DIFFERENTIAL EFFECTS OF TRANSCRANIAL MAGNETIC STIMULATION OF LEFT AND RIGHT POSTERIOR PARIETAL CORTEX ON MENTAL ROTATION TASKS

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Abstract

A recently published study used the interference strategy of transcranial magnetic stimulation (TMS) to demonstrate the role of the right posterior parietal cortex (PPC) in the mental rotation of alphanumeric stimuli. We used similar stimulation parameters over the same left and right PPC regions, and examined the ability to rotate more complex 3D Shepard and Metzler (1971) images. There was reduced accuracy of performance with both right and left PPC stimulation for different angles of rotation of the visual stimuli. Right PPC stimulation led to reduced accuracy to rotate stimuli by 120°, whereas left PPC stimulation affected 180° rotation. We hypothesise that the two hemispheres make different contributions to the processing underlying visuospatial mental imagery: the right PPC is important for spatial rotations through smaller angles; the left hemisphere has a unique role when the stimuli to be compared are rotated through 180°, a task that engages verbal strategies due to the well-documented special nature of enantiomorphs.

Key words: TMS, Shepard-Metzler, posterior parietal, enantiomorphs

Introduction

Mental rotation is a well-studied paradigm of imagery. The landmark investigation by Shepard and Metzler (1971) showed that response times increased linearly as a function of angular disparity, a robust effect that has been replicated on many occasions. Based on their observations, Shepard and Metzler (1971) proposed that mental rotation involves subjects imagining a rotated shape passing through intermediate orientations until it matches the target. The larger the rotation angle from upright, the greater the required rotation and the longer the response times (Shepard and Metzler, 1971).

Human lesion studies (Mehta and Newcombe, 1991; Ratcliff, 1979), animal investigations (Ockleford et al., 1977) and neuroimaging techniques (Alivisatos and Petrides, 1997; Cohen et al., 1996; Harris and Miniussi, 2003; Harris et al., 2000; Pegna et al., 1997) have all contributed to the evidence that the posterior parietal cortex (PPC) plays an important role in carrying out processes required for mental rotation. The differential contribution of the left relative to the right cerebral hemisphere is, however, a topic of debate, and the extensive discussion by Harris et al. (2000) suggests that methodological differences between neuroimaging techniques and experimental procedural differences in the tasks used may account for differences in activation patterns between published studies. In this paper, we address the issue of lateralisation of processing with the interference methodology of transcranial magnetic stimulation (TMS).

TMS can disrupt the processing of a targeted brain area for a limited period. TMS induces an electric current in a small region of the brain by delivering a rapidly varying high magnetic field produced by a stimulating coil held over the targeted brain region. The resulting disruption of activity in the targeted brain region leads to an alteration in, or suspension of, behaviour consequent upon that brain activity. This "virtual lesion" allows the attribution of a process to an anatomical location (Walsh and Pascual-Leone, 2003).

The aim of the present investigation was to confirm the involvement of the right PPC in mental rotation (Harris and Miniussi, 2003; Harris et al., 2000) and also to investigate whether and to what extent the left PPC is recruited for the rotation of more complex Shepard and Metzler (1971) stimuli, as predicted by Harris and Miniussi (2003) and Carpenter et al. (1999).

Materials and Methods

Subjects

Twenty healthy right-handed subjects were recruited from the general population (mean age = 24.7 years, 10 males and 10 females). They provided written informed consent and received a small payment for their participation and the study was approved by the institutional ethics committee of the University of New South Wales.

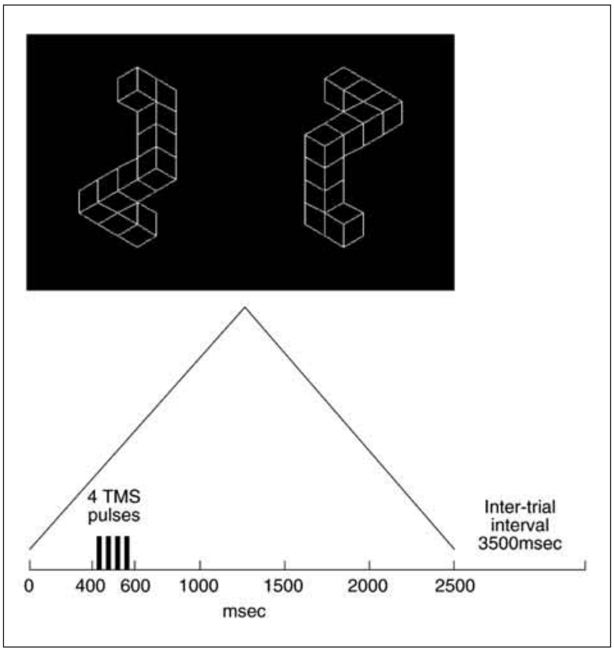

Fig. 1 – *One stimulus presentation trial. A pair of 3D stimuli was presented in the centre of a computer monitor for 2500 msec during which subjects were to identify the rotated stimulus on the right as the same or a mirror-image version of the stimulus on the left. 400 msec after stimulus onset, 4 magnetic pulses were given for a duration of 200 msec. After the stimulus disappeared, a 3500 msec inter-trial interval followed. There were 38 trials in a block.*

TMS

A MagPro X100 stimulator (Medtronic, Skovlunde, Denmark) was used to deliver pulses at 60% of maximum machine intensity (di/dt = 92 μA/msec). A fluid-cooled figure-of-eight coil with 50 mm loop diameter was used. Four pulses at 20 Hz were time-locked to be delivered 400 msec after onset of presentation of the visual stimuli (at 400, 450, 500 and 550 msec). A timeline of one experimental trial is shown in Figure 1.

The site of stimulation was located according to the method used by Harris and Miniussi (2003) where the PPC was approximated to lie under the point halfway between CP4 and P4, and CP3 and P3 on the international 10-20 system of electroencephalography (EEG) montages. Subjects wore a custom-designed neoprene cap with these points marked out, making repeated coil localisation more reliable. Each subject received 304 pulses in total.

The coil was positioned throughout each trial with the handle pointing in an anterior direction. Subjects reported no significant discomfort from the stimulation. Sham stimulation was given to the left and right sites with the coil held perpendicular to the scalp, with the edge of one wing in contact with the scalp surface.

Task

Eight white 3D figures taken from Shepard and Metzler (1971) were presented on a black background. Pairs of stimuli were presented on a 15" monitor (60 Hz refresh rate), with the stimulus on the left being the target to which the right-sided stimulus was matched. The stimulus on the right could be rotated 0°, 60°, 120° or 180° and subjects were instructed to rotate the stimulus to the "upright" position of the left stimulus and then judge if it is the same or a mirror of the target. The stimuli were rotated in depth, as per Shepard and Metzler (1971) where a non-rigid transformation was used to correspond to a rigid rotation of a 3D object. Subjects were seated 60 cm from the monitor (visual angle ~ 5°) and pressed a key on a computer keyboard with their right index finger for a normal stimulus and with their right thumb for a mirror presentation.

Stimuli were presented for 2500 msec followed by a 3500 msec interval with a blank screen. This inter-trial interval was designed to comply with the TMS safety recommendations of Wasserman (1998). Subjects were instructed to respond as quickly and accurately as possible whilst the stimuli remained on-screen and any response made after this was scored as incorrect. A total of 38 stimuli were presented in a block, lasting for 3 min and 48 sec.

In order to minimise testing time and to allow the subjects to become familiar with the task, a practice phase was performed one day prior to testing. Under testing, the task was performed four times in total, during left and right active and sham stimulation and stimulation order was counterbalanced across subjects. Stimulation was given over one site/task block and accuracies and response times were recorded.

RESULTS

Our data showed the typical trend first observed by Shepard and Metzler (1971) that reaction time increases linearly with angular disparity. The exception to this finding was for 180° rotation, for which reaction times did not increase from those rotated by 120°, under either real or sham stimulation. No significant main effects of stimulation were evident on the response times of subjects, using a repeated measures analysis of variance (ANOVA) [F (1, 18) = 1.408, p = .251], and no significant interaction occurred between type and side of stimulation and angle of rotation [F (3, 54) = .466, p = .220]. The results of the reaction times are presented in Figure 2.

To examine the effect of repetititve transcranial magnetic stimulation (rTMS) on accuracy of performance, a repeated-measures ANOVA with stimulation type (real, sham) × side (left, right) × angle (0°, 60°, 120°, 180°) as within-subject factors found a significant main effect of stimulation [F (1, 18) = 5.489, p = .031]. There was, as expected, a significant difference in