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12 Investigation of the Resultant Changes in Corticospinal Excitability by Syllogistic Reasoning

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I. Introduction

Reasoning is the cognitive activity of evaluating arguments. All arguments involve the claim that one or more propositions (the premises) provide some grounds for accepting another proposition (the conclusion). Deductive arguments can be evaluated for validity. Valid deductive arguments involve the claim that their premises provide absolute grounds for accepting the conclusion. Goel et al. (1997, 1998) reported that positron emission tomography (PET; Oxygen 15 [O15]) during syllogistic reasoning revealed activation of the frontal and temporal regions of the left hemisphere (LH). In another early PET (O15) study conducted by Osherson et al. (1998) using similar stimuli, activation of the right occipital lobe, right basal ganglia, and left prefrontal cortex (PFC) was observed. More recently, Goel et al. (2000, 2003) performed functional magnetic resonance imaging (fMRI) studies and deduced that logical reasoning is a function of a large neural network consisting of the left and right PFCs (left to right [L > R]), left temporal lobe, and the left and right parietal lobules (L > R). However, in these studies only PET or fMRI was performed, and the time resolution was unclear. The aim of this study is to investigate changes in corticospinal excitability during syllogistic reasoning by using transcranial magnetic stimulation (TMS) and determine which hemisphere is dominant during deductive reasoning.

II. Method

1. Subjects

A total of 5 normal subjects (4 men and 1 woman) (mean age, 30.8 years) volunteered to participate in the study. None of the subjects had any psychiatric or significant past medical history or any contraindications to TMS (Wassermann, 1998). Informed consent was obtained from all subjects.

2. Handedness

The handedness of the subjects was evaluated using the Edinburgh inventory, which consists of 12 items; the scores were calculated using the following formula:

$$H = 100 \cdot \sum X\,(i, R) - \sum X\,(i, L) / \sum X\,(i, R) + \sum X\,(i, L),$$
$$-100 \leq H \leq +100$$

where $\sum X\,(i, R)$ and $\sum X\,(i, L)$ are the positive values for the i^{th} item in the right and left columns, respectively (Oldfield, 1971).

3. Stimuli

We organized 32 reasoning (valid, 16; invalid, 16) and 8 control trials. A rest trial consisting of 8 null events (Table 1) was common to all the trials. The reasoning trials consisted of categorical syllogisms in which the terms "all," "some," and "none" were considered as quantifiers for each of the premises as well as for the conclusion. Half of the syllogisms were valid, and the remaining, invalid. The 3 parts of the syllogism, i.e., premise 1 (P1), premise 2 (P2), and the conclusion (Co) were presented sequentially. The subjects were instructed to consider both premises and draw a conclusion after the presentation of the second premise. In the control trials, the same arguments were used; however, the 3rd sentence was altered such that the 3 sentences did not constitute an argument. In the rest trials, subjects were made to view a blank screen.

Table 1. Sample stimuli.

	Valid	Invalid
Reasoning	P1: All mammals are vertebrate animals. P2: All cats are mammals. P3: All cats are vertebrate animals.	P1: All mammals are vertebrate animals. P2: All cats are mammals P3: All vertebrate animals are cats.
Control	P1: All mammals are vertebrate animals. P2: All cats are mammals. Co: All pumpkins are healthy.	
Rest		

4. Stimuli presentation

The sentences appeared on the screen individually in succession, with the first sentence appearing at 0 s; the second, at 4 s; and the last, at 8 s. All sentences remained on the screen until 8 s after the presentation of the 3rd sentence. The duration of each trial was 20 s; the subjects were given 4 s (after the disappearance of all sentences) to indicate whether the arguments were valid or invalid (Fig.1).

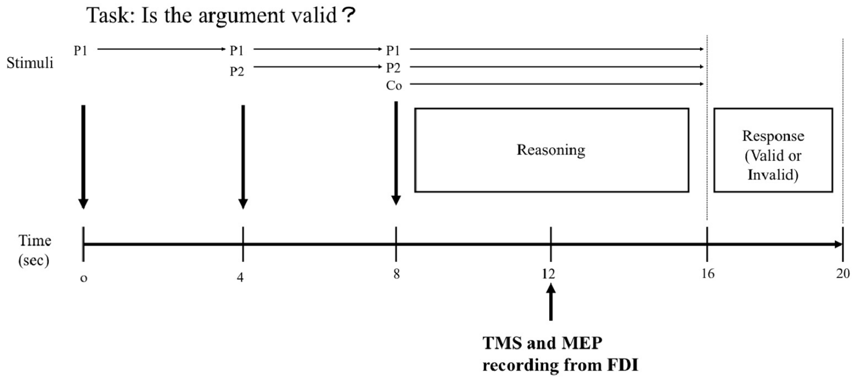

Fig. 1. Stimuli presentation. See text.

5. TMS

Subjects were seated in a reclining chair and instructed to keep their arms and hands relaxed during the experiment. Motor evoked potentials (MEPs) induced by single-pulse TMS were recorded from the right and left first dorsal interosseous (FDI) muscles. Silver/silver chloride surface electrodes were placed over the muscle belly (active electrode) and over the tendon of the muscle (reference electrode). A circular ground electrode (diameter, 30 mm) was placed on the dorsal surface of the wrist. The MEPs were amplified and bandpass filtered at 20–2000 Hz using Neuropack 8 (Nihon Kohden Corporation, Tokyo, Japan).

TMS was performed with 70-mm figure-of-eight-coils and Magstim 200 stimulators (Magstim Company, Dyfed, UK). Stimulation was delivered to the “optimal scalp site,” which was defined as the site at which TMS induced MEPs of maximal amplitude in the contralateral FDI. The coil was positioned tangentially to the scalp, pointing anteriorly, and oriented at an angle of 45° from the midsagittal axis. Initially, the motor threshold (MT) in the FDI was determined. MT was defined as the minimum intensity of TMS required under conditions of muscle relaxation to elicit FDI MEPs with peak-to-peak amplitude >50 μV in at least 5 of the 8 successive trials (Rossini et al., 1994). The intensity of TMS was set at a value approximately 20% greater than the MT in order to consistently evoke MEPs with peak-to-peak amplitudes of approximately 1 mV.

In each set of trials, single-pulse TMS was delivered at 4 s after the presentation of the last sentence (Fig.1).

6. Experimental design

The experiment was designed to examine the effect of syllogistic reasoning on the motor responses elicited by single-pulse TMS of the FDI muscles. Each subject performed 2 blocks of experiments. In the first block, single-pulse TMS was applied to the right hemisphere, and MEPs were recorded from the left FDI muscle. In the second block, single-pulse TMS was applied to the left hemisphere, and MEPs were recorded from the right FDI muscle. One block comprised 32 sets of trials (valid reasoning, 8; invalid reasoning, 8; control trials, 8; and rest trials, 8). Thus, a total of 32 MEPs were recorded from the FDI muscle in each block. In each set of trials, namely, the reasoning, control, or rest trials, the stimuli were intermixed and presented to the subjects randomly.

III. Results

All subjects were right-handed (Edinburgh quotient, 86.0 ± 5.1). The mean data from all 5 subjects are presented in Fig.2. The MEPs in the left hand induced by single-pulse TMS on the right hand motor cortex during the reasoning trial were larger than during the control trial. In contrast, in the case of the right hand, slightly smaller MEPs were obtained during the reasoning trial than during the control trial (Fig. 2A). However, no statistically significant differences were observed between the MEPs in the right and left hands. Compared to valid reasoning, invalid reasoning had a greater effect on the left hand MEPs. Valid reasoning inhibited the responses of the right hand muscles, while invalid reasoning had no effect on these muscles. Fig. 2B shows that the left hand MEPs elicited during

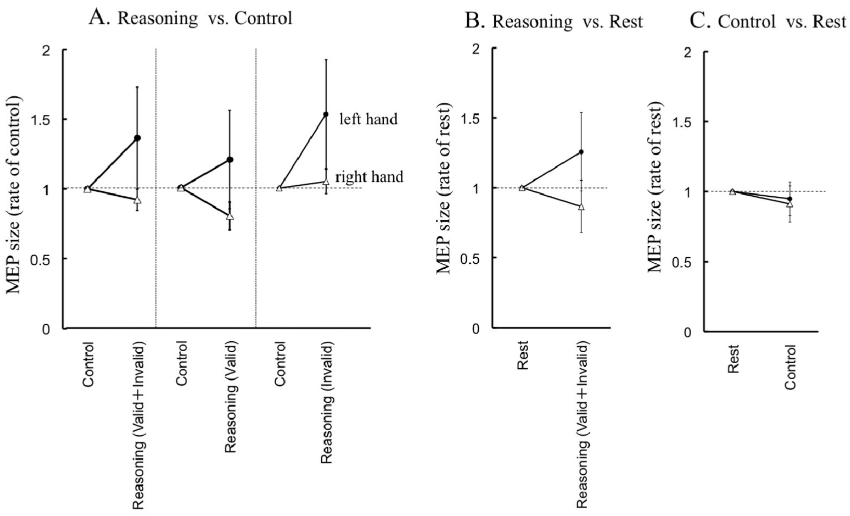

Fig. 2. Mean (± standard error) data pertaining to the left (circles) and right (triangles) hands of the 5 subjects.

the reasoning trial were larger than those elicited during the rest trial. In contrast, the right MEPs elicited during the reasoning trial were smaller than those elicited during the rest trial. Fig. 2C shows that the MEPs elicited during the control trial were almost the same as those elicited during the rest trial.

IV. Discussion

The results of the present study indicate that deductive reasoning increases the activity of the right hand motor cortex and has little or no effect on the left hand motor cortex. However, statistical analysis showed that deductive reasoning did not significantly affect the activity of the motor cortex. Several studies on deductive reasoning involving PET (O15) and fMRI have revealed activation of the left and right occipital and parietal cortices, and the left lateral temporal and prefrontal cortices (Acuna et al., 2002; Christoff et al., 2001; Goel et al., 2000; Goel & Dolan, 2000, 2001, 2003; Goel et al., 1995, 1997, 1998; Houde et al., 2000; Knauff et al., 2002; Kroger et al., 2002). The results of these studies indicate that the left hemisphere is dominant during deductive reasoning. However, our results indicate that the right hand motor cortex is dominant during deductive reasoning. The difference between results of the present study and those of previous reports may be expressed as follows. Activation of the left parietal and prefrontal cortices may cause a relative reduction in the activity of the left motor cortex, which in turn may cause a relative increase in the activity of the right motor cortex. If this assumption is correct, our results are consistent with those of previous reports.

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