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Neurodoping: Brain stimulation as a performance-enhancing measure

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Key words

Brain stimulation; elite performance; doping

Abstract

Doping may be defined, broadly, as the use of unauthorised means to increase performance in sport. Doping is most commonly associated with the use of drugs. In this paper I discuss the use of emerging techniques for the modulation of brain activity in healthy people using electric or magnetic fields, and suggest how they might be used to enhance physical and mental performance in sports. I will suggest that neurodoping may have different uses in different sports, and I argue that each sport must determine whether neurodoping should be considered as cheating, or should be considered a legitimate aid to training or performance.

1. Introduction

In modern sport there is huge pressure to improve performance rapidly and to be consistent in delivering results, both in amateur and professional circles. This pressure drives many to boost their performance using additional measures. Some of these measures are relatively innocuous, such as when an amateur golfer books an intensive coaching holiday. However some performance-enhancing measures, such as injecting drugs or transfusing blood, are usually thought to be counter to the ethos of most sports. In this paper I will discuss some recent advances in neuroscience that suggest that the skills and abilities underpinning sports performance can be enhanced using technologies that change the activity of the brain. These factors may include motor learning, enhanced muscular strength or reduced fatigue, or even changes to mental state or concentration.

I will argue in this paper that modulating the activity of the brain during training or during sport will lead to benefits comparable to those of using drugs. The devices needed to generate these effects are already available, and are currently in use in laboratories or clinics to produce short- or long-term changes in performance. I will argue that brain stimulation, or neurodoping, will become a key technology for the future of sport and sports medicine. While many of the ideas in this Opinion article are speculative, I believe that the scientific basis has been demonstrated, and the utility of brain stimulation in sport should be investigated fully. Like any new and potentially performance-enhancing measure, the safety and the ethics of using brain stimulation must be considered carefully.

1.1 Brain stimulation techniques

Two main brain stimulation techniques are available. Transcranial magnetic stimulation (TMS) involves the discharge of brief magnetic pulses through a stimulating coil held against the subject's head. This rapidly-changing magnetic field induces electric currents in the brain tissue near to the centre of the coil. The immediate effect of this is to generate action potentials in those cells, followed by a refractory period as the cell recovers. The fire-and-recover pattern is most visible when a TMS pulse is triggered over the hand area of primary motor cortex: muscle activity of the contralateral hand, measured with electromyography, shows a burst (called the motor evoked potential) followed by relative quiescence (called the silent period) [1]. Recent developments in the application of TMS have involved temporally patterning the pulses delivered by the stimulator to induce both inhibitory and excitatory effects in the target brain area (called theta-burst stimulation [2]). These effects outlast the stimulation phase by several tens of minutes, with the possibility of longer-term reorganisation of brain activity if the stimulation is applied at regular intervals [3].

Transcranial current stimulation (tCS) comes in two common variants. Transcranial direct current stimulation (tDCS) involves passing a weak electric current from a negative electrode (cathode) to a positive electrode (anode). The magnitude and polarity of the electric field at the brain surface near the electrodes determines its effect: cells in the vicinity of the anode will tend to increase in excitability, through a process thought to involve a modulation of the resting membrane potential of the cells [4]; conversely cells near the cathode become less active through the same process. Transcranial alternating current (tACS) uses a similar principle, except that the current alternates at a specific frequency. Researchers typically apply tACS with a frequency related to functionally-relevant oscillatory brain potentials such as might be seen with electroencephalography [5, 6].

tCS has a number of advantages over TMS. The technology is cheaper and more portable. Indeed wireless tCS stimulators are now commercially available, and websites exist that give instructions for home-made tCS stimulators. TMS is however a more focal technique, with a relatively small area of the brain being affected by the stimulation, whereas the electric field induced by tCS spreads across the whole brain surface [7, 8]. In this article I will deal with both techniques, highlighting where one may be more advantageous than the other..

2. State of the art in brain stimulation

2.1 What can we do with brain stimulation?

I foresee two domains where neurodoping may potentially change performance in sport. These divide into immediate gains from increasing cortical excitability, versus longer-term gains from stimulation during training.

In the "acute" phase following stimulation, participants have demonstrated enhanced motor skills including: improved time-to-fatigue [9]; response time [10]; and tremor suppression [11]. The effect of tDCS is maximal shortly after the end of stimulation and declines over roughly a 20-60 minute period, depending on the stimulation parameters [12]. The effects of theta-burst TMS last for a similar length of time but with the peak of effect some five minutes after the end of stimulation. So it is possible to envision a time when an athlete might take a "hit" of stimulation before shooting a pistol or setting off on a ski slalom.

A second use of neurodoping might be in skill acquisition. Skills learned in the context of anodal tDCS are acquired more rapidly [13] and reproduced more accurately [14] than those learned without. Sports performance at the highest levels require good technique and good timing. These are skills learned during training, so enhancing the efficiency of learning during the training phase will be of greater benefit at competition time. I suggest that an athlete could use these techniques to make training more efficient, and thereby gain an advantage.

It is possible that neurodoping will add little to the performance of elite athletes. Most studies of brain stimulation recruit non-expert, healthy participants from the community of the laboratory (in practical terms, university students) and test in conditions where performance is likely to be changed but not reach its maximum. Elite athletes who are already performing close to the physical limits of the human body may not gain from the potential benefits of brain stimulation. Further research is needed to explore whether neurodoping and elite performance are compatible.

2.2 Can it be detected? What are the risks?

There is no known way to detect reliably whether or not a person has recently experienced brain stimulation. A modern technique for analysing brain composition is magnetic resonance spectroscopy (MRS), which can detect changes in the concentration of neurotransmitters and related metabolites. Theta-burst TMS appears to affect inhibitory processing by gamma-amino butyric acid (GABA) while not affecting excitatory processing involving glutamate [15]. Anodal and cathodal tDCS modulate GABAergic and glutamatergic processing differently [16, 17]. When looking specifically at the brain region targeted by TMS or tDCS, the changes in brain chemistry are on the order of 10% in metabolite concentration, and require carefully controlled conditions to pick out the signal from the noise. Several factors means that MRS is unlikely to be of practical utility in detecting neurodoping. First the cost of the procedure is high (£500 per hour at my institution), and needs to be performed before and after the (possible) stimulation to show a difference. Second, MRS currently cannot survey the whole brain so a candidate region must be selected for comparison. Finally the brain changes resulting from stimulation may not be distinguishable from the normal changes related to performance, so the risk of false-positives is high.

The risks of using brain stimulation are thought to be relatively low, when used within established safety parameters. Altering cortical excitability increases the likelihood of inducing a seizure, especially in people who may already be predisposed. To date, this has occurred in experiments with TMS but not with tDCS [18]. The additional risks of multi-session stimulation in altering seizure risk are not known, nor is it well understood how stimulation may interact with other drugs that the person is taking.

3. Ethical issues

There is an argument that human enhancement of any type is not wrong in sport or in any other context. For example, Savulescu and colleagues [19] have argued that enhancing performance with drugs is analogous to an act of creativity whose only limit should be the safety of the participant. So by this argument regulating pharmacological enhancers places an unnecessary constraint on the limits of human achievement. Allowing drug enhancement would simply add another option for athletes who wish to choose among all of the available means of improving their overall performance. While the analogy is not perfect with the kind of neuro-enhancement I have discussed, nonetheless brain stimulation offers a potential adjunct for immediate performance or for training and should be considered as if it were another form of drug doping.

A related question about the use of human enhancement is whether the performance shown by the person is “authentically” theirs. If a neuro-enhanced sprinter is faster in reacting to the starter's pistol, is that advantage hers or should the stimulator be given the credit? Cohen Kadosh and colleagues have recently argued [20,21] that brain training with tDCS enhances the person's own latent cognitive abilities and increases the efficiency of a training programme. Thus brain stimulation mediates a person's ability but does not enhance it in the strictest sense.

A third argument is practical: as discussed above it is not possible, as far as is known, to determine whether a person has or has not had brain stimulation. This makes neurodoping virtually undetectable, which is analogous to the status that doping via erythropoietin (EPO) held in endurance sports until the last decade. It is possible, if not likely, that records will be set by people who have trained under the influence of anodal tDCS, or who have walked out on the field after a period of theta-burst TMS.

Each sport determines its own rules. I would suggest that each sport determine whether neurodoping poses a risk to its ethos. For example, performance in a sport such as pistol-shooting would be greatly improved by tremor reduction [22], so governing bodies should decide whether shooters should be prevented from using tACS during or immediately before competing to reduce tremor [11], just as beta-blockers are banned in many sports. Conversely a tennis player's performance in a match is heavily influenced by the probability of regularly getting the first service in [23], which is a skill learned in training and therefore potentially susceptible to neurodoping. Neurodoping is one of many potential forms of enhancement that may affect sports performance, and the development of the technology should be mirrored by a development in how we view and deal with such enhancements [24].

4. The future

What is the future likely to hold for research into brain stimulation? At present we do not have a good way to determine appropriate doses of stimulation in a given situation [25]. This will be needed if brain stimulation were to be used outside of the lab or the clinic to guarantee safety and efficacy. We do not have a sense of how mood or mental state can be manipulated with brain stimulation. While TMS and tDCS have been used to address neurally-mediated mental disorders such as depression [26] and addiction [27], the more subtle and fragile states of concentration and immersion, sometimes called "flow" [28], needed for good performance have not been induced in the lab. A small number of papers have hinted that aspects of flow, such as insight or creative thinking [29,30], may be encouraged, however this is far from the immersive state experienced by elite athletes [31, 32]. A further avenue of exploration will be the ability of brain stimulation to enhance specific functional activity in the brain. For example, the beta frequency range in electroencephalography (15-35 Hz) is often associated with motor control. However enhancing beta power with tACS has led to contradictory findings across studies [33-35]. This article has not considered other promising advances in brain stimulation such as the use of random electrical noise [36] or steady-state magnetic fields [37] for modulating cortical activity. Finally, the studies mentioned in this article have mainly involved experiments where the subject sits in a chair to receive stimulation and to perform a task. The practicalities of brain stimulation have until now meant that whole-body movements such as gait and posture have been difficult to study. The advent of wireless or wearable stimulators will remove this restriction and will accelerate the use of brain stimulation in studying and enhancing sport-relevant motor performance.

An obvious area for future research will be the relative contribution of neurodoping to different phases of the training and performance cycle. I have suggested that there may be differences between the immediate and the long-term effects of neuromodulation; relating these effects to the phases of an athlete’s programme will help coaches to understand when and how to incorporate brain stimulation into training. This will have the desirable additional effect of minimising the dose of stimulation delivered to the athlete.

The cognitive and motor acts of sporting performance are extreme versions of people’s activities of daily living. There is clearly an important exchange between people who wish to improve skills in sport and those who wish to rehabilitate motor function after brain injury or physical trauma. I would urge researchers to be more explicit about this dialogue: a finding that might be of use in training hurdlers to time their leaps may also help amputees to time stepping up stairs. Conversely, brain stimulation to increase alertness in people with dementia may increase a goalkeeper’s awareness of attacking players in soccer. This knowledge exchange will make scientific discovery more efficient, and will bring new perspectives to old problems.

5. Conclusion

In this article I have suggested that emerging technologies in the fields of neuroscience and medicine may in the future translate to become performance-enhancing measures in sports. I have suggested on principled and practical grounds that neuroenhancement during training should not be considered to be unethical in sport. If used within known safety limits these technologies may increase the performance of athletes and increase the enjoyment of spectators.

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