Investigating Neuroplastic Changes in the Human Brain Induced by Transcranial Direct (tDCS) and Alternating Current (tACS) Stimulation Methods

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Preface

It has been 211 years since C. Grapengiesser first published a book entitled *Galvanism to Cure Some Diseases* (original title: *Galvanismus zur Heilung einiger Krankheiten*) describing the successful use of galvanic currents in treating several patients with pain and strokes. A comparatively short time of slightly more than a decade has passed since tDCS with weak currents in the range of 1 to 2 mA was reintroduced as an additional tool to repetitive transcranial magnetic stimulation (rTMS) for the induction of plastic after-effects in the treatment of brain diseases. Successful quantification of tDCS plasticity-promoting effects by single-pulse TMS has established the usefulness of this non-invasive electrical stimulation method. Generally speaking, applying anodal tDCS to the surface of both the motor and the visual cortex increases cortical excitability, probably by depolarizing pyramidal cell bodies in layer V and thereby increasing the spontaneous firing rates, whereas applying a cathodal current results in the reverse effect by hyperpolarizing cell bodies. Further technical development of transcranial alternating current stimulation (tACS) now permits external interference with the cortical oscillations that play a major role in the temporal coherence between different cortical areas. Transcranial ACS in the ripple-frequency range and a special form of tACS, called high-frequency transcranial random noise stimulation (tRNS), also generate cortical after-effects which, unlike those produced by anodal tDCS, are independent of the direction of current flow. In contrast, inhibition or excitation now may be determined by modulating intensity.

What features of electrical stimulation methods may render them superior to rTMS? Both tDCS and tACS, as well as rTMS, produce cortical excitability changes over time. However, tDCS/tACS application is distinctly cheaper since it can be performed with a small low-priced battery-driven portable stimulator also suitable for home use. Furthermore, since it produces less acoustic noise, skin sensation, like itching or tingling, or muscle twitching, it is more suitable for double-blind, sham-controlled studies and for clinical applications. On its own, or in combination with other methods, such as cognitive tasks, pharmacological interventions, functional brain mapping, electroencephalography or transcranial electrical brain stimulation, it can also be used to investigate, for example, the location and relative timing of task-related brain activity, excitability changes of neural tissues and circuits, and functional significance of circumscribed and remote brain areas with regard to a given visual, motor, or cognitive task. The induction of relatively long lasting changes in cortical excitability can modify behavior and improve learning, an enduring and exciting challenge for scientists and clinicians.

The aim of this issue is to summarize and update research and clinical findings with regard to the application of electrical stimulation methods in combination with other techniques. In the first article, Bikson, Rahman, and Datta describe how computational models can underpin the design and evaluation of stimulation montages and thus contribute to the validation of tDCS. In the second article, Miniussi, Brignani, and Pellicciari summarize recent findings regarding the combination of transcranial electrical stimulation with electroencephalography. Kuo and Nitsche present knowledge gathered about the potential of tDCS and tACS to study and modify cognitive processes in healthy humans, and they discuss options for future research. The review, written by Turi, Paulus, and Antal, focuses on the combined use of a non-invasive application of tDCS and functional magnetic resonance imaging (fMRI) and on MR spectroscopy. Finally, Rothwell summarizes problems facing investigators with regard to the variety of possible paradigms that can be applied within clinical populations.

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