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Brain regions involved in prospective memory as determined by positron emission tomography

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Abstract

Prospective memory (PM) refers to the functions that enables a person to carry out an intended act after a delay. Despite the ubiquity of this behaviour, little is known about the supporting brain structures and the roles that they play. In this study, eight healthy participants performed four different PM tasks, each under three conditions: a baseline, and two conditions involving an intention. In the first of the intention conditions, subjects were asked to make a novel response to a certain class of stimuli whilst performing an attention-demanding task. However, the expected stimuli never actually occurred. In the second intention condition subjects were expecting to see these stimuli as before, and they did occur on $\approx 20\%$ of trials. Relative to the baseline condition, increases in regional cerebral blood flow (rCBF) as estimated by oxygen-15 positron emission tomography technique across all four tasks were seen in the frontal pole (Brodmann's area 10) bilaterally, right lateral prefrontal and inferior parietal regions plus the precuneus when subjects were expecting a PM stimulus regardless of whether it actually occurred. Further activation was seen in the thalamus when the PM stimuli occurred and was acted upon, with a corresponding rCBF decrease in right lateral prefrontal cortex. It is argued that the first set of region play a role in the maintenance of an intention, with the second set involved additionally in its realisation.

Keywords: Frontal lobes; Intention; Executive; Positron emission tomography; Functional imaging

1. Introduction

Prospective memory (PM), or the "realisation of delayed intentions" ([26], p. 1) is an ability which is at the heart of competent behaviour in everyday life. Without PM functions one could not carry out an intended future action without continuous verbal rehearsal of the intention until the appropriate time (or context) occurred. In this way PM functions serve to bind together complex goal-directed behavioural sequences and enable a person to carry out their plans and wishes in a meaningful order and at the appropriate time. Neurological patients who have lost this ability demonstrate the importance of PM to everyday life competency. Despite high IQ and no problems with language, perception or retrospective memory, they are nevertheless severely impaired in everyday life (see Ref. [13] for review).

Tasks or situations that stress PM can easily be characterised. First, they involve a delay interval (or "retention interval" ([26], p. 2)) between forming an intention and carrying it out. For some [2], this interval may only be a matter of seconds, but most investigators [1,8,17,20,24,25,27,37,45,46,49,51,53,63,72] consider that the retention interval is typically much longer, ranging from a minute or more to several hours.

A second characteristic, which is agreed by most commentators, is that situations tapping PM abilities involve both an ongoing[1] and a PM task. The demands

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[1] There are many terms in the prospective memory literature for the task in which the participant is engaged until the retrieval context occurs. In an attempt to avoid terminological confusion, the delegates at the First International Conference on Prospective Memory (University of Hertfordshire, UK, July 2000) carried a vote for researchers in this area to use the term "ongoing task". It was preferred principally because of its theoretically neutral character.

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of the ongoing task are often unrelated to the PM intention or retrieval context. However, the ongoing task must be such that it prevents a simple verbal (or sub-vocal) rehearsal strategy [24,52]. Indeed, it is this characteristic more than any other which distinguishes a typical PM task from a vigilance one (see [24,52] for discussion on this point). As regards the retrieval context (i.e. the situation, event or time where the intended action should be performed), the currently most discussed forms are either event-based intentions (i.e. "when x occurs then do y") or time-based ones (i.e. "at time x, do y"; see [25]).

A third feature of PM is that the delayed action is self-initiated [19]. This demand implies that ongoing task performance should not halt or change at the point where the intention should be carried out, and that the retrieval cue or context should not interfere with performance of the ongoing task [12].

Many everyday situations conform to these criteria. Consider for instance the circumstance where one wishes to remember to send an important letter at lunchtime tomorrow. Clearly one would not normally indulge in verbal rehearsal of the intention until the retrieval context (i.e. lunchtime tomorrow) occurred. Instead, one's attention would be given over (even if only momentarily) to many events in the intervening period. Thus the first two criteria are met: that there should be a retention interval, and that verbal rehearsal cannot be maintained continuously during the whole of that interval. (In this situation the intervening events between forming the intention to send the letter and lunchtime tomorrow would count as the "ongoing task".) The third criterion – that of self-initiated retrieval – would also be met in this naturalistic example, supposing that one did not use a reminder such as an alarm as an aid.

1.1. Candidate brain regions involved in prospective memory

There is a current consensus amongst investigators that at least some of the processes which are critical to realising delayed intentions are supported by brain structures located in the frontal lobes and related structures [3,4,16,17,67], although there are currently only a few studies that suggest a finer level of discrimination. One of these is the study of Burgess et al. [14]. They reviewed the lesion loci of five neurological cases, whose everyday life impairments included failure to create and carry out intentions, taken from the case studies of Eslinger and Damasio [28], Shallice and Burgess [66] and Goldstein et al. [36] using the Damasio and Damasio [23] method of CT scan analysis. Burgess et al. [14] found that all the cases had sustained damage to at least one of the following frontal areas: left frontal pole and surrounding regions (Damasio and Damasio region LF04, which encompasses parts of Brodmann's areas (BAs) 8–10), left anterior cingulate (Damasio and Damasio region LF01) and right dorsolateral prefrontal cortex (RDLPFC; Damasio and Damasio region RF07). Burgess et al. [14] also report these regions, in addition to the left posterior cingulate and forceps major region, as implicated in performance of a multitasking test requiring PM in 60 neurological patients with circumscribed cerebral lesions. They contend that the anterior and posterior cingulates are involved in the basic retrospective memory components of PM, with RDLPFC involved in planning and creation of intentions [35], and BA 10 critical to maintenance of intentions.

Interestingly, these findings find some support in a positron emission tomography (PET) study by Okuda et al. [55,73]. In this study subjects were taught a set of 10 nouns ("targets") before the scanning began. There were two scanning phases: "experimental" and "control". During the experimental scanning phase participants were required to repeat verbally a series of 10 sets of five nouns that were presented to them auditorily. Occasionally, one of the stimuli they heard was a target word that they had learnt before scanning, and subjects were instructed to tap with their left hand when they heard these. The control scanning phase consisted merely of the word string repetition task alone. The subjects repeated both tasks in random order. Okuda et al. [55] found regional cerebral blood flow (rCBF) increases in the experimental (i.e. the PM) condition, compared with the control task in the following regions: Left hemisphere: anterior cingulate gyrus (BA 24), superior frontal gyrus (BA 10), and parahippocampal gyrus (BA 28); Right hemisphere: inferior and middle frontal gyri (BA 8, 9 and 47). In addition there was involvement of the frontal lobe medially (BA 8) (Talairach and Tournoux [69] co-ordinates 0, 40, 41).

These two studies, despite using different methods, show a number of areas of agreement, and together provide some hypotheses both regarding the regions of the brain involved in PM, and the roles that they play. Thus both studies suggest involvement of the anterior cingulate gyrus plus BA 8–10, especially on the left, plus some involvement more dorsolaterally in the right frontal lobe. However, there is less agreement between them as to the roles these regions play in the realisation of a delayed intention. Thus Okuda et al. [55] suggest that the right middle frontal activation reflects the extra load upon memory in a PM task, with the left BA 10 and right BA 47 regions "related to the process of holding intention of future behaviour" (p. 130) while the left parahippocampal activation reflects the novelty detection requirements of the task. However, in the Burgess et al. lesion study [14], the suggested role of the right frontal lobe is in the creation of intentions (as a function of planning), with an area which includes left