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The role of the rostral frontal cortex (area 10) in prospective memory: a lateral versus medial dissociation

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Abstract

Using the $H_2{}^{15}O$ PET method, we investigated whether previous findings of regional cerebral blood flow (rCBF) changes in the polar and superior rostral aspects of the frontal lobes (principally Brodmann's area (BA) 10) during prospective memory (PM) paradigms (i.e. those involving carrying out an intended action after a delay) can be attributed merely to the greater difficulty of such tasks over the baseline conditions typically employed. Three different tasks were administered under four conditions: baseline simple RT; attention-demanding ongoing task only; ongoing task plus a delayed intention (unpracticed); ongoing task plus delayed intention (practiced). Under prospective memory conditions, we found significant rCBF decreases in the superior medial aspects of the rostral prefrontal cortex (BA 10) relative to the baseline or ongoing task only conditions. However more lateral aspects of area 10 (plus the medio-dorsal thalamus) showed the opposite pattern, with rCBF increases in the prospective memory conditions relative to the other conditions. These patterns were broadly replicated over all three tasks. Since both the medial and lateral rostral regions showed: (a) instances where rCBF was lower during a more effortful condition (as estimated by increased RTs and error rates) than in a less effortful one; and (b) there was no correlation between rCBF and RT durations or number of errors in these regions, a simple task difficulty explanation of the rCBF changes in the rostral aspects of the frontal lobes during prospective memory tasks is rejected. Instead, the favoured explanation concentrates upon the particular processing demands made by these situations irrespective of the precise stimuli used or the exact nature of the intention. Moreover, the results suggest different roles for medial and lateral rostral prefrontal cortex, with the former involved in suppressing internally-generated thought, and the latter in maintaining it.

Keywords: Executive function; Frontal lobes; Delayed intention; Frontal pole

1. Introduction

"Prospective memory" (PM) is the field of enquiry concerned with how people create, maintain and execute intended actions after a delay period ("delayed intentions"). For most commentators this function is not supported by a single construct (e.g. [10,23,33,37,50,52]) and there are many different types of situations that involve prospective memory [14]. However the cardinal features of a prospective memory situation are shown in Table 1.

The study of the cognitive neuroscience of prospective memory is currently in its infancy. Nevertheless, a number of recent studies using different methodologies have suggested that processes supported by the fronto-polar and superior rostral aspects of the frontal lobes (approximating Brodmann's area (BA) 10) play a particularly important role in this function. A more precise characterisation of the role that this region plays is however currently hindered by one possibility which would compromise the utility of these findings for theorising. The present study seeks to investigate this possibility. We will first describe the evidence, and then outline the potential confound.

In a previous study, Burgess et al. [4] investigated regional cerebral blood flow changes in eight participants performing four different tasks, each under three conditions. The first condition (baseline) was subject-paced, and consisted of making judgements about two objects appearing together (e.g. which of two digits is the largest, or which of two letters comes nearer the start of the alphabet). The second condition consisted of the baseline task, but subjects were also told that if a particular combination of stimuli appeared (e.g. two vowels, two even numbers) they were to respond in

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Table 1
Features of a typical situation involving prospective memory

1	There is an intention, or multiple intentions [30] to act (or in some circumstances, to withhold a routine act)
2	The act cannot be performed immediately
3	The intention is to perform the act in a particular circumstance (the "retrieval context" [15]). In event-based studies, the retrieval context is signalled by a cue (the "intention cue")
4	The delay period between creating the intention and occurrence of the appropriate time to act (the "retention interval") is filled with activity known as the "ongoing task" [15]
5	Performance of the ongoing task prevents continuous, conscious rehearsal of the intention over the entire delay period. Typically this is because the activity is too demanding of attentional resources, or the delay period is too long
6	The intention cue (or retrieval context) does not interfere with, or directly interrupt, performance of the foreground task. Intention enactment is therefore self-initiated [24,49]
7	In most situations involving prospective memory no immediate feedback is given to the participant regarding errors

a different way (press a particular key combination). However in this condition ("expectation") none of these stimuli actually appeared. In the third condition participants were given the same instructions and stimuli as in the first, except that the expected PM stimuli did occur (after a delay, and on 20% of trials), and participants had the chance to respond to them ("execution" condition). In the terminology of prospective memory researchers, the last two conditions were "prospective memory" (PM) conditions in that they involved a delayed intention, and had the characteristics outlined in Table 1.

Burgess et al. [4] considered the rCBF changes between conditions that were common across the four tasks. Relative to the baseline condition, rCBF increases were seen in the frontal pole (BA 10) bilaterally, right DLPFC (BA 45/46) and right inferior parietal regions (BA 7, 19, 39, 40), precuneus, plus decreases in left fronto-temporal regions (BA 38, 47 and insula) when the participants were expecting to see a stimulus, even though it did not occur. Further increases were seen in the thalamus when the intention cues were seen and acted upon, with a corresponding decrease in right DLPFC. It was concluded that at least some of the rCBF changes in the expectation condition were most likely associated with intention maintenance, with those in the execution condition associated with recognising and responding to prospective memory cues.

The brain region regarded as especially significant as regards intention maintenance was BA 10, on the grounds of two previous studies. In the first [43] participants were taught a set of target nouns before scanning began. During scanning they were required to repeat verbally sets of five nouns that were presented to them. Occasionally one of these was one of the pre-learnt targets, and the participant was required to respond to them by tapping with their left hand. The contrast condition consisted of word string repetition alone. Okuda et al.'s [43] results implicated a number of frontal regions, including the right dorsolateral, ventrolateral (BA 8, 9, 47) and midline medial cortices (BA 8), and the anterior cingulate gyrus, plus the left parahippocampal gyrus. Most significantly for cross-study comparisons, they also implicated the left frontal pole (BA 10) in prospective memory (see also [42]).

The second supporting study was a human group lesion study [3] which showed that subjects whose lesions involved the medial anterior and polar regions of the left frontal lobe (principally BA 10) showed isolated problems with carrying out intended actions after a filled retention interval (see also [3] for details of single-case human lesion studies). Thus there seemed to be both within- and cross-method support for a role of BA 10 in prospective memory functions. Furthermore, the Burgess et al. [4] study suggested that this role was material- and stimulus non-specific, and probably involved more with maintenance rather than execution of the delayed intention.

However one possible explanation for the Burgess et al. [4] findings is that the activations seen in the expectation condition could be due to task difficulty or increased stimulus processing demands rather than anything to do with delayed intentions per se. This argument is given weight by recent findings of haemodynamic changes in fronto-polar regions associated with performance improvements in a variety of types of task [27,56]. One conception of what happens in a typical PM situation (see Table 1) is that the extra demand to recognise a PM cue might require the stimuli to be processed to a greater semantic "depth". Moreover it is plausible that compared with the ongoing task alone, giving a subject an additional (PM) instruction might encourage subjects to adopt a more cautious attitude to the stimuli or concentrate more closely on the task in general. These putative explanations sit in direct competition with the view of the BA 10 involvement in PM as non-specific to particular materials or stimuli, and its engagement in situations involving a delayed intention.

Certainly they are prima facie explanations for the other rCBF changes seen in Okuda et al. [43] and Burgess et al. [4]. Thus there are many functional imaging studies of a wide range of attention-demanding tasks that were not designed to have a delayed intention component. Most implicate right dorsolateral prefrontal cortex (DLPFC) (typically Brodmann's area (BA) 46) and right parietal (typically BA 40) regions (e.g. [9,16,28,35]). A regular but less consistent finding is the involvement of the anterior cingulate (e.g. [9,55]). In general the findings do not seem sensitive to the exact nature of the task, with these regions variously