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Repetitive transcranial magnetic stimulation over the left parietal cortex facilitates visual search for a letter among its mirror images

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ABSTRACT

Interference by task irrelevant information is seen in visual search paradigms using letters. Thus, it is harder to find the letter 'N' among its mirror reversals 'И' than vice versa. This observation, termed the reversed letter effect, involves both a linguistic association and an interference of task irrelevant information — the shape of 'N' or 'И' is irrelevant, the search requires merely distinguishing the tilts of oblique bars. We adapted the repetitive transcranial magnetic stimulation (rTMS) methods that we previously used, and conducted three rTMS experiments using healthy subjects. The first experiment investigated the effects of rTMS on the left and right posterior parietal cortex (PPC) on the search performance. The second experiment focused on the role of the left PPC. The third experiment explored whether another left posterior region, known to be involved in word reading (ventral occipito-temporal cortex, vOTC), plays a role. We found that rTMS on right PPC and left VOTC had no effect on the speed and accuracy of the visual search regardless of whether the target is 'N' or its mirror reversal. In contrast, rTMS on the left PPC speeded up the search on finding target 'N' among its mirror images. We suggest that left PPC is involved in letter recognition, and that rTMS on left PPC facilitated our visual search task by reducing task interference triggered by task irrelevant letter recognition.

1. Introduction

Task irrelevant information has been shown to interfere in a variety of cognitive and perceptual tasks. Typical examples are: Stroop effect (Stroop, 1935), global precedence in Navon letters task (Navon, 1977), Simon effect (Simon and Rudell, 1967; Umiltá and Nicoletti, 1990), and the Flanker effect (Eriksen and Eriksen, 1974). The Stroop effect is manifested in the reduced accuracy and speed in naming the ink color (e.g., green) of a word when the literal meaning of the word is another color (e.g., red). In the Navon letter task, observers trying to name many identical letters, for example, 'A', arranged in a global array shaped like, for example, 'H', are slower than if the array is shaped like 'A' instead. The Simon effect refers to the observation that, when observers try to, e.g., press a left or right button to report a green or a red object, respectively, their response is slower and less accurate when the green or red object is in the right or left part of the display, respectively, opposite to the lateral side of the associated response button (Umiltá and Nicoletti, 1990; Lu and Proctor, 1995). The flanker effect is the tendency to incorrectly report the direction of the central target arrow when the flanking arrows point in the opposite direction, for example in this stimulus $\ll > \ll$. These four examples indicate that the tasks elicited the processing of the task irrelevant information: the literal meaning of the text in the Stroop effect, the global array shape in the Navon task, the spatial location of the reported object in the Simon effect, and the property of the flanking arrows in the flanker effect. The processing of irrelevant information, when it is in conflict, caused interference to the task performance.

A large body of neuroimaging and transcranial magnetic stimulation (TMS) studies has reported a role of the medial prefrontal cortex (mPFC) and especially the anterior cingulate cortex (ACC), dorsolateral prefrontal cortex (DLPFC), and posterior parietal cortex (PPC) in conflicting or interfering conditions (see Nee et al. (2007), for a meta-analysis). ACC activation is widely observed in tasks requiring participants to resolve response conflict (e.g., in Flanker or Stroop tasks, Botvinick et al., 1999, 2001, 2004; van Veen et al., 2001; Ridderinkhof et al., 2004; Chen et al., 2006;

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Botvinick, 2007; Carter and van Veen, 2007).

Meanwhile, TMS over the right PPC produced a reduction of the Simon effect (Schiff et al., 2011). In these studies, the results were interpreted as the disruption of the spatial representation following TMS.

Interference by task irrelevant information is also seen in visual search paradigms developed by Zhaoping and Guyader (2007) and Zhaoping and Frith (2011). In these studies, the search task is to find a uniquely oriented bar in a visual display. However, this target bar is embedded in an object shape that is identical to the shape of many other objects in the display. For example, the target bar can be an oblique bar tilted 45° clockwise from vertical, and it intersects a horizontal or vertical bar to make an 'X' shape. Meanwhile, the display contains many other 'X' shapes, each made by intersecting an oppositely tilted oblique bar (45° counterclockwise from vertical) and a cardinal (horizontal or vertical) bar. Although the target bar is unique in the display by its low level feature, its orientation, the object shape ('X') that it is embedded in is not unique in the display. The shape information is task irrelevant, however, it interferes with the search task and prolongs the reaction time for the task decision (Zhaoping and Guyader 2007). In a repetitive-transcranial magnetic stimulation (rTMS) study (Oliveri et al., 2010), we documented that rTMS in the right but not left PPC reduced significantly the task reaction times (RTs) in this visual search task. Notably, a paradoxical facilitation, manifested again as a significant reduction in RTs in the same task, was reported in a group of patients with right parietal lesions (Mangano et al., 2014). These findings suggest that the right PPC is involved in processing the task irrelevant shape information, and that rTMS on the right PPC reduced such task irrelevant processing to make the search faster.

Zhaoping and Frith (2011) extended the visual search paradigm to task-irrelevant shapes of letters. For example, in a search display containing a letter 'N' among many of its mirror reversals 'И', the unique target is the left tilted oblique bar in 'N'. However, the same zig-zag shape shared by N and its mirror reversals confused the observers and prolonged their RTs, even though the task does not require any letter or shape recognition. This interference by the task-irrelevant shape is weaker when the target bar is the oblique bar in the mirror reversal, 'И', displayed among many normal 'N's. The difference in the interference is termed the reversed letter effect (Frith, 1974). This finding suggests a possible role of familiarity (Treisman and Souther, 1985; Wang et al., 1994; Malinowski and Hübner, 2001; Wolfe, 2001) and reading processes in the zig-zag shape recognition that leads to the interference.

There is some TMS evidence suggesting that right and left PPC may be differentially involved in processing sensory information according to whether the information has linguistic associations (Cattaneo et al., 2008, 2009). Using the TMS-adaptation paradigm, Cattaneo et al. (2009) found a faster detection of the adapted letters after TMS of left but not the right PPC. In addition, they showed that this effect of the left PPC was independent of whether the letters were in capital or lower case, suggesting a causal role of the left PPC in abstract letter processing rather than a mere visual form processing. Related to the findings, a functional magnetic resonance imaging (fMRI) study by Callan et al. (2005) reported that activation of the left PPC is associated with processing visual shapes as letters when the visual forms carried phonological information. Meanwhile, a given auditory or visual stimulus, e.g., a letter presented in acoustic or visual form, elicited left PPC activation when the task was to discriminate phonological information but not when the task was to discriminate its non-linguistic attributes (Salo et al., 2013).

Noting that the reversed letter effect involves both a processing of task irrelevant information and a linguistic association, we aim by the current rTMS study to investigate whether the right PPC and/or left posterior regions (left PPC, left ventral occipito-temporal cortex) play a role in the reversed letter effect. We adapted the rTMS methods that we previously used in Oliveri et al. (2010) onto the letter stimuli, and conducted three experiments using healthy subjects. The first experiment investigated the effects of rTMS on the left and right PPC on the task performance. Since the first experiment suggested that rTMS on the left PPC reduces RTs in our visual search task, the second experiment focused on the left PPC to verify this finding. The third experiment explored whether another left posterior region, known to be involved in word reading (ventral occipito-temporal cortex, vOTC, Duncan et al., 2010), played a role.

2. Material and methods

2.1. Participants

A sample of 88 healthy right-handed subjects (17 males, 71 females; mean age: 24 ± 3 years) participated in three experiments. All participants were literate Italian native speakers and were naive to the purposes of the study. They had normal or corrected to normal vision. There was no previous history of neurological or psychiatric disorders. For each subject, we obtained written informed consent for participation in the studies.

2.2. Experiment 1: Left–right PPC rTMS

The aim of the first experiment was to investigate the contributions of left and right PPC to visual search in stimuli involving linguistically meaningful symbols ("N" see target-in-N stimulus in Fig. 1) and linguistically meaningless symbols ("И" see target-in-

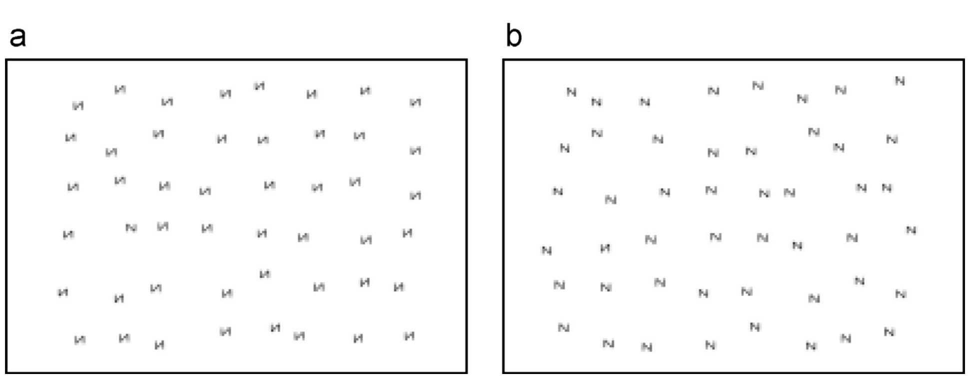

Fig. 1. Experimental stimuli. (a) In target-in-N stimulus, the target bar was in an object shape 'N' contained familiar verbal information. (b) In target-in-reversed N stimulus, the target bar was in an object shape 'И' which was the mirror reversal of 'N'.