tACS was delivered at an intensity of 1 peak-to-peak milliampere. TMS was applied over the sponge electrode used for tACS overlying the left M1 and 10 MEPs/condition were recorded from the right First Dorsal Interosseus (FDI), during online neuronavigation.

In order to exclude that the observed effects might be due to biophysical interactions of the electric fields produced by tACS and TMS, rather than by interactions with cortical neurons, the experiment was then repeated by applying tACS (5 Hz and 20 Hz) and TMS on the ulnar nerve at the elbow.

A repeated measures ANOVA followed by Bonferroni corrected post-hoc comparisons showed that the corticospinal output resulted in a better reactivity when tACS was applied on the left M1 at 20 Hz. This was reflected by a significant enhancement of the MEPs size obtained during tACS at 20 Hz with respect to all the other conditions (i.e., Basal, 5 Hz, 10 Hz, 40 Hz and 20 Hz on the parietal site). Peripheral tACS was uneffective.

Results originally provides causal evidence that 20 Hz rhythm of the motor cortex plays a specific role in corticospinal facilitation.

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Effects of transcranial direct current stimulation on electroencephalographic activity

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Transcranial direct current stimulation (tDCS) is a non invasive technique used to manipulate cortical excitability through weak electric currents applied to the head (usually equal or less than 2 mA). Although the effects of weak electrical currents on tissue have been known for centuries, only recently tDCS has been revalued after that its efficacy has been definitively proved (Nitsche & Paulus, 2000). These authors tested the functional effects of tDCS by studying changes in motor evoked potentials (MEPs) elicited in a hand muscle by transcranial magnetic stimulation (TMS). Results, subsequently confirmed by further investigations, showed that the effects induced by tDCS over the motor cortex are dependent on the current polarity: anodal stimulation increases excitability, while cathodal polarization decreases it. Since tDCS has been proved to induce long lasting modulations of cortical excitability (Nitsche & Paulus, 2001), there is a growing interest in using it as tool for improving cognitive and behavioural functions in patients with neurological diseases. However, there are still many unresolved questions concerning its mechanisms of action, including how currents spread to the cortex. Although tDCS involves the direct induction of intracerebral current flow, few studies explored the impact of tDCS on electroencephalographic (EEG) activity (e.g., Ardolino et al., 2005; Polania et al., in press).

Aim of the current study was to investigate the short and long lasting effects induced by tDCS on spontaneous and evoked cortical EEG activity during the application of a standard protocol proved to be effective in modulating corticospinal excitability. Since EEG is assumed to reflect excitability of neuronal populations, it was expected to provide a central measure of tDCS effects.

A group of young healthy right-handed subjects participated in this study. Anodal and cathodal tDCS were delivered to every subject above the motor cortical representational field of the right first dorsal interosseous, identified by the use of TMS. The order of tDCS application was randomized across subjects. The EEG activity was recorded from 10 scalp electrodes positioned according to functional criteria and to the 10-20 International system. MEPs (i.e., peripheral indexes of excitability) were evaluated before and after tDCS application, in order to confirm the efficacy of the stimulation protocol in the present experiment. Concurrently to MEPs, we measured TMS evoked potentials (TEPs), which may be considered as a central index of excitability (Casali et al., 2010; Casarotto et al., 2010). To elicit MEPs and TEPs, 100 TMS pulses were delivered with a random inter stimulus interval of 2-4 s. In addition to MEPs and TEPs, we acquired also EEG activity at rest and collected reaction times during a simple detection task. In order to assess the duration of the effects, all the measures (i.e., MEPs, TEPs, EEG at rest, behavioural performance) were evaluated before tDCS as baseline, immediately after and 30 minutes after tDCS.

The tDCS-induced changes on peripheral and cortical responses to TMS were evaluated respectively analyzing the peak to peak amplitude of MEPs and the cortical local field power of TEPs for the right and left hemisphere. The EEG activity at rest was investigated by calculating the power of all the frequencies in the range between 2 and 45 Hz. Reaction times of the right and left hand, respectively contralateral and ipsilateral to the stimulation side, were compared considering the polarity of stimulation. Statistical analyses were performed for each index to reveal changes between pre- and post- anodal and cathodal tDCS.

Consistently with the expectations, results showed that motor corticospinal excitability increased after anodal tDCS and decreased after cathodal tDCS, as revealed by MEPs modulations. Interestingly, also TEPs components were modulated according to tDCS polarity and consistently with MEPs modulations: TEPs amplitude increased after anodal tDCS and decreased after cathodal tDCS. This effect was localised to the left stimulated hemisphere, while no difference in TEPs amplitude was observed over the right hemisphere. Also behavioural results revealed that tDCS effects were focalised to the stimulated area, since reaction times were modulated by the tDCS polarity only when subjects responded with the right hand contralateral to the stimulated side and not with the left hand ipsilateral to the stimulated side. The most of the results were maintained 30 minutes after tDCS. No relevant modulations were observed in EEG activity at rest. In both anodal and cathodal tDCS, indeed, an increase of power was present in low frequency bands (i.e, theta and alpha), suggesting a general effect not specifically related to the stimulation.

These data provide for the first time direct evidence that tDCS induces modulations of the motor cortical excitability. A complete picture emerges, in which peripheral and central indexes of excitability (i.e., MEPs and TEPs) as well as behavioural measures are all consistently modulated by electrical stimulation. These data show also that EEG responses to TMS are reliable indexes for measuring cortical excitability. Thus, they may be employed to detect changes in the state of cortical circuits also in those areas without a peripheral correlate.

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