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Research report

The hippocampus plays a role in the recognition of visual scenes presented at behaviorally relevant points in time: Evidence from amnestic mild cognitive impairment (aMCI) and healthy controls

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ABSTRACT

When people perform an attentionally demanding target task at fixation, they also encode the surrounding visual environment, which serves as a context of the task. Here, we examined the role of the hippocampus in memory for target and context. Thirty-five patients with amnestic mild cognitive impairment (aMCI) and 35 healthy controls matched for age, gender, and education participated in the study. Participants completed visual letter detection and auditory tone discrimination target tasks, while also viewing a series of briefly presented urban and natural scenes. For the measurement of hippocampal and cerebral cortical volume, we utilized the FreeSurfer protocol using a Siemens Trio 3 T scanner. Before the quantification of brain volumes, hippocampal atrophy was confirmed by visual inspection in each patient. Results revealed intact letter recall and tone discrimination performances in aMCI patients, whereas they showed severe impairments in the recognition of scenes presented together with the targets. Patients with aMCI showed bilaterally reduced hippocampal volumes, but intact cortical volume, as compared with the controls. In controls and in the whole sample, hippocampal volume was positively associated with scene recognition when a target task was present. This relationship was observed in both visual and auditory conditions. Scene recognition and target tasks were not associated with executive functions. These results suggest that the hippocampus plays an essential role in the formation of memory traces of the visual environment when people concurrently perform a target task at behaviorally relevant points in time.

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1. Introduction

According to the traditional method of experimental psychology, investigators use a target task that captures the central focus of attention (James, 1890). Recently, it has been demonstrated that images that are exposed together with targets of an unrelated task are better recalled than images that are presented with behaviorally irrelevant distractors or alone (Lin et al., 2010; Swallow and Jiang, 2010). A possible explanation is that attention boosts not only the target task but also the encoding of its background context. For example, Swallow and Jiang (2010) presented a series of photographs of natural and urban scenes with a distractor or a target and asked participants to remember these images. Concurrently with the scene encoding task, participants pressed a key when a colored square appeared in the middle of the images, an odd auditory tone was exposed, or a red "X" embedded among other colored letters were detected. Surprisingly, the target task did not disturb scene encoding. In contrast, participants displayed better memory for scenes presented together with the target task than for scenes presented with irrelevant distractors (Swallow and Jiang, 2010).

Lin et al. (2010) asked the participants to complete an attentionally demanding letter detection or auditory tone discrimination target task, while also viewing a series of briefly presented natural and urban scenes. When there was no target task, memory recall for the scenes was at chance level. However, participants remembered the scenes surprisingly well when they were presented concurrently with a target task at fixation. Lin et al. (2010) concluded that visual scenes outside the spatial focus of attention are encoded at behaviorally relevant points in time, although this task is not suitable for disentangling encoding and retrieval.

Swallow and Jiang (2010) called this phenomenon the attentional boost effect. However, its mechanism has not been clarified. There are at least three potential explanations (Swallow and Jiang, 2011). The first possibility is a simple attentional cuing effect. In target detection tasks, behaviorally relevant events elicit an attentional orienting response, which enhances not only the target event, but also the processing of stimuli that are presented concurrently with the target (Duncan, 1980). The second possibility implies that the target generates a reward signal (Seitz and Watanabe, 2009), and following the rules of reinforcement learning, scenes that are presented with targets may be reinforced because they signal the rewarding event. The third possibility is a perceptual grouping mechanism, assuming that if scenes and targets are bound together as a single perceptual object, then enhanced attention to one part of it (i.e., to the target) will also lead to increased attention to the other part of the object, in this case, the scene (Driver and Baylis, 1989). However, Swallow and Jiang (2011) demonstrated that these three mechanisms could not fully explain the attentional boost effect in a simple and parsimonious manner. First, targets and context images must overlap in time for the enhancement of memory (targets appearing 100 msec before or 100 msec after the image without temporal overlap do not facilitate memory of the contextual image), but they need not be synchronized (no need of common onset for target and context image, which is an important grouping cue). This suggests that perceptual grouping cannot fully explain the effect. Second, the overlap of the target and context image is not sufficient; focused attention to targets did not enhance memory for task-irrelevant images when participants are asked to ignore background scenes, which suggests that focused attention to target does not boost background scene encoding under all circumstances and it can be intentionally inhibited (Swallow and Jiang, 2011).

Swallow and Jiang (2011) suggested that grouping might occur after perceptual processing when the item is bound to the context in memory (see also Polyn and Kahana, 2008). According to the item-in-context theory, the medial temporal lobe, including the hippocampal formation, is essential for the encoding of objects in their appropriate context (Dickerson and Eichenbaum, 2010; Eichenbaum et al., 2007). In the above-described paradigm, the target may refer to the item, and the background scene may represent the context. In the present study, we explored the role of the hippocampus in the encoding and retrieval of targets and background scenes. We used two complementary approaches. First, we examined the relationship between hippocampal volume and scene recognition performance in healthy volunteers. Second, we investigated scene recognition in patients with amnestic mild cognitive impairment (aMCI) who exhibit marked hippocampal atrophy and declarative memory impairments (Collie and Maruff, 2000; Gauthier et al., 2006; Petersen et al., 1999; Shi et al., 2009). The main hypothesis was that the atrophy of the hippocampal region in aMCI disrupts the integration of target and scene and primarily affects context encoding (Dickerson and Eichenbaum, 2010). In addition, given that some patients with aMCI show deficits in attention and executive functions (Kramer et al., 2006; Levy-Gigi et al., 2011; Price et al., 2010), we also investigated the relationship between executive and attentional functions and performance on the target task. This is an important control condition because if patients fail to recall the target, scene recognition deficits can be the result of generalized cognitive dysfunctions and not a specific item-context binding deficit. Finally, we tested the perception and short-term recall of single scenes in aMCI in order to exclude the possibility that patients are not able to reconstruct and retrieve briefly presented complex visual information.

2. Materials and methods

2.1. *Participants*

Thirty-five individuals with aMCI and 35 healthy controls participated in the study (Table 1). We used the Mayo Clinic Alzheimer's Disease Research Center criteria for the diagnosis of aMCI (Knopman et al., 2003; Petersen et al., 1999): "A. The presence of a new memory complaint, preferably corroborated by an informant; B. Objective evidence of impairment of short-term memory (for age); C. Normal general cognitive functions; D. No substantial interference with work, usual social activities, or other activities of daily living; E. No dementia." (Knopman et al., 2003) Exclusion criteria included history of neurological or psychiatric disorders, head trauma,