Neuropsychologia 46 (2008) 2958–2965

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Medial prefrontal cortex plays a critical and selective role in 'feeling of knowing' meta-memory judgments

Mandana Modirrousta*, Lesley K. Fellows

Department of Neurology and Neurosurgery, McGill University, Montreal Neurological Institute, 3801 University Street, Montreal, Quebec H3A 2B4, Canada

ARTICLE INFO

Article history:
Received 1 October 2007
Received in revised form 30 May 2008
Accepted 8 June 2008
Available online 21 June 2008

Keywords:
Episodic memory
Frontal lobes
Anterior cingulate cortex
Human
Lesion

ABSTRACT

The frontal lobes are thought to play a role in the monitoring of memory performance, or 'meta-memory', but the specific circuits involved have yet to be definitively established. Medial prefrontal cortex in general and the anterior cingulate cortex in particular, have been implicated in other forms of monitoring, such as error and conflict monitoring. Here, we tested the hypothesis that medial prefrontal cortex plays a critical role in memory monitoring, aiming to determine whether this region contributed to all, or only some classes of meta-memory judgments. We also investigated the relationship between these judgments and memory performance itself. Three types of meta-memory judgment were measured in 5 subjects with focal damage to medial prefrontal cortex, with maximal overlap in dorsal anterior cingulate cortex, compared to 19 healthy, demographically matched control subjects performing a face–name episodic memory task. Judgment-of-learning accuracy was not affected by such damage. In contrast, both recall confidence and feeling-of-knowing judgments were impaired. Memory performance was itself impaired in the patient group, so we performed a second experiment to examine the relationship between memory and meta-memory deficits. In an easier memory task, where patients performed as well as controls, recall confidence accuracy improved to within the control range despite medial prefrontal damage. In contrast, feeling-of-knowing judgments remained less accurate in the patient group. These results argue that medial prefrontal cortex plays a critical role in generating accurate recall confidence and feeling-of-knowing judgments, but is not necessary for judgment-of-learning. The role of this region in feeling-of-knowing seems to be, at least in part, independent of its role in memory itself.

1. Introduction

Effective performance monitoring is an important aspect of adaptive behaviour. Self-monitoring, conceptualized in various ways, has long been linked to the frontal lobes in general, and more recently to medial prefrontal cortex (mPFC) specifically. For example, dorsal anterior cingulate cortex (ACC) has been implicated in response conflict monitoring (Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; van Veen, Cohen, Botvinick, Stenger, & Carter, 2001; Yeung, Cohen, & Botvinick, 2004), and dorsal and ventral ACC in error monitoring (Dehaene, Posner, & Tucker, 1994; Holroyd & Coles, 2002; Holroyd, Dien, & Coles, 1998). Functional imaging studies have also identified mPFC more generally as important in the 'default mode' of brain function, attributed to a putative role for this region in "chronic self-evaluation" (Beer, 2007).

Self-monitoring of learning and memory performance has been studied for decades, producing a body of work that has remained relatively separate from performance monitoring research focusing on response conflict or errors (Blake, 1973; Hart, 1967; Koriat, 1993, 1997; Lovelace, 1984; Nelson, 1996; Nelson & Dunlosky, 1991; Nelson & Narens, 1990). Interestingly, cognitive neuroscience research again suggests a role for the frontal lobes in at least some of the processes supporting such memory 'performance monitoring', with preliminary evidence implicating mPFC more specifically.

Meta-memory has been operationalized in terms of prospective and retrospective monitoring engaged at different stages during acquisition, retention, and retrieval. Such monitoring is thought to interact with control processes to support optimal memory performance (Koriat, Ma'ayan, & Nussinson, 2006; Nelson & Narens, 1990; Pannu & Kaszniak, 2005). The focus here is on a subset of these meta-memory judgments: The monitoring that occurs during the acquisition and retention phases of memory is termed judgment-of-learning (JOL) (Nelson & Dunlosky, 1991). In experimental paradigms, JOL is typically measured either immediately after a learning session, or after a delay (i.e. "How well did you learn the material you just studied?") (Nelson & Dunlosky, 1991; Nelson & Narens, 1990). When memory is subsequently

* Corresponding author. Tel.: +1 514 398 2083; fax: +1 514 398 1338.
E-mail address: mandana.modirrousta@mcgill.ca (M. Modirrousta).

0028-3932/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2008.06.011

tested through recall, the monitoring of memory retrieval can be assayed by retrospective confidence judgments (RCJ) after the recall attempt (i.e. "How sure are you that you have correctly recalled the material?") (Pannu & Kaszniak, 2005). Finally, feeling-of-knowing (FOK) measures capture an individual's prospective sense of the likelihood of successful recognition, typically after a failed recall attempt (i.e. "How likely are you to recognize the correct answer from a list?) (Janowsky, Shimamura, & Squire, 1989; Nelson & Narens, 1990). Such judgments can be compared in an absolute sense, both to each other, and to actual memory performance. More frequently, experimenters have asked how closely these judgments are correlated with memory performance; that is, how well these judgments discriminate between different degrees of recall or recognition accuracy (Pannu & Kaszniak, 2005).

There is on-going debate about the relationship of these judgments to each other, and to memory *per se*. One view is that all judgments draw on a direct assessment of memory "strength" (Dougherty, 2001; Jang & Nelson, 2005). Alternatively, cue-based theories propose that memory judgments rely on additional information, such as characteristics of the to-be-learned items, of the study period, and of the learner, that might be expected to be correlated with memory performance, either alone or in addition to information about retrievability (Gigerenzer, Hoffrage, & Kleinbolting, 1991; Koriat, 1997). Empirical data demonstrate commonalities between different forms of memory judgment. For example, retrievability does seem to be a factor in both JOL and RCJ (Nelson, 1996; Nelson & Narens, 1990). However, the accuracies of these judgments are not necessarily correlated in healthy participants (Leonesio & Nelson, 1990), and may be differentially influenced by experimental manipulations (Busey, Tunnicliff, Loftus, & Loftus, 2000; Dougherty, Scheck, Nelson, & Narens, 2005) suggesting that JOL and RCJ may rely on different weightings of the available cues, retrievability amongst them (Dougherty et al., 2005). Similarly, JOL and FOK have been shown to differ in their reliance on various sources of information (Schwartz, 1994). Koriat has proposed that FOK judgments are based initially on the familiarity of the cue; sufficient familiarity leads to a second stage in which FOK is 'fine-tuned' based on retrievability (Koriat & Levy-Sadot, 2001; Metcalfe, Schwartz, & Joaquim, 1993)

In principle, neuropsychological studies can help adjudicate questions about the dissociability of the processes involved in memory and meta-memory, as well as provide insight into the brain substrates of these processes. A dissociation between memory and FOK performance was reported in patients with medial temporal lobe amnesia (Shimamura & Squire, 1986). In the same study, patients with amnesia due to Korsakoff's syndrome demonstrated impairments in both memory and FOK. The same investigators subsequently reported intact RCJ in Korsakoff's patients (Shimamura & Squire, 1988). A similar pattern of impaired FOK and intact RCJ has also been reported in patients with Alzheimer's disease (Pappas et al., 1992).

The findings in Korsakoff's patients suggested a role for the frontal lobes in FOK, at least, and indicated that this might be linked to impaired memory. The role of the frontal lobes in meta-memory, particularly memory monitoring, has since been pursued in studies of patients with focal brain damage, with mixed results. Janowsky et al. (1989) examined FOK accuracy with both semantic and episodic memory tests in 7 patients with frontal damage. They found a FOK deficit (in the presence of intact memory) but only after a delay of 1–3 days between learning and memory tests, and only in episodic memory. Other work using episodic memory tasks in a larger sample ($N = 30$) found that frontal damage was associated with worse JOL accuracy (Vilkki, Servo, & Surma-aho, 1998; Vilkki, Surma-aho, & Servo, 1999).

To our knowledge, only 2 frontal lobe-focused studies have measured more than one class of meta-memory judgment in the same patients, and none have tested the two that require the prospective assessment of memory performance (i.e. JOL and FOK), together. Schnyer et al. (2004) investigated RCJ and FOK in a group of patients with frontal damage ($N = 14$) performing an episodic verbal memory task. They reported a deficit in FOK but not in RCJ. Only 6 patients had clear FOK impairments; post hoc lesion analysis indicated that right ventromedial prefrontal cortex was the common area damaged in these patients. The patients with frontal lobe damage also had memory impairments, but statistical analyses suggested that the FOK deficit was not solely related to memory performance. Pannu et al. reported the opposite result: In their hands, patients with frontal damage ($N = 9$; including 3 with damage due to head trauma) were less accurate in their RCJ, but intact in making FOK judgments, albeit in a semantic memory task (Pannu, Kaszniak, & Rapcsak, 2005).

Several recent studies have used fMRI to examine the neural basis of memory monitoring in healthy individuals. Schnyer et al. found that accurate FOK judgments in a sentence completion recognition memory task were associated with activation in bilateral ventral mPFC (Schnyer, Nicholls, & Verfaellie, 2005). Two recent studies reported enhanced medial PFC (including dorsal ACC) activity for high compared to low confidence trials in quite different recognition tasks (Chua, Schacter, Rand-Giovannetti, & Sperling, 2006; Moritz, Glascher, Sommer, Buchel, & Braus, 2006). Another study using an episodic recognition task, but a different analytic approach, reported parametric increases in activity in many prefrontal areas, including mPFC/ACC, with increasing levels of FOK (Kikyo & Miyashita, 2004); similar prefrontal areas were also implicated in FOK in a semantic memory task (Kikyo, Ohki, & Miyashita, 2002). Activity in more ventral mPFC has also been linked to JOL ratings, and correlated with individual differences in the accuracy of such ratings, while more dorsal mPFC activity was found to be related to both predicted and actual recognition memory performance in the same study (Kao, Davis, & Gabrieli, 2005).

While the existing evidence clearly implicates PFC in meta-memory, it remains unclear which area or areas within PFC are critical, and for which meta-memory processes. Indeed, it seems likely that multiple regions within PFC may be involved in this relatively complex set of processes. The existing neuropsychological literature leaves a number of questions unanswered. Patient groups have been anatomically heterogeneous, a wide variety of memory paradigms and meta-memory measures have been used, and only one study has addressed, post hoc, the regional specificity of PFC involvement in meta-memory. Somewhat surprisingly, given that dorsal ACC appears to be the most consistent mPFC correlate of meta-memory in fMRI work, that study suggested right ventral mPFC as a key region, at least for FOK.

Post hoc lesion overlap analyses are a relatively weak form of evidence, because lesion location is not randomly distributed in human studies. Common patterns of damage related to the underlying etiology of the damage can result in spurious findings (Kimberg, Coslett, & Schwartz, 2007). Motivated by the putative role of dorsal ACC in other forms of performance monitoring, and by fMRI studies implicating this region in meta-memory, the present study focused *a priori* on mPFC, enrolling participants with lesions overlapping in dorsal ACC. We aimed to test whether this frontal sub-region plays a critical role in meta-memory, to determine whether this was manifest in both prospective and retrospective memory judgments, and to determine the relationship between memory and meta-memory performance in these patients.