Cyborg Virtues: Using Brain Stimulation for Moral Enhancement

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1 Introduction

Drawing links between brain structure and moral behavior has been a focus of research since at least the unfortunate case of Phineas Gage [1]. In 1848, Gage was a foreman overseeing the laying of tracks, when a freak accident drove an iron bar through his skull, destroying his left frontal lobe. After his improbable survival, Gage's personality was alleged to have changed for the worse, although he apparently recovered all his social and emotional capacities in later years. The Gage case was subsequently enlisted by both proponents and critics of the theory that specific mental capacities were localized in specific brain regions. The debate over the degree of brain localization of cognitive functions continues to this day, and for good reason since it was implicated in the rise of pseudoscience and unethical neurosurgeries. The pseudoscience of phrenology, for instance, used the idea of brain localization to attempt to identify correlations between moral traits and the shape of the skull. The concept of brain localization led to psychosurgeries and frontal lobotomies as treatments for behavioral disorders [2].

Given the fraught history of pseudoscience and horrifying medical practices associated with brain localization, this chapter's proposal that we may be able to enhance moral behavior by stimulating specific brain regions is rightfully approached with a good deal of caution. Nonetheless, decades of research on brain lesions, brain imaging experiments, and brain stimulation studies have shown that, while any cognitive function enlists multiple brain areas in complex ways, functions are more or less localized to specific areas.

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The debate over whether cognitive functions are localized is confined to neuroscience, but there is an enormous widespread interest in the prospect of brain stimulation and brain–computer interfaces. Since researchers first demonstrated in the 1950s that electrodes in the brain's pleasure center could be used to control behavior, even to the detriment of self-preservation [3, 4], the cyborg with brain–computer interfaces has elicited both horror and enthusiasm. The term cyborg was coined in 1960 in an essay proposing that astronauts' physical and mental state should be monitored remotely so that ground control could administer psychiatric drugs if necessary [5]. Despite a thousand science-fictional images of humans used as batteries by the Matrix or assimilated by the Borg, there are now hundreds of thousands of people with brain stimulation devices implanted to treat depression and epilepsy [6], and many more experimenting with magnetic and electrical stimulation of the brain, as I review in the next section. The entrepreneur Elon Musk has tapped into this popular enthusiasm with his Neuralink project.

This chapter is also situated in the debate over "moral enhancement" in the neuroethics literature [7–9]. As moral neuroscience ballooned in the last two decades, bioethicists have proposed multiple ways that moral sentiments, cognition, and behavior, such as empathy, could be improved through pharmacological and genetic interventions. However, few have addressed using direct brain stimulation for moral enhancement. The techniques are relatively new and taking pills is more practical than non-invasive brain stimulation, not to mention brain surgery. On the other hand, drugs impact the entire brain and body, while targeted brain stimulation can have a much more precise impact. In the next section, I review some of the existing brain stimulation modalities and make the case that emerging neurotechnologies will soon allow for more precise control of the moral brain.

2 Brain Stimulation and Brain–Computer Interfaces

The impact of brain stimulation on cognition and behavior is partly a function of the kind of stimulation being used. Transcranial electrical and magnetic stimulation, from outside the skull, can be focused but not very precisely and not very deeply. Implanted electrodes just impact the neurons they are directly in contact with although those neurons can trigger activity in many parts of the brain. Stimulation methods can both inhibit and induce emotion and cognition and have transient or longer-lasting effects. Brain stimulation can change the expression of neurochemicals and genes, induce the growth of new neurons [10], or destroy tissue permanently.

Noninvasive methods include

- **Transcranial Direct Current Stimulation (tDCS)** involves passing a weak electrical current directly through the scalp into the brain between two or more electrodes. The electrical current can excite or inhibit neuronal signaling in the targeted area depending on whether the current generated has a positive or negative charge. In 2020, the US Food and Drug Administration (FDA) approved the experimental use of tDCS for depression, and research is ongoing on its use for attention deficit disorder, brain injuries and stroke, language and movement disorders, pain, and addiction. A recent meta-analysis of tDCS studies found that it is "definitely effective" in treating depression, and "probably effective" for pain, fibromyalgia, migraine, Parkinson's, stroke rehabilitation, epilepsy, schizophrenia, and alcohol addiction [11]. Patients can apply tDCS at home under a doctor's direction, and tDCS devices are commercially available for the adventurous.

- **Transcranial Magnetic Stimulation (TMS)** involves passing an electrical current through wire coils on the scalp, inducing magnetic fields that excite or inhibit neurons' electrical activity. The FDA approved the use of TMS as a treatment for depression in 2013, for obsessive-compulsive disorder in 2018, and for nicotine addiction in 2020. Unlike tDCS, there is not yet a commercially available portable TMS apparatus although they are being developed [12]. TMS can be focused to a roughly 2 mm diameter, exciting about 130 neurons [13], down to a depth of 3 cm [14]. Side effects are rare and mild, such as a transient headache. Treatments can be one-off or repeated, and research is ongoing on TMS' effects on depression, pain, dystonia, and epilepsy.
- **Transcranial Focused Ultrasound Stimulation (tFUS)** has been developed more recently, with intended applications for depression [15] and the kinds of applications being investigated for TMS and tDCS. Focused sound waves inhibit or excite neurons via a mechanical effect on ion channel gating, rather than electrical modulation of neural signaling, and thereby tFUS produces less heat and potential cell damage than tDCS and TMS. The FDA approved tFUS as a therapy for tremors in 2016. The sound waves can be tuned to target either excitatory or inhibitory neurons [16]. An advantage of tFUS over tDCS and TMS is that it can be focused down to 1 mm [16] and can reach deeper parts of the brain.

Invasive methods of stimulating targeted areas of the brain include

- **Vagus Nerve Stimulation (VNS)** involves placing electrodes in the vagus nerve, which runs from the abdomen, through the neck, and into the brainstem. The FDA approved VNS as a treatment for intractable epilepsy and depression in 2005. Research is ongoing in using vagus nerve stimulators to control obesity, manage pain, and reduce systemic inflammation [17], even for reviving people in vegetative states [18]. While the electrodes are in the neck, VNS impacts many cortical functions [19], for instance, by changing activity in the anterior cingulate cortex [20].
- **Deep Brain Stimulation (DBS)** uses electrodes placed directly in the brain. The FDA approved DBS for tremor and Parkinson's disease in 1997, dystonia in 2003, obsessive-compulsive disorder (OCD) in 2009, epilepsy in 2018, and Parkinson's disease in 2020 [21]. DBS has been explored as a therapy for pain, Tourette's syndrome, depression, and obesity. As with vagus nerve stimulators, the DBS electrode has a wire connected to a pulse generator and battery, usually implanted in the clavicle or abdomen.

The next stage of brain stimulation involves more “closed-loop” integration of stimulation with sensors, more computing power, and more miniaturization.

Closed Loop Integration. An example of closed-loop feedback is using EEG to detect when a driver is falling asleep, triggering a tDCS helmet to wake them up [22]. Sensors implanted alongside or as part of a DBS electrode can detect the characteristic cascades of neural firing that indicate an imminent epileptic seizure [23], tremors [24], or the onset of depression, triggering the DBS electrode to stop them [25]. A system developed at NYU detects pain signals in the anterior cingulate cortex, triggering stimulation of the prefrontal cortex that provides pain relief [26].

Onboard Computing. Researchers have been implanting computer chips with electrodes and communication capabilities into the brain and other neural tissue since the 1990s. Since the interpretation of neural signals requires complex software, the goal is specialized, microscopic chips [27] the most publicized of which is the Neuralink technology being developed by Elon Musk. The current Neuralink unit reports neural firings through 1000 electrodes, each about 4–6 microns wide, to a specialized coin-sized computer chip that is 23 mm wide and 8 mm deep [28], sitting on the surface of the cortex under the skull. Although current models connect these chips to computers outside the skull using wires, they will eventually connect wirelessly with another implanted unit that will then connect wirelessly with devices outside the skull. The devices are powered by a daily, wireless inductive charge from outside the skull. Neuralink’s electrode “threads” are not only much smaller than previous electrodes but also more flexible and thus less likely to damage tissue. By comparison, DBS uses 4–8 electrodes, each about 800 times bigger than Neuralink’s threads. The Neuralink system is currently being evaluated by the FDA, with expectations for approval in 2022.

Miniaturization. “Neural dust” is an example of the advancing miniaturization of brain–computer interfaces. Proposed in 2011 and now being developed for medical use [29], neural dust combines sensors and communication links into a device the size of a grain of sand, powered by piezoelectric crystals that turn ultrasound energy into electricity. Compared to electrodes, neural dust can be introduced with minor invasive surgery and a much larger brain area. Researchers are already creating neural models from networks of dozens of these units in rodent brains, with plans to scale up to hundreds [30]. The new NeuroSWARM system does not require any power source. It uses devices only 63 nanometers wide—smaller than the average virus—to convert neural electrical signals into near-infrared optical signals that can be detected outside the skull [31, 32].

External and internal brain stimulation is already capable of changing moral sentiment, cognition, and behavior, as I review below. Given the rapid progress in brain stimulation and brain–computer interfaces, however, it seems likely that these systems will eventually also be able to recognize emotions and behaviors, and selectively enhance or suppress them. For instance, just as a seizure has a discernible neural cascade signature, so might the brain have discernible signatures for depression, addictive relapse, or explosive anger, which an implant could then suppress. Before reviewing which parts of the brain might be targeted for moral enhancement, however, we require a short review of the relationship of theories of virtue to moral neuroscience.

3 A Neurologically Grounded Model of the Virtues

In previous work [33–35], I have proposed a model of six moral virtues that bears a rough correspondence to cross-cultural taxonomies of virtue, personality psychology, and the emerging neuroscience of morality. The six virtues I have proposed are self-control, caring, fairness, intelligence, positivity, and transcendence. Each of these virtues correlates with the "five-factor" or OCEAN personality traits, as well as with specific neurotransmitters and neuroanatomical areas. For instance, self-control is correlated with the personality trait of conscientiousness, variations in dopaminergic genes, and the size and activity of the prefrontal cortex. Positive mood is correlated with the personality trait of neuroticism, variation in serotonergic genes, and the function, and connectivity of multiple brain regions [36]. The personality trait of open-mindedness, which is a component of the "intellectual virtues," is correlated with fairness, intelligence, and transcendence [37–40].

Not all six virtues are recognized by every religious or secular virtue model, and the model has only an indirect relationship to virtues like faith, filial piety, or loyalty. I introduce the model here only as a valuable heuristic for the project of moral enhancement. One advantage of such a model is that it suggests the importance of the prudential balance of multiple virtues in a mature moral character. Much of the debate has charged that one or the other form of moral enhancement will be inadequate or have perverse effects without acknowledging that the project of character building proposed by theologians and philosophers has always involved the maturation of multiple virtues that balance one another. Virtue can become a vice if practiced without self-control and intelligence, or "prudence." Unchecked positivity can lead to recklessness, and intelligence can be sterile without empathy and social intelligence.

In "Virtue Theory for Moral Enhancement," for instance, Fabiano [41] agrees with the importance of a balanced approach to moral enhancement, noting that a multi-virtue model also reduces the likelihood of someone becoming so different after enhancement that they have committed identity suicide. "An increase in a currently desirable moral trait would constantly be evaluated against a wider background of other traits and contexts to be considered a true moral enhancement." But then Fabiano proposes the Social Value Orientations (SVO) model as a framework for moral enhancement, a model of four moral types, individualistic, competitive, cooperative, and altruistic. Johnson [42] points out that SVO really only addresses one dimension of virtue, self-centeredness vs. other orientation, and thus fails the test of articulating the critical balance of virtues.

A second virtue of defining moral enhancement through the lens of virtue theory is that it suggests that moral enhancement can be beneficial to both the individual and society. Moral enhancement advocates coming from a more hedonic utilitarian framework, like Perrson and Savulescu [43], identify ethics with altruism and argue that moral enhancement requires self-sacrifice for collective well-being. Virtue models tend to argue for a eudaemonic understanding of happiness over a hedonic one; the rewards of a mature moral character are superior to hedonic gratification. In general, people with more self-control, empathy, or intelligence are both better citizens and have more fulfilled lives.

3.1 Self-Control and Addiction

Since the origins of Greek and Indian philosophy, the capacity for self-control has been considered a fundamental moral virtue. Enacting every other virtue requires self-control, and many of the classical vices—lust, greed, anger, sloth—are an absence of self-control in the face of overwhelming urges. The treatments for some psychiatric disorders, such as attention deficit disorder, have the direct or indirect goal of enhancing self-control. The prefrontal cortex (PFC) is the newest part of the mammal brain. It is the locus for self-awareness, executive functioning, planning and supervising action, such as moral decisions, and the regulation of emotions [44]. The PFC occupies about 10% of the volume of the cerebral cortex and has many substructures with their own localized functions, such as self-monitoring, suppressing impulses, and switching attention from task to task.

When the PFC is impaired or weakened in relation to the other brain parts, it can lead to risk-taking, impulsiveness, criminality, and aggression. It is hard to escape the conclusion that the PFC is the seat of reason, constantly attempting to rein in the animalistic impulses and emotional responses from the other parts of the brain. While this is a useful model for much of moral neuroscience, which often involves a balance between the fast, hot impulses from the limbic or other systems and the slow, cool work of the PFC [45], we need to remind ourselves again that the PFC is the agent of the passions, long term or short term, and not a rational actor struggling to free itself from the cortical mob [46].

Within the PFC, the dorsolateral region (dlPFC) lies behind the right and left sides of the forehead and is the part most often implicated in executive functions, such as planning, abstract reasoning, impulse inhibition, working memory, and the ability to switch tasks. The dlPFC is central to inhibiting selfish impulses to act following prosocial norms [47]. The dlPFC is also a central structure in the "dual process" model of moral neuroscience proposed by Greene et al. [48], which is similar to the slow and fast thinking model advanced by Kahneman [45]. The dual-process model focuses on the dlPFC's "slow," deliberative role in making moral judgments, balanced against the "fast" impulses "driven by automatic, intuitive, emotional heuristics that are relatively insensitive to the consequences of an action" [49]. Using tDCS to excite the dlPFC helps insulate reasoning from emotion [50, 51]. From this perspective, a large part of character development involves strengthening the dlPFC's deliberative role until the fast impulses from the amygdala, limbic system, and temporoparietal junction (TPJ) are in better accord with deliberative judgments, the turning of conscious moral effort into automatic moral habits [52].

While many reject widespread neuromodulation as a threat to autonomy and self-control, self-applied neuromodulation would enhance our autonomy by allowing us to align our short-term preferences with our long-term ones [53]. For instance, stimulation of the dlPFC contributes to self-control as a treatment for addiction. Bolloni et al. [54] and Antonelli et al. [55] reviewed more than two dozen "encouraging" studies on treating addictions to food, cocaine, nicotine, alcohol, heroin, and amphetamines with TMS excitation of the dlPFC. Lapenta et al. [56] likewise reviewed dozens of studies of tDCS applied to the dlPFC and concluded that it generally helped treat addiction, although the methods employed vary widely [56]. A meta-analysis of a dozen addiction treatments using either tDCS or TMS, applied to the dlPFC, found “a large positive main effect” on reducing addictive cravings [57]. Using TMS, tDCS, tFUS, and DBS to stimulate the anterior cingulate cortex (ACC), a structure below the PFC that evaluates how rewarding something will be, or the nucleus accumbens (nAC), which pumps out dopamine in response to addictions, are also proving to be effective targets for treating addiction [58–61].

While too much of most virtues becomes a vice, there is less risk from too much self-control, and thus there is a little less concern about the side-effects of brain stimulation for self-control. Some researchers attribute problems like obsessive-compulsive disorder or eating disorders to excessive self-control, but the evidence suggests that these problems are just another example of *lack* of self-control, in this case over one’s own controlling behaviors. In a 2011 review, Grant and Schwartz argued that there is little evidence that there is any cost to high levels of self-control although excessive delaying of gratification might be a candidate. “Individuals with extreme self-control may never consume and thus never experience pleasure” [62].

3.2 Intelligence, Memory, and Learning

Much of the widespread enthusiasm for brain stimulation and implants like Neuralink stem from hopes that they will allow the enhancement of cognitive speed, learning, and memory in the healthy. Recent meta-analyses and systematic reviews of tDCS’ impacts on cognition show that it can enhance processing speed, working memory, and executive functions in patients with psychiatric disorders [63, 64], and improve working and episodic memory, and reaction time and accuracy, in the healthy [65–69]. A 2020 literature review found that tDCS was effective in many studies in improving the cognitive deficits of ADHD, including response inhibition, working memory, attention, and cognitive flexibility [70]. The dlPFC is the preferred target for cognitive enhancement, followed by the TPJ. In one study, the positive effects of stimulation on memory lasted up to a month [65].

Some people experience transient itching, tingling, headaches, or burning sensations when using tDCS [71] but a 2017 review found no *serious* adverse effects have been reported in tDCS experiments [72]. There have been cases in which deep brain stimulation for Parkinson’s caused cognitive decline [73], and there is the possibility of adverse consequences from too much attention, memory, or speed from brain stimulation. Stimulants, for instance, have a U-shaped relationship with cognitive performance, with optimal dosing depending on the person; too much stimulant, or any stimulants at all for some, degrades cognitive performance [74, 75]. As targeting becomes more precise, use more continuous, and especially when the stimulation is directly into the brain through electrodes, there will need to be careful calibration to avoid adverse side effects.

3.3 Empathy and Pro-Social Behavior

There are at least two kinds of empathy, emotive and cognitive. Emotive empathy stems from old mammalian brain structures that generate sympathetic emotions in us when we see others stub their toes or get a hug. On the other hand, cognitive empathy is more of a prefrontal phenomenon, requiring a sophisticated "theory of mind" that gives us insight into what others are feeling even if we do not directly witness their emotions. The prefrontal cortex in general, and the dlPFC in particular, is key to pro-social behavior by recognizing and suppressing impulses such as anger and aggression. Damage to the dlPFC is tied to increased aggression, and reduced empathy and pro-social behavior. Stimulating the dlPFC with tDCS or TMS increases trust and cooperation [76, 77] and decreases anger and aggression [78, 79]. Moreover, stimulating the dlPFC with anodal tDCS excitation increases empathy and pro-social behavior, while *inhibiting* the dlPFC with cathodal tDCS *decreases* empathy and pro-social behavior [80].

Among the other parts of the brain important for controlling anger and aggression, or promoting empathy and pro-social behavior, are the ventromedial prefrontal cortex (vmPFC) and the temporo-parietal junction (TPJ). While the dlPFC and TPJ mediate the reasoning component of cognitive empathy, the vmPFC—through its connections to the amygdala among other bits—mediates whether you can understand and predict other people's emotions, "affective theory of mind" [81, 82]. Damage to the vmPFC impairs the ability to recognize emotions in other people's faces, for instance [83], and stimulating the vmPFC calms the amygdala and reduces fear [84]. A meta-analysis of studies applying tDCS to the vmPFC also found an increase in empathy and a decrease in aggression [85, 86]. As for the TPJ, which is key to altruism and theory of mind, a meta-analysis found that anodal, excitatory tDCS applied to the TPJ improves cognitive empathy in healthy adults [87] while inhibiting the TPJ with TMS reduces attention to other people's beliefs and interests in moral decision-making [88].

Again, regulators, clinicians, and users should pay close attention to any side effects of these therapies, and every virtue needs to be balanced and tempered by the rest. As Aristotle warned, too much compassion can become a vice. In *Against Empathy* [89] Bloom argued that emotional empathy, as opposed to cognitive empathy, often leads moral decision-making astray, prioritizing a baby in a well over a hundred thousand victims of a natural disaster. Excessive visceral empathy can also make us trust the untrustworthy, underestimate bad actors, and lead to burn-out and distress. Boosting oxytocin not only increases trust in members of one's in-group, but also aggression against out-groups [90–93].

3.4 Fairness

There are two aspects of fairness's virtue: internal and external, or metacognitive and distributional preferences. The metacognitive part involves self-awareness of one's biases, and habits of mind like "intellectual humility." The distributional part is related to our willingness to sacrifice for more equal outcomes, and our willingness to judge friends and foes by the same moral yardstick and utilitarian or egalitarian preferences involve many parts of the brain, including the prefrontal cortex, parietal and temporal lobes, ACC, and insula [94–97].

However, the favorite target for the neuromodulation studies of fairness has been the dlPFC. Exciting the dlPFC with tDCS enhances metacognition [98], reduces emotional and implicit biases [67], and (usually) reduces the willingness to accept unfair offers in laboratory game experiments [99]. Applying tDCS on the right dlPFC can enhance (with positive anodal excitation) or depress (with negative cathodal inhibition) the willingness to distribute benefits to the least well-off, or in Rawlsian terms, to put oneself "behind the veil of ignorance" [97, 100–103]. Likewise, *stimulating* the dlPFC tips moral decision-making from emotive empathy for individuals to utilitarian reasoning [84, 88, 89] while *inhibiting* the dlPFC with TMS increases sensitivity to harming individuals even if justice or the utilitarian calculus requires it [103].

The insula, coupled to the amygdala, is key to processing disgust, such as the disgust components of racial bias [104], and empathic reactions to others' pain. Applying anodal and cathodal tDCS to the left insula, respectively, enhances and decreases self-reported feelings of disgust, and the absolutist, deontological moral judgments associated with disgust [105, 106].

The cognitive domains also assess self-interest, complicating the model that stimulating prefrontal control is always good for fairness. Sometimes stimulating the PFC enhances preferences for fair outcomes, but sometimes it doesn't [96, 107]. Sometimes, it just makes us more sensitive to being the victim of unfairness without wanting more fairness for others [108]. Many consider pure utilitarian reasoning without any empathy for harm to individuals (pushing the fat man onto the tracks in the trolley problem, for instance) to be psychopathic. Indeed, psychopaths are more consistent utilitarians [109]. One could imagine that a brain stimulation for pure fairness would be more welcome for judges in the courtroom and generals on the battlefield than when among friends and family. In short, simply being more rational and less emotive does not guarantee fairness without a larger ensemble of moral values that steer us from self-interest to prosociality, informed but not governed by empathy and moral reasoning.

3.5 Positive Mood and Depression

Happiness has a lot of different meanings in philosophy, psychology, and neuroscience. For instance, being in a positive mood can be distinguished from feeling a sense of meaning and purpose. Most religious and philosophical systems see happiness or positive mood as a benefit of living a virtuous life rather than a virtue in itself. Often they will distinguish the contentment that results from virtue as a higher order of happiness, *eudaemonia*. Nonetheless, many philosophies recognize aspects or correlates of positive mood as virtues. "Hope" in "faith, hope, and charity" is a positive future orientation correlated with positive mood [110]. Likewise, one of the core virtues in Buddhism is *viriya or* vigor. While being depressed makes it more challenging to achieve one's own goals or help others, possessing hope, optimism, or vigor, and generally being positive, is not only rewarding in itself but makes it more likely you will be productive and helpful to others [111].

While people living with chronic pain or depression can be subjectively happy in other ways, neuromodulation to treat pain and depression is one powerful way to contribute to subjective well-being. Many studies now show that enhancing prefrontal control with DBS electrodes reduces the effect of pain [112]. Systems are being developed that stimulate the PFC only after detecting the unique signature of pain from sensors in the ACC [113].

As with pain, meta-analyses show that brain stimulation is an effective treatment for severe depression [101–103]. Focusing ultrasound on the right inferior frontal gyrus (rIFG), another key mood and emotional regulation area, enhances mood and emotional regulation [15]. TMS applied to the frontal lobes increased perseverance by shortening the giving-up response [114]. As with pain, progress is also being made in closed-loop neuromodulation using sensors to detect the onset of depression and disrupt it with DBS electrodes in the ventral capsule/ventral striatum [115].

Treating chronic pain and depression raises fewer flags than the eventual use of neuromodulation to enhance mood in the healthy. Initially coined by science fiction author Larry Niven in the 1960s [116], the term "wireheading" has come to refer to people addicted to inducing pleasure with brain electrodes. Michael Chrichton's 1972 novel *The Terminal Man* imagined an epilepsy patient with DBS electrodes who becomes addicted to the euphoria the electrodes induce until he is driven to a murderous rage [117]. Nonetheless, with appropriate technical safeguards in place to control the risk of overuse and adverse side-effects, neuromodulation for moderate enhancement of mood in the healthy, which appears to be safe and effective [118], would likely have many positive effects for individuals and society [111].

3.6 Selflessness and Transcendent Experiences

A final complement to the other virtues, and a capstone to character formation, is the capacity to experience altered states of consciousness that turn off the default mode network, our constant stream of self-referential thoughts [119–124]. Mindfulness meditation and psychedelics, for instance, both disrupt the "default mode network" with lasting positive impacts such as reducing anxiety and addictive cravings. These transcendent states give people distance from their habitual thoughts and behavior and boost equanimity and pro-social behavior [120–123, 125, 126]. Neuroimaging and neuromodulation are identifying which parts of the brain are key to such experiences.

As with the other virtues, multiple brain regions are implicated in experiences of awe or oneness, but the most common foci in studies of the spiritual brain are the parietal cortex, insula, and temporo-parietal junction (TPJ). Imaging shows that the right parietal cortex is less active during spiritual experiences [124, 127–130], and damage in the parietal region can cause spontaneous transcendent experiences and radical changes in religiosity [131, 132]. The insula and TPJ integrate physical sensations into a model of the body in space, anchoring our subconscious sense of self, while damage to or inhibition of the insula or TPJ can create out-of-body or "oneness" experiences [133]. Stimulating the right TPJ with tDCS reduces egocentric perspective-taking [134]. Deep brain stimulation of the dorsal anterior insula can induce ecstatic experiences in epilepsy patients [135]. "Flow" states involve reducing the interference of the default mode network with behavior, and getting into flow states can be facilitated by applying tDCS to the medial prefrontal cortex (mPFC) [136], the dlPFC, and the parietal cortex [137].

It is possible that brain stimulation for transcendent experiences could become habit-forming and disabling although studies of psychedelic use suggest the risk is low for those without mental health problems, and psychedelic use can be beneficial for those with mental health problems [126, 138]. Even long-term subclinical use of psychedelics or "microdosing" appears to be safe [139]. Nonetheless we don't want people accidentally entering a higher plane of being while driving or cooking, or having disorienting "flashbacks," so there will need to be close scrutiny of the side effects of and contextual regulation of transcendent brain stimulation.

4 The Ethics of Neuromodulating for Moral Enhancement

We will soon have technologies that allow the neuromodulation of many parts of the brain, complementing and probably going farther than psychopharmaceuticals. As we continue applying neuromodulation to the treatment of psychiatric disorders we will be obliged to regulate their potential use in criminal rehabilitation and enthusiasts' self-application of these technologies [140, 141]. Models of the multiple virtues to be cultivated in a mature moral character can hopefully address some of downsides of enhancing single virtues, and point to the multiple areas of the brain that will require sensors, chips and electrodes for "virtue engineering" [142].

All neuromodulation therapies require regulation to determine efficacy and side effects, and the more invasive the technology, the higher the safety and efficacy bar they will need to meet. Non-invasive brain stimulation is already widely available for consumers. While the severely disabled may be permitted to consent to brain implants, devices that could be permitted for use inside healthy brains will take some time. However, the most pressing ethical issues with moral neuromodulation are less regulatory and more philosophical and phenomenological [143, 144]. Under what conditions can someone consent to use brain stimulation to change their most fundamental thoughts and emotions? Do people using such devices feel less authentic [145, 146]? Addressing these questions will be increasingly relevant as neuromodulation becomes more common.

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