



Transcranial Magnetic Stimulation Trains at 1 Hz Frequency of the Right Posterior Parietal Cortex Facilitate Recognition Memory

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Neuroimaging, neuropsychological, and brain stimulation studies have led to contrasting findings regarding the potential roles of the lateral parietal lobe in episodic memory. Studies using brain stimulation methods reported in the literature do not offer unequivocal findings on the interactions with stimulation location (left vs. right hemisphere) or timing of the stimulation (encoding vs. retrieval). To address these issues, active and sham 1 Hz repetitive transcranial magnetic stimulation (rTMS) trains of 600 stimuli were applied over the right or left posterior parietal cortex (PPC) before the encoding or before the retrieval phase of a recognition memory task of unknown faces in a group of 40 healthy subjects. Active rTMS over the right but not the left PPC significantly improved non-verbal recognition memory performance without any significant modulation of speed of response when applied before the retrieval phase. In contrast, rTMS over the right or the left PPC before the encoding phase did not modulate memory performance. Our results support the hypothesis that the PPC plays a role in episodic memory retrieval that appears to be dependent on both the hemispheric lateralization and the timing of the stimulation (encoding vs. retrieval).

Keywords: rTMS (repetitive transcranial magnetic stimulation), recognition memory, memory retrieval, episodic memory, posterior parietal cortex

INTRODUCTION

Episodic memory is subserved by a distributed cortical-hippocampal network encompassing dorsolateral prefrontal (DLPFC) and lateral parietal cortex (Teyler and Di Scenna, 1986; McClelland et al., 1995; Nadel et al., 2000; Winocur and Moscovitch, 2011; Watrous et al., 2013). Non-invasive brain stimulation techniques, such as TMS and transcranial direct current stimulation (tDCS) can provide a causal test to modulate cortico-hippocampal connectivity and to measure corresponding changes in memory performances (Kim et al., 2016).

An open question that can be usefully addressed by these techniques is the effect of the timing of the stimulation on memory recognition, i.e., in encoding or retrieval phases.

Previous TMS studies investigating the role of parietal and frontal cortex in memory encoding and retrieval often used an event related high-frequency rTMS approach, known as an interference method, that can increase the timing for the information processing or modify criteria for response

decision and thus allows to deduce if the stimulated area is causally engaged in the task under investigation. rTMS studies using this approach have shown that disrupting the right DLPFC impairs retrieval of previously learned items (Rossi et al., 2001; Sandrini et al., 2003; Gagnon et al., 2010).

When exploring the role of the parietal cortex using the same method, the findings are most contrasting. A study by Rossi et al. (2006), using on-line 20 Hz rTMS to either the left or the right intraparietal sulcus during a yes/no recognition memory task for visual scenes, failed to report a significant impact of the stimulation on the memory performances of healthy controls. In contrast, an fMRI-guided rTMS approach by Manenti et al. (2010), consisting of an fMRI-based target area selection on an individual basis followed by on-line 10 Hz rTMS trains, provided for the first time evidence that the parietal cortices have a necessary role during episodic retrieval of abstract words. In their fMRI experiment, the authors found that encoding was selectively associated with an activation of the left DLPFC, whereas retrieval selectively activated the inferior parietal lobules (supramarginal and angular gyri) bilaterally, as well as the right DLPFC. Indeed, 10 Hz rTMS caused a slowing down of performance during abstract word retrieval when applied over the left inferior parietal cortex and the right DLPFC.

More recently, rTMS investigations of different left parietal regions during episodic memory retrieval documented that transient on-line 20 Hz rTMS of the angular gyrus significantly decreased item-recognition accuracy as compared with superior parietal lobe stimulation, especially for the criterion of source memory judgments (Sestieri et al., 2013).

Complementary findings on this topic are offered by studies applying tDCS or TMS off-line, i.e., before the encoding or the retrieval phase of a memory test, in order to modulate the excitability of the parietal regions as part of the cortical-hippocampal network associated to memory. An advantage of this brain stimulation approach is that it allows modulation of plasticity of the stimulated as well as of interconnected brain areas in a memory circuit (Kim et al., 2016).

Some tDCS studies suggest that increasing excitability of the parietal regions during retrieval may improve memory performance. Pisoni et al. (2015) tested the effects of anodal tDCS in bilateral temporal and parietal regions in healthy subjects performing a verbal memory recognition task requiring to make old/new judgments. Anodal tDCS to bilateral parietal regions significantly increased the discrimination sensitivity compared to a sham stimulation condition. More recently, Vulić et al. (2021) compared the effects of two types of anodal tDCS over the left PPC on cued recall of face-word associations, i.e., standard tDCS and frequency-modulated tDCS oscillating in theta rhythm (5 Hz). This study shows that both types of parietal stimulation led to enhanced associative memory performance and highlights the potential of oscillatory tDCS protocols for memory enhancement. In this context, an interesting method to investigate cortical-hippocampal structures is to target with TMS the cortical sites based on their high fMRI connectivity with anatomically defined hippocampal locations. Wang et al. (2014) applied off-line trains of high-frequency (20 Hz) rTMS to a left parietal site for 5 days and found

an improvement of associative memory of previously learned items. A role of the left parietal cortex using this method was confirmed by further studies using high-frequency rTMS trains (Nilakantan et al., 2017; Kim et al., 2018; Tambini et al., 2018). A recent study using off-line rTMS over the left parietal cortex at different frequencies reported facilitation of memory retrieval following the application of continuous theta burst stimulation (cTBS) associated with corresponding increases in fMRI connectivity between the hippocampus and cortical areas (Hermiller et al., 2019).

In contrast, other studies aimed at investigating the role of low-frequency off-line rTMS of frontal and parietal regions of the cortical-hippocampal network in recognition memory. Turriziani et al. (2012) first reported facilitation of non-verbal recognition memory when 1 Hz rTMS trains were applied over the right DLPFC before the recognition but not before the encoding phase in both healthy subjects and patients with mild cognitive impairment. Interestingly, these authors found that the application of high-frequency rTMS to the right DLPFC, using the intermittent Theta Burst Stimulation (iTBS) protocol, worsened recognition memory performance. The same pattern of results was then replicated using cathodal tDCS in healthy subjects (Smirni et al., 2015).

Here we investigated whether 1 Hz rTMS applied to the posterior parietal cortex (PPC) modulates recognition memory tasks depending on the hemisphere (i.e., right vs. left) and on the timing of the stimulation (i.e., encoding vs. retrieval) of the task.

MATERIALS AND METHODS

To investigate the role of PPC in the non-verbal recognition memory we conducted two rTMS experiments employing a cross-over sham-controlled design with stimulation condition (sham vs. active rTMS) as within-subject factor and side (left vs. right PPC) as between-subjects factor.

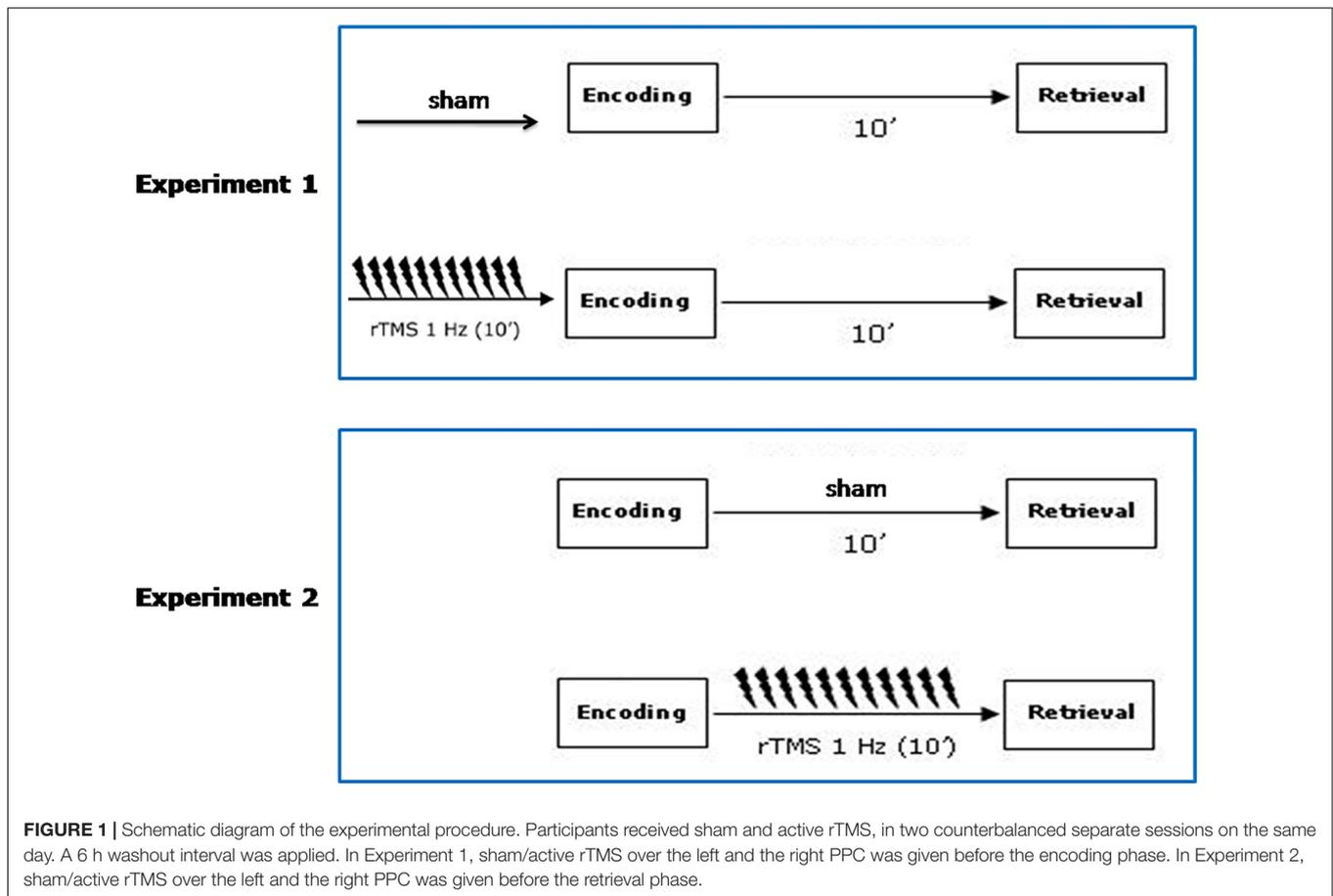
In experiment 1, subjects received sham and active rTMS over the left and the right PPC before the encoding phase.

In experiment 2, subjects received sham and active rTMS over the left and the right PPC before the retrieval phase. See **Figure 1** for a schematic diagram of the experimental procedure.

Participants

We recruited 40 right-handed participants (5 males, 35 females; mean age: 22 ± 4 years; education level: 14 ± 1 years) out of which 20 were enrolled in Experiment 1 (4 males, 16 females; mean age: 22 ± 3 years; education level: 14 ± 2 years) and 20 in Experiment 2 (1 male, 19 females; mean age: 22 ± 6 years; education level: 14 ± 1 years) and half of each was assigned to either left or right PPC group ($N = 10$) receiving sham and active rTMS. All the participants were native Italian speakers, naive to the purposes of the study. Inclusion criteria were: normal or corrected to normal vision, no previous history of neurological or psychiatric problems. Participants were free of any medication and they were screened for exclusion criteria for TMS (Rossi et al., 2011).

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the local



Bioethics Committee of the University of Palermo (n° 26/2020). Written informed consent was obtained from all subjects.

characteristics, neutral expression, and no obvious distinguishing features.

Experiment 1: 1 Hz Repetitive Transcranial Magnetic Stimulation of the Posterior Parietal Cortex Before the Encoding Phase

The aim of the first experiment was to investigate the effect of the left and right PPC before the memory encoding.

Materials

The materials used have been employed in previous studies where they have been described in detail (Turriziani et al., 2012, 2019; Smirni et al., 2015). The experimental task is an Italian version (Smirni et al., 2010) of the Recognition Memory Test. The stimuli used were unknown faces. To apply different stimuli in sham and rTMS sessions, we used two computerized parallel forms of stimuli: the first (Form A) was the Faces Recognition Test from Smirni et al. (2010); the second (Form B) was a parallel form of the same test (Smirni et al., 2018). In both Forms, there was a study phase, we termed this “encoding phase,” followed by a test phase, we termed this “retrieval phase.”

In the encoding phase stimuli were 30 faces. The faces were black and white photographs of Caucasian women, approximately 25 years old, with Italian physiognomic

Procedure

Procedures were identical in both forms (A and B). Sham and active rTMS were given before the encoding phase, in two separate sessions on the same day, separated by a 6 h delay. In each condition (sham or active rTMS) the subjects were administered either the Form A or the Form B of recognition tests. Administration of these two tasks was counterbalanced across subjects, for Form A and Form B and for sham and active rTMS conditions.

In the study phase, stimuli were presented individually in the center of a 15” computer screen over a white background for 2,000 ms. The stimuli were preceded by a fixation point lasting 500 ms. The inter-stimulus interval (ISI) was 3,500 ms.

Participants were instructed to judge whether the stimulus presented in the study phase was “pleasant” or “unpleasant” to focus subjects’ attention in stimulus encoding. Participants responded by pressing one of two designated keys on the keyboard.

Therefore, in the first session (sham or active rTMS) the task requires incidental encoding whereas in the second session we cannot exclude that subjects had the previous experience of needing to remember faces for subsequent recognition.

The recognition phase was administered after a delay interval of 10 min. During this interval, in all experimental conditions, the examiner engaged the subjects in an everyday conversation focusing on various life topics.

In the recognition phase, a three alternative forced-choice recognition memory task was administered. Thirty stimulus triplets were presented. In each triplet, the target was presented with two other similar distractors, vertically arranged. The target was presented in a balanced order either in the upper, lower, or middle quadrant of the screen.

The distractors were two faces with physiognomic characteristics similar to the target. This similarity was previously established in a pilot study, in which participants were asked to judge the face similarity based on hair and color configuration, eyes color and shape, nose and mouth shape.

The recognition trial began with a fixation point of 500 ms, followed by the presentation of the triplets (target and two distractors) for 2,000 ms, followed by the presentation of followed by a blank screen for 3,000 ms. The ISI was 3,500 ms. Subjects were asked to recognize the previously presented stimuli by pressing one of three designated keys on the keyboard using the right index finger from the onset of the test stimuli until 3,000 ms after its disappearance. If unsure they were asked to guess.

Responses were measured in terms of accuracy and reaction times (RTs). Accuracy was considered as the number of correct targets that participants were able to identify in the three forced-choice recognition memory test. The RTs were considered as the time interval from the onset of the test stimuli to the subject's response.

Repetitive Transcranial Magnetic Stimulation Protocol

A MagStim Super Rapid magnetic stimulator (Whitland, United Kingdom) was used. The stimulator was connected to a focal figure-of-eight coil (diameter: 70 millimeters). In each condition (sham and active rTMS), the center of the coil wings was positioned at a position on the scalp corresponding to P3 and P4 sites of the 10–20 EEG system as well-established targets for PPC stimulation (e.g., see Mangano et al., 2015; Bjekić et al., 2019). In the rTMS condition, the figure-of-eight coil was applied tangentially on the target scalp site, with the handle pointing posteriorly, to induce a current with posterior-to-anterior direction in the underlying brain areas. In the sham condition, rTMS was applied, with the coil held close to the PPC but angled away. The same intensity and timing of rTMS were used for sham stimulation. In this case, the coil was still centered on P3 and P4 sites, but it was held perpendicular to the scalp surface, so that scalp contact and discharging noise were quite similar to those for active stimulation, but the induced magnetic field did not activate cortical neurons. The coil was maintained on the target scalp site with the same orientation across sessions using a mechanical arm while the participants quietly sat.

For each scalp site, an rTMS train of 10 min duration and 1 Hz frequency (600 stimuli) was applied at an intensity of 90% of the resting motor threshold (MT) which was defined as the minimal TMS intensity capable of inducing a reliable muscle twitch in

the contralateral hand on 50% of trials within a sequence of ten consecutive trials (Rossini et al., 1994).

MT was determined on the same hemisphere of the stimulated left or right PPC.

There were not interhemispheric differences in MT values between the left and the right hemisphere either in experiment 1 (MT left group: $55 \pm 8\%$; MT right group: $55 \pm 7\%$; $p = 0.97$) or in experiment 2 (MT left group: $56 \pm 5\%$; MT right group: $58 \pm 7\%$; $p = 0.35$).

We also conducted the simulations of the electric field patterns that rTMS would evocate in cerebral cortices of the subjects using SimNIBS 3.0 (Saturnino et al., 2019; **Figure 2**).

Experiment 2: 1 Hz Repetitive Transcranial Magnetic Stimulation of the Posterior Parietal Cortex Before the Retrieval Phase

The aim of the second experiment was to investigate the effect of the left and right PPC before the memory retrieval.

The same stimuli, procedures, and rTMS protocol as those administered in experiment 1 were used, with the exception that subjects received sham and active rTMS to PPC before the retrieval phase.

Data Analysis

We calculated the accuracy, that is the percentage of correctly recognized items in the three forced-choice recognition memory test, and the averaged reaction times (RTs), defined as the time interval from the onset of the test stimuli to the correct button presses.

Data were analyzed with separate ANOVAs on the accuracy and the averaged RTs, with Side (left vs. right hemisphere) as between-subjects factor and Condition (sham, active rTMS) as within-subjects factor with simple planned contrasts between sham and active rTMS conditions and between left and right group in each conditions (left rTMS vs. right active rTMS; left sham vs. right sham). Value of $p < 0.05$ was considered as significant.

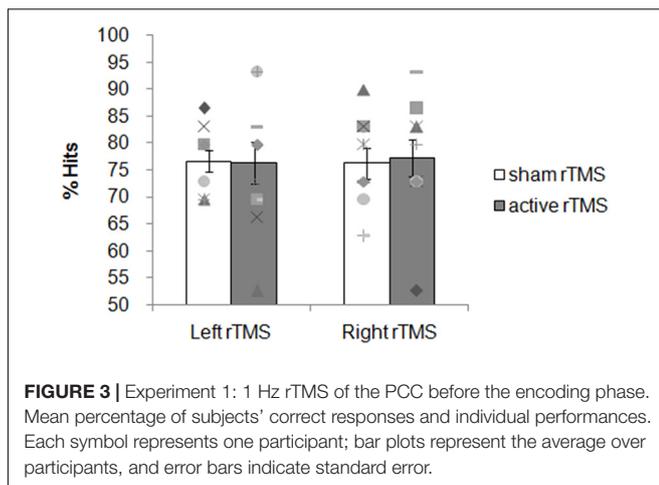
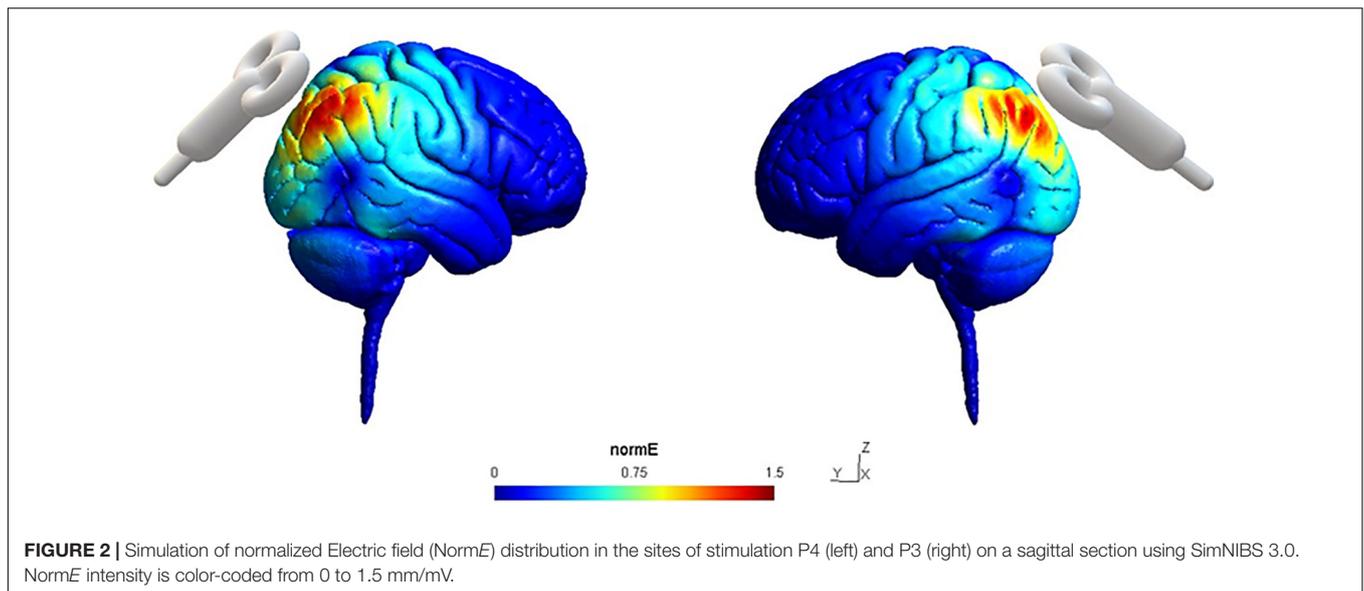
Finally, we calculated the sensitivity index as a measure of participants ability to discriminate between signal and noise dividing the number of correct responses by the total number of trials (Stanislaw and Todorov, 1999). A value of 0.3 was considered as indicating chance performance.

RESULTS

Experiment 1: 1 Hz Repetitive Transcranial Magnetic Stimulation of the Posterior Parietal Cortex Before the Encoding Phase

Accuracy

Overall participants were accurate choosing the correct answer more often than predicted by chance. The mean percentage of correct responses for the sham and active rTMS conditions,



respectively, were: 77 ($SD = 6$) and 76 ($SD = 12$) for the left group; 76 ($SD = 9$) and 77 ($SD = 11$) for the right group.

The ANOVA on the accuracy showed no significant main effects for factors Side [$F(1, 18) = 0.01$; $p = 0.9159$], Condition [$F(1, 18) = 0.01$; $p = 0.9163$] nor Side \times Condition interaction [$F(1, 18) = 0.05$; $p = 0.8336$; **Figure 3**]. Planned contrasts revealed no significant difference between sham and active rTMS [$F(1, 19) = 0.01$; $p = 0.91$]. The contrast between left and right sham rTMS was not significant [$F(1, 18) = 0.009$; $p = 0.93$] as well as the contrast between right active rTMS and left active rTMS [$F(1, 18) = 0.03$; $p = 0.84$].

Reaction Times

The averaged RTs for the sham and active rTMS conditions, respectively, were: 1,849 ms ($SD = 154$) and 1,971 ms ($SD = 154$) for the left group; 1,925 ms ($SD = 283$) and 1,913 ms ($SD = 324$) for the right group. No significant main effects on the averaged RTs for the factors Side [$F(1, 18) = 0.01$; $p = 0.9225$], Condition

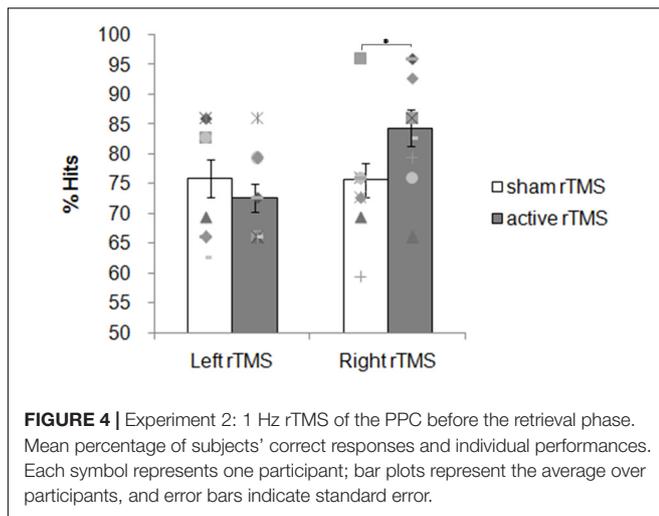
[$F(1, 18) = 1.47$; $p = 0.2408$], nor Side \times Condition interaction [$F(1, 18) = 2.12$; $p = 0.1630$] were found. Planned contrasts revealed no significant difference between sham and active rTMS [$F(1, 19) = 1.39$; $p = 0.25$]. The contrast between left and right sham rTMS conditions was not significant [$F(1, 18) = 0.57$; $p = 0.45$] as well as the contrast between right active rTMS and left active rTMS [$F(1, 18) = 0.24$; $p = 0.62$]. These results indicate that active rTMS over the left and right PPC at encoding did not modulate the performance on the non-verbal recognition memory task.

Experiment 2: 1 Hz Repetitive Transcranial Magnetic Stimulation of the Posterior Parietal Cortex Before the Retrieval Phase Accuracy

Overall participants were accurate choosing the correct answer more often than predicted by chance. The mean percentage of correct responses for the sham and active rTMS conditions, respectively, were: 76 ($SD = 10$) and 72 ($SD = 7$) for the left group; 76 ($SD = 9$) and 84 ($SD = 10$) for the right group. The ANOVA on the accuracy showed no significant main effects for the factors Side [$F(1, 18) = 3.02$; $p = 0.09$] and Condition [$F(1, 18) = 1.21$; $p = 0.28$]. A significant interaction Side \times Condition was found [$F(1, 18) = 6.13$; $p = 0.02$; $\eta_p^2 = 0.25$; **Figure 4**]. The contrast between sham and active rTMS was not significant [$F(1, 19) = 0.95$; $p = 0.34$]. Planned contrasts revealed that right active rTMS significantly improved subjects' accuracy when compared with left active rTMS [$F(1, 18) = 9.21$; $p = 0.007$; $\eta_p^2 = 0.33$] while there was no significant difference between left and right sham rTMS conditions [$F(1, 18) = 0.006$, $p = 0.93$; $\eta_p^2 = 0.0003$].

Reaction Times

The averaged RTs for the sham and active rTMS conditions, respectively, were: 1,813 ms ($SD = 296$) and 1,794 ms ($SD = 304$)



for the left group; 1,956 ms ($SD = 253$) and 1,881 ms ($SD = 367$) for the right group. The ANOVA on the averaged RTs showed no significant main effects for any factor Side [$F(1, 18) = 0.74$; $p = 0.40$], Condition [$F(1, 18) = 1.87$; $p = 0.18$] nor Side \times Condition interaction [$F(1, 18) = 0.68$; $p = 0.41$]. Planned contrast revealed no significant difference between sham and active rTMS [$F(1, 19) = 1.89$; $p = 0.18$]. The contrast between left and right sham rTMS conditions was not significant [$F(1, 18) = 1.35$, $p = 0.26$] as well as the contrast between right active rTMS and left active rTMS [$F(1, 18) = 0.32$; $p = 0.57$]. These results indicate that active rTMS over the right, but not left, PPC before the retrieval phase significantly improves non-verbal recognition memory performance without any significant modulation of speed of response.

DISCUSSION

The main results of the present study show that 1 Hz rTMS of the right PPC selectively enhanced item-recognition accuracy when it was applied before the retrieval phase, whereas no effects were found when rTMS was administered over the left PPC or before the encoding phase over either the right or the left PPC.

These results are in accord with neuroimaging findings documenting the role of PPC in recognition memory (Cabeza and Nyberg, 2000; Rugg et al., 2002; Wagner et al., 2005). Moreover, the process-specific effect of TMS related to the retrieval but not to the encoding phase of a recognition memory task is in line with previous studies reporting involvement of the PPC in the retrieval phase of long term memory (e.g., Manenti et al., 2010; Sestieri et al., 2013, 2017).

A recent meta-analysis of the TMS effects for neuromodulation of episodic memory (Yeh and Rose, 2019), has not documented clear-cut different effects of rTMS when stimulating the left or the right hemisphere during either encoding or retrieval. The present results add new findings to this debate, by showing modulation of episodic memory linked

to both hemispheric lateralization and timing of the stimulation, which may be important for future research.

Concerning the hemispheric lateralization, as discussed in the Introduction, previous findings suggest that the retrieval-related activity may be stronger in the left hemisphere (but see Koen et al., 2018 for a revision of the role of the left angular gyrus in encoding). Our data suggest that 1-Hz rTMS delivered to the left PPC does not affect facial memory retrieval.

Indeed, the question of a possible hemispheric specialization of PPC in memory retrieval is still open. Lesion studies that found memory-related deficits following parietal lesions recruited mostly patients with bilateral lesions (Berryhill et al., 2007; Drowos et al., 2010; Simons et al., 2010). Neuroimaging studies reported left-lateralized parietal activations although the degree of fMRI lateralization is not the same across studies. Consequently, most TMS studies delivered rTMS stimulation only to left PPC regions (Sestieri et al., 2013; Wang et al., 2014; Nilakantan et al., 2017; Kim et al., 2018; Tambini et al., 2018). Other TMS studies that stimulated both left and right PPC employed verbal stimuli and found memory-related effects during left PPC rTMS (Manenti et al., 2010). On the other hand, in the present study, we used non-verbal stimuli, and thus we cannot exclude the influence of modality specific memory effects on hemispheric lateralization during retrieval. With respect to the timing of the stimulation, we found specific TMS effects related to the retrieval phase. It may be interesting to note that most TMS studies in the literature apply forms of intentional encoding, while in the present study we used incidental encoding at least in our first session. According to the level of processing framework (Craik and Lockhart, 1972), deep (i.e., semantic) compared to shallow (i.e., perceptual and incidental) encoding benefits later retrieval (Galli, 2014). Moreover, dorsal vs. ventral PPC areas make opposite contributions during encoding (Uncapher and Wagner, 2009). Since we stimulated a single region of the PPC, it may be that the lack of rTMS effects on encoding in the present study is related to both the nature of encoding (incidental rather than intentional) and the stimulated parietal site.

Results of the present study show an improvement of the performance despite the use of a neuromodulation paradigm that is usually characterized as inhibitory for the stimulated cortex, at least at the motor cortical level (Pascual-Leone et al., 1998; Thickbroom, 2007). One may therefore think that the effects of TMS may differ according to the targeted region (e.g., motor cortex vs. prefrontal/parietal cortex). Related to this, our results are in line with a previous study documenting an improvement on the same recognition memory task after 1 Hz rTMS of the right DLPFC in healthy subjects and in patients with mild cognitive impairment (Turriziani et al., 2012) and, more recently, in patients with Alzheimer's disease (Turriziani et al., 2019). This result is also in accord with the literature on TMS effects on episodic memory, showing larger facilitatory effects of 1 Hz rTMS compared with other stimulation frequencies (Yeh and Rose, 2019).

We adopted an off-line low-frequency rTMS protocol that is regarded to induce plastic effects even at brain sites distant from those stimulated. As a consequence, one of the explanations proposed to account for this memory facilitation after 1 Hz rTMS

inhibition of the right DLPFC or PPC, pointed to the modulation of excitability of the target region as well as of anatomically and functionally interconnected brain structures such as the middle temporal lobe (e.g., Simons and Spiers, 2003; Wagner et al., 2005; Vilberg and Rugg, 2008).

The present results could also be consistent with the Attention to Memory model (Cabeza et al., 2008; Ciaramelli et al., 2008, 2020), according to which activity of the dorsal parietal cortex maintains retrieval goals, which modulate memory-related activity in the medial temporal lobe. We suggest that the improvement of recognition memory after 1 Hz rTMS of the right PPC could be correlated with the high functional connectivity between the lateral parietal cortex and the hippocampus (Kahn et al., 2008), likely mediated by lateral parietal projections to retrosplenial and parahippocampal cortex (Mesulam et al., 1977; Cavada and Goldman-Rakic, 1989a,b; Vincent et al., 2006, 2008).

Our results are in line with those of a recent study, testing the relationships between memory retrieval and hippocampal fMRI connectivity using rTMS at different frequencies (Hermiller et al., 2019). The authors reported facilitation of memory retrieval following the application of continuous theta burst stimulation (cTBS) over the left parietal cortex. Individual differences in retrieval improvements following cTBS were associated with corresponding increases in fMRI connectivity between the hippocampus and cortical areas, consistent with the idea that the influence of TMS of the parietal cortex may be related to the ability to distally target the hippocampus and contiguous regions of the mesial temporal lobe.

Facilitation of recognition memory following 1 Hz rTMS of the right hemisphere is not at odds with the findings of memory retrieval facilitation using high-frequency rTMS of the left hemisphere reported in previous rTMS studies. In both cases, i.e., high-frequency rTMS of the left parietal cortex or low-frequency rTMS of the right parietal cortex would facilitate guided retrieval of relevant memory representations via facilitation of network connectivity mediated by transcallosal interactions.

The present study has some limitations to be considered when interpreting these results. The first one is the small numerosity of the sample. *Post hoc* power analyses conducted using G*Power 3 software (Faul et al., 2007) revealed that the observed power

for experiment 1 was 0.31 and 0.93 for the accuracy and RTs results, respectively; while the observed power for experiment 2 was 0.99 and 0.77 for the accuracy and RTs results, respectively, suggesting that the study was underpowered. Another limit is that we targeted a single region of the parietal cortex. Since several parietal sub-regions probably play distinct roles during memory retrieval (Hutchinson et al., 2014), the present results cannot test different accounts, based on the role of attention (Cabeza et al., 2008; O'Connor et al., 2010), event representation (Vilberg and Rugg, 2008; Shimamura, 2011), or decision making (Donaldson et al., 2010) processes.

Another limit of the study is in the sham/control procedure. In fact, tilting the coil away from the target scalp site does not induce the same kind of somatosensory stimulation as active stimulation, a problem existing in many TMS studies even when a sham coil is used.

In summary, we have demonstrated that 1 Hz rTMS of the right PPC selectively enhanced recognition memory when it was applied before the retrieval phase. Further research employing different memory stimuli and targeting different parietal sites in a representative sample, will be required.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Bioethics Committee of the University of Palermo. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MO, DS, and PT designed the research. GRM and DS collected the data. GRM, VT, and PT analysed and discussed the data. GRM, MO, and PT wrote the manuscript.

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