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Learned control over distraction is disrupted in amnesia

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Abstract

Recent studies have demonstrated that brief periods of training facilitate the ability to overcome distraction upon future encounters with a given task, and these effects have been proposed to rely on relational memory systems that enable individuals to link specific attentional states to their learned context. In the current work we examined whether medial temporal lobe (MTL) structures critical for relational and contextual learning participate in driving these effects. A group of amnesic patients with bilateral MTL damage and a group of matched comparisons both completed an attentional capture task in which a brief training session typically leads to decreased distraction in a subsequent testing session. Whereas comparisons showed normal training-related decreases in distractibility, amnesic patients did not, indicating that MTL-mediated learning plays a critical role in the ability to use past experience to overcome distraction. This suggests a tight linkage between MTL-dependent relational learning mechanisms and cognitive control.

Keywords

Attentional Capture; Relational Memory; Medial-Temporal Lobe; Distraction; Amnesia

Theories of attention and cognitive control typically propose that the ability to implement goal-directed control over distraction relies primarily on prefrontal working memory mechanisms responsible for actively maintaining immediate task priorities (Desimone & Duncan, 1995; Miller & Cohen, 2001). However, it has also been proposed that goal-directed control can operate more or less automatically on the basis of learned task representations, suggesting a complementary control mechanism that might attenuate distraction without relying on limited-capacity executive processes such as working memory (Norman & Shallice, 1986; Schenider & Shiffrin, 1977; Logan, 1988). Consistent with such a view, recent studies have demonstrated that past experience plays a critical role in determining distraction (e.g., Leber & Egeth, 2006; Vatterott & Vecera, 2012), and it has been shown that these effects reflect relational learning processes that tie information regarding particular attentional states to their learned context (Cosman & Vecera, 2012; Leber, Kawahara, & Gabari, 2009).

Medial temporal lobe (MTL) structures are critical for general relational encoding (Cohen & Eichenbaum, 1993; Konkel et al., 2008), and MTL damage has been shown to disrupt relational influences on gaze and attentional control in particular (Ryan, Althoff, Whitlow, & Cohen 2000; Chun & Phelps, 1999). These deficits likely arise from an inability to effectively represent the relationships between disparate perceptual elements in the

environment, leading to an inability to effectively use relational information in the service of attentional control. In addition to encoding perceptual relationships, it may be the case that the MTL is also important for the experience-dependent linkage of internal attentional states with the context in which they occur. Here, we show that amnesic patients with bilateral MTL damage fail to use past experience to overcome distraction during an attentional capture task, despite their generally normal ability to overcome distraction during a training session. This indicates a novel role for MTL memory structures in goal-directed attentional control processes typically thought to rely primarily on prefrontal cortex, and suggests that relational memory systems are critical for establishing long-term representations responsible for driving attentional control.

Method

Four densely amnesic patients with bilateral MTL damage, and four age- and sex-matched neurologically healthy comparisons, performed a visual search task known to show robust influences of past experience on distraction by a salient, task-irrelevant distractor item (Leber & Egeth, 2006; Figure 1a). Participants first completed a training session where they were instructed to search for a circle among *heterogeneously* shaped non-targets (diamonds, squares, and triangles), reporting the orientation of a line embedded inside of the circle. This session was directly followed by a testing session in which the task was identical, but the search array was composed of *homogeneously* shaped diamond non-targets. In both sessions, participants were told to ignore a salient red distractor item that appeared unpredictably on half the trials (see supplementary methods for further patient and task details).

When the homogeneous search task is performed in isolation the salient distractor interferes strongly with task performance, with robust distraction being the default under these particular stimulus conditions (Theeuwes, 1992, 2010; Kawahara, 2010). Conversely, in the heterogeneous search task interference from the distractor is minimal, owing to the increased strength and specificity with which goal-directed cognitive control processes operate to bias competition in favor of the target under these stimulus conditions (e.g., Bacon & Egeth, 1994). Critically, when neurologically healthy participants train briefly on the heterogeneous search task prior to the homogeneous search task, as in the current design, distractor effects in homogeneous displays are similarly attenuated (Leber & Egeth, 2006). These effects of learning on attentional control appear to be long-term, persisting across delays of up to a week (Leber et al., 2009), and are strongly context-dependent (Cosman & Vecera, 2012). Of primary interest in the current work was whether, relative to healthy comparisons, amnesic patients would show an impaired ability to use past experience to overcome attentional capture following a brief (~5 minute) delay between heterogeneous training and homogeneous testing sessions.

Results

Correct reaction times greater than 3SDs above individual means were eliminated from further analysis in each group, resulting in a loss of 1% of the data in normal comparison participants and 3% of the data in the patient group. Given our small sample size, mean correct reaction times and error rates for training and testing sessions (Figure 1b) were analyzed using non-parametric permutation tests (Good, 1994) similar to those used in previous studies involving small-sample neuropsychological methods (see Olson et al., 2006; Berryhill & Olson, 2008; Konkel et al., 2008). In order to perform these tests, we conducted a standard parametric mixed-model ANOVA on both RT and error rate data to obtain F statistics. In order to calculate significance values, we randomly permuted RT/error data across each independent variable (group or distractor presence), and recomputed a new F-statistic on the permuted data. We repeated this process 1000 times, and used the one-

tailed proportion of F-scores that fell above that of the initial F-test as the level of significance (the p-values reported below). An analogous procedure was employed for planned comparisons (t-tests), and all statistical procedures were carried out in MATLAB.

For training RTs, there was no main effect of distractor presence ($F(1,6) < 1$, $p = .77$) but a marginally significant effect of participant group was observed, $F(1,6) = 91.8$ $p < .07$, (amnesics $\bar{x} = 1575$ ms ($\sigma = 462$), comparisons $\bar{x} = 1073$ ms ($\sigma = 298$)), and looking at the individual data in Table 1 it can be seen that, with the exception of one particularly slow amnesic patient and one particularly fast comparison, RTs were generally similar across individuals in each group during training. Importantly, there was no interaction between group and distractor presence, indicating that the amnesic patients were not generally more distractible than comparisons ($F(1,6) < 1$, $p = .63$). Further, this lack of an interaction wasn't due to a simple ceiling effect in the amnesic patients; even in the fastest quartile of RTs there were no significant differences in RT for distractor present vs. absent trials, $t(3) < .47$, $p = 0.33$, and there was no evidence of distraction in even the fastest responding amnesic patients.

For testing RTs, we observed a significant effect of group, $F(1,6) = 129.4$ $p < .05$, (patient group $\bar{x} = 1285$ ms ($\sigma = 327$), comparison $\bar{x} = 965$ ms ($\sigma = 186$)), but not distractor presence $F(1,6) = 3.8$ $p = .10$. However, during testing we also observed a significant interaction between group and distractor presence, $F(1,6) = 6.2$ $p < .05$ with a significant capture effect in the amnesic patients (131ms, $t(3) = 2.28$, $p = .05$) but not comparisons (-15ms, $t(3) = 1.6$, $p = .18$; see Figure 2), indicating that the amnesic patients failed to use past experience to overcome attentional capture. There were no significant effects observed for error rates across either training or testing sessions.

Finally, in order to rule out the possibility that comparisons' lack of capture during testing arose due to an inability of our stimuli to generate capture effects, a separate group of healthy comparisons ($n = 10$) completed only the testing portion of the experiment in the absence of training. We observed a robust capture effect, with slower RTs on trials in which the salient distractor was present (803ms), compared to when it was absent (775ms), $t(9) = 3.8$, $p = .004$, demonstrating that the lack of attentional capture during the testing session in the comparison participants is the result of a learning process and not an idiosyncrasy in our task.

Discussion

The fact that amnesic patients showed a normal ability to overcome distraction during the training session argues against interpretations of these results in terms of non-specific attentional impairments or impaired on-line representation of task priorities, instead indicating a novel role for the medial temporal lobes in the acquisition of learned control over distraction. With respect to the mechanisms of this effect, we propose that sufficient experience with a given task leads to the formation of a memory trace that links the internal state of the attentional system to contextual attributes of the task being performed, influencing control upon future encounters with that task (Cosman & Vecera, 2012). Such a view is broadly consistent with theories of automaticity and attentional control proposing that task experience leads to the rapid acquisition of episodic traces that can be used in the service of goal-directed control (Logan, 1988; 2002).

Furthermore, recent studies have demonstrated extensive overlap in the brain systems responsible for the goal-directed control of attention to both perceptual inputs and episodic memory representations (see Cabeza et al., 2008). The current results suggest a bi-directional relationship between the mechanisms subserving goal-directed attentional control

and episodic memory processes, raising the possibility that “attentional episodes” linked to performance of a particular task may directly influence cognitive control processes responsible for overcoming distraction by task-irrelevant information upon future encounters with the same or similar tasks. However, given that we have recently shown in a nearly identical task that learned control effects such as these arise regardless of awareness (Cosman & Vecera, 2012), we hesitate to call these episodic memory effects *per se* since explicit awareness is often considered to be requisite for episodic memory proper (e.g., Squire, 1992). Instead, we argue that MTL-dependent relational memory mechanisms important for encoding relationships between stimuli in the environment may also participate in linking internal attentional states with the context in which they arise, even when these relationships occur implicitly (see Cosman & Vecera, 2012; Olsen et al., 2012). In this way, MTL structures may enable the rapid acquisition and storage of distributed relational representations of a task that may then be used to supplement more ‘discrete’ working memory representations typically thought to drive attentional control processes (e.g., “target templates” Desimone & Duncan, 1995).

Although an explanation in terms of relational learning deficits fits well with the proposed functions of the MTL, a possible alternative exists. Specifically, it may be the case the rather than the MTL being necessary for attentional learning in our task, it may instead be involved more broadly in overriding attentional capture during homogeneous visual search tasks such as that used in the testing session. Under this view, it is possible that training on the heterogeneous search task actually did decrease capture relative to baseline in the amnesics, but this was insufficient to entirely override capture during the homogeneous testing session. Thus it may be the case that the medial temporal lobe is involved in attenuating capture in homogeneous search displays regardless of past experience, and damage to the MTL may have influenced on-line attentional control during the testing session rather than influencing control through impaired learning.

However, given the large magnitude of the capture effects observed in amnesics during the testing session, as well as the intact ability of these patients to overcome distraction during the training session, it seems unlikely that the training session had more than a minimal influence on attentional capture during testing. Nevertheless, it is impossible to rule out this possibility with the current dataset, and it would thus be beneficial for future work to probe non-mnemonic accounts of MTL involvement in attentional control. Regardless of the precise mechanism, the current work provides strong evidence that the medial temporal lobe memory system can directly participate in the goal-directed control of visual attention, and offers one means through which past experience may influence control over distraction by salient, task-irrelevant visual information.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
An example of the displays and timing parameters used during training and testing sessions.

Figure 2.

Overall reaction time and error rates (bottom of each column) for each condition of interest in both healthy comparisons and amnesic patients during the training and testing sessions. Error bars represent 95% confidence intervals calculated for each within-subject factor (Cousineau, 2005; Morey, 2008).

Figure 3. Magnitude of distractor-related slowing for each group during training and testing sessions, calculated by subtracting distractor absent from distractor present reaction times. Circles indicate distractor effects of individual participants in each group.

Table 1
Average Reaction Time by Condition and Group

	Training		Testing	
	Distractor Absent	Distractor Present	Distractor Absent	Distractor Present
Patients				
MTL 1	2298	2278	1577	1868
MTL 2	1490	1487	1165	1286
MTL 3	1126	1127	885	903
MTL 4	1407	1388	1251	1345
Comparisons				
HC 1	1493	1500	1162	1137
HC 2	1012	999	912	875
HC 3	1323	1380	1090	1112
HC 4	790	790	726	701