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Superior parietal cortex and the attention to delayed intention: An rTMS study

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ABSTRACT

Prospective memory (PM) is the ability to remember to carry out an intention when the appropriate cue occurs. This study aimed to investigate whether the superior parietal cortex is causally involved in PM and, if so, what is its functional role. We applied repetitive transcranial magnetic stimulation (rTMS) to the left and right superior parietal cortex, and we evaluated the TMS effects on two different PM tasks that required to direct the attention towards either the external stimuli ('Monitoring-load' task) or the intention in memory ('Retrospective-load' task).

rTMS of left parietal cortex produced a facilitation of PM performance in both tasks. This was coupled by slower responses to the ongoing activity, for left and right parietal stimulation, but selectively in the 'Retrospective-load' condition.

The present results suggest that superior parietal cortex is causally involved in biasing top-down attentional resources between the external, ongoing stimuli and the internal, PM intentions. The possible physiological mechanisms underlying the TMS-related improvement in PM performance are discussed.

1. Introduction

> *Survage: Why did you paint a portrait of me with only one eye?*
> *Modigliani: Because you look at the world with one eye; with the other, you look into yourself.*
> *(Dan Frank, 2001)*

Prospective memory (PM) consists in remembering to execute delayed intentions when the appropriate moment or event – the PM cue – occurs, carrying out such intentions in coordination with other ongoing activities. PM is considered to be a multi-phase process, comprising the phases of intention encoding, intention maintenance, intention retrieval and execution (Marsh et al., 2002; Kliegel et al., 2002). Furthermore, PM relies upon multiple processes, which can be clustered under the terms 'strategic monitoring' and 'spontaneous retrieval'. Strategic monitoring consists of a set of top-down attentional and memory processes needed to monitor the environment for the presence of the PM cue and to maintain the intention active and refreshed in memory. Spontaneous retrieval consists of bottom-up processes, such as the automatic capture of attention by the PM cue and the activation of intention from memory (Einstein and McDaniel, 2005). Many factors were shown to modulate the extent to which the two kinds of processes are recruited. For example, strategic monitoring is particularly recruited when the PM cues are nonfocal (i.e., when PM cue features are not easily extracted from processing of the ongoing stimuli) or nonsalient, whereas spontaneous retrieval occurs when the PM cues are focal (i.e., when processing of the PM cue features is stimulated by processing of the ongoing stimuli) or salient (Einstein et al., 2005).

In recent years, there has been a growing interest in understanding the neural mechanisms of PM and in identifying the brain regions involved in each phase and process of PM (e.g., Gilbert et al., 2012; Rusted et al., 2011; see Burgess et al., 2011; and Cona et al., 2015, 2016, *for recent reviews*).

One of the key regions supporting PM is the anterior prefrontal cortex (aPFC; Brodmann Area, BA 10), which acts as a gateway mechanism between stimulus-independent and stimulus-oriented thoughts (Burgess et al., 2007, 2011; Gilbert et al., 2005). More specifically, the lateral parts of the aPFC mediate stimulus-independent processes, which include maintaining the PM intention active in memory, whereas the medial parts of the aPFC support stimulus-oriented processes, such as processing of the ongoing stimuli (Barban et al., 2014; Benoit et al., 2012; Burgess et al., 2007, 2011; Gilbert

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et al., 2005, 2006). In such a way, aPFC regions orchestrate and distribute the resources allocated for the PM task and the ongoing activity, allowing an individual to perform both tasks simultaneously.

Two recent meta-analyses showed that, aside from the aPFC, the frontoparietal networks are crucially involved in PM tasks (Cona et al., 2015, 2016). In particular, the dorsal frontoparietal network (i.e., dorsolateral prefrontal cortex (DLPFC), premotor regions, frontal eye fields (FEF), superior parietal lobule and precuneus) was found to be involved mainly in the maintaining phase, whereas the ventral frontoparietal network (i.e., ventrolateral prefrontal regions, inferior parietal lobule and supramarginal gyrus) was found to be more active during the retrieval phase. According to the Attention to Delayed Intention (AtoDI) model, the dorsal frontoparietal network would support the allocation of top-down attention, which would be directed both externally, towards the environment for monitoring the presence of the PM cue, and internally, towards the representation of intention for keeping it active in memory. By contrast, the ventral frontoparietal network would underpin the bottom-up attention, which would be captured externally, by the PM cue, and internally, by the representation of the associated intention (Cona et al., 2015).

Several other works found consistent activations of the frontoparietal regions (e.g., Barban et al., 2014; Beck et al., 2014; Landsiedel and Gilbert, 2015). The AtoDI account is also supported by the findings of recent PM studies, which proposed that strategic monitoring – consisting of top-down attentional and memory processes – are supported mainly by dorsal frontoparietal regions (Beck et al., 2014; Gonneaud et al., 2014). Also, a transcranial magnetic stimulation (TMS) study showed that the right DLPFC is causally involved in strategic monitoring whereas the left inferior parietal lobule is involved in retrieval of intention (Bisiacchi et al., 2011).

So far, no study has ever investigated whether the superior parietal cortex causally contributes to PM and, if so, what is its functional role. In order to answer these questions, we applied off-line repetitive TMS over the left and right superior parietal cortex and we evaluated the possible TMS effects on the performance in two PM tasks that vary for the type of load required, in line with the logic underlying the study by Meier and Zimmermann (2015). One of the PM tasks used in our study was indeed characterized by high monitoring load (i.e., 'Monitoring-load' PM task). The PM cue was nonfocal and nonsalient compared to the ongoing stimuli, thus a great amount of top-down attentional resources towards the external stimuli was required to accomplish this task. The other PM task was instead characterized by high retrospective load (i.e., 'Retrospective-load' PM task), as it comprised multiple intentions to remember. In this condition, the attention was required to be directed mainly toward the internal intentions stored in memory. Moreover, in order to minimize the monitoring load, the PM cues were very salient and distinctive compared to the ongoing stimuli.

Based on the AtoDI model, we can make some predictions: if the superior parietal cortex mediates the allocation of attention towards the external stimuli, we should expect to observe an effect of superior parietal cortex stimulation mainly in the Monitoring-load PM task. By contrast, if the superior parietal cortex supports the allocation of attention towards the internal representation of the intention, we should expect to observe an effect of TMS mainly in the Retrospective-load PM task.

Importantly, the investigation of the TMS effects on the performance in the ongoing task executed concurrently with the two types of PM tasks helped us to better disentangle these two types of attention.

2. Materials and method

2.1. Participants

Twenty-two students of the University of Padua took part in the experiment (14 females; mean age: 23.6; range: 21–28).

Participants had normal or corrected-to-normal vision, and were all right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). All were healthy, with no history of head injury or physical, neurological, or psychiatric illness. They were all checked for TMS exclusion criteria (Rossi et al., 2009). They gave informed written consent before participating in the experiment. The study was carried out in accordance with the guidelines of the Declaration of Helsinki and was approved by the ethical committee of the Department of General Psychology, University of Padua.

2.2. Stimuli and apparatus

Participants seated in front of a color monitor screen at a distance of about 60 cm. The experiment was run using the E-Prime software system. An ongoing task and a PM task were administered. The ongoing task was a lexical decision task (LTD).

Stimuli were valid Italian words and pronounceable nonwords. Word stimuli were selected from the "Corpus e Lessico di Frequenza dell'Italiano Scritto" (CoLFIS) database (http://linguistica.sns.it/CoLFIS/Formario.htm) and could range from 5 to 9 letters in length. Nonwords were pseudo-word stimuli, created from the used words by changing one or two letters.

In the ongoing task, participants were required to decide whether each string of letters presented on the screen was a word or a nonword, by pressing the "N" key with the right index finger or the "M" key with the right middle finger, respectively. All participants were instructed to respond as quickly and accurately as possible.

The psycholinguistic variables of words (mean length and mean frequency) were matched across all the experimental sessions and stimulus types (e.g., ongoing words *versus* PM trials). The stimuli were presented in black in the center of a white screen.

Together with the ongoing task, participants were asked to accomplish a PM task. More specifically, the participants were instructed that, when a particular stimulus occurred, i.e. the PM cue, they had to make a PM response instead of pressing the keys for the ongoing lexical decision task. Two different PM conditions were designed, which vary as a function of the type of load allocated for the PM task (monitoring load versus retrospective load). Half the participants underwent the Monitoring-load condition, whereas the other half underwent the Retrospective-load condition.

In Monitoring-load condition, participants were required to press the 'Z' key with their left index finger whenever they saw a pre-selected syllable (e.g., 'sti') within the string of letters. This task is indeed typically known as effective in emphasizing monitoring processes (e.g., Einstein et al., 2005; Scullin et al., 2010). In Retrospective-load condition, participants were given three distinct PM cue-intention associations to remember. For example, they were instructed to remember to press, using their left hand, the 'Q' key if they saw the word 'marrone' (brown), the 'W' key for the word 'giallo' (yellow) and the 'E' key for the word 'viola' (violet).

Notably, in order to minimize the monitoring load, participants were informed that these words were always underlined, thus they were more salient compared to the other strings of letters. Each session comprised 150 ongoing trials and 10 PM trials (frequency of the PM cue: 6.25%).

As each participant underwent three separate sessions – one for each TMS condition – three different versions of the PM plus ongoing task were created (version A, version B, and version C). The words across the mappings were equated on word frequency and number of letters, therefore the ongoing and the PM tasks across the versions were equally difficult[1]. The three versions were counterbalanced across participants.

The PM cues in the other two versions of the Monitoring-load

[1] A pilot study confirmed that the 'A', 'B', 'C' versions of the PM tasks were equivalent in terms of difficulty.