Medial temporal lobe contributions to short-term memory for faces

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Abstract

The role of the medial temporal lobes (MTL) in short-term memory (STM) remains a matter of
debate. While imaging studies commonly show hippocampal activation during short-delay
memory tasks, evidence from amnesic patients with MTL lesions is mixed. It has been argued that
apparent STM impairments in amnesia may reflect long-term memory (LTM) contributions to
performance. We challenge this conclusion by demonstrating that MTL amnesic patients show
impaired delayed matching-to-sample (DMS) for faces in a task that meets both a traditional
delay-based and a recently proposed distractor-based criterion for classification as a STM task. In
Experiment 1, we demonstrate that our face DMS task meets the proposed distractor-based
criterion for STM classification, in that extensive processing of delay-period distractor stimuli
disrupts performance of healthy individuals. In Experiment 2, MTL amnesic patients with lesions
extending into anterior subhippocampal cortex, but not patients with lesions limited to the
hippocampus, show impaired performance on this task without distraction at delays as short as 8s,
within temporal range of delay-based STM classification, in the context of intact perceptual
matching performance. Experiment 3 provides support for the hypothesis that STM for faces relies
on configural processing by showing that the extent to which healthy participants' performance is
disrupted by interference depends on the configural demands of the distractor task. Together, these
findings are consistent with the notion that the amnesic impairment in STM for faces reflects a
deficit in configural processing associated with subhippocampal cortices and provide novel
evidence that the MTL supports cognition beyond the LTM domain.

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Keywords

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The medial temporal lobes (MTL) have long been recognized as a critical neural substrate for long-term declarative memory. Until recently, however, it was thought that they play little or no role in short-term memory (STM) (Baddeley & Warrington, 1970; Scoville & Milner, 1957). Evidence hinting at a possible contribution of the MTL to STM comes from recent observations of activity in the hippocampus (Axmacher et al., 2007; Hannula & Ranganath, 2008; Luck et al., 2010; Mitchell, Johnson, Raye, & D'Esposito, 2000; Nee & Jonides, 2011; Nichols, Kao, Verfaellie, & Gabrieli, 2006; Olsen et al., 2009; Piekema, Kessels, Mars, Petersson, & Fernandez, 2006; Piekema, Kessels, Rijpkema, & Fernandez, 2009; Ranganath, Cohen, & Brozinsky, 2005; Ranganath & D'Esposito, 2001; Schon, Ross, Hasselmo, & Stern, 2012) as well as activity in subhippocampal MTL cortex (Bergmann, Rijpkema, Fernandez, & Kessels, 2012; Hannula & Ranganath, 2008; Luck et al., 2010; Olsen et al., 2009; Piekema, Kessels, Rijpkema, & Fernandez, 2009; Ranganath & D'Esposito, 2001; Schon, Ross, Hasselmo, & Stern, 2012) when information of various kinds is retained over a period of seconds. For example, recruitment of the anterior hippocampus has been observed when face stimuli are maintained over an interval of just 7s in a delayed matching-to-sample task (Nichols et al., 2006). High-resolution MRI of the MTL has replicated and extended this result, revealing persistent, performance-related activity in the anterior hippocampus, entorhinal cortex, and perirhinal cortex in a delayed face matching-to-sample task for the duration of a 30s delay between study and test faces (Olsen et al., 2009). While such neuroimaging results document MTL activity during STM tasks, they leave open the question as to the *necessity* of the MTL for STM. Such evidence can only come from lesion studies, but to date, neuropsychological evidence for MTL contributions to STM is mixed.

Initial evidence that the MTL does not participate in STM came from reports of amnesic patients who were able to retain information over brief delays despite severe deficits in long-term memory (Baddeley & Warrington, 1970; Cave & Squire, 1992; Scoville & Milner, 1957; Wickelgren, 1968). This notion has been further supported by more recent reports of intact short-delay memory performance in amnesic patients with lesions primarily limited to the hippocampus (Baddeley, Allen, & Vargha-Khadem, 2010; Jeneson, Mauldin, Hopkins, & Squire, 2011; Jeneson, Mauldin, & Squire, 2010; Jeneson, Wixted, Hopkins, & Squire, 2012; Shrager, Levy, Hopkins, & Squire, 2008). For example, Shrager et al. (2008) found that amnesic patients with lesions primarily restricted to the hippocampus were able to retain words in memory at delays up to 14s and could retain single faces in memory at delays up to 7s. However, other studies have reported deficits in MTL amnesia in similar tasks that require maintaining information in memory over a matter of seconds (Aggleton, Shaw, & Gaffan, 1992; Buffalo, Reber, & Squire, 1998; Ezzyat & Olson, 2008; Hannula, Tranel, & Cohen, 2006; Hartley et al., 2007; Nichols et al., 2006; Olson, Moore, Stark, & Chatterjee, 2006; Olson, Page, Moore, Chatterjee, & Verfaellie, 2006; Owen, Sahakian, Semple, Polkey, & Robbins, 1995; Piekema et al., 2007; Rose, Olsen, Craik, & Rosenbaum, 2012; Ryan & Cohen, 2004; Warrington & Taylor, 1973). For example, Olsen and colleagues

(2006; 2008) and Nichols et al. (2006) found that amnesic patients with MTL damage were impaired at remembering single faces over delays of just 4–7s and Ezzyat and Olson (2008) found that MTL amnesics were less accurate than controls at remembering single faces at delays as short as 1s, even though performance on a perceptual control task was intact. Interestingly, many of the reports of impaired STM in amnesia have come from patient populations whose MTL damage either included regions outside the hippocampus or was not quantified (Aggleton, Shaw, & Gaffan, 1992; Buffalo, Reber, & Squire, 1998; Ezzyat & Olson, 2008; Hartley et al., 2007; Nichols et al., 2006; Olson, Moore, Stark, & Chatterjee, 2006; Olson, Page, Moore, Chatterjee, & Verfaellie, 2006; Owen, Sahakian, Semple, Polkey, & Robbins, 1995; Piekema et al., 2007; Ryan & Cohen, 2004; Warrington & Taylor, 1973). However, impaired STM has also been reported in patients whose MTL damage was thought to be primarily limited the hippocampus (e.g., Hannula, Tranel, & Cohen, 2006; Rose, Olsen, Craik, & Rosenbaum, 2012). Thus, the status of STM in amnesia remains an open question and further research is needed to define whether and how the MTL contributes to memory performance on short-delay tasks.

One possibility is that the MTL is only necessary for short-delay memory tasks that draw upon long-term memory (LTM), and that deficits observed in amnesia on short-delay tasks reflect impairments in LTM rather than STM. Although impairments in amnesia have been observed in tasks that fall within the traditional conception of short-term memory (Atkinson & Shiffrin, 1968; Cowan, 1988; Peterson & Peterson, 1959), it has been argued that such delay-based criteria are not sufficient to determine whether a task draws upon STM or LTM, and that memory deficits in amnesia could reflect LTM impairments even at short delays (Buffalo et al., 1998; Jeneson et al., 2011; Jeneson et al., 2010; Shrager et al., 2008; Warrington & Taylor, 1973). Similarly, it has been argued that neuroimaging evidence of neural activity in the MTL during short-delay tasks could reflect LTM encoding-related processes rather than STM per se (Ranganath et al., 2005; Ranganath & D'Esposito, 2001; Schon, Hasselmo, Lopresti, Tricarico, & Stern, 2004).

To determine more clearly whether short-delay tasks rely on STM or LTM, Shrager et al. (2008) proposed an additional distractor-based criterion for STM classification that is independent of retention interval (see also Jeneson & Squire, 2012). Specifically, Shrager et al. proposed susceptibility to interference as such a criterion: They suggested that short-delay tasks can be classified as relying on STM only if delay-period interference disrupts task performance. This proposal is based on the notion that STM entails the active maintenance of information that is susceptible to interference and the assumption that LTM is immune to such interference. When this classification was applied in the context of tasks administered to amnesic patients, Shrager et al. found that MTL amnesic patients were impaired only on short-delay tasks in which delay-period interference *did not* disrupt control performance (meeting their classification as a LTM task) but showed intact performance on short-delay tasks in which delay-period interference *did* disrupt control performance (meeting their classification as a STM task). While these results support the notion that amnesic deficits on short-delay tasks reflect impairments in LTM rather than STM, it is important to note that the distractor tasks used by Shrager et al. did not require extensive processing of distractor stimuli (simply requiring counting the number of distractor faces

presented during the delay period between study and test faces or deciding whether one of the distractor faces was Bill Clinton). The degree to which distraction disrupts short-delay memory performance may depend on the nature and difficulty of the distractor task.

A second possibility is that MTL contributions to short-delay memory depend on the nature of the information maintained over the delay and the degree to which this information is verbalizable. Indeed, many of the reports of preserved short-delay memory in amnesia have involved maintaining easily verbalizable material (Baddeley et al., 2010; Baddeley & Warrington, 1970; Rose et al., 2012), which may be supported by rehearsal in the phonological loop and processing in extra-MTL regions such as the frontal cortex, parietal cortex, and cerebellum (e.g., Awh, Jonides, Smith, Schumacher, Koeppe, & Katz, 1996; Desmond, Gabrieli, Wagner, Ginier, & Glover, 1997; Jonides, Schumacher, Smith, Koeppe, Awh, et al., 1998; Paulesu, Frith, & Frackowaik, 1993; Schumacher, Lauber, Awh, Jonides, Smith, & Koeppe, 1996; Trost & Gruber, 2012). However, preserved short-delay memory in MTL amnesia has also been reported in tasks involving nonverbalizable material (e.g., Baddeley et al., 2010; Jeneson et al., 2011; Shrager et al., 2008). Non-famous faces are one class of nonverbalizable material that has produced particularly mixed results in amnesia, with reports of both preserved short-delay memory (Shrager et al., 2008; Warrington & Taylor, 1973) and impaired short-delay memory (Ezzyat & Olson, 2008; Nichols et al., 2006; Olson et al., 2006; Olson et al., 2008; Rose et al., 2012). Important questions remain about the status of short-delay memory for faces in amnesia and the factors that determine whether short-delay memory for faces is impaired or preserved following MTL damage.

Faces are an interesting class of stimuli for several reasons. First, our extensive experience with faces results in perceptual expertise, with associated greater STM capacity for faces than for other objects (Curby & Gauthier, 2007). Second, faces are relationally complex but are perceived holistically (i.e., as an integrated entity). The holistic representation of faces results from configural processing in which individual facial features are bound into a single unit or configuration (Maurer, Le Grand, & Mondloch, 2002; Piepers, & Robbins, 2012; Rhodes, 1988; Sergent, 1984). In the LTM domain, configural processing and memory for such unitized representations has been associated with neural substrates in the subhippocampal MTL cortex, such as perirhinal cortex (e.g., Haskins, Yonelinas, Quamme, & Ranganath, 2008; Preston & Gabrieli, 2008). Specifically, subhippocampal regions are thought to support configural processing or intra-item binding (i.e., the binding of information encoded as a single unit, such as faces). In contrast, the hippocampus is thought to support relational processing or inter-item binding (i.e., the binding of information that is not encoded configurally as a single unit, such as object-location associations) (Eichenbaum, Schoenbaum, Young, & Bunsey, 1996; Giovanello, Keane, & Verfaellie, 2006; Preston & Gabrieli, 2008; Quamme, Yonelinas, & Norman, 2007). By extension, an important outstanding question is whether STM for faces depends on the integrity of the subhippocampal cortex rather than the hippocampus proper, and whether STM for faces in amnesia is intact when lesions are restricted to the hippocampus but impaired when lesions extend into MTL cortex.

The current study first investigates whether the MTL plays a critical role in STM for faces by testing the status of short-delay memory for faces in MTL amnesia on a task that meets

both the traditional delay-based criterion and the distractor-based criterion for STM classification (Shrager et al., 2008). In Experiment 1, we determine whether a short-delay face matching task is disrupted in healthy individuals by delay-period interference that requires extensive processing of distractor stimuli, such that the task meets the proposed distractor-based criterion for classification as a STM task. In Experiment 2, we test whether MTL amnesic patients are impaired on this task without distraction at delays as short as 8 sec (within the temporal range of delay-based STM classification). If MTL amnesics are impaired on a short-delay memory task that meets both delay-based and distractor-based criteria for classification as a STM task, this would provide novel evidence that the mnemonic contributions of the MTL extend into the STM domain. Furthermore, we investigate whether the status of short-delay memory for faces in amnesia depends on the locus of neural damage within the MTL by comparing the performance of patients with MTL damage limited to the hippocampus to that of patients whose MTL damage includes subhippocampal regions of MTL cortex. In Experiment 3, we investigate one potential underlying mechanism, configural processing, that may support STM for faces, by comparing the effect of configural versus featural interference on performance in the short-delay face memory task. If configural interference disrupts face memory performance to a greater extent than featural interference, this would provide evidence that configural processing supports STM for faces and would point to MTL-mediated configural processing as a possible basis of the observed STM impairment in amnesia.

Experiment 1

In Experiment 1, we examine whether a delayed matching-to-sample task using faces as stimuli meets the proposed distractor-based criterion for STM classification by determining whether performance is disrupted by a distractor task that extensively engages the same domain of working memory and uses the same type of stimuli as the delayed matching-to-sample task. Healthy participants were tested on a delayed face matching-to-sample task and had to make gender discriminations about distractor faces presented during the delay. If delay-period processing of distractor faces disrupts participants' ability to make match/mismatch decisions about study and test faces, this would qualify the delayed face matching-to-sample task as a STM task according to the proposed distractor-based criterion (Shrager et al., 2008).

Method

Participants—Sixteen healthy participants took part (mean age = 61 years, mean education = 14 years, mean verbal IQ = 105; healthy participants were matched in terms of mean age, education, and verbal IQ to the patients in Experiment 2, all *t*'s < .84). All participants were paid for their participation and provided informed consent in accordance with the procedures of the Institutional Review Boards at Boston University and the VA Boston Healthcare System.

Stimuli—Face stimuli (512 study-test faces and 320 distracter faces) were gathered from various face databases, including tarrlab.com (Images courtesy of Michael J. Tarr, Brown University, http://www.tarrlab.org/), AT&T database of faces (AT&T Laboratories,

Cambridge, http://www.cl.cam.ac.uk/research/dtg/attarchive/facedatabase.html), Yale Face Database B (Gerghiades, Belhumeur, & Kriegman, 2001), Georgia Tech Face Database (www.anefian.com/face_reco.htm), the grayscale NIST FERET database (http://www.nist.gov/humanid/colorferet/home.html), NIST Mugshot Identification Database (MID) (http://www.nist.gov/srd/nistsd18.cfm), and the Psychological Image Collection at Stirling (PICS) (http://pics.psych.stir.ac.uk/). All faces were Caucasian, forward facing, and included hair, but were free of jewelry or facial hair (see Figure 1A for example stimuli). The 512 study-test faces were all male, whereas the distractor faces included 160 female faces and 160 male faces.

Study-test faces were divided into eight sets of 32 pairs. One of the faces in each pair was designated as a test face. The study face was designated as the other face in the pair (mismatch) for half of the pairs, and the same face as the test face (match) for the other half of the pairs. The assignment of each pair as a match or mismatch pair was counterbalanced across subjects to ensure that each test face appeared equally as often as a match or a mismatch face and each set of faces rotated through each condition (see below) across subjects.

Subjects performed eight study-test blocks: four blocks with an 8s delay between study and test faces, and four blocks with a 15s delay between study and test faces. Two blocks within each delay condition contained distraction between study and test, and two blocks within each delay condition did not contain distraction between study and test, resulting in four main conditions: 8s distraction, 8s no-distraction, 15s distraction, and 15s no-distraction.

Distractor faces were divided into two sets of 160 faces (80 male, 80 female), containing 32 trials of five faces. The number of male faces in each trial ranged from one to four and was evenly distributed across the trials (i.e., eight trials had one male face, eight trials had two male faces, eight trials had three male faces, eight trials had four male faces). Each set of distractor faces was viewed twice during the experiment (with a different, randomized order of presentation) but was not repeated within the same condition for any one subject to ensure that each distraction condition (8s or 15s) was paired once with each set of distractor faces for each subject. The pairing of distractor sets to conditions was counterbalanced across subjects.

Procedure—Each subject was tested in two sessions. Each session included one block of each condition, with the order of conditions counterbalanced across subjects and the specification that subjects always alternated between distraction and no-distraction conditions. During each session, subjects were given practice trials before starting the task. Subjects were first given a practice block of two 8s no-distraction trials. They were also given a practice block of two 8s distraction trials immediately before their first distraction block. If the first block was a no-distraction block, subjects were given this block before the practice distraction trials. If the first block was a distraction block, they were given the practice distraction trials immediately following the no-distraction practice trials.

The experimental task design is presented in Figure 1A. On all trials, subjects were first shown a blank screen for 1000ms, followed by a central fixation cross for 1000ms, another

blank screen for 1000ms, and a study face for 1000ms. Subjects were told to remember the identity of the study face over the subsequent delay. For the no-distraction trials, a blank screen followed the study face for either a 7983ms delay (8s delay condition) or a 14983ms delay (15s delay condition)[1], followed by the test face in which the subjects reported whether the test face did or did not match the study face. For the distraction trials, an ISI of 4003ms followed the study face, and was followed by presentation of the five distractor faces, one at a time, for 579ms each with a 17ms ISI between each distractor face. Following the distractor faces, there was an additional ISI of 1000 ms (8s delay condition) or 8000 ms (15s delay condition). This timing ensured that the same amount of time passed between the study and test faces in the no-distraction and the distraction conditions. Subjects were told to remember the identity of the study face over the delay and also (in the distraction condition) to count the number of male faces presented in the intervening period. Test faces in both conditions remained on the screen until subjects made a verbal response. In the distraction condition, subjects first reported the number of male faces presented during the distractor period and then reported whether or not the test face matched the study face.

Results

The results from Experiment 1 are presented in Figure 1B. Compared to the no-distraction condition, distraction reduced subjects' mean accuracy (hits minus false alarms) at both the 8s delay (92% to 72%) and the 15s delay (89% to 73%). To verify the reliability of these effects, mean accuracy in each condition was entered into a 2×2 repeated-measures ANOVA with factors of delay (8s, 15s) and distraction (no-distraction, distraction). ANOVA confirmed that performance was disrupted with distraction (main effect of distraction, $F(1,15) = 37.51$, $p < .001$, $\eta_p^2 = .71$). There was no difference in performance on the 8s and 15s trials (main effect of delay, $F(1,15) = 0.19$, $p > .50$, $\eta_p^2 = .01$) and distraction had a similar effect on performance at both delays (distraction x delay, $F(1,15) = 0.83$, $p > .30$, $\eta_p^2 = .05$).

Discussion

Healthy participants were presented with pictures of individual faces and their memory for each face was tested after a short (8s) or longer (15s) delay. During the delay period, subjects either viewed a blank screen (no-distraction condition) or made gender discriminations about five serially presented distractor faces (distraction condition). We found that delayed face matching-to-sample performance decreased following distraction at both the short and longer delays. These results stand in contrast to the lack of an effect of interference on delayed matching-to-sample performance observed by Shrager et al. (2008) when subjects had to either count the number of distractor faces presented during a 14-second delay period or decide whether one of the distractor faces was Bill Clinton.

Our findings further clarify the conditions that are required to test whether performance in short-delay memory tasks is sensitive to interference. Logie, Zucco and Baddeley (Logie, Zucco, & Baddeley, 1990) highlighted the importance of a match between the processing

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[1]These delay intervals were chosen to approximate those used in Shrager et al. (2008) based on calculation of the interval needed to present their maximum number of distractors, but Shrager et al. (2008) refer to these as 7s and 14s delay conditions.

resources required by the distractor task and those needed to maintain the to-be-remembered information. More specifically, they showed that the maintenance of nonverbalizable stimuli was disrupted by a distractor task that required visual imagery but not one that required mental arithmetic. Conversely, maintenance of verbalizable stimuli was disrupted by a distractor task that required mental arithmetic, but not one that required visual imagery. Shrager et al. (2008) acknowledged the importance of engaging the same domain of working memory in the memory task and the distractor task, and noted that their first distractor task (counting faces) may not have achieved this aim. Thus, they included a second distractor task that required processing of face identity (identifying the presence of Bill Clinton's face among a set of distractor faces), with the assumption that this task would provide the requisite load to reveal any potential interference effect. The absence of an interference effect with their distractor task, however, contrasts with our finding of an interference effect when the distractor task required gender judgments. Presumably, the gender task, which required processing of every distractor face, imposed a greater load than did the face identity task in Shrager et al. (2008), in that processing in their task could be aborted once the target face had been encountered. These findings highlight the fact that a demand on similar processing resources in the memory and distractor task may not, by itself, be adequate to induce interference, but that the distractor task must engage those processing resources to a sufficient degree. This notion is consistent with the view that there is a necessary trade-off between maintenance and processing in working memory that is mediated by a common demand on attention, and that memory traces decay only when processing activities sufficiently drain attentional resources so as to disrupt maintenance (Barrouillet & Camos, 2012; Cowan, 1999).

Returning to the primary aim of Experiment 1, we found that performance in the delayed face matching-to-sample task was disrupted by interference, thus qualifying this task as a STM task according to the proposed distractor-based criterion (Shrager et al., 2008). As such, the task is appropriate for our examination of the role of the MTL in STM.

Experiment 2

In Experiment 2, we aim to examine whether MTL amnesic patients show impaired performance on the delayed face matching-to-sample task used in Experiment 1. The face delayed matching-to-sample task was administered to amnesic and control participants without distraction in the 8s and 15s delay conditions. Critically, not only does this task meet the proposed distractor-based criterion as a STM task (Experiment 1), but the inclusion of an 8s delay condition also clearly qualifies it as a STM task according to the traditional delay-based criterion (Atkinson & Shiffrin, 1968; Cowan, 1988; Peterson & Peterson, 1959).

In Experiment 2a, MTL amnesic patients and control subjects were tested on the task from Experiment 1 (without distraction). Experiment 2b constituted a control condition aimed at ruling out perceptual impairments at the level of face discrimination as the possible cause of any observed STM impairment in the MTL amnesic patients. Here, participants completed a face-matching task in which pairs of faces were presented simultaneously and same/different judgments were required.

Experiment 2a: Face Memory without Distraction

Method

Participants: Nine amnesic patients with MTL lesions participated in the study (Table 1). Eleven healthy controls also participated and were matched to the patient group in terms of mean age (59.18 years, $SD = 10.94$), education (16.09 years, $SD = 3.18$), and verbal IQ (106.36, $SD = 12.94$) (all t's < .69). All participants were paid for their participation and provided informed consent in accordance with the procedures of the Institutional Review Boards at Boston University and the VA Boston Healthcare System.

To assess the extent of patients' neural damage, structural magnetic resonance imaging (MRI) scans were collected for five of the patients. (MRI could not be obtained for the remaining patients because of medical contraindications, but MTL pathology can be inferred on the basis of etiology and neuropsychological profile.) Information about the acquisition and analysis of MRI scans and lesion volumetrics has been previously reported for patients P01, P02, P04, P05 (Kan, Giovanello, Schnyer, Makris, & Verfaellie, 2007). For P09, lesion volumetric analysis of medial temporal lobe regions was performed in a semi-automated fashion using ITK-SNAP (www.itksnap.org) (Yushkevich et al., 2006) following the same segmentation parameters. Quantitative analysis compared patients' regional brain volumes (corrected for intracranial volume) to volumes from eight age- and gender-matched control subjects. Two of the anoxic patients (P05 and P09) had damage limited to the hippocampus and two of the encephalitic patients (P01 and P02) and one of the anoxic patients (P04) had damage to the hippocampus and surrounding parahippocampal gyrus (volume reductions >2 SDs from the control mean; see Table 1). For the encephalitic patient P06, a computerized tomography (CT) scan was available and visual inspection indicated extensive hippocampal and parahippocampal gyrus damage. Measurements of frontal, parietal, occipital, and lateral temporal cortex were also made to assess the possibility of additional damage outside the MTL in patients for whom whole-brain volumetrics were available (P01, P02, P04, P05). No common volume reductions were found outside the MTL. We were particularly interested in the possibility of neural damage in the fusiform cortex, given the importance of this area for face processing. The only volume reduction in fusiform cortex was found in the left fusiform gyrus of the patient whose etiology included left temporal lobectomy (P04), and inclusion or exclusion of this patient did not affect results. The neuropsychological profiles of all patients indicate impairments isolated to the domain of memory with profound impairments in new learning (Table 1).

Stimuli: Experiment 2a used a subset of face stimuli used in Experiment 1 (256 study-test faces, divided into four sets of 32 pairs). As in Experiment 1, one of the faces in each pair was designated as a test face. The study face was designated as the other face in the pair (mismatch) for half of the pairs, and the same face as the test face (match) for the other half of the pairs. The assignment of each pair as a match or mismatch pair was counterbalanced across subjects, to ensure that each test face appeared equally often as a match or a mismatch face, and each set of faces appeared equally often in the 8s and 15s conditions across subjects.

Procedure: Patients and controls performed two sessions of the task, with each session containing two study-test blocks (one 8s delay block and one 15s delay block). The order of the 8s and 15s delay blocks for each session was counterbalanced within and across subjects, resulting in each condition appearing an equal number of times as the first block and the second block. During each session, subjects were given a practice block of two 8s delay trials before starting the task.

As in Experiment 1, subjects were first shown a blank screen for 1000ms, followed by a central fixation cross for 1000ms, another blank screen for 1000ms, and a study face for 1000ms. Subjects were told to remember the identity of the study face over the subsequent delay. A blank screen followed the study face for either a 7983ms delay (8s delay condition) or a 14983ms delay (15s delay condition), followed by the test face in which the subjects reported whether or not the test face matched the study face (see Figure 2A). The test face remained on the screen until subjects made a verbal response.

Results—Results from Experiment 2a are presented in Figure 2B. Patients' mean accuracy (hits minus false alarms) was reduced compared to controls' both in the 8s delay condition (78% vs. 96%) and the 15s delay condition (72% to 95%). To verify the reliability of these effects, mean accuracy in each condition was entered into a 2×2 mixed model ANOVA with factors of delay (8s, 15s) and group (patients, controls). ANOVA confirmed that patients' performance was impaired compared to controls' (main effect of group, $F(1,18) = 11.74$, $p = .003$, $\eta_p^2 = .40$). There was no difference in performance in the 8s versus the 15s condition (main effect of delay, $F(1,18) = 2.96$, $p > .10$, $\eta_p^2 = .14$) and the performance difference between groups was similar in both delay conditions (group x delay, $F(1,18) = 1.04$, $p > .30$, $\eta_p^2 = .06$).

In order to investigate more precisely the anatomical basis of the delayed matching-to-sample impairment in amnesia, performance was separately analyzed for the patients with volumetrically confirmed damage limited to the hippocampus (P05, P09; H-only group) and for the patients with volumetrically or visually confirmed MTL damage that included the hippocampus and subhippocampal cortex (P01, P02, P04, P06; H+ group). A 3×2 ANOVA with factors of group (controls, H+ patients, H-only patients) and delay (8s, 15s) revealed that performance differed across groups (main effect of group, $F(2,14) = 9.71$, $p = .002$, $\eta_p^2 = .58$) and that this difference in group performance varied according to delay (group x delay, $F(2,14) = 4.59$ $p = .03$, $\eta_p^2 = .40$). Follow-up analysis revealed that the performance of the H+ patients was impaired compared to controls, whereas performance of the H-only patients was intact. Specifically, when data from the H+ patients were entered into 2×2 ANOVA with factors of delay (8s, 15s) and group (H+ patients, controls), there was a main effect of group, $F(1,13) = 17.85$, $p < .001$, $\eta_p^2 = .58$) and a group x delay interaction ($F(1,13) = 8.67$, $p = .01$, $\eta_p^2 = .40$). Although H+ patients demonstrated greater impairment in the 15s delay condition (mean accuracy = 60%) than in the 8s delay condition (mean accuracy = 73%), H+ patients' memory impairment was significant at both delays ($t(13) = 5.71$ $p < .001$, $d = 3.17$ and $t(13) = 2.85$, $p = .01$, $d = 1.58$, respectively). In contrast, when data from the H-only group were entered into a 2×2 ANOVA with factors of delay (8s, 15s) and group (H-only patients, controls), there was no main effect of group, $F(1,11) = 2.06$, $p > .10$, $\eta_p^2 = .16$. Further follow-up analyses using a modified t-test for single cases

(Crawford & Howell, 1998) confirmed that even at the shortest delay (8s) there was no evidence that either of the patients with damage limited to the hippocampus performed differently than controls (both $ts(10) = 0.83$, $ps > .20$, $z_{CC}s = .87$), whereas memory performance of each of the patients in the H+ group was reduced compared to controls ($ts(10) > 1.74$, ps ≤ .056, $z_{CC}s > 1.82$). The single case analyses for the H+ group indicate that the impairment for the H+ group as a whole was not driven solely by the low performance of P06.

Experiment 2b: Face Matching Task

Method

Participants: The same groups of patients and controls tested in Experiment 2a were tested in Experiment 2b, with the exception of one control subject who was lost to follow up.

Stimuli: The same face stimuli used in Experiment 2a were used in Experiment 2b (256 study-test faces, divided into four sets of 32 pairs). For each pair, one of the faces was designated as the target face. Half of the pairs were used in match trials, in which two identical target faces were presented. The other half of the pairs were used in mismatch trials, in which the target face was presented with its mate. The assignment of each pair to the match or mismatch conditions was counterbalanced across subjects, to ensure that each target face appeared equally often in the two conditions. Critically, the two faces were presented simultaneously in Experiment 2b, with no intervening delay.

Procedure: Each subject performed one session of the matching task, consisting of 32 trials (Figure 3A). Prior to the start of the matching task, subjects were given two practice trials. On each trial, subjects were first shown a blank screen for 1000ms, followed by a central fixation cross for 1000ms. After the fixation-cross disappeared, two faces simultaneously appeared on the screen side-by-side for 2000ms. Subjects were asked to determine whether the two faces matched, meaning that they were the same picture, or did not match, meaning that they were different pictures. A blank screen followed presentation of the faces and remained present until subjects made a verbal decision about whether the two faces did or did not match.

Results—Performance on the face matching task is presented in Figure 3B. Mean accuracy (hits minus false alarms) on the face matching task did not differ between patients (92%) and controls (97%) ($t(17) = 0.99$, $p > .30$, $d = 0.48$), indicating that patients could discriminate the faces used in this experiment as well as controls. Follow-up analyses confirmed that face matching performance did not differ from controls for both the patients with confirmed damage limited to the hippocampus ($t(10) = 0.02$, $p > .50$, $d = 0.01$) and for the patients with confirmed MTL damage that included the hippocampus and subhippocampal cortex ($t(12) = 0.39$, $p > .50$, $d = 0.23$). Finally, when data across Experiment 2a and 2b were entered into ANOVA with factors of group (control, H+ patients, H-only patients) and delay (8s, 15s, match), there was a significant group x delay interaction ($F(4,26) = 11.23$, $p < .001$, $\eta_p^2 = .63$), confirming that the memory impairment in H+ patients depended on the presence of a temporal delay between study and test faces.

Discussion: Experiment 2a and Experiment 2b

In Experiment 2a, we demonstrated that amnesic patients with MTL damage were impaired at a delayed face matching-to-sample task that met both the traditional delay-based criterion and the recently proposed distractor-based criterion for classification as a STM task. In Experiment 2b, with stimuli that were identical to those used in Experiment 2a, we found that face matching performance did not differ between patients and controls. The finding that patients could discriminate between the same faces used in Experiment 2a as well as controls argues against the possibility that the STM impairment observed in Experiment 2a was simply due to patients' inability to visually discriminate between study and test faces. While it is possible that patients may demonstrate deficits in other perceptual tasks, for example tasks that use stimuli with higher feature ambiguity, the results of Experiment 2b confirm that our patients do not have perceptual deficits at the level of face stimulus matching that could account for the deficits observed in the present STM task.

Our findings also elucidate the neural basis of this STM impairment in MTL amnesia. Amnesic patients' performance differed as a function of the extent of MTL lesion. Patients with a volumetrically documented lesion restricted to the hippocampus performed as well as controls, suggesting that STM for faces does not depend on the hippocampus. In contrast, four patients with documented lesions extending into anterior subhippocampal cortices showed impaired performance relative to control subjects. These findings suggest that the face STM impairment observed in amnesia may be linked specifically to lesions of the subhippocampal cortex rather than the hippocampus proper. Taken alone these findings must be interpreted with caution, given that the patients with H+ lesions also had greater volume reduction in the hippocampus than did the H-only patients. It is notable, however, that our interpretation is consistent with converging evidence for a role of anterior subhippocampal cortices, and in particular the perirhinal cortex, in both short-delay and long-delay memory for faces (e.g., Preston et al., 2010; Schultz, Sommer, & Peters, 2012).

Experiment 3

In Experiment 3, we test a hypothesis about the mechanism underlying the STM impairment in the H+ amnesic group in Experiment 2a. In light of the evidence that subhippocampal cortices play a critical role in configural processing in the service of LTM (Haskins, Yonelinas, Quamme, & Ranganath, 2008; Giovanello et al., 2006; Preston & Gabrieli, 2008; Quamme et al., 2007) we hypothesize that the this brain region may play a similar role in STM. Specifically, given the extensive evidence that face recognition relies on configural processing and the binding of individual features into a unitized representation (Maurer, Grand, & Mondloch, 2002; Rhodes, 1988; Sergent, 1984), it seems likely that STM for faces relies on the encoding and maintenance of such bound representations such that a failure in configural binding might underlie the STM impairment that we observed in the H+ amnesic group.

To test the hypothesis that STM for faces depends on configural processing, we examined, in healthy individuals, whether two distractor tasks that differ in their demands on configural processing would differentially disrupt delayed face matching-to-sample performance. As a "configural" distractor, we used the same gender discrimination task used in Experiment 1,

given that this task has been shown to rely on configural processing (Zhao & Hayward, 2010). As a "featural" distractor, we used a task that required subjects to judge whether faces had visible teeth, thus requiring part-based processing of only a single feature. Although face processing is inherently configural in nature, we reasoned that the teeth discrimination task would impose a lower configural demand than the gender discrimination task. If STM performance is worse in the context of the gender discrimination task than the teeth discrimination task, this would suggest that configural processing plays an important role in supporting STM for faces.

Materials and Methods

Participants—Eighteen healthy participants took part (mean age = 65 years, mean education = 16 years, mean verbal IQ = 104; healthy participants were matched in terms of mean age, education, and verbal IQ to the patients in Experiment 2; all t's < 1.85). All participants were paid for their participation and provided informed consent in accordance with the procedures of the Institutional Review Boards at Boston University and the VA Boston Healthcare System.

Stimuli—Stimuli consisted of six sets of 32 pairs taken from the stimuli used in Experiment 1. As in Experiment 1, one of the faces in each pair was designated as a test face. The study face was designated as the other face in the pair (mismatch) for half of the pairs, and the same face as the test face (match) for the other half of the pairs. The assignment of each pair as a match or mismatch pair was counterbalanced across subjects, to ensure that each test face appeared equally often as a match or a mismatch face. Each participant received three of the six stimulus sets. The assignment of each set of faces was counterbalanced across the three main conditions (no distraction, configural distraction, and featural distraction) to ensure that each test face appeared equally often as a match or a mismatch face and each set of faces rotated through each condition across subjects.

Distractor faces consisted of 320 face stimuli gathered from various face databases (see Experiment 1 and http://www.face-rec.org/databases/). All faces were forward facing, and included hair, but were free of jewelry or facial hair. To accommodate the two distractor tasks, half of the stimuli were male faces and half were female faces. Additionally, half of the male and female faces had visible teeth whereas half of the faces did not have visible teeth. Faces were organized into 64 sets of five faces, of which 16 sets contained one male face, 16 sets contained two male faces, 16 sets contained three male faces, and 16 sets contained 4 male faces. Within each of the 16 sets of faces, four subsets contained one face with teeth, four subsets contained two faces with teeth, four subsets contained three faces with teeth, and four subsets contained four faces with teeth. The 64 sets of faces were divided into two lists that contained an equal number of sets with 1–4 male faces and an equal number of sets with 1–4 faces with teeth. The assignment of distractor list to configural or featural distraction was counterbalanced across subjects.

Procedure—Participants performed three blocks of delayed matching-to-sample trials with an 8s delay. One block contained no distraction during the delay between study and test faces, one block contained configural distraction during the delay, and one block contained

featural distraction during the delay, with the order of blocks counterbalanced across participants. For the distraction blocks, subjects were told to remember the identity of the study face over the delay and to count either the number of male faces presented in the intervening distractor period (configural distraction) or the number of faces displaying teeth in the intervening distractor period (featural distraction). Test faces remained on the screen until subjects made a verbal response. Subjects first responded to the distractor question and then reported whether or not the test face matched the study face.

Pilot data were collected to establish that the configural and featural distractor tasks were equated for difficulty. The 64 sets of distractor faces were presented to thirty undergraduate participants, who performed the configural distractor task with half of the faces and the featural distractor task with the other half. Participants reported the number of male faces (configural distraction) or the number of faces displaying teeth (featural distraction) in each set by typing their response into a numeric keypad as quickly and accurately as possible. Subjects' performance did not differ across the two distractor tasks in terms of mean accuracy (configural distractor mean = 91%; featural distractor mean = 89%; $t(58) = 1.43$, $p > .10$, $d = 0.38$) or mean reaction time (configural distractor mean (correct trials only) = 546.91ms; featural distractor mean (correct trials only) = 516.02ms; $t(58) = 0.88$, $p > .30$, $d = 0.23$), confirming that the configural and featural distractor tasks were equated for difficulty.

Results

We first examined performance in the configural and featural discrimination distractor tasks. Importantly, there was no difference in performance accuracy in the two tasks (configural distractor mean = 82%; featural distractor mean = 85%; $t(17) = .079$, $p > .40$, $d = 0.20$), ensuring that any differential effect of the two distractor tasks on STM performance could not be attributed to differential engagement in the two distractor tasks. The results for the STM task are presented in Figure 4B. Mean accuracy (hits minus false alarms) was reduced both in the featural distraction condition (mean = 82%) and in the configural distraction condition (mean = 77%) compared to the no distraction condition (mean = 91%), and the performance reduction was numerically greater in the configural than in the featural condition. ANOVA confirmed the performance disruption with distraction (main effect of distraction, $F(2,34) = 7.48$, $p = .003$, $\eta_p^2 = .31$). Pairwise comparisons confirmed that this performance disruption was significant for both featural distraction ($t(17) = 2.05$, $p = .03$, $d = 0.56$, 1-tailed) and configural distraction ($t(17) = 3.63$, $p = .001$, $d = 0.98$, 1-tailed), and that configural distraction had a greater impact on delayed matching-to-sample performance than featural distraction ($t(17) = 1.97$, $p = .03$, $d = 0.29$, 1-tailed).

Discussion

In Experiment 3, we demonstrated that the degree to which performance in the delayed face matching-to-sample task was disrupted by a distractor task depends on the configural processing load of the distractor task: Performance was worse with the distractor task that made greater demands on configural processing (gender discrimination). We note that even in the teeth discrimination task some degree of whole-face processing likely occurred (cf. the composite face effect; Hole, 1994; Richler, Tanaka, Brown, & Gauthier, 2008; Young,

Hellawell, & Hay, 1987) which may explain in part the decline in STM performance in that condition compared to the no-distractor condition. Importantly, however, the larger disruption in STM in the condition with greater configural demands provides support for the notion that STM for faces requires the maintenance of configural information. These findings are consistent with the hypothesis that the observed STM impairment for faces in amnesic patients with damage to subhippocampal MTL cortex reflects a disruption of configural processing.

General Discussion

The current study found that amnesic patients with MTL damage are impaired at remembering single faces over delays as short as 8 seconds (Experiment 2a), an impairment that occurred in the context of intact perceptual matching of the same stimuli (Experiment 2b). Notably, the study-test delay in this task falls within traditional delay-based limits of STM and the task meets a recently proposed distractor-based criterion for STM classification (Experiment 1). Thus, we interpret the impairment in amnesia on this task as reflecting a deficit in STM rather than being an artifact of the well-documented LTM impairment in amnesia. These findings add to a growing body of literature indicating a role for the MTL in short-delay memory tasks and clarify that this role is specifically related to STM.

The observation that MTL lesions impair STM for faces sheds new light on current controversies about the nature and necessity of MTL processes for STM. While STM has traditionally been regarded as independent of the MTL, accumulating evidence from neuroimaging studies has challenged this notion by demonstrating hippocampal activity (Axmacher et al., 2007; Hannula & Ranganath, 2008; Nichols et al., 2006; Olsen et al., 2009; Piekema et al., 2009; Ranganath et al., 2005; Ranganath & D'Esposito, 2001; Schon et al., 2012) as well as subhippocampal activity (Ranganath & D'Esposito, 2001; Schon et al., 2012) when nonverbal information is maintained over short delays. However, neuroimaging evidence cannot demonstrate whether MTL activity is *necessary* for short-delay memory and it has been unclear whether the MTL activity observed in short-delay tasks specifically relates to STM function. It has been suggested alternatively that MTL activity during short-delay tasks may simply reflect feed-forward projections from extra-MTL cortices that are responsible for the encoding and short-term maintenance of stimulus representations (Olsen et al., 2009). Another suggestion is that this MTL activity reflects stimulus novelty or LTM encoding signals that are not directly related to the short-term maintenance of information (Ranganath et al., 2005; Ranganath & D'Esposito, 2001; Schon et al., 2004). Both of these possibilities suggest that MTL processes are not necessary for STM and make the prediction that MTL lesions should leave STM performance intact. By demonstrating that MTL amnesics are impaired on a STM task, the current study provides evidence against this notion. Without negating the possibility that some of the MTL activity observed during short-delay tasks may reflect processes not specifically related to STM, the current results provide compelling evidence that the MTL does play a critical role in STM.

Our results support and extend prior reports of impaired short-delay memory in MTL amnesia (Aggleton et al., 1992; Buffalo et al., 1998; Ezzyat & Olson, 2008; Hannula et al.,

2006; Hartley et al., 2007; Nichols et al., 2006; Olson, Moore, et al., 2006; Olson, Page, et al., 2006; Owen et al., 1995; Piekema et al., 2007; Rose et al., 2012; Ryan & Cohen, 2004; Warrington & Taylor, 1973) by demonstrating that STM for faces is impaired in patients with subhippocampal lesions but is intact in patients with lesions limited to the hippocampus. It is noteworthy that a majority of the MTL amnesic patients in the Shrager et al (2008) study, which demonstrated intact short-delay memory for faces, had lesions limited to the hippocampus. Our findings help explain the variability across studies concerning the status of short-delay memory for faces in MTL amnesia (Ezzyat & Olson, 2008; Nichols et al., 2006; Olson, Moore, et al., 2006; Rose et al., 2012; Shrager et al., 2008; Warrington & Taylor, 1973), and suggest that STM for faces may be impaired only in patients with subhippocampal lesions. The one apparent contradiction to this pattern comes from the developmental amnesic HC (Rose et al., 2012), described to have damage limited to the hippocampus, who showed impaired STM for non-famous faces. It should be noted, however, that the absence of extrahippocampal MTL damage was inferred on the basis of visual inspection and was not volumetrically confirmed.

The results of Experiment 3 suggest that the impairment in patients with subhippocampal lesions may be due to the configural processing demands of the task. In particular, Experiment 3 demonstrated that the degree to which STM for faces is disrupted by a distractor task in healthy participants depends on the degree to which the distractor task requires configural processing. This finding suggests that the maintenance of configural information is critical to successful performance on this task, and is consistent with the notion that impaired performance in amnesia is due to a failure of MTL-mediated configural processing mechanisms. Demands on a similar configural memory mechanism may explain deficits in MTL amnesia in short-delay memory tasks for other complex novel stimuli that are processed as single units, such as fractals (Holdstock, Gutnikov, Gaffan, & Mayes, 2000) and visual patterns (Owen et al., 1995; Sidman, Stoddard, & Mohr, 1968).

The fact that the STM impairment for faces was present only in patients with subhippocampal lesions is consistent with the proposed specialization within the MTL in service of LTM, whereby subhippocampal MTL cortex supports configural (intra-item) binding and memory for unitized associations (Eichenbaum et al., 1996; Norman & O'Reilly, 2003; Haskins et al., 2008; O'Reilly and Rudy, 2001; Preston & Gabrieli, 2008). Indeed, neuroimaging data suggest a role for subhippocampal cortices, and specifically perirhinal cortex, in face encoding and retrieval (Preston et al., 2010; Schultz et al., 2012) and more generally, in the memorial binding of unitized associations (Haskins, Yonelinas, Quamme, & Ranganath, 2008) and item-related elements, such as object-color associations (Diana et al., 2010; Staresina & Davachi, 2008). Further support comes from neuropsychological findings demonstrating that memory for unitized associations is relatively preserved following hippocampal damage but is impaired following MTL damage that extends into MTL cortex (Giovanello et al., 2006; Quamme et al., 2007). The current findings extend this functional specialization to the STM domain by demonstrating that STM for faces, a task that requires configural processing, was impaired selectively in patients with subhippocampal lesions.

The intact performance in the present study of the two patients with lesions limited to the hippocampus is consistent with the notion that the kind of mnemonic binding mediated by the hippocampus is distinct from that mediated by subhippocampal cortices. More specifically, it has been proposed that the hippocampus supports relational binding and memory for inter-item associations that are not unitized (Cohen et al., 1999; Cohen & Eichenbaum, 1993; Diana, Yonelinas, & Ranganath, 2007; Konkel & Cohen, 2009). Further, such hippocampally-mediated relational processing is thought to be important for binding novel relations in memory both in the short and long term (Cashdollar et al., 2009; Finke et al., 2008; Hannula et al., 2006; Jonides et al., 2008; Olsen et al., 2009; Olson, Page, et al., 2006; Rose et al., 2012). This proposal provides a straightforward account of impaired short-delay memory performance in MTL amnesia on tasks that require maintenance of the association between items, the association between an item and its location (Finke et al., 2008; Olson, Moore, et al., 2006; Olson, Page, et al., 2006), or the location of objects within a scene (Cashdollar et al., 2009; Hannula et al., 2006). It also accounts for the preservation of STM on tasks that require only intra-item binding (as is the case in the present study) in patients with lesions limited to the hippocampus.

The above considerations highlight that understanding MTL contributions to STM, and resolving discrepancies in the literature about the status of STM in MTL amnesia, requires consideration both of the nature of the binding processes required by a task and the precise MTL region that is implicated in that type of binding. In this context, it is worth emphasizing that some STM tasks make no demands on either configural or relational binding and, as such, their preservation in MTL amnesia is explicable in the present framework. Prominent among those are tasks that entail maintenance of easily verbalizable material. Indeed, MTL amnesics show spared STM for words (Baddeley et al., 2010; Baddeley & Warrington, 1970), nameable shapes (Baddeley et al., 2010), and famous faces (Rose et al., 2012). Intact performance in amnesia in these instances may be due to the fact that maintenance can be supported by rehearsal in the phonological loop (e.g., Rose et al., 2012), which is thought to depend on a network of frontal, parietal and cerebellar regions (Awh et al., 1996; Desmond, Gabrieli, Wagner, Ginier, & Glover, 1997; Jonides et al., 1998; Paulesu, Frith, & Frackowiak, 1993; Schumacher et al., 1996; Trost & Gruber, 2012). Many standard neuropsychological tests of STM, such as Corsi Blocks and Letter-Number Sequencing, similarly may make limited demands on the integration and/or maintenance of bound information, which may explain why performance on these tasks is unaffected by MTL lesions.

Finally, on a different note, findings of impaired STM in amnesia raise questions regarding the potential contribution of perceptual impairments to deficits in STM. This issue is particularly compelling in light of our finding that the STM impairment was specifically linked to damage to anterior subhippocampal cortices. Anterior subhippocampal cortex, and specifically perirhinal cortex, has been implicated, not only in mnemonic processing, but also in perceptual processing of complex visuospatial stimuli including faces (Barense, Henson, Lee, & Graham, 2010; Iidaka, Harada, Eifuku, Nakata, & Sadato, 2012; Lee, Scahill, & Graham, 2008; Preston et al., 2010; Schultz et al., 2012). Some of this evidence has come from studies showing that patients with MTL lesions involving perirhinal cortex show impaired performance on perceptual tasks that involve discrimination of stimuli with

high feature overlap, which therefore require integration of features (Graham, Barense, & Lee, 2010). It has been argued that apparent STM deficits for complex visual stimuli in amnesia may actually be the consequence of perceptual impairments (Graham et al., 2010). The finding of preserved face matching in the current study provides evidence against this interpretation of our results (see also Ezzyat & Olson, 2008). One could argue however, that we cannot exclude the possibility of subtle perceptual impairment in our patients, which might manifest only in face matching tasks that use stimuli with higher feature ambiguity than did ours. By this view, it is possible that the face representations formed by the amnesic patients in our study were less robust than those of healthy individuals. As a consequence, amnesics' face representations may have been susceptible to accelerated degradation, leading to impaired short-delay matching performance (Olsen et al., 2012; Warren, Duff, & Trannel, 2011). This argument, however, begs the question as to whether accelerated degradation is better characterized as a deficit in perception or STM. The question as to how best characterize the impairment in short-delay visuospatial memory tasks in amnesia is likely to continue to generate vigorous debate, but it is noteworthy that MTL-mediated configural-relational processing is a central tenet on both sides of the debate.

Conclusions

In summary, our findings demonstrate impaired performance in amnesia on a short-delay face matching task that meets both a traditional time-based as well as an interference-based criterion for classification as a STM task. By demonstrating in healthy individuals that the extent to which performance is disrupted by interference depends on the configural processing demands of the distractor task, our findings point to impaired MTL-mediated configural processing as a possible source of the observed STM impairment in the present study. Finally, the absence of impairment in patients with documented lesion limited to the hippocampus suggests that the STM impairment for faces may be specifically linked to subhippocampal cortices. These findings point to the necessary role of MTL structures in STM and highlight that their contribution can best be understood with reference to the types of binding operations required.

Acknowledgments

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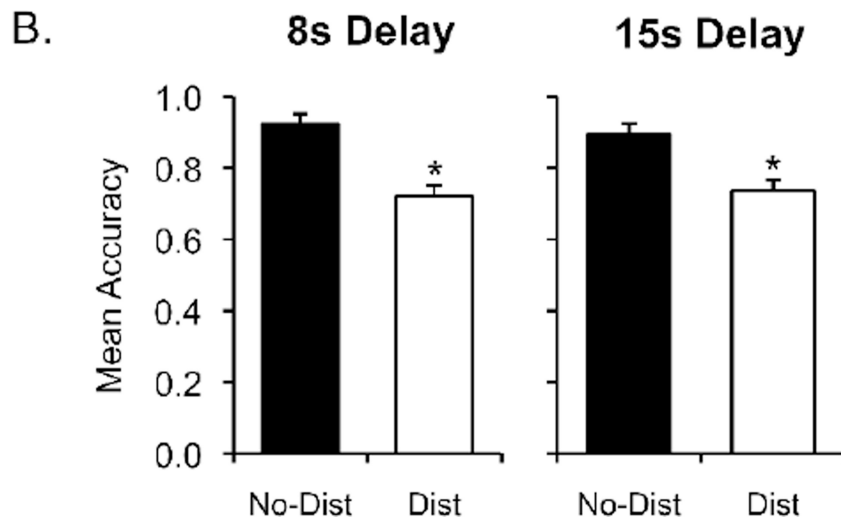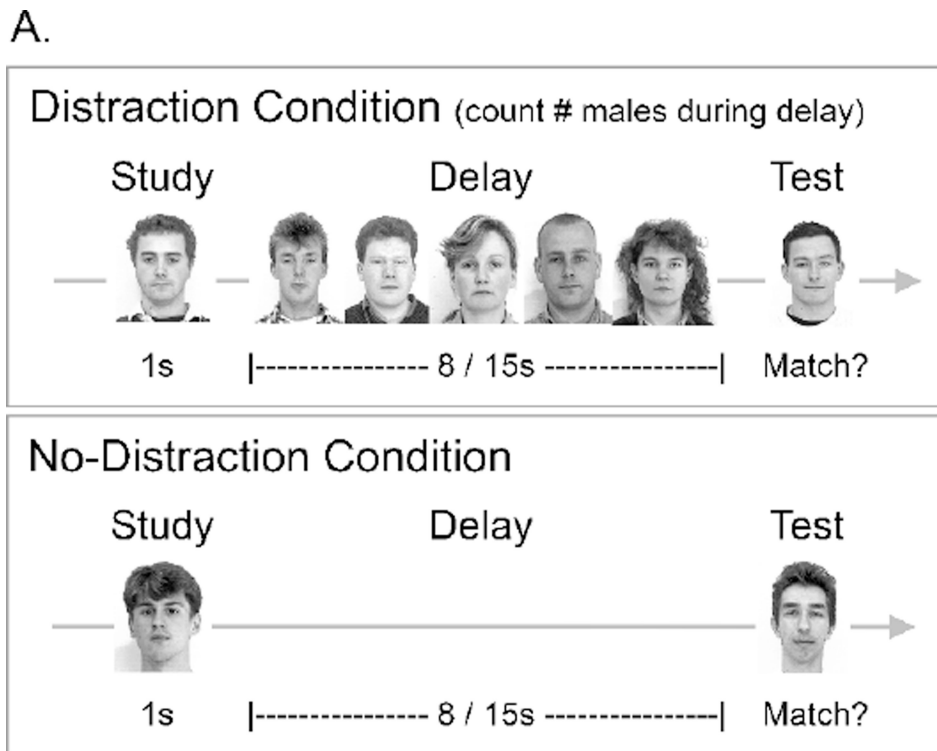
A.

B.

Figure 1.
(A) Experiment 1 task design. (B) Results from Experiment 1. Mean accuracy (hits – false alarms) for healthy participants on the delayed face matching-to-sample task at 8s and 15s delays without distraction (black bars) and with distraction (white bars). Error bars represent within-subject standard error. * $p < .005$ compared to performance without distraction.
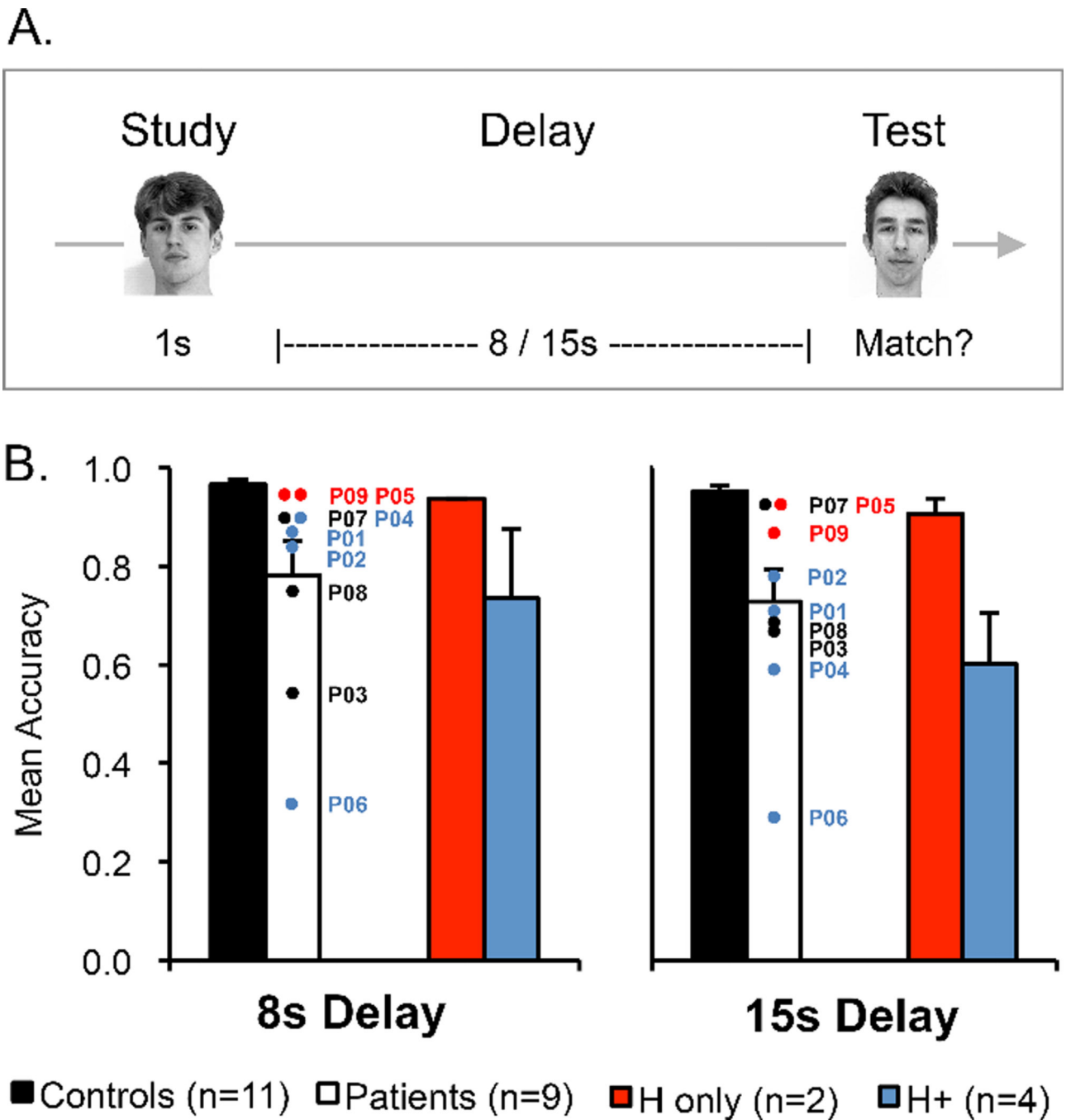
Figure 2.
(A) Experiment 2a task design. (B) Results from Experiment 2a. Mean accuracy (hits – false alarms) for controls (black bars), the whole amnesic patient group (white bars), amnesic patients with confirmed MTL damage limited to the hippocampus (H-only; red bars), and amnesic patients with MTL damage that included the hippocampus and subhippocampal cortex (H+; blue bars) on the 8s and 15s delayed face matching-to-sample task without distraction. Error bars indicate SEM.
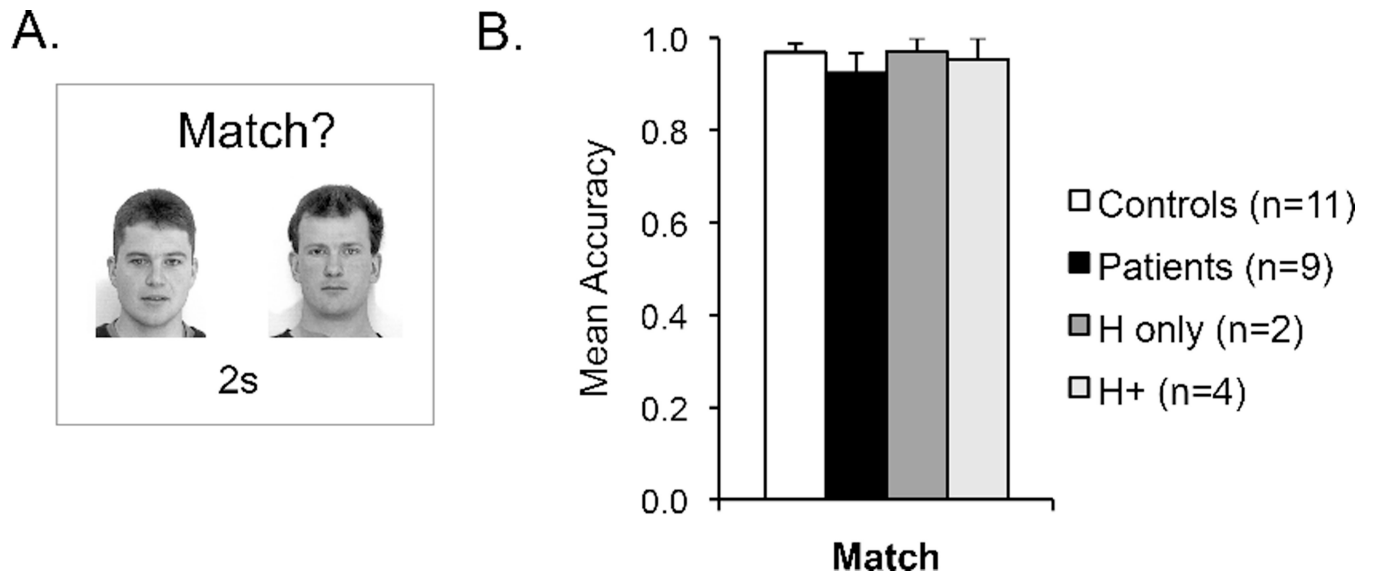
Figure 3.
(A) Experiment 2b task design. (B) Results from Experiment 2b. Mean accuracy (hits – false alarms) for healthy controls (white bar), the whole amnesic patient group (black bar), amnesic patients with confirmed MTL damage limited to the hippocampus (H only; dark grey bars), and amnesic patients with MTL damage that included the hippocampus and subhippocampal cortex (H+ group; light grey bars) on the face matching task. Error bars indicate SEM.
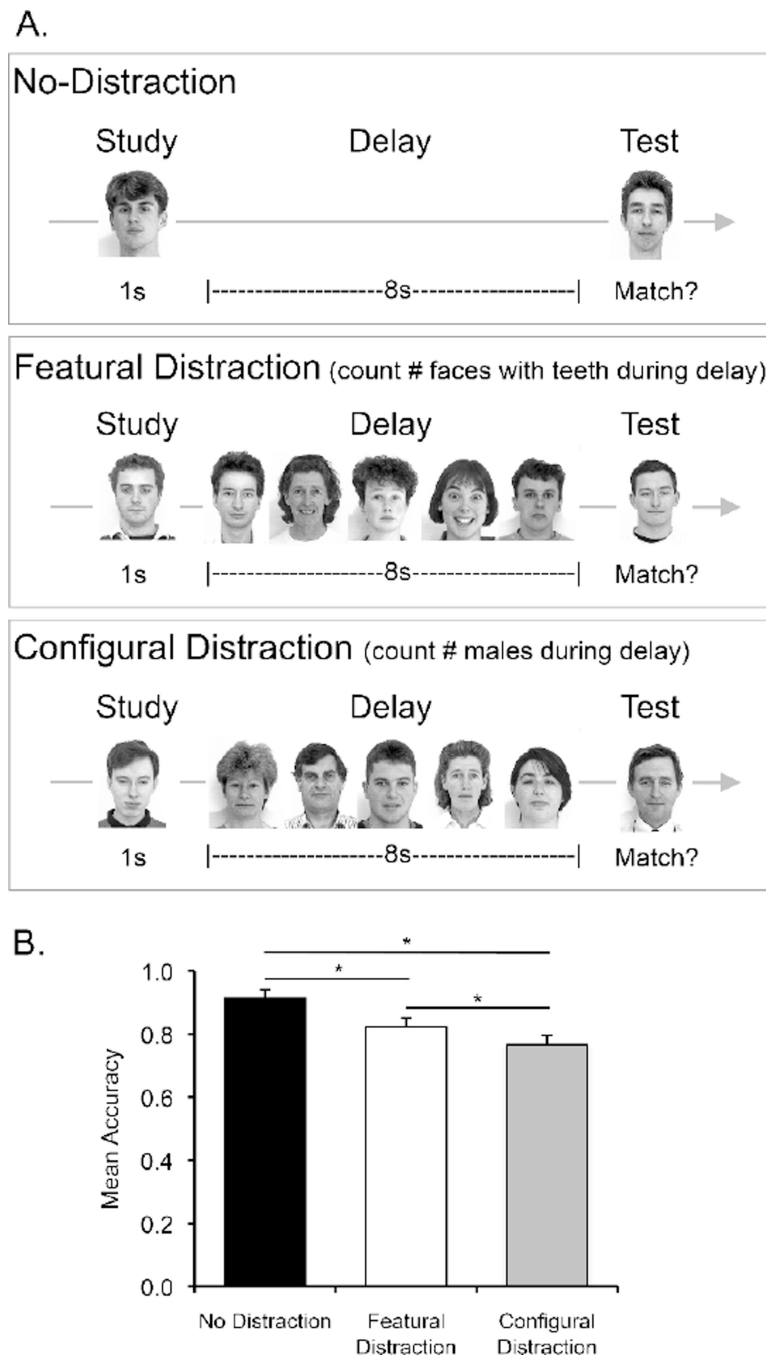
Figure 4.
(A) Experiment 3 task design. (B) Results from Experiment 3. Mean accuracy (hits – false alarms) for healthy controls on a 8s delayed face matching-to-sample task with no-distraction (black bar), featural distraction (white bar), and configural distraction (grey bar). Error bars represent within-subject standard error. * $p < .05$ (1-tailed).

Table 1

Patient Demographic, Neuropsychological and Neurological Characteristics

Patient	Etiology	Age	Edu	WAIS,III	WMS,III				Hipp Vol Loss	Subhipp Vol Loss
				VIQ	GM	VD	AD	WM		
P01	Encephalitis	55	14	92	45	56	55	85	73%	78%*
P02	Encephalitis	66	12	106	69	68	77	111	66%	72%+
P03	Anoxia	60	12	83	52	56	55	91	N/A	N/A
P04	Anoxia + left temporal lobectomy	46	16	86	49	53	52	93	63%	60%^
P05	Anoxia	54	14	111	59	72	52	96	22%	-
P06	Encephalitis	82	18	135	45	53	58	141	N/A	N/A
P07	Anoxia	58	17	134	70	75	67	126	N/A	N/A
P08	Anoxia	60	16	110	62	68	61	92	N/A	N/A
P09	Anoxia	55	18	119					58%	-

Note. Age = Age (years); Edu = Education (years); WAIS, III = Wcchslcr Adult Intelligence Scale. III; VIQ = Verbal IQ; WMS, III = Wcchslcr Memory Scale. III; GM = General Memory; VD = Visual Delayed; AD = Auditory Delayed; WM = Working Memory; Hipp Vol Loss = Bilateral Hippocampal Volume Loss; Subhipp Vol Loss = Parahippocampal Gyrus Volume Loss;

*
= volume loss in bilateral anterior parahippocampal gyrus and left posterior parahippocampal gyrus.

+
= volume loss in bilateral anterior parahippocampal gyrus and right posterior parahippocampal gyrus.

^
= volume loss in left anterior parahippocampal gyrus.