Transcranial direct current stimulation for rehabilitating the brain

Reports of therapeutic application of electricity sources to the scalp – including electric fish! – are at least 2000 years old; but systematic appraisal of the value of transcranial direct current stimulation (tDCS) is relatively recent. tDCS involves tonic application of low electrical current to the scalp over specific areas of the brain. It is expected to modulate brain functioning, such as specific cognitive, motor, or sensory functions. It relies on simple, low-cost technology and is relatively easy to apply. Adverse effects (e.g. temporary discomfort at the site of the stimulation) are generally mild and well-tolerated. Most tDCS protocols involve cerebral stimulation, but cerebellar and spinal applications have also been studied. Cerebellar tDCS has been shown to modulate motor control, learning, and emotional processing.[1] Short spinal stimulation can induce long-lasting changes in excitability related to spinal function, but possibly also to brain function through activation of afferent pathways.

tDCS has been suggested for cognitive enhancement as well as treatment in a host of neurological and psychiatric conditions, e.g. stroke, Parkinson disease, Alzheimer disease, epilepsy, schizophrenia, depression, autism, attention-deficit–hyperactivity disorder, and pain. Yet the evidence base and translation potential in healthy individuals and those with disability still lacks coherence. This may be due to the heterogeneity of protocols used and to marked interindividual differences in response to tDCS.

Our understanding of the precise neurophysiological effects remains incomplete. Evidence suggests that tDCS exerts a sub-threshold modulation of the neuronal membrane resting potential. Anodal tDCS enhances excitability and spontaneous firing of cortical neurons by depolarizing the membrane; cathodal tDCS decreases excitability and firing through hyperpolarization. The outcome also depends on the relative sensitivity of the different neuron segments, e.g. the axon is more sensitive to tDCS than the soma, and the orientation of the electrical field with respect to the neuron determines the direction of the effect. Recent evidence emphasizes the role of voltage-dependent effects through calcium signalling within wide astrocytes networks coupled by gap junctions, resulting in NMDA receptor-dependent synaptic plasticity.[2] tDCS may affect homeostatic mechanisms or signal-to-noise ratio, leading to changes in spontaneous activities as well as brain processing.

Improved understanding of the mechanisms of tDCS has influenced its use in rehabilitation research. For example, with a view to enhancing motor recovery after stroke, anodal stimulation of the affected hemisphere could be contemplated to increase excitability of the affected motor cortex. Alternatively, cathodal tDCS could be delivered to the unaffected hemisphere to diminish the effect of transcallosal inhibitory projections from the non-affected to the affected cortex, hopefully restoring the excitability of the affected hemisphere, thus facilitating functional recovery.[3] Similar reasoning has been followed to mitigate visuospatial neglect, aphasia, dysphagia, cognitive decline, depression, or central pain that may occur post-stroke.

Given the wide range of potential applications, it is tempting to explore the eventual benefits of tDCS in children with neurodevelopmental disabilities, perhaps combined with conventional rehabilitation approaches.[4] Reports are limited in children (with conditions such as epilepsy, stroke, or autism). Indeed, extrapolation to children of adult montages or findings raises concerns, as optimal doses for short- and long-term safety have not been clearly established. Modelling studies predict variable efficacy in paediatric populations due to age-dependent anatomical features such as skull thickness, amount of extra-axial cerebrospinal fluid, brain maturation, and plasticity.[5] In addition, there are likely to be unknown condition-dependent and perhaps individual-specific factors. These add to ethical issues raised by the lack of knowledge about neurophysiological effects on maturation and potential of neuroplastic changes, including the risk of inducing maladaptive plasticity.

Because of its high accessibility and promising findings, it is urgent to develop tDCS clinically and as a tool to better understand the brain.

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