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The promises and perils of non-invasive brain stimulation

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ABSTRACT

Non-invasive brain stimulation promises innovative experimental possibilities for psychology and neuroscience as well as new therapeutic and palliative measures in medicine. Because of its good risk–benefit ratio, non-invasiveness and reversibility as well as its low effort and cost it has good chances of becoming a widespread tool in science, medicine and even in lay use. While most issues in medical and research ethics such as informed consent, safety, and potential for misuse can be handled with manageable effort, the real promise of brain stimulation does raise one prominent moral worry: it may lay the foundation of reliable, precise and stable manipulations of the mind. This article addresses this worry and concludes that it is not the possibility of manipulation, but the shift in our understanding of our mind which stands in need of careful consideration.

1. Introduction

The stimulation of the brain by electromagnetic means is a recurring topic in two fields of literature: recent publications in neuroscience and psychiatry and classic as well as modern science fiction dystopias. Current scientific literature welcomes the increasing success of brain stimulation with good reason. With equally good reason, science fiction dystopias from ‘Neuromancer’ to ‘Do androids dream of electric sheep’ are at best ambivalent about the possibilities of stimulating the human brain and mind.

The reality of brain stimulation looks nothing like the fantasies in literature and the movies. Instead of recreational systems as in the opening scenes of Philip K. Dick's ‘Do androids dream of electric sheep’ or brain–computer interaction as in William Gibson's ‘Neuromancer’ brain stimulation starts out much more matter-of-factly and less controversially: Non-invasive technologies like tDCS and TMS were first introduced in medical research, have become more widespread in clinics and are getting introduced into medical offices. They are used as tools in neuroscientific research and promise a number of therapeutic benefits in treating psychiatric diseases, in pain relief and other domains.

While praise for the responsible use of these technologies is a bit premature at this early stage of the development and dissemination, brain stimulation technologies have yet to fall into any of the moral traps expounded in fictional literature. Paradoxically, it turns out that for this to happen, they need to be developed in exactly the way which is required for furthering their medical and research purposes. In a way a discussion of how to keep the promises of brain stimulation technology for research and medicine is at the same time a guide into the moral traps of mind modulation.

In the following I will start with an overview of non-invasive brain stimulation technologies and the typical issues in clinical and medical ethics which apply to these. Subsequently, I will discuss the moral perils of perfecting these technologies for research and medical purposes.

1.1. The stimulating technologies

Technologies for non-invasive brain stimulation like transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (TDCS) have recently received a lot of attention and development effort. Especially TMS has been used and tested in a significant number of experimental and therapeutic trials. Both technologies are expected to experience further developments that will result in significant increases of therapeutic and research applications.

TMS electrically stimulates brain tissue via localised magnetic field pulses and was first introduced in 1985. The underlying electromagnetic and physiological principles have been known for quite a while (Horvath, Perez, Forrow, Fregni, & Pascual-Leone, 2011).

A TMS-system consists of a pulse generator producing an alternating current in a coil. The current's change produces a magnetic field, the shape of which depends on the shape of the coil. Typical coil forms are circular or a figure of 8. The magnetic field, if applied to a person's head, transverses the cranium unimpeded and induces an electric field in the tissue below. The magnitude of this electric field depends on the time rate of change of the magnetic field and thus ultimately on the rate of current change in the coil. The electric field in the brain tissue results in different neuronal and behavioural effects. As with invasive stimulation techniques like DBS, the precise mechanisms underlying these effects are subject to disagreeing theories.

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The key methods in TMS based research are virtual lesions for functional analysis and for chronometry. Virtual lesions are produced by single or multiple magnetic pulses aimed at specific brain areas. The magnetic pulse induces an electric field, which in turn hyperpolarizes the nerve cells in the targeted area. Thus the standard activity of the neurons is inhibited for a short time (depending on field strength, number and pattern of pulses, targeted area, coil size and shape, etc.) Virtual lesions are produced while or shortly before a test subject performs some experimental task. If the virtual lesion causes degradation in task performance, the targeted area is involved in the neural processing of the task. Negative results on the other hand (no degradation) do not support definitive claims about the role of the brain area. Chronometry involves measuring the delay between cognitive stimulus and virtual lesion which is required in order to distort stimulus processing. From this information the temporal pattern of neural processing can inferred.

In addition to lesions, TMS in lower doses can raise or lower the excitability in a targeted brain area. Such a decrease (depression) or increase of neuronal excitability is a valuable tool in research. Changes in task performance after a non-lesioning TMS treatment can hint at the functional relevance of a targeted brain area. According to the current state of knowledge, rTMS with a frequency below 1 Hz reduces the excitability of a target area's neurons, while a higher frequency increases it. For a detailed overview of the TMS measures see Rossini and Rossi (2007).

The most common medical use of TMS is the examination of cortical connectivity, be it corticospinal motor projections, corticocortical connectivity or intracortical circuits. The first FDA-approved therapeutic use of rTMS is for drug refractory depression (Horvath et al., 2010). The fields of inquiry which have been investigated with the help of TMS become more numerous by the day. A recent overview (Rossi, Hallett, Rossini, & Pascual-Leone, 2009) lists the following (partially overlapping) domains, many of which have been investigated by more than one study: attention, body processing, change blindness, episodic memory, face perception, face, body and object discrimination, FEF, form-specific priming, language, phonetic verbal fluency, memory, mental imagery, mental rotation, motor behaviour, muscle contraction, number processing, object categorization, orienting and motor attention, phonological judgment, digit span, pattern span, sensorimotor processing, sentence comprehension, short-term memory, spatial priming, synaesthesia, task switching, time perception, visual motion, visual perception, visual processing, visual search, visuospatial attention, visuomotor processing, word recognition, working memory.

tDCS requires a much less complex machinery. Two surface electrodes are used to apply small electrical currents of typically 1–2 mA to the scalp. The exact size (up to ca. 35 cm^2), polarity and placement of the electrodes depend on the brain function under study and the intended effect. The current travels from one electrode to the other through the scalp and cortex. tDCS typically uses currents which are too small to create action potentials in the cortex, they merely affect the resting potential of the neurons.

The setup of tDCS is exceptionally simple to realise with cost-efficient parts. For this reason there is currently not much interest on the side of providers of medical equipment to produce specialized systems. This simple setup has already found imitation by hobbyists falling back on 9 V batteries and off the shelf resistors (Fox, 2011).

As with TMS, there is still debate about the exact mechanisms of tDCS, but generally speaking, anodal stimulation of a cortical area raises excitability while cathodal stimulation lowers it. The effects of tDCS are divided into short- and long-term ones by some authors and explained by different mechanisms. Short term effects are thought to be caused by polarization effects on the cortical neurons, long-term effects either by NMDA receptor effects or by alterations in neural membrane functions (Utz, Dimova, Oppenlander, & Kerkhoff, 2010). The typical design of tDCS studies looks for a change in task performance, be it memory, motor control or cognitive processes. Some of the more prominent studies have investigated improved learning behaviour (Clark et al., 2012) or reduced pain perception (Antal, Terney, Kuhnl, & Paulus, 2010). Key measures of the tDCS effects are either response time or performance in task dependent experiments, individual reports or PET imaging, which can reveal changes of cortical excitability after modulation.

While the number of studies with tDCS seems to be significantly lower than those with TMS, a vast array of different motor- and cognitive processes have been investigated. The domains mentioned in reviews of tDCS studies comprise inter alia hand motor performance, neuromuscular fatigue, excitability of the leg corticospinal tract, motor learning, visual sensitivity or motion discrimination, spatial tactile acuity, tactile discrimination of vibratory stimuli, attention, visual target detection, visual memory recall, depression, affect and mood, pain perception, sleep efficacy, risk behaviour, word recognition memory.

2. The promises of non-invasive stimulation

Currently most therapeutic uses of TMS or tDCS are at the early stages of approval and clinical trials. As mentioned before, the first FDA approval for TMS in major, drug refractory depression came in 2008 (Horvath et al., 2010). Nonetheless, non-invasive brain stimulation technologies raise high expectations for our scientific endeavour to understand the living brain as well as for our medical endeavour to treat psychiatric and neurological diseases.

2.1. Scientific promises

Being able to manipulate the object of scientific interest opens up the whole realm of experimental inquiry and takes a scientific endeavour beyond passive observation. Tools for manipulating the entity in question are thus invaluable from a scientific point of view. The possibility of manipulating cognitive neuroscience's object distinguishes brain stimulation technologies from other technologies in modern neurosciences, even from the publicly much celebrated imaging technologies.

While it has been possible to physically manipulate the brain in the past, non-invasive brain stimulation does provide something entirely new. With tDCS or TMS, one can reversibly and focally manipulate the active brain including the mental processes it produces. The manipulation of the active brain was previously performed with less local precision and often with the risk of harm or destruction: surgery and drugs were the only tools available. The more targeted, non-destructive manipulation of the brain's activity was hitherto mostly a question of using the natural input-channels, namely sensory channels; manipulation consisted of psychological experimentation and not physical manipulation of the brain.

Non-invasive brain stimulation makes is possible to devise psychological experiments in which experimental manipulation does not work via mental but via mechanical paths. As a possible target for manipulation the active brain becomes an interesting entity for experimental science in a way it has never been before. Accordingly, a lot of energy goes into devising experimental procedures and technologies while neuroscience continues to mature.

Making the active brain accessible for experimental manipulation does change our epistemic access to it. While the active brain has hereto only been manipulated indirectly via behavioural and cognitive manipulations, it now becomes the object of direct manipulation and technologically structured investigations. It thus turns into a proper object of technology. This change in epistemic access will most probably bring about a different public attitude towards the non-research related manipulation of the active brain. How this attitude will change is not easily predicted, but one might speculate—informed by the present open propagation of pharmaceutical enhancement