A transcranical direct current stimulation study on working memory

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In the present study we investigated the effects of transcranial Direct Current Stimulation (tDCS) applied over parietal lobe on working memory (WM). tDCS is a non-invasive method for modulating cortical excitability by weak electrical current applied constantly over time to enhance (anodal stimulation) or reduce (cathodal stimulation) the excitation of neuronal populations, with maximal effect on the stimulated area beneath the electrodes (Priori et al., 2003; Nitsche et al., 2008; Utz et al., 2010). In recent years, to investigate the neural basis of WM processes, variants of the "*n*-back" procedure (Gevins & Cutillo, 1993) have been employed in many human studies. In the most typical variant of this task, the volunteer is required to monitor a series of stimuli presented centrally and to respond whenever a stimulus is presented that is the same as the one presented *n* trials previously, where *n* is a prespecified integer, usually 1, 2, or 3. The task requires the simultaneous engagement of several retention – and control related operations and is therefore assumed to place great demands on a number of key processes within working memory. Transcranial Magnetic Stimulation (Mottaghy, 2006) and neuroimaging (Owen et al., 2005) data show a bilateral parietal involvement during verbal WM. Moreover, functional Magnetic Resonance Imaging studies report an increase (Kirshen et al., 2005) or a decrease (Garavan et al., 2000) in activations with task practice in this brain region.

The aim of this study was to clarify the role of the two hemispheres according to the type of processes involved (maintenance vs. manipulation) by up-modulating posterior parietal cortex (PPC) of one hemisphere and simultaneously down-modulating the corresponding region in the contralateral hemisphere by means of bilateral tDCS. To do so we tested verbal WM (1-back and 2-back) before tDCS began and after it ended.

A group of healthy volunteers participated in the study. Participants were randomly assigned into one of three groups to receive either (1) active stimulation with the anodal electrode over the right PPC and the cathodal electrode over the left PPC (referred to as LHC-RHA group); (2) active stimulation with the anodal electrode over the left PPC and the cathode over the right PPC (referred to as LHA-RHC group); or (3) sham stimulation (referred to as SHAM group). The direct current was delivered by a battery driven, constant current stimulator (neuro-Conn GmbH, Ilmenau, Germany) through a pair of saline-soaked sponge electrodes (35 cm^2, intensity 1.5 mA, duration 13 min). The electrodes were placed on the left and right PPC, centred respectively over P3-P4 (10-20 EEG electrode scalp positioning system).

In each group, sham stimulation was always the first type of stimulation followed by verbal WM tasks (referred to as "pre" stimulation). After ten minutes of rest there was a second period of stimulation (active or sham) and then WM tasks again (referred to as "post" stimulation).

There were not differences between the three groups in the "pre" stimulation phase for both tasks. However, when we compared the difference in reaction time (RTs) between "post" and "pre" stimulation (delta RTs) we found a double dissociation. In the 1-back task, there was a significant difference between SHAM and LHA-RHC group. On the contrary in the 2-back task, there was a significant difference between SHAM and LHC-RHA group. Regarding the direction of the effect, tDCS abolished the practice-dependent proficiency increase in WM in both tasks.

At the cognitive level, this double dissociation could be explained by a different demand on processes involved in these tasks. Although in 2-back the load is higher than in 1-back, this more demanding task also requires wide manipulation of information rather than simple selection and maintenance of information. Specifically, when the WM load increases, there is a greater demand on some categories of cognitive processes, such as updating of information, temporal ordering and inhibition.

At the neuroanatomical level, our results can be explained by a change in the balance of activity between the two hemispheres according to the verbal WM load. In conclusion we were able to show, by means of parietal tDCS, a double dissociation of verbal WM load effects induced by differential bilateral hemispheric modulations.

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