Brain and Cognition 76 (2011) 369–381

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

The neural correlates of everyday recognition memory

F. Milton [a,*], N. Muhlert [b], C.R. Butler [c], A. Benattayallah [d], A.Z. Zeman [a,b]

[a] Department of Psychology, University of Exeter, Exeter, UK
[b] Department of Neurology, Peninsula Medical School, University of Exeter, UK
[c] University of Oxford, Oxford, UK
[d] Peninsula MR Research Centre, Peninsula Medical School, Exeter, UK

ARTICLE INFO

Article history:
Accepted 12 April 2011
Available online 10 May 2011

Keywords:
fMRI
Recognition memory
SenseCam
Recollection
Familiarity

ABSTRACT

We used a novel automatic camera, SenseCam, to create a recognition memory test for real-life events. Adapting a 'Remember/Know' paradigm, we asked healthy undergraduates, who wore SenseCam for 2 days, in their everyday environments, to classify images as strongly or weakly remembered, strongly or weakly familiar or novel, while brain activation was recorded with functional MRI. Overlapping, widely distributed sets of brain regions were activated by recollected and familiar stimuli. Within the medial temporal lobes, 'Remember' responses specifically elicited greater activity in the right anterior and posterior parahippocampal gyrus than 'Know' responses. 'New' responses activated anterior parahippocampal regions. A parametric analysis, across correctly recognised items, revealed increasing activation in the right hippocampus and posterior parahippocampal gyrus (pPHG). This may reflect modulation of these regions by the degree of recollection or, alternatively, by increasing memory strength. Strong recollection elicited greater activity in the left posterior hippocampus/pPHG than weak recollection indicating that this region is specifically modulated by the degree of recollection.

1. Introduction

Recognition memory enables us to judge that a current stimulus has been encountered previously. It is widely thought to be facilitated by two distinct processes: *recollection*, the process by which items are recognized on the basis of the retrieval of contextual details; and *familiarity*, the process by which items are recognized on the basis of perceived memory strength (Mandler, 1980). An alternative view proposes that, rather than reflecting distinct underlying processes, familiarity and recollection differ in the strength of a common memory signal (e.g., Dunn, 2004).

The neural correlates of recognition memory have recently been subject to intense investigation using functional imaging techniques. The majority of these imaging studies have used laboratory stimuli. Thus, such studies have examined the ability to recognize words (Eldridge, Knowlton, Furmanski, Bookheimer, & Engel, 2000), faces (Gonsalves, Kahn, Curran, Norman, & Wagner, 2005), objects (Vilberg & Rugg, 2007), and visual scenes (Montaldi, Spencer, Roberts, & Mayes, 2006).

Several approaches have been taken to distinguish the processes of recollection and familiarity. These include the use of confidence ratings, associative recognition, source memory, and the remember–know (R–K) paradigm (for a review, see Yonelinas, 2002). We adopted the last of these here. The R–K paradigm (Tulving, 1985) requires participants to specify whether an item is recognized on the basis of familiarity alone ('know' judgment) or whether they can recollect contextual details from their original encounter with the item ('remember' judgment). While the underlying conceptual distinction between familiarity and recollection is clear, it is likely that everyday recognition commonly engages both processes to some degree.

Studies using the R–K paradigm have often found increased hippocampal and posterior parahippocampal gyrus (pPHG) activity for remember compared with know responses (Eldridge et al., 2000; Wais, 2008; Woodruff, Johnson, Uncapher, & Rugg, 2005). By contrast, familiarity is typically linked to perirhinal and anterior parahippocampal (aPHG) regions (Henson, Cansino, Herron, Robb, & Rugg, 2003; Strange, Hurlemann, Duggins, Heinze, & Dolan, 2005). These regional activations broadly support *dual-process* accounts of recognition memory (Aggleton & Brown, 1999; Diana, Yonelinas, & Ranganath, 2007), which propose that recollection is supported by the hippocampus and pPHG, whereas familiarity is supported by aPHG, and in particular the perirhinal cortex.

Recent evidence has suggested that brain activation during recollection and familiarity may be modulated by the strength of these processes. For example, Vilberg and Rugg (2007) found that the extent of neural activation during recollection varied with the amount of detail recollected. Specifically, Vilberg and Rugg identified regions activated by recollection which were sensitive to the amount of information recalled in the right precentral gyrus,

* Corresponding author. Address: Washington Singer Laboratories, University of Exeter, Exeter EX4 4QG, UK.

E-mail address: f.n.milton@ex.ac.uk (F. Milton).

0278-2626/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandc.2011.04.003

left fusiform gyrus and left inferior lateral parietal cortex. Medial temporal lobe (MTL) activation was not modulated by memory strength or amount of information recalled. In contrast, Staresina and Davachi (2008) found that left hippocampal activity increased relative to the number of pieces of contextual information retrieved. In a study investigating levels of familiarity, increasing familiarity resulted in linearly decreasing activation in the perirhinal cortex, insula and left superior temporal cortex (Montaldi et al., 2006). However, the level of familiarity had no effect on hippocampus activation. These findings are broadly in line with dual-process accounts of recognition memory.

Some studies, however, have failed to support the distinction between recollection and familiarity processes. For instance, Gonsalves et al. (2005) found a graded decrease in activation in the parahippocampal and perirhinal cortices corresponding to the distinctions between remembered items, which elicited maximal suppression, known items and new items, which elicited the least suppression. This suggests that memory strength is signalled by levels of activity in both perirhinal and parahippocampal cortices.

The majority of previous recognition memory studies have used lab-based stimuli. However, some recent work has examined the neural substrates of more naturalistic forms of recognition memory (Cabeza et al., 2004; Epstein & Higgins, 2007; St. Jacques, Rubin, LaBar, & Cabeza, 2008). For instance, Cabeza et al. (2004), asked participants to take photos in specified campus locations, and subsequently scanned them whilst they distinguished between pictures they had taken and pictures of the same places taken by other participants. Results showed greater activation for their own pictures in the medial prefrontal cortex, pPHG, and in the hippocampus. Nevertheless, this study was not specifically designed to explore the neural basis of recollection and familiarity memory. Furthermore, the method of stimulus acquisition (i.e., participants actively taking photos) encouraged greater intentional encoding of the scenes than is typically the case for real-life memory encoding. Investigating the neural processes underlying different types of recognition memory in less artificial circumstances is a natural next step.

The current study used automatically captured everyday images and a modified R–K technique, assessing the strength of recollection and familiarity, to examine the functional imaging correlates of human recognition memory. Images of everyday scenes were captured by a novel wearable camera, SenseCam (Hodges et al., 2006), which is activated by a range of environmental sensors and takes on average one image every 30 s (Berry et al., 2007). The resulting photographic diary of the day's activities allowed assessment of memory for everyday scenes taken without user involvement.

The use of SenseCam has a number of advantages in the study of everyday recognition memory. First, the automatic capture of images reduces the intentional encoding of the items that will be tested later. Second, SenseCam provides an opportunity to study recognition of everyday scenes and events which differ in several ways from laboratory stimuli: they are typically of greater perceptual complexity, are likely to encourage more extensive processing of spatial information and are more personally relevant. Third, the richness of stimuli from an everyday environment and the potential wealth of associations are likely to result in the retrieval of varying levels of contextual information, facilitating comparisons between memories which vary in their strength of recollection. This final opportunity is linked to a potential disadvantage of these stimuli in the study of the contrast between recollection and familiarity: in everyday surroundings, processes of familiarity and recollection are intertwined. In particular, images which are classified as 'familiar' in our study depict scenes which may have supplied the context for recollection of pre-experimental memories: this potentially complicates interpretation of some of our results.

SenseCam images were presented during functional magnetic resonance imaging to participants who indicated whether the photos were strongly or weakly recollected, strongly or weakly familiar, or novel. Using this approach, we address the following questions: (i) Which brain regions support recognition memory for everyday events? (ii) Is activity in these brain regions modulated across memory types (Weak Know, Strong Know, Weak Remember, Strong Remember)? (iii) Is there evidence for a dissociable pattern of activation within different regions of the MTL? (iv) How does the pattern of activity for everyday recognition memory relate to theories developed on the basis of standard laboratory based experiments?

2. Method

2.1. Participants

Fifteen right-handed, healthy, participants who were students at the University of Exeter (eight male, seven female), ranging in age from 18 to 25 years, took part in the study. Participants were paid £15 for their participation. All participants gave informed consent.

2.2. fMRI data acquisition

Images were collected using a 1.5-T Phillips Gyroscan magnet, with a Sense coil. A T2*-weighted echo planar sequence was used (Tr = 3000 ms, Te = 45 ms, flip angle = 90°, 32 transverse slices, $3.5 \times 2.5 \times 2.5$ mm). Two hundred and eighty volumes were acquired in each of the two runs per subject. An additional five "dummy" scans were performed before each run prior to the start of the stimulus sequence. Standard volumetric anatomical MRI was performed after functional scanning by using a 3-D T1-weighted pulse sequence (Tr = 25 ms, Te = 4.1 ms, flip angle = 30°, 160 axial slices, $1.6 \times 0.9 \times 0.9$ mm).

2.3. Equipment

The SenseCam (sized 6.5 cm wide × 7 cm high × 1.5 cm long; see Fig. 1a) is built around a PIC 18F8722 6 MIPS microcontroller with 128 KB of flash memory (Hodges et al., 2006). SenseCam is worn round the neck, with pictures captured using a fish eye lens. This maximizes the field-of-view and ensures that objects at head height were photographed. Images were captured automatically approximately every 30 s.

2.4. Procedure

Participants wore a SenseCam for 2 days whilst undertaking their everyday activities. Participants were encouraged to participate on days when they would be active and this instruction was repeated on collection of the camera. All participants complied with this request and experienced a number of unique events which took place in diverse locations. The camera was returned the following day and the images processed. Approximately 36 h after wearing the camera, participants completed the scanning session.

The events recorded by participants were all characteristic of everyday experiences. In other words, the personal significance of events was low and generally consistent across participants. Images were excluded from the selection process if they were of poor quality (usually induced by excessive movement), of ambiguous locations (e.g., ceilings, floors, non-distinct buildings), if they showed the identical event to a previous image, or if they were likely to be of high personal significance or emotionality (no