus, cingulate and other limbic regions, previously described as the Circuit of Papez. Our findings suggest that activity in two distinct networks of brain regions contribute to the subjective experience of "knowing you know" through memory monitoring processes and signaling subjective confidence level for recognition memory.
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Introduction

The ability to accurately evaluate one's own memory performance is a critical feature of normal memory function. Confidence judgments are one commonly used method for determining an individual's belief that the information retrieved from memory is accurate. The degree of confidence that an individual expresses in a memory plays a critical role in how an outsider evaluates the verity of that memory (Wells et al., 2002). Furthermore, functional magnetic resonance imaging (fMRI) studies of encoding (Kirchhoff et al., 2000; Sperling et al., 2003; Wagner et al., 1998) and retrieval (Eldridge et al., 2000; Henson et al., 1999a, 2000) have used a combination of subjective confidence and objective accuracy to define successful memory. Despite the common use of subjective confidence judgments, surprisingly, little is known about the neural mechanisms underlying confidence assessment and other metamemory processes engaged in "knowing you know."

Confidence judgments involve both the cognitive process of confidence assessment and the subjective feeling of confidence. One common use of confidence judgments in studies of recognition memory assumes that it reflects memory strength, especially in studies that use signal detection theory and receiver-operating characteristics (ROC) (Yonelinas, 1994). However, the use of confidence ratings in these procedures has been questioned on a theoretical level because it assumes that the classifier maintains an ordered set of criteria, which may not be the case (Malmberg, 2002). Moreover, laboratory manipulations have shown behavioral dissociations between confidence and accuracy (Brewer et al., 2002; Busey et al., 2000; Shaw and Zerr, 2003), suggesting that they may not be based on entirely the same information. In addition to the strength of the memory trace, it has been hypothesized that confidence ratings also may rely on ease of retrieval, retrieval fluency, ease of processing the retrieval cue, and also heuristics about the study and test conditions and heuristics about a subject's own memory (Busey et al., 2000). Some or all of these factors may contribute to the subjective *level* of confidence that a subject experiences for a given memory, and thus, high and low confidence decisions might differ on these dimensions. Furthermore, the cognitive processes underlying confidence assessment requires subjects to introspectively consider these factors. Thus, confidence

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in recognition memory may be based on factors other than memory strength and may differ from simple recognition tasks.

Although research to date has not isolated the cognitive process of confidence assessment from the subjective feeling of confidence, several studies have investigated other subjective aspects of memory. Using a procedure in which subjects indicated during retrieval whether they specifically recollect an item ("remember") or whether it just seems familiar ("know"), greater activity for correct "remember" trials compared to correct "know" trials has been shown in left prefrontal, left lateral parietal, and posterior cingulate regions (Eldridge et al., 2000; Henson et al., 1999a), and also in the medial temporal lobe (MTL) (Eldridge et al., 2000). In contrast, the right prefrontal cortex and anterior cingulate showed greater activity for correct "know" compared to correct "remember" trials (Eldridge et al., 2000; Henson et al., 1999a). Using confidence judgments, Henson et al. (2000) showed greater activity in the right prefrontal cortex for low confidence correct trials compared with high confidence correct trials. Another recent study examined recollection and familiarity using confidence ratings and showed that anterior prefrontal, medial, and lateral parietal regions modulated based on familiarity confidence, and that medial prefrontal, medial parietal, and medial temporal regions distinguished recollection and familiarity (Yonelinas et al., 2005). These studies reported neural differences based on subjective aspects of memory, but the paradigms that were used did not allow a distinction between the processes involved in subjective assessment of one's own memory on the one hand, and retrieval processes on the other because, in these studies, the subject's behavioral response included both subjective and objective aspects of memory. Further work that isolates the different contributions of memory monitoring and subjective experience of memory is needed in order to better elucidate the contributing mechanisms to "knowing you know".

In this study, we report the specific neural mechanisms supporting confidence assessment as distinct from recognition judgments, and the neural correlates of high and low confidence,

respectively. We used a well-characterized face–name associative paradigm, for which we have previously reported two findings during encoding related to *subsequent* subjective confidence level (Chua et al., 2004; Sperling et al., 2003). We undertook the present study to examine the neural correlates of confidence in recognition memory during recognition and confidence assessment. We scanned during encoding, recognition, and a post-recognition confidence assessment task. This design allows us to investigate the pattern of activation associated with the underlying cognitive *processes* of confidence assessment as compared with those underlying recognition. We also investigated the neural mechanisms associated with the subjective *level* confidence by comparing activation during high versus low confidence trials.

Materials and methods

Subjects

Twenty right-handed, healthy young subjects (ages 20–33, 10 F/ 10 M) participated in this study. All subjects were free from psychiatric and neurologic illness, and none were taking medications with known central nervous system effects. All subjects were screened for contraindications to MRI. Each subject provided written informed consent in a manner approved by the Human Research Committee at Massachusetts General Hospital, Boston, MA.

For two of the 20 subjects, only partial data were collected due to time constraints and scanner malfunction. For one subject, 9 out of 10 runs were collected, and for the other subject, 5 out of 10 runs were collected.

Cognitive Task

In a mixed event-related/block design, subjects were scanned during encoding, recognition, and post-recognition confidence
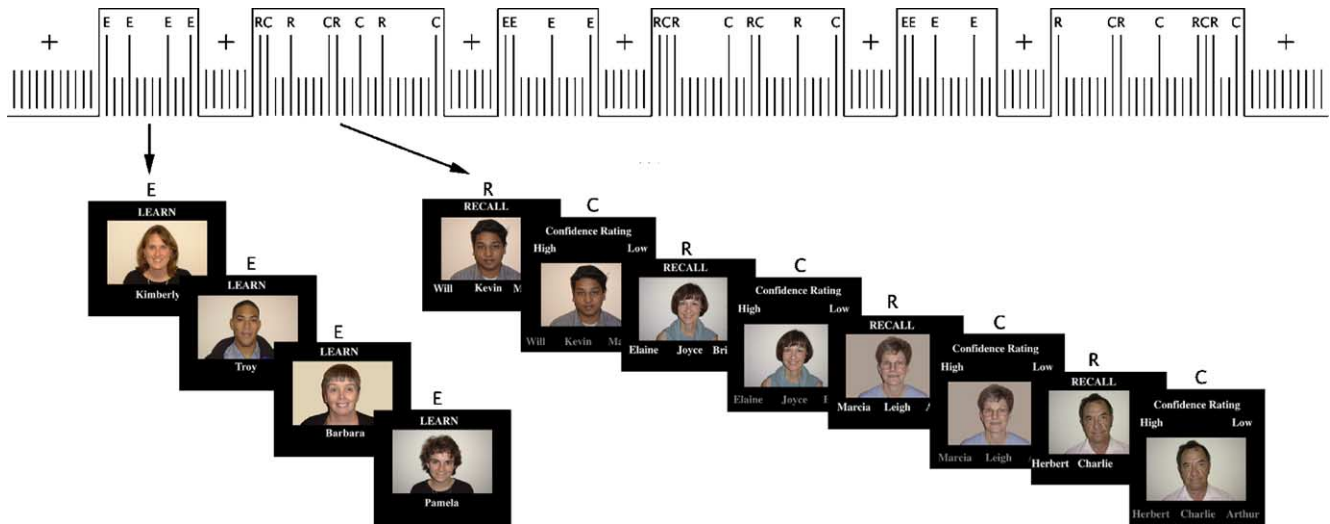

Fig. 1. Schematic of the face–name associative paradigm used to study confidence in recognition memory. Stimuli were presented in a mixed block/event-related design with each run consisting of 3 encoding (ENC) blocks, 3 recognition/confidence assessment blocks (REC/CONF), and alternating blocks of visual fixation. Each large tick mark represents a single presentation of a 3.5-s face–name stimulus followed by 0.5 s of fixation. Each smaller tick mark represents 1 s of visual fixation. In each encoding block, subjects viewed four novel face–name pairs (E) with intermixed fixation trials. In each recognition/confidence assessment block, subjects viewed four faces that were encoded approximately 5 min earlier in the previous run. In the recognition task (R), subjects chose the correct name among three names. Then, after a varying inter-stimulus interval, in the confidence assessment task (C), subjects indicated whether they had high or low confidence that they chose the correct name.

assessment tasks using a face–name associative memory paradigm (Fig. 1). Encoding stimuli consisted of digital photographs of unfamiliar faces paired with a fictional first name. Each face was presented against a black background with the name printed in white underneath. Recognition stimuli consisted of each face seen during encoding with three names presented underneath the face (1 correct, 2 incorrect). One of the distracter names was previously paired with a different face to ensure that the decision about the correct name was not based solely on familiarity of the name. The other distracter name was a new name that had not been presented during encoding. Following recognition, subjects viewed confidence judgment stimuli. These were similar to the recognition stimuli, but the names were presented in grey and above the face with the words "high" and "low" printed in white below the face. The name choices were presented to avoid working memory components that could be associated with holding the name choices online. Printed in white above each stimulus were words that instructed the subject to "learn" the name and the face during the encoding trials, to try to "recall" the name associated with the face during recognition and to make a "confidence rating" during the assessment task. Each encoding block consisted of 4 encoding stimuli, and each retrieval block consisted of 4 recognition stimuli and 4 confidence assessment stimuli. The encoding block lasted 24 s, and the recognition/confidence assessment block lasted 48 s. Fixation blocks were very short to maximize scanner time and lasted only 6 s and were mainly included to allow time for task switching. Prior to each block, subjects viewed instructions that specified whether the block was an encoding or retrieval block and the specific task instructions. For encoding stimuli, subjects were instructed to try to remember the name associated with the face and to make a purely subjective decision about whether or not the name "fit" the face to aid in the associative memory process. Subjects indicated with a button press if "yes" they thought the name fit the face, "no" the name did not fit the face, or "don't know" if they were unsure if the name fit the face. This task was chosen because it requires subjects to attend to both the name and the face and therefore aids in the associative memory process. Although this task could lead subjects to focus on specific facial features, it would still require the formation of an association. For the recognition task, subjects indicated whether the name they were asked to learn earlier was presented on the "left", "middle", or "right". For the confidence assessment task, subjects indicated with a button press whether they had "high" or "low" confidence that they had chosen the correct name.

Subjects viewed 120 stimuli for each task across 10 runs that each lasted 4 min and 24 s. Each recognition/confidence block occurred in the subsequent run to the corresponding encoding blocks, approximately 5 min later. Prior to functional image acquisition, subjects were given a "practice run" in which they encoded faces that were retrieved in the first run. Stimuli were presented for 3.5 s each and were randomly intermixed with brief periods of visual fixation (white cross-presented on a black background). Each stimulus was followed by 0.5 s of fixation, which was then followed by periods of visual fixation ranging from 0 to 6 s. Fixation trials were intermixed with stimuli using a jittered design and optimized using OptSeq (http://surfer.nmr.mgh.harvard.edu). This was done for stimuli within each block rather than for the whole run. Because of the design constraint that confidence assessment stimuli followed recognition stimuli, the recognition/confidence assessment block was optimized for separating the recognition and confidence assessment trials, and the optimized

sequence was determined as if there was one stimulus type. Thus, after each recognition trial, there was a varying period of fixation before the confidence assessment trial. Stimuli were presented using MacStim 2.5 on a Macintosh G3 computer and viewed using a rear projection system.

Functional imaging

The fMRI data were collected on a Siemens 3 T Trio scanner (Siemens Medical Systems, Iselin, NJ) with a 3-axis gradient head coil using a gradient-echo echo-planar pulse sequence (TR = 2000 ms, TE = 30 ms, Flip Angle = 90, 28 oblique coronal slices perpendicular to the anterior commissure–posterior commissure line, 5 mm slices, skip 1 mm). Each functional run consisted of 132 time points and lasted 4 min and 24 s.

Data analysis

The results from the cognitive task were analyzed using Microsoft Excel and SPSS. Response types were categorized as High Confidence Correct (HC-Correct), High Confidence Incorrect (HC-Incorrect), Low Confidence Correct (LC-Correct), and Low Confidence Incorrect (LC-Incorrect) for the two tasks of interest, recognition (REC), and confidence assessment (CONF). Thus, there were four behavioral response types for each of the two decisions of interest, and also for encoding, resulting in 12 conditions of interest for each subject. Some subjects had trials in which they did not respond, which was included as a separate "junk" condition, which was modeled but not analyzed further. A minimum of 3 trials per condition were modeled. Additionally, the encoding trials from the tenth run comprised an additional condition that was modeled but not analyzed further, since subjects did not perform recognition or confidence rating tasks on these trials. Repeated measures ANOVAs and two-tailed paired t tests comparing the number of trials per condition and the reaction times for each condition were performed in SPSS.

The fMRI data were preprocessed and analyzed using SPM99 (Wellcome Department on Cognitive Neurology) for Matlab (Mathworks, Inc.). Images were motion corrected using sinc interpolation. The data were then spatially normalized to an EPI template based on the MNI1305 stereotactic space and then spatially smoothed using an 8-mm full width half maximum isotropic Gaussian kernel. Data were analyzed according to a random effects general linear model in SPM. First, data were analyzed at the subject-level, with all runs concatenated and treated as a single time series and modeled with the canonical hemodynamic response function only. Even though the paradigm was a mixed block and event-related design, data were only analyzed as event-related because we were primarily interested in the confidence assessment task, and this was combined in a block with recognition. The results from the encoding portion of this study will be reported in a subsequent manuscript. In order to eliminate low frequency noise, data were analyzed using a high pass filter of 140 s. Each model for a single subject included regressors for each run because the runs had been concatenated in time. At the second step, data were averaged together treating each subject as a random effect.

Whole-brain statistical maps were thresholded at $P < 0.001$ (uncorrected at the voxel level) and considered significant at $P < 0.05$ corrected for multiple comparisons at the cluster level, unless otherwise noted. As a prelude to our main comparisons of interest, we contrasted REC > Fixation, and CONF > Fixation in order to serve as a basis for our higher level comparisons. We then

compared all recognition and all confidence trials collapsed across behavioral responses. However, our main comparison of interest for examining differential brain activity between tasks held behavioral response constant and compared REC HC-Correct versus CONF HC-Correct. We confined these analyses to HC-Correct responses because (1) the vast majority of responses were HC-Correct, yielding the most power to detect differences between processes, while holding behavioral response constant, (2) these trials were less likely to be contaminated by further attempts at memory retrieval after a failed recognition, (3) previous studies have primarily utilized HC-Correct of similar conditions to define "successful memory", and (4) we were primarily interested in understanding the neural mechanisms supporting the subjective experience of "knowing you know". Thus, the REC HC-Correct versus CONF HC-Correct contrasts, in both directions, are the cleanest comparison in this study that demonstrate the brain regions that show different neural activity during the cognitive processes underlying recognition and confidence assessment.

Our second set of contrasts of interest examined the neural correlates of the subjective level of confidence. Thus, we examined the main effect of confidence by comparing All HC versus All LC ("HC-Correct + HC-Incorrect" to "LC-Correct + LC-Incorrect"). We did this comparison for both the recognition and confidence assessment processes.

We also generated contrasts that held accuracy constant and compared HC-Correct to LC-Correct and HC-Incorrect to LC-Incorrect, which were especially important given the relatively fewer number of incorrect trials. We then used a masking approach (Cabeza et al., 2002) to determine which voxels were active in both of these contrasts. Masks for the appropriate contrasts were multiplied together, yielding a new mask that contained voxels that were active for each contrast at $P < 0.001$ with a 20-voxel extent threshold.

Percent signal modulation for functionally defined regions of interest (ROI) was determined using the SPM ROI toolbox (http://spm-toolbox.sourceforge.net). ROIs were defined by including all significant voxels within a 6-mm radius of a peak voxel from a contrast of interest and from the "conjunction" analyses (Cabeza et al., 2002). Graphs were generated using Microsoft Excel. Statistical significance for these ROIs was based on contrasts in SPM99 and was used to illustrate the direction of change in the MR response.

Results

Behavioral results

During the recognition/confidence phase, subjects correctly chose the name identified with the face with high confidence (HC-Correct) for $65.9 \pm 13.9\%$ of the trials, and each subject performed above the chance rate of 33%. For the face–name pairs on the recognition test, the majority of responses were HC-Correct (78 ± 20 trials), with fewer HC-Incorrect (6 ± 4), LC-Correct (14 ± 9), and LC-Incorrect (16 ± 9) response types.

During recognition, a repeated measures 2×2 factorial ANOVA revealed significant main effects of both confidence and accuracy for reaction time. High confidence responses (HC-Correct: 2.08 ± 0.23 s; HC-Incorrect: 2.28 ± 0.38 s) were made faster than low confidence responses (LC-Correct: 2.75 ± 0.33 s; LC-Incorrect: 2.82 ± 0.34 s) ($F(1,19) = 100.9$, $P < 0.00001$), and correct responses

were made faster than incorrect responses ($F(1,19) = 11.3$, $P < 0.003$). There was no significant interaction for reaction time between confidence and accuracy. During confidence assessment, subjects made the high confidence decisions (HC-Correct: 0.88 ± 0.20 s; HC-Incorrect: 0.95 ± 0.31 s) faster than the low confidence decisions (LC-Correct: 1.11 ± 0.35 s; LC-Incorrect: 1.10 ± 0.34 s) ($F(1,19) = 10.3$, $P < 0.005$), but there were no significant main effects of accuracy or significant interaction effects for reaction time.

Distinct neural network involved in memory monitoring

We were interested in comparing Recognition (REC), and Confidence Assessment (CONF). We first compared each task to visual fixation in order to form a basis for our direct comparisons of REC to CONF. Comparisons of REC and CONF to fixation all showed significant activation in bilateral prefrontal, thalamic, cingulate, posterior MTL, posterior parietal, and fusiform cortices ($P < 0.001$ voxel level, $P < 0.05$ corrected at the cluster level). Activation in the prefrontal cortex included anterior, dorsolateral, and posterior regions of the inferior frontal gyrus bilaterally but showed a greater extent of activation in the left hemisphere. During CONF, there was also activation in bilateral orbitofrontal regions.

We then directly compared the recognition and confidence assessment tasks collapsed across behavioral responses (All REC versus All CONF) to determine which regions showed the most consistent differences between the two tasks. All REC > All CONF showed greater activity in the left and right cuneus (BA 30) and also in the midbrain. All CONF > All REC showed greater activity in the bilateral lateral parietal (BA 40), insula (BA 13), superior frontal (BA 10/9), dorsal medial prefrontal (BA 9), and right orbitofrontal (BA 47) regions. MR Signal timecourses revealed that these differences were often driven by both signal increases above baseline for CONF and decreases below baseline during REC.

In order to examine the specific neural correlates of the process of confidence assessment, we held that behavioral response constant and compared REC HC-Correct > CONF-HC-Correct (Table 1), which showed activation in dorsal anterior cingulate and right fusiform cortices (Fig. 2). MR signal timecourses revealed that the differences in relative activation for REC HC-Correct > CONF HC-Correct were driven by larger *increases* in MR signal during recognition and smaller increases above baseline or signal close to baseline during confidence assessment. CONF HC-Correct > REC HC-Correct showed activation in right orbito-

Table 1
Peak MNI coordinates showing significant differences ($P < 0.001$ voxel level, $P < 0.05$ corrected at the cluster level) during recognition and confidence assessment for high confidence correct responses

| Region	BA	x	y	z	Z score	Extent
Recognition > Confidence assessment						
Left cingulate gyrus	32/24	−6	27	36	4.29	170
Right fusiform gyrus	36	45	−54	−27	4.57	98
Confidence assessment > Recognition						
Right superior frontal gyrus	10	27	63	−6	4.72	69
Left inferior parietal lobule	40	−60	−45	27	4.30	175
Right and left precuneus	31	15	−51	30	4.26	480
Left lingual gyrus	18	−12	−81	−12	4.22	217
Right inferior parietal lobule	40	51	−42	24	4.07	286
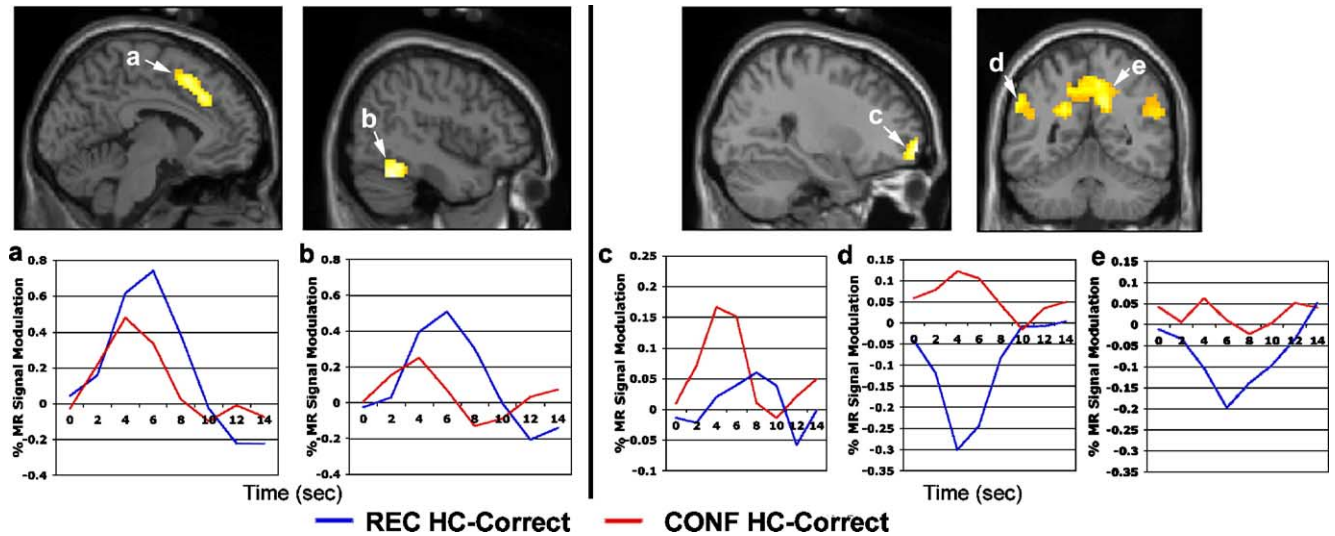
Fig. 2. Regions showing differential activation during the processes of recognition and confidence assessment. Whole-brain analyses in SPM99 showed greater activation during recognition than confidence assessment for high confidence correct responses in anterior cingulate (a) and fusiform (b) regions. Extracted MR signal timecourses during recognition and confidence assessment show that these differences were driven by increases in MR signal. Several regions showed the opposite pattern with greater activation during confidence assessment than recognition, including orbitofrontal (c), lateral parietal (d), and medial parietal (e) regions. Extracted MR signal timecourses revealed that the differences in the parietal regions were typically driven by decreases during recognition (d, e) and sometimes also by small increases during confidence assessment (d).

frontal, bilateral lateral parietal, precuneus/posterior cingulate, and left extrastriate cortices. MR signal timecourses showed that the differences in CONF HC-Correct > REC HC-Correct were often driven by a *decrease* during recognition (Figs. 2d, e) and a small *increase* during confidence judgments (Fig. 2d).

Because the statistical maps differed for All CONF > All REC and CONF HC-Correct > HC-Correct, we conducted exploratory analyses at a threshold of $P < 0.05$ for each contrast. At this lowered threshold, the posterior cingulate showed differential

activity for All CONF > REC. Similarly, CONF HC-Correct > REC HC-Correct showed map-wise differences at this decreased threshold in superior frontal, dorsal medial prefrontal, and insular regions.

Functional neuroanatomy underlying subjective confidence level

After examining the *process* component of confidence assessment, we next examined the neural correlates of the subjective
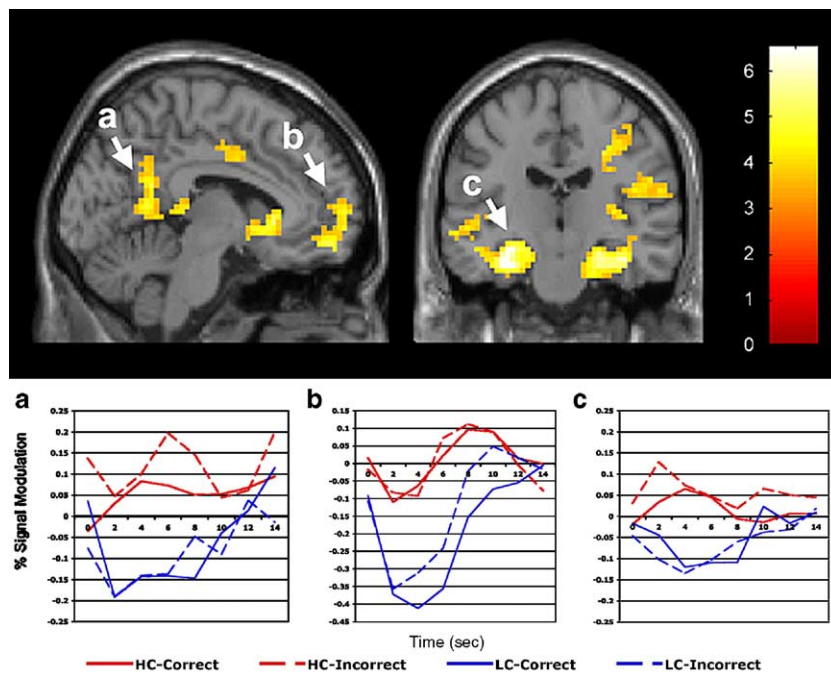

Fig. 3. Regions showing significant differences for high and low confidence trials during confidence assessment for both correct and incorrect responses. These regions included anterior and posterior cingulate (a), medial prefrontal (b), and the MTL (c). The extracted MR signal timecourses show that the significant differences were typically driven by small increases in signal during high confidence responses and decreases in signal during low confidence responses.

Table 2
Regions showing significant differences (presented in MNI coordinates; $P < 0.001$ voxel level, $P < 0.05$ corrected at the cluster level) during confidence assessment between high and low confidence responses

Region	CONF HC>CONF LC					CONF HC-Correct>CONF LC-Correct					CONF HC-Incorrect>CONF LC-Incorrect				
	x	y	z	Z score	Extent	x	y	z	Z score	Extent	x	y	z	Z score	Extent
Left medial temporal lobe	−30	−21	−18	5.37	406	−30	−39	−15	4.60	271	−24	−24	−21	3.97	91
Right medial temporal lobe	27	−9	−21	4.94	978	36	−30	−18	5.22	365	27	−12	−24	4.01	32
Right paracentral lobule	18	−42	54	4.57	113										
Right insula	36	−12	18	4.49	289	36	−12	15	3.86	123					
Right posterior cingulate	6	−57	21	4.45	333	6	−54	24	3.72	64					
Left medial frontal gyrus	−3	63	6	4.36	630	−3	57	−12	4.92	430					
Left middle temporal gyrus	−48	−66	12	4.15	111	−48	−69	21	4.41	53					
Left inferior frontal gyrus	−51	−6	15	4.01	163										
Right middle temporal gyrus	60	−3	−15	4.01	69	39	−57	12	4.04	136	45	−54	−3	3.97	111
Right precentral gyrus	33	−15	45	3.94	120										
Left cingulate gyrus	−3	3	39	3.52	76										
Right postcentral gyrus						27	−39	63	4.66	192					
Left caudate											−9	21	6	3.98	99
Right caudate											18	33	6	4.24	59

level of high (HC) versus low confidence (LC) during confidence assessment. The contrast HC>LC showed significant differences in several limbic regions, including the MTL, anterior and posterior cingulate, and medial prefrontal regions (Fig. 3). Activation in the MTL was quite extensive, including both anterior and posterior hippocampal and parahippocampal regions, and extended anteriorly past the amygdala–hippocampus border. Extracted MR signal timecourses revealed that the differences in activation were primarily driven by *decreases* in MR signal during LC with *increases* during HC (Fig. 3). The contrast LC>HC revealed no significant differences.

We then examined effects of high and low confidence levels during the process of confidence assessment while holding accuracy constant and compared HC-Correct versus LC-Correct and HC-Incorrect versus LC-Incorrect (Table 2) because the HC>LC results could have been driven by the relatively larger number of HC-Correct responses. The HC-Correct>LC-Correct contrast showed greater activation in many of the same regions, with greater activation in MTL, ventromedial prefrontal, superior parietal, lateral tempo-parietal, insula, and posterior cingulate regions. No regions showed significantly greater MR signal for LC-Correct>HC-Correct responses. Even with decreased power
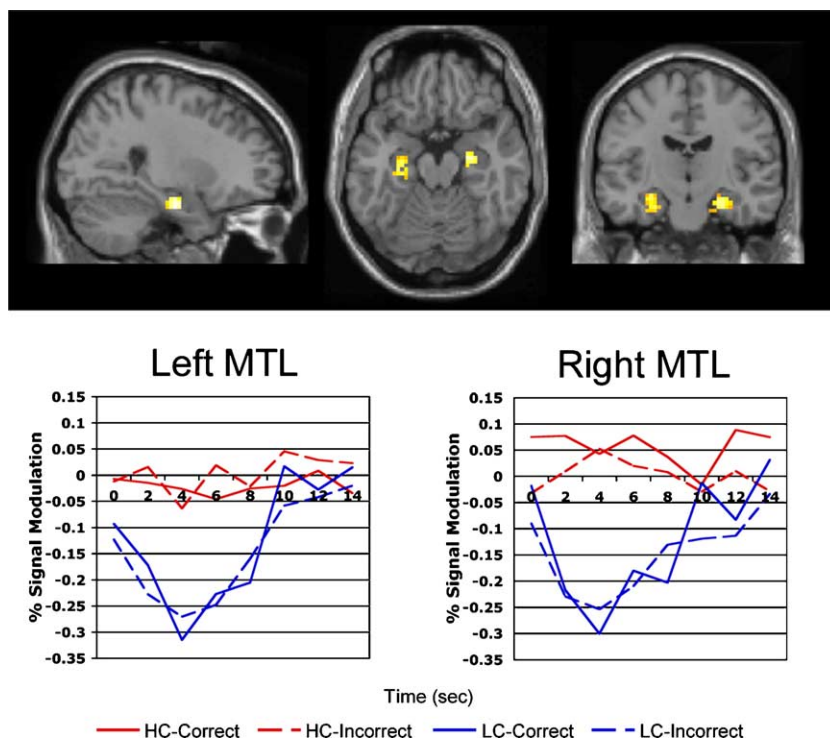

Fig. 4. The MTL was the only region that showed significant differences for both the HC-Correct>LC-Correct and HC-Incorrect>LC-Incorrect contrasts and is shown on a coronal slice (left: −24, −24, −21; right: 27, −12, −24). The extracted MR signal timecourses show that both LC-Correct and LC-Incorrect responses show similar decreases relative to both baseline and to HC-Correct and HC-Incorrect responses.
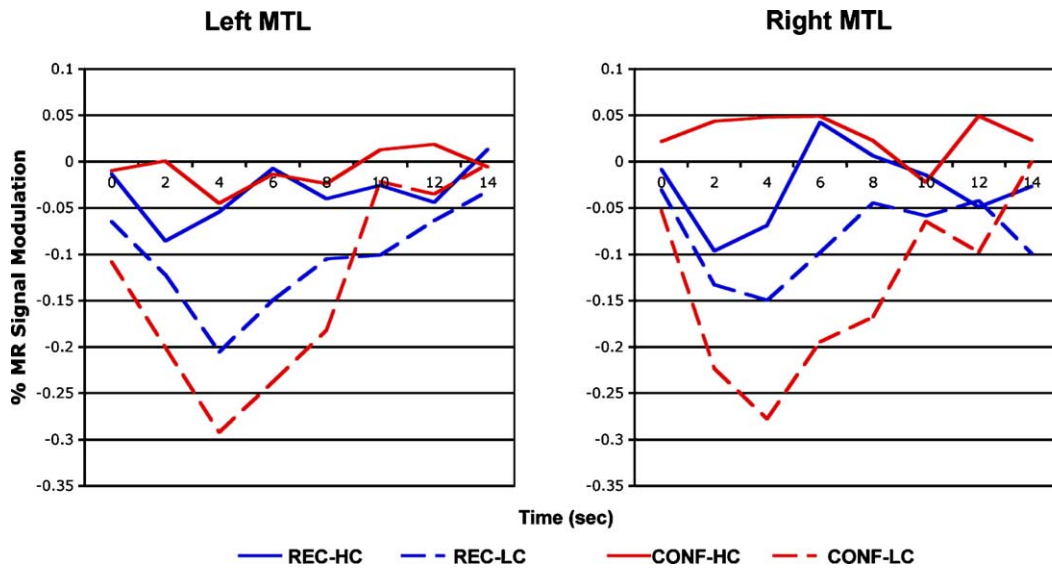
Left MTL   **Right MTL**

Fig. 5. The MR signal timecourses in the left MTL (−24, −24, −21) and right MTL (27, −12, −24) during recognition, and confidence assessment for high and low confidence trials. For high confidence trials (solid lines), the MR signal is similar to baseline during recognition (blue) and confidence assessment (red). For low confidence trials (dotted lines), the MR signal showed signal decreases during recognition (blue) and confidence assessment (red).

because of few trials, the HC-Incorrect>LC-Incorrect contrast showed greater activation in bilateral MTL and caudate regions, and in a right middle temporal region. No regions showed significantly greater activation for LC-Incorrect>HC-Incorrect responses. We then used a masking approach (Cabeza et al., 2002) and showed that the bilateral MTL were the only regions significantly active in both contrasts. This activation was centered in the hippocampus proper (left: −24, −24, −21; right: 27, −12, −24). Extracted MR signal timecourses revealed that these differences were driven by decreases during low confidence responses (Fig. 4).

We extracted the MR signal timecourses for HC and LC responses for REC and CONF in the MTL ROI (Fig. 5). The MR signal in the MTL was similar to baseline for HC responses during REC and CONF but showed large deactivations for LC during CONF and smaller deactivations for LC during REC.

In order to separate trials in this event-related design, we used variable inter-stimulus intervals (ISI) between trials. This design constraint, coupled with the consistent sequence of the recognition trial followed by confidence assessment trial, brings up the possibility that subjects may have assessed their confidence during the post-recognition fixation period. This would be most likely if, by chance, all of the high confidence responses occurred after longer periods of fixation. However, repeated measures ANOVA showed no significant differences in fixation length between recognition and confidence judgment trials ($F(3,57)=1.96$, $P<0.147$). Furthermore, this possibility seems unlikely because the reaction time data indicate differences between high and low confidence responses during confidence assessment.

Discussion

In this study, we isolated the neural mechanisms supporting two distinct components of confidence judgments: (1) the process of confidence assessment and (2) the subjective level of confidence expressed. We examined the *process* of confidence assessment by

comparing recognition trials to confidence assessment trials holding behavioral response constant, and we examined the *level* of confidence by comparing high to low confidence trials during confidence assessment. Medial and lateral parietal regions showed greater activation during confidence assessment compared to recognition, suggesting that these regions may play a specific role in the process of post-retrieval memory monitoring. By contrast, modulation in a network of limbic regions was based on high or low confidence in one's recognition decision, suggesting that activity in these regions reflects the subjective experience of recognition success or failure. Of particular interest, regions in the medial temporal lobe (MTL), which are known to be critical for objective memory functions, also demonstrated modulation based on confidence level for recognition memory.

The medial and lateral parietal regions that showed differential activation during confidence assessment and recognition are typically more active at baseline than in a wide variety of cognitive tasks (Gusnard and Raichle, 2001; Lustig et al., 2003; Mazoyer et al., 2001; Raichle et al., 2001; Shulman et al., 1997) and have also shown spontaneous correlated activity (Greicius et al., 2003, 2004). These regions have been categorized as part of the "default" network and are thought to be involved in cognitive functions that are carried out during a resting or baseline state, including self-referential processing, introspective mental activity, integration of emotional and cognitive processing, online monitoring, and gathering information about internal and external environments (Gusnard and Raichle, 2001; Raichle et al., 2001). In our study, confidence assessment, unlike recognition, showed no evidence of signal decreases but did show some evidence of signal increases, which suggests the possibility that the process of confidence assessment engages the hypothesized self-monitoring function of the "default" network.

Other studies have shown differential activation in parietal regions during memory retrieval, including tasks that use a combination of objective and subjective measures (Eldridge et al., 2000; Henson et al., 1999a, 2000), straightforward old–new decisions (Herron et al., 2004; Heun et al., 2004; Leube et al.,

2003; Velanova et al., 2003; Wheeler and Buckner, 2003), and false recognition (Heun et al., 2004; Kahn et al., 2004; Slotnick and Schacter, 2004; Wheeler and Buckner, 2003). Recent work has shown that there may be functionally distinct regions within the lateral parietal cortex. The parietal activations in our study are more similar in both location and pattern of MR signal to the more lateral and posterior regions of the lateral parietal cortex, which have been associated with increases during remember responses and decreases during other responses (Wheeler and Buckner, 2004), and our discussion of lateral parietal cortex refers to these specific subregions. Recent work has shown that these regions are specifically associated with retrieval or retrieval decisions (Shannon and Buckner, 2004). Maril et al. (2005) also showed greater activity in these regions during intermediate recall states, which may be related to increased memory monitoring demands. Recent work has also shown that anterior and posterior prefrontal and medial and lateral parietal regions modulated based on the level of familiarity confidence, and it has been hypothesized that these regions may be involved in either post-retrieval monitoring or executive control (Yonelinas et al., 2005). Our study, which directly examines the monitoring process separately, provides support for the hypothesis that activations in medial and lateral parietal subregions are related to memory monitoring by demonstrating greater activity in these regions during confidence assessment compared to recognition.

In addition to these lateral and medial parietal regions, a right orbitofrontal region also showed greater activation during confidence assessment compared to recognition, which was driven solely by differences in activation above baseline. The lateralization is consistent with previous work on retrieval monitoring from neuroimaging (Dobbins et al., 2004; Henson et al., 1999b, 2000; Mitchell et al., 2004) and neuropsychology (Schacter et al., 1996). In addition to monitoring, it has been suggested that right lateralized prefrontal activations are related to personal relevance (Schmitz et al., 2004). In the Yonelinas et al. (2005) study mentioned previously, a left anterior prefrontal region modulated based on familiarity using a word task, indicating this region might be involved in memory monitoring or other executive functions. Our findings suggest that the specific location of prefrontal activation may be related to the specific monitoring demands of confidence assessment, and that the lateralization is consistent with other monitoring tasks.

Our two comparisons of confidence assessment and recognition yielded slightly different statistical activation maps. These discrepancies may be related to power and effect size given that in both cases lowering the threshold to $P < 0.05$ shows similar statistical maps for the two comparisons. Alternatively, these regions may show an interaction effect between behavioral response and task, including the possibility of the posterior cingulate being preferentially involved in correct high confidence judgments, but we cannot directly test this given the differences in power among the different behavioral response types.

Several design constraints in this study must be acknowledged. Recognition trials were invariably followed by confidence assessment trials, thus the experienced subject may have begun or completed confidence assessment before the stimulus onset. In such cases, it is possible that the default-like activity revealed by this comparison reflects a return to the default state after completing the task. Future experiments that include trials for which subjects do and do not make confidence assessments after recognition will have to address this issue. Another possible

interpretation of the default activity is that the confidence assessment task was not cognitively demanding enough to disengage subjects from their default processing. This idea is plausible since the reaction times for recognition trials and confidence assessment trials were not matched, and the confidence assessment trials were indeed much shorter.

Further analyses showed that a different set of brain regions, including hippocampal, parahippocampal, amygdalar, thalamic, anterior and posterior cingulate, and medial prefrontal cortices, modulated based on subjective experience of high or low confidence *level*. A very similar set of regions was previously characterized as a "circuit" by Papez (1995) in 1937. This circuit, which specified a pathway from the hippocampal formation to the mamillary bodies then to the anterior nuclei of the thalamus to the cingulate gyrus, was originally proposed to be responsible for the subjective experience of emotion. In a recent study, comparisons of remembered items, which may be accompanied by the highest confidence, to high confidence old responses revealed a similar statistical map to our own comparison of high to low confidence responses (Yonelinas et al., 2005). Consistent with the hypothesis that these regions modulate based on confidence level, the medial parietal and medial prefrontal regions in the Yonelinas et al. (2005) study appeared to show a "U"-shaped curve with greater activity for high confidence old and high confidence new items compared to low confidence old and low confidence new items. Although the Yonelinas et al. (2005) study showed a different pattern in the hippocampus with a trend for activity to decline with increasing familiarity, our findings lead us to the interpretation that activation of this limbic circuit is related to subjective confidence level.

Several of the regions in this limbic circuit have been previously implicated in specific aspects of confidence assessment, such as memory and self-referential processing. Studies of autobiographical memory have demonstrated activation in a combination of MTL, medial prefrontal, and posterior cingulate/retrosplenial cortices (Cabeza et al., 2004; Maguire and Frith, 2003; Ryan et al., 2001). Medial prefrontal regions in particular have been related to personal episodic memory (Levine et al., 2004). Furthermore, other studies that involve self-referential processing but do not clearly invoke episodic retrieval also report medial prefrontal involvement (Gusnard et al., 2001; S.C. Johnson et al., 2002; Kelley et al., 2002), and this region is hypothesized to be involved in representations of the self (Frith and Frith, 1999). A similar medial prefrontal region has also been shown to be involved in a different memory monitoring task using fMRI (Schnyer et al., 2005). The posterior cingulate, in contrast, is thought to be more involved integrating memory and emotion (Maddock, 1999).

The MTL is known to have a critical role in episodic memory (Squire, 1992). Traditional conceptions of MTL function have focused on its role in objective aspects of memory function, but our data suggest that the MTL also plays a role in subjective aspects of memory as well. It is possible that the relationship to confidence level appears because high confidence trials in our own study, regardless of their accuracy, may be associated with access to more retrieved features than low confidence trials, which would be consistent with fMRI reports of MTL activation associated with recollection (Eldridge et al., 2000; Yonelinas et al., 2005). However, recent studies have demonstrated that specific regions in the MTL, such as the parahippocampal cortex, may contribute to confidence through retrieval content, other regions, such as the amygdala, may contribute to confidence independent of retrieved

content (Kensinger and Schacter, 2005; Sharot et al., 2004). Our data specifically suggest that signal decreases in the MTL may be related to a subjective feeling of doubt in one's own memory regardless of accuracy. It should be noted that *signal decreases* below baseline may be an accurate description only for tasks using a passive baseline, as it has been shown that tasks using active and passive baseline tasks can show the opposite sign (Stark and Squire, 2001). However, what is most important is the observed difference in MTL activity between high and low confidence responses for both correct and incorrect responses, which indicates that the MTL plays a role in subjective aspects of memory.

Our findings related to the confidence level expressed must be interpreted with some caution. There were relatively few HC-Incorrect, LC-Correct, and LC-Incorrect trials, thus making it difficult to make strong conclusions about high confidence trials overall compared to low confidence trials. Despite low power to detect effects, we did observe very significant differences in the MTL. Furthermore, the extracted MR signal timecourses display similarities grouped by confidence for both correct and incorrect responses. A second issue is that high confidence responses were faster than low confidence responses during both recognition and confidence assessment. We believe that these reaction time differences are correlated to confidence level and likely reflect meaningful differences related to certainty or doubt for high and low confidence responses.

In this study, we have reported two confidence-related patterns of activation: one related to the *process* of confidence assessment and one to subjective confidence *level*. Anatomic and functional connections between the limbic and frontal and parietal regions are necessary to support the integration of these two aspects of confidence in recognition memory. The MTL showed the strongest effect of subjective confidence level, and the MTL has been shown to have anatomical connections to lateral and medial parietal regions in monkeys (Lavenex et al., 2002; Meguro et al., 1999). Furthermore, fMRI analyses have suggested that the anterior and posterior cingulate, medial prefrontal, orbitofrontal cortex, inferior parietal, and parahippocampal cortices are functionally connected (Greicius et al., 2003). Thus, there is support that the two networks engaged in metamemory processes in our study have functional–anatomic connections in humans and likely interact.

Our findings may have interesting implications for patients with neurological disorders that affect both objective and subjective aspects of memory, such as Alzheimer's disease (AD) (Barrett et al., 2005; Sevush and Leve, 1993; Starkstein et al., 1997) and Korsakoff's syndrome (Shimamura and Squire, 1986), who often show lack of awareness of their own memory impairment, known as "memory anosognosia". Interestingly, the severity of memory impairment and the degree of anosognosia are sometimes dissociated (Gil et al., 2001; Schacter, 1991). Furthermore, AD patients have shown abnormalities on resting PET (Herholz et al., 2002; K. A. Johnson et al., 1998) and fMRI (Greicius et al., 2004; Lustig et al., 2003) studies in the lateral and medial parietal regions and in the posterior cingulate. Future research using a similar fMRI paradigm to assess the pattern of activation during confidence rating in AD patients will address the possibility that alterations in these regions underlie the metamemory disturbances commonly seen in AD.

In summary, this study demonstrates that modulation of activity within two previously described neural networks contribute to the subjective experience of "knowing you know." First, in isolating the process of confidence assessment from recognition, we showed evidence for specific neural processes related to memory monitor-ing in bilateral medial and lateral parietal regions, which have previously been implicated in self-monitoring. Second, we found that modulation of activity in a different network of brain regions was related to the confidence level expressed. This network of limbic regions has previously been hypothesized to underlie the subjective experience of emotion, and we now extend this to subjective experience of remembering. Our work also reveals that the BOLD signal in the MTL is correlated with subjective aspects of memory, in addition to objective aspects of memory. Future experiments will serve to elucidate the integration of these two neural systems in metamemory processes.

Acknowledgments

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