SPECIAL SECTION

INFERIOR PARIETAL rTMS AFFECTS PERFORMANCE IN AN ADDITION TASK

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Abstract

Neuropsychological and neuroimaging studies strongly suggest that the inferior parietal cortex is important for calculation. However, the evidence from neuroimaging experiments for a left hemispheric dominance in calculation is not as clear as one would expect from the studies of patients. Often a concomitant activation of the homologous inferior parietal region of the right hemisphere is reported in the same tasks. The objective of this study was to replicate basic findings of acalculic patients and to investigate discrepancies between data from patients and results from neuroimaging studies in an addition task. Repetitive transcranial magnetic stimulation (rTMS) was applied over inferior parietal areas and the adjacent intraparietal sulcus (IPS) while subjects solved double-digit addition tasks. From studies of acalculic patients it was hypothesised that left hemispheric rTMS stimulation should result in longer reaction times (RTs) in the addition task. On addition trials without TMS subjects showed the classical problem size effect with longer RTs the larger the sum of the two operands. Magnetic stimulation over left inferior parietal areas disrupted performance significantly. The effect was specific to the left hemisphere stimulation. There was no increase in RTs for rTMS stimulation over the right hemisphere.

Key words: acalculia, addition, problem size effect, inferior parietal lobe, angular gyrus

Introduction

A large part of our current knowledge of numerical processing is derived from neuropsychological assessment of patients who present with specific mathematical difficulties following brain injury. There is strong agreement that disturbances in arithmetical calculation are more often observed after damage to the dominant (typically left) hemisphere and that the inferior parietal lobe seems to be of particular importance (Cipolotti et al., 1991; Grafman et al., 1982; Henschen, 1919; Mayer et al., 1999). Recently, several neuroimaging studies with healthy subjects have investigated which brain circuits are active during various calculation tasks. It is clear that the left inferior parietal lobe is active during most calculation tasks (Chochon et al., 1999; Cowell et al., 2000; Gruber et al., 2001; Zago et al., 2001). However, the evidence from neuroimaging experiments with respect to hemispheric dominance in calculation is not as clear cut as one would expect from the findings from patients. Often a concomitant activation of the homologous inferior parietal region of the right hemisphere is reported in the same tasks (Chochon et al., 1999; Dehaene et al., 1996; Kazui et al., 2000). There thus exists a discrepancy between results from neuroimaging data which indicate an important role of both left and right inferior parietal areas in calculation, and the data from patients suggesting a left hemisphere dominance for calculation abilities. Dehaene (2000; Dehaene and Cohen, 1995; Dehaene et al., 2003) addresses this discrepancy in his Triple Code Model. According to this model a bilateral approximate quantity representation is accessed whenever numbers are processed (Dehaene and Cohen, 1991; Cohen and Dehaene, 1996), but only the left hemisphere has access to the verbal code that is necessary to solve exact calculations (Dehaene and Cohen, 1995; Dehaene et al., 1999). The objective of our experiment was to investigate whether transcranial magnetic stimulation (TMS) can be used to replicate basic findings with patients and to address discrepancies between data from patients and results from neuroimaging studies in an addition task.

Recently several experiments with TMS have been reported in which studies originally carried out on patients have been successfully transferred from the clinic to the experimental laboratory and from patients to normal subjects (e.g., Pascual-Leone et al., 1994; Walsh et al., 1998).

For our investigations we chose to focus on a calculation task rather than on the more fundamental process of number representation, because numerical transcoding and simple numerical tasks such as number comparison are often well-preserved even in patients with severe acalculia (Cipolotti and van Harskamp, 2001). There are however many cases with impaired calculation in the literature. Warrington's (1982) patient D.R.C., for example, showed inaccurate performance of simple addition after a left parietal intracerebral haematoma. Van Harskamp and Cipolotti (2001) reported a patient (F.S.) with intact number transcoding skills after a left cerebral vascular incident. He showed a severe impairment in simple addition while his ability to multiply and subtract was flawless. Patient J.B. described by Delazer and Benke (1997) showed the typical symptoms of Gerstmann's syndrome after a left parietal glioblastoma. She had no problems identifying the larger of two Arabic numerals and she was fine with multiplication, but she was impaired on addition, subtraction and division. It is evident how variable the numerical abilities of these three patients are although they show lesions in roughly the same brain area and exhibit a common impairment on addition.

The goal of the current experiment was to test the effect of TMS on calculation in normal subjects. They had to solve addition tasks and TMS was used to investigate the contribution of left and right parietal lobes in this task. We looked at the contribution of two areas in the inferior parietal lobe (angular gyrus – ANG – and supramarginal gyrus – SMG) and the adjacent areas in the intraparietal sulcus (IPS). In many patients with acalculia both these areas are probably damaged (Cipolotti and van Harskamp, 2001). It is known, however, that at least in animals the homologues of these two regions differ in anatomical connexions as well as in function (Andersen et al., 1985; Colby, 1999; Cavada and Goldman-Rakic, 1989a) and there is evidence that these two regions in the inferior parietal lobe might also subserve different functions in humans (Rushworth et al., 2001a, 2001c; Shikata et al., 2003). It has been suggested that the ANG might be important for visuospatial processing (Ashbridge et al., 1997; Müller et al., 2003) while the SMG might be more closely associated with motor attention (Deiber et al., 1996; Rushworth et al., 2001a, 2001b, 2001c) or verbal memory functions (Paulesu et al., 1993; Zatorre et al., 1992).

Based on evidence from behavioural experiments on mathematical cognition, from acalculic patients and from neuroimaging studies of calculation the research hypotheses for the currrent experiment were as follows: for trials without TMS stimulation it was expected that the larger the size of the sum of the two operands the longer would be the reaction times (RTs) (the classical problem-size effect; Ashcraft and Battaglia, 1978; Groen and Parkman, 1972; LeFevre et al., 1996; Miller et al., 1984). Furthermore, left inferior parietal TMS stimulation was expected to interfere with subjects' ability to solve addition tasks and to result in an increase in RTs in the addition task. However, there should be no effect of right inferior parietal stimulation.

Materials and Methods

Stimuli and Apparatus

Subjects sat in a lighted room at a distance of approximately 50 cm from a screen. The experiment was controlled by a PC running the SuperLab software, version 1.04. Stimuli were presented centrally on a 17-in. colour monitor and appeared as white against a black background. The stimuli consisted of a set of 40 different double-digit addition tasks (ranging from 21 + 22 to 49 + 47; ties were excluded). Numbers were displayed using the Arial font (type size = 30 points) and when viewed from the distance of 50 cm they subtended 6.5° of visual angle. Subjects wore rubber bathing caps on which the relevant co-ordinates of the International 10/20 electroencephalography (EEG) system (AEEGS, 1991) were marked. For generating the magnetic pulses a Magstim stimulator, Model Super Rapid (The Magstim Company Limited, Whitland, UK) with a 70 mm figure of eight coil was used. The maximal magnetic field strength at the coil surface was 1.8 Tesla.

Procedure

In each block, the addition tasks ranged from 21 + 22 to 49 + 47. In each trial the task (e.g., 22 + 34) was first displayed for 300 msec followed by an inter-stimulus interval of 300 msec. Then a two forced response choice was displayed for 200 msec consisting of the correct answer (i.e., 56) and an incorrect answer (see Figure 1).

The incorrect answer was always one unit larger or smaller than the correct answer (e.g., the distractor for 56 was 57) to enforce exact calculation. Subjects were required to indicate with one of two possible key presses whether the correct response was on the right or the left of the fixation point. The location of the correct answer (right or left of the fixation point) was counter-balanced. The index fingers of the right and left hands were used to indicate the "right" and "left" responses respectively. The intertrial interval was two seconds. The order of the addition trials appearing on the screen was pseudo-random within each block. During each session subjects performed 4 blocks of 50 trials, preceded by an initial training block of 50 non-TMS trials. On 10 trials in each experimental block repetitive transcranial magnetic stimulation (rTMS) was applied over the subject's scalp for 500 msec at 10 Hz. The rTMS stimulation began with the onset of the inter-stimulus interval and lasted until the onset of the inter-trial interval. It thus spanned the time interval when the solution was presented on the screen. The rTMS trials occurred pseudo-randomly with the constraint that after four blocks each of the 40 addition tasks had been displayed 5 times, one of