BY ALICIA ROMANO

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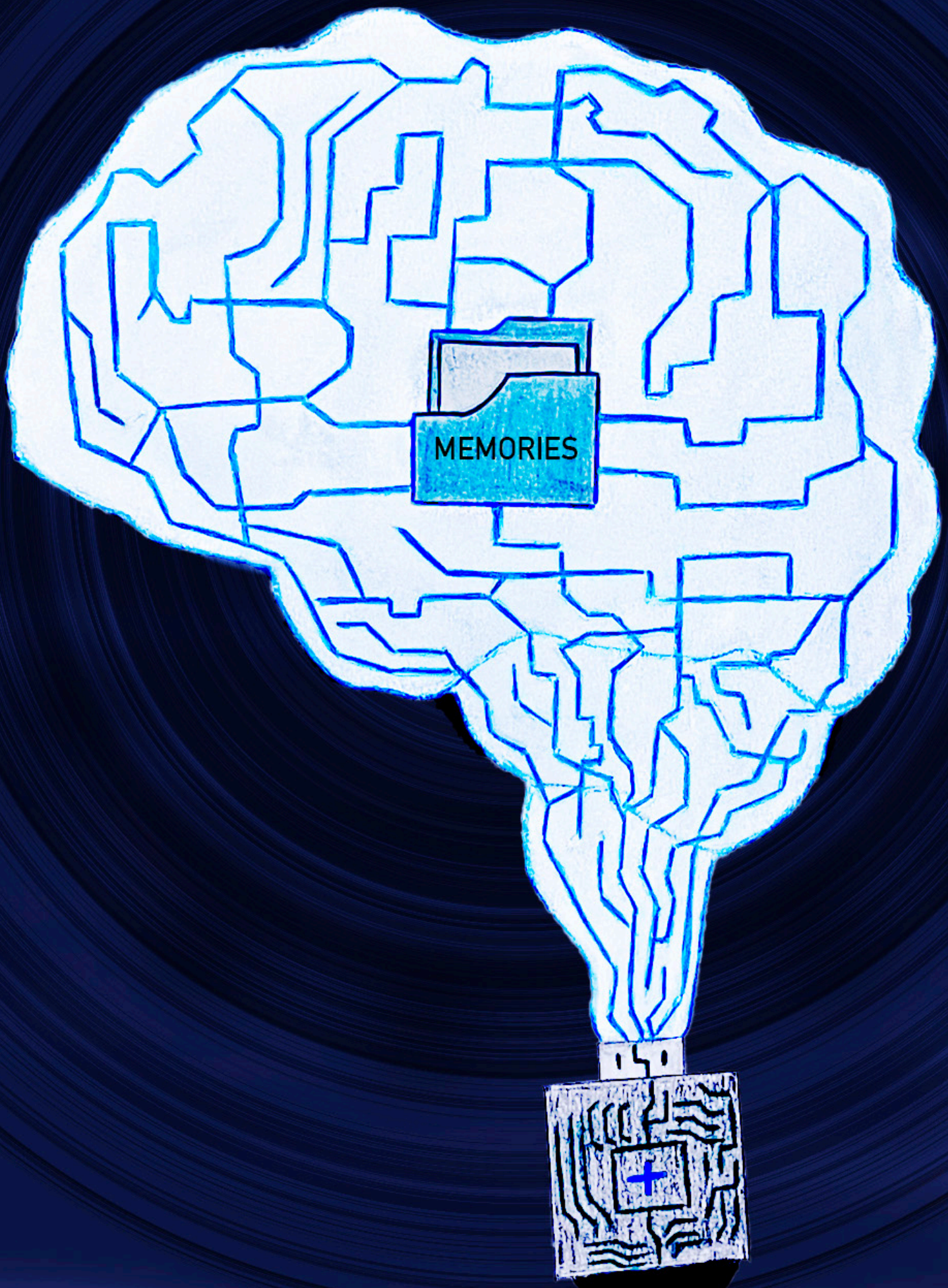

Cognitive Enhancement in the 21st Century: Is Black Mirror Becoming a Reality?

INTRODUCTION

Imagine a world in which all your memories can be recorded and played back at will through an embedded chip–a concept explored in the Black Mirror episode "The Entire History of You." In this alternate reality, humans receive an implant behind their ear which can do exactly that [1]. However, what if this is closer to our reality rather than some distant dystopia? Perhaps we will even reach a point where our thoughts can be decoded and read, such as in the Black Mirror episode "Crocodile" [1]. In fact, we have already approached these abilities to record memories and mind-read [2, 3]. Furthermore, scientists have demonstrated the capacity to transfer such memories and thoughts, a concept known as brain-to-brain communication [2, 4]. In one study, five groups consisting of three participants each were playing a Tetris-like game, though one individual called the "Receiver" was unable to see the screen. The other two, called the "Senders," would make a decision as to how to manipulate the incoming shape and send this information to the receiver via magnetic stimulation of the occipital cortex. On average, the groups were able to complete the task with an average of 81.25% accuracy [4]. While this is quite an accomplishment, it is still far from being perfected and implemented into our daily lives. Neurotechnological development continues to accelerate rapidly though [5], so one can only imagine where we will be in a few decades.

One path neurotechnology is following investigates influencing cognition, which involves the processes of acquiring and understanding knowledge; this means modulating acts such as thinking, perceiving, remembering, and reasoning [6]. Cognitive augmentation can manifest as the alleviation of symptoms in treatment-resistant depression, memory compensation in patients with dementia, improvement in reading performance in those with dyslexia, and numerous other ways [7, 8, 9]. This area of research has gained noteworthy momentum recently. Publications on deep brain stimulation, a form of cognitive enhancement, has expanded from a mere 75 articles published in 2000 to 741 published in 2010 [5]. The popularization of this field will not exclusively impact scientists though; as demand for neurotechnology increases, it is projected that the market size will nearly triple in the next 10 years to over $38 billion [10]. Thus, one can only conclude that society, down to the individual, will face significant changes–conceivably to the point of Black Mirror becoming more of a reality show. Though there are numerous advantages to this kind of technology, the extent of its potential may lead us down a similar dystopian path if left unregulated. Therefore, ethical considerations are an essential part of this field in order to ensure our privacy and autonomy are protected. With investigations on cognitive enhancement and neurotechnology growing and becoming more commonplace, we may be forced to adapt our understanding of what it means to be human.

TECHNOLOGICAL FORMS OF COGNITIVE ENHANCEMENT

Scientists have already discovered ways to physically alter cognition through noninvasive and invasive brain stimulation [11]. Unlike invasive brain stimulation (IBS), noninvasive brain stimulation (NIBS) does not require surgical interventions, making it a safer and more accessible method [11]. NIBS includes technologies such as transcranial magnetic stimulation (TMS) and transcranial electrical stimulation (tES); the former is performed by sending electromagnetic waves via a coil placed against the scalp, whereas the latter places an electrical conductor known as electrodes on the scalp [12]. A prominent method for IBS is deep brain stimulation (DBS), in which electrodes are surgically implanted into the brain to very precisely modulate neuronal activity [13].

Various other forms of brain stimulation are available as well, with one impressive development called neurofeedback. By merging brain recording and stimulating devices, users

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Table 1

Types of Brain Stimulation

Type	Subtypes	Function	Implications
Transcranial Magnetic Stimulation (TMS)	Repetitive Transcranial Magnetic Stimulation (rTMS)[b] and Deep Transcranial Magnetic Stimulation (dTMS)[c]	Coils with electrical currents inside are placed against the scalp to produce a magnetic field, which influences current flow in the brain[a]	Majorly used for mental disorders such as treatment-resistant depression[d], anxiety, post-traumatic stress disorder, obsessive-compulsive disorder, and schizophrenia[c]
Transcranial Electrical Stimulation (tES)	Transcranial Direct-Current Stimulation (tDCS) and Transcranial Alternating-Current Stimulation (tACS)[a]	Electrodes are attached to the scalp to inject small currents[a]	Popular for cognitive enhancement[a]
Deep Brain Stimulation (DBS)		Electrodes are surgically implanted into specific sites in the brain, using electrical pulses to modulate neuronal activity[a]	Commonly used to treat movement, mental, and memory disorders[a]

[[d]16, [b]17, [c]18, [a]19].

waves, which may optimize meditation and creativity; alpha waves, which are involved in alertness and peacefulness; beta waves, which play a role in several cognitive functions such as thinking and focusing; and gamma waves, which are related to higher cognitive tasks like learning and problem-solving [15]. With an abundance of ways to physically augment our brain function, its applications hold potential for yet another giant leap for mankind, but due diligence must be exercised to ensure this leap is in the right direction.

APPLICATIONS OF COGNITIVE ENHANCEMENT

Both NIBS and IBS have shown great capacities in ameliorating symptoms in psychiatric and neurological disorders when other treatment options appear inauspicious [20]. These therapies typically involve patients with prolonged illnesses like depression, schizophrenia, attention deficit hyperactivity disorder (ADHD), and dementia, to name just a few [12]. A common goal is to promote the brain's plasticity, a process in which neurons reorganize their structure, function, and connections [21].

Alzheimer's disease (AD) has been a prominent area of interest due to the considerable challenges in treating it. A primary attribute of this neurodegenerative disease is a steep decline in cognitive function and, in turn, quality of life [22]. Promisingly, though, a meta-analysis including 32 studies found that certain types of TMS and tES–specifically repetitive TMS (rTMS) and transcranial direct current stimulation (tDCS), respectively–were able to immediately rehabilitate cognitive abilities in those with AD [23]. Another study with epileptic patients demonstrated improvement in cognitive functions by stimulating the hippocampus–a brain region critical for memory. The results yielded a 35% increase in short-term and long-term visual memory [24]. Additionally, stroke patients can also benefit from cognitive enhancement due to its ability to restore speech and motor functions [7]. Thus, these technologies illustrate the possibility

of improving the well-being of people facing severe adversities.

Various stimulation techniques can be applied to psychiatric illnesses as well. 30.9% of depressed individuals do not respond to treatments such as medication and therapy, but brain stimulation provides a hopeful alternative route [25]. DBS presents promising outcomes, in both the short and long term [26]. Patients immediately experienced "sudden calmness or lightness," "disappearance of the void," and increased "connectedness" and interest [26]. Even at the six month follow-up, 67% of participants were in remission, meaning they no longer met the criteria for depression [26].

These applications have also displayed positive effects on healthy individuals, such as in the case of creativity and performance, attention, perception, and, of course, memory [7, 27]. For example, tDCS is able to enhance cognitive processes such as attention, learning, memory, decision-making, and problem-solving [8]. A review assessing cerebellar tDCS addresses its enhancing effects on motor control and learning and recognizing emotions in others as well [28]. Even a musician's skills are able to improve through neurofeedback—specifically in

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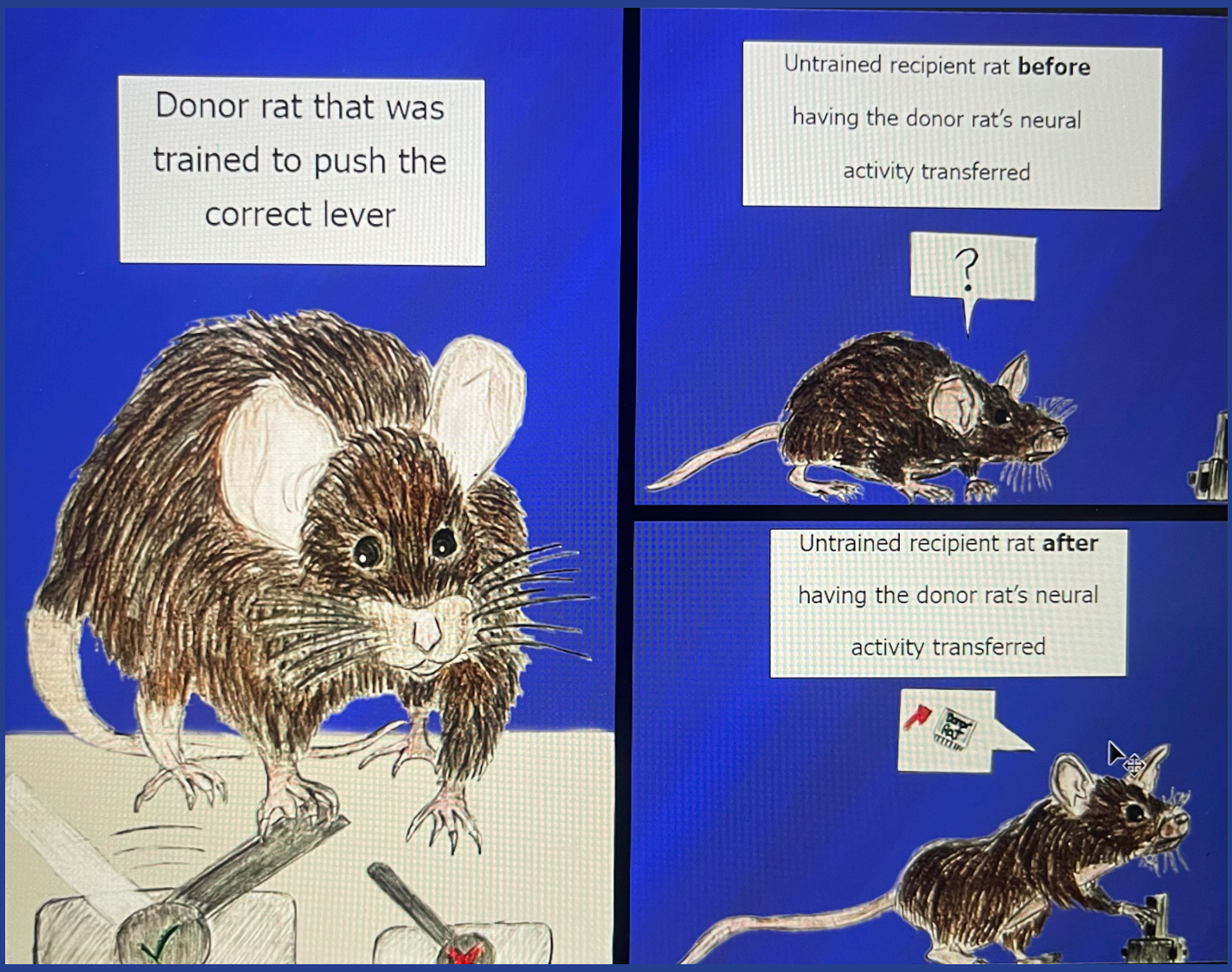
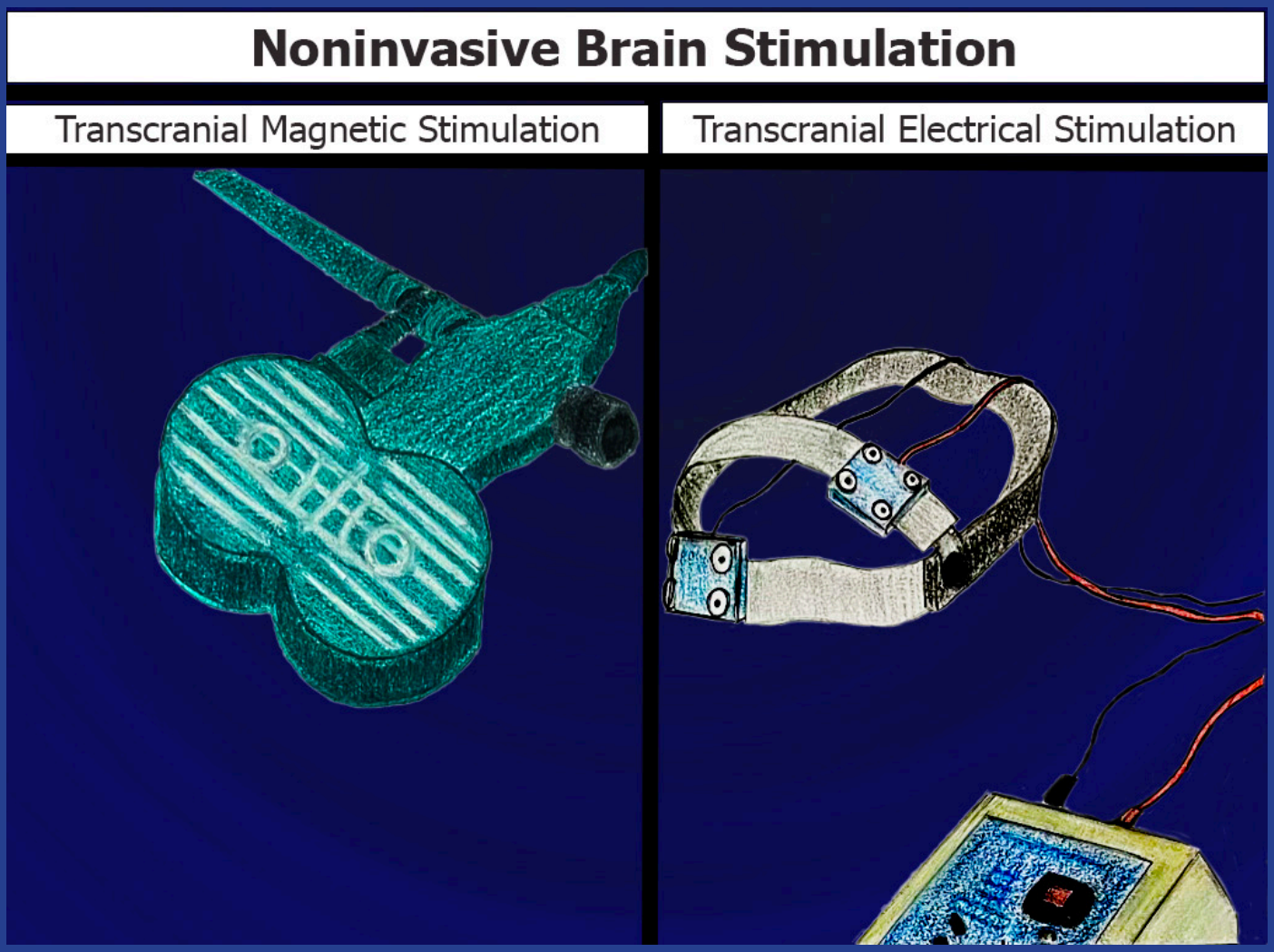


creativity, accuracy, interpretive imagination, and expressive range [27]. This is far from an exhaustive list of neurotechnology's capabilities, and while this may be exciting, these tools must be used conscientiously as society starts to implement them.

ETHICAL CONSIDERATIONS

What does this mean for humanity? While the potential benefits of such technologies are limitless, do we trust that access to our most private information will only be used for good? On the other side of the same coin, to what extent will we allow our minds to be manipulated? Society already accepts various forms of our experiences being augmented, from psychiatric medications to prosthetics, so where will the line be drawn? While there are innumerable questions to pose, one thing is for sure: regulations must rapidly be put in place to ensure the safety of humanity, lest we find ourselves in a real-life Black Mirror episode.

Some primary concerns involve agency, privacy, equality, and human identity altogether. One's agency and identity have the potential to be compromised due to neurotechnology's ability to manipulate our brain, and, thus, our thoughts, emotions, and behaviors. Even if thoughts are not manipulated, but rather read, consequences could still be disastrous. The episode "Crocodile" illustrates just how much of a threat this could be: because memories can be retrieved by other people, a woman involved in manslaughter finds herself in a series of murders to try to prevent her memories from being discovered [1]. Though this is a bit of a hyperbolic example, the episode highlights some more realistic issues, such as how unreliable and suggestible human memory can be. If the legal system were to integrate mind-reading technologies, who's to say testifiers won't misremember things and provide faulty evidence, or even have their memories manipulated to sway the trial? This could hurt certain populations, and there is concern about how neurotechnology will exacerbate inequality outside of the court as well. As wealthy people will have more resources to obtain these technologies, the gap with the rest of the population will only continue to expand. Addressing these ethical concerns and establishing regulations is paramount to ensuring neurotechnology is here to benefit society rather than upend it. Regardless, what it means to be human and how society functions is bound to be redefined in light of such advancements.



I., Basta, I., Savic, A., Stojanovic, V. R., & Kacar, A. (2022). Physical and Mental Aspects of Quality of Life in Patients with Charcot-Marie-Tooth disease Type 1A. Frontiers in Neurology, 13. doi: 10.3389/fneur.2022.852150

13. Rossor, A. M., Polke, J. M., Houlden, H., & Reilly, M. M. (2013). Clinical Implications of Genetic Advances in Charcot-Marie Tooth Disease. Nature Reviews Neurology, 9, 562-571. https://doi.org/10.1038/nrneurol.2013.179
14. Fridman, V., & Saporta, M. A. (2021). Mechanisms and Treatments in Demyelinating CMT. Neurotherapeutics, 18, 2236-2268. https://doi.org/10.1007/s13311-021-01145-z

LEVADOPA AND PARKINSON'S

1. Fahn, S., Oakes, D., Shoulson, I., Kieburtz, K., Rudolph, A., Lang, A., Olanow, C. W., Tanner, C., & Marek, K. (2004, December 9). Levodopa and the progression of parkinson's disease. The New England journal of medicine. https://pubmed.ncbi.nlm.nih.gov/15590952/
2. Hastings, E., & Burdett, T. (n.d.). Trait: Parkinson disease. GWAS catalog. https://www.ebi.ac.uk/gwas/efotraits/MONDO_0005180
3. Can environmental toxins cause parkinson's disease? John Hopkins Medicine. (n.d.). https://www.hopkinsmedicine.org/health/conditions-and-diseases/parkinsons-disease/can-environmental-toxins-cause-parkinson-disease
4. Hauser, R. A., & Grosset, D. G. (2011, March 16). [123i]fp-cit (DaTscan) Spect Brain Imaging in ... - wiley online library. Wiley Online Library. https://onlinelibrary.wiley.com/doi/10.1111/j.1552-6569.2011.00583.x
5. Hauser, R. A. (2009, June). Levodopa: Past, Present, and Future. Karger Publishers. https://karger.com/ene/article/62/1/1/124490/Levodopa-Past-Present-and-Future
6. Abbott, A. (2010, August 25). Levodopa: The story so far. Nature News. https://www.nature.com/articles/466S6a
7. Choi, J., & Horner, K. A. (2023, June 26). Dopamine agonists - statpearls - NCBI BOOKSHELF. National Library of Medicine. https://www.ncbi.nlm.nih.gov/books/NBK551686/
8. LeWitt, P. A., Stocchi, F., Arkadir, D., Caraco, Y., Adar, L., Perlstein, I., Case, R., & Giladi, N. (2022, November 10). The pharmacokinetics of continuous subcutaneous levodopa/carbidopa infusion: Findings from the ND0612 Clinical Development Program. Frontiers in neurology. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9686322/

COGNITIVE ENHANCEMENT IN THE 21ST CENTURY: IS BLACK MIRROR BECOMING A REALITY?

1. Jones, A., Brooker, C., Rhoades, J., & Ali, B. (2011-present). Black mirror. Zeppotron; House of Tomorrow; Broke & Bones.
2. Deadwyler, Sam A., et al. "Donor/recipient enhancement of memory in rat hippocampus." Frontiers in Systems Neuroscience, vol. 7, 2013, https://doi.org/10.3389/fnsys.2013.00120.
3. Drew, Liam. "The Rise of Brain-Reading Technology: What You Need to Know." Nature News, Nature Publishing Group, 8 Nov. 2023, www.nature.com/articles/d41586-023-03423-6.
4. Jiang, Linxing, et al. "BrainNet: A multi-person brain-to-brain interface for direct collaboration between Brains." Scientific Reports, vol. 9, no. 1, 2019, https://doi.org/10.1038/s41598-019-41895-7.
5. Swetnam, Michael, et al. "Potomac Institute for Policy." Potomac Institute for Policy Studies, Apr. 2013, potomacinstitute.org/images/studies/NTFSReport-FINAL.pdf.
6. "Cognition." Encyclopædia Britannica, Encyclopædia Britannica, inc., 1 Dec. 2023, www.britannica.com/topic/cognition-thought-process.
7. Clark, Vincent P., and Raja Parasuraman. "Neuroenhancement: Enhancing brain and mind in health and in disease." NeuroImage, vol. 85, 2014, pp. 889–894, https://doi.org/10.1016/j.neuroimage.2013.08.071.
8. Coffman, Brian A., et al. "Battery powered thought: Enhancement of attention, learning, and memory in healthy adults using transcranial direct current stimulation." NeuroImage, vol. 85, 2014, pp. 895–908, https://doi.org/10.1016/j.neuroimage.2013.07.083.
9. Turker, Sabrina, and Gesa Hartwigsen. "The use of non-invasive brain stimulation techniques to improve reading difficulties in dyslexia: A systematic review." Human Brain Mapping, vol. 43, no. 3, 2021, pp. 1157–1173, https://doi.org/10.1002/hbm.25700.
10. "Neurotechnology Market (by Product Type: Neurostimulation, Neurosensing, Neuroprostheses, Neurorehabilitation; by Conditions: Cognitive Disorders, Pain Treatment, Urinary and Fecal Incontinence, Epilepsy, Parkinson's Disease, Hearing Conditions, Sleep Disorder, Depression, Others; by End-Use: Ambulatory Surgical Centers, Hospitals, Homecare Facilities, Others) - Global Industry Analysis, Size, Share, Growth, Trends, Regional Outlook, and Forecast 2023-2032." Precedence

Research, 2022, www.precedenceresearch.com/neurotechnology-market.

11. Teunisse, Wessel, et al. "Human enhancement through the lens of experimental and speculative neurotechnologies." Human Behavior and Emerging Technologies, vol. 1, no. 4, 2019, pp. 361–372, https://doi.org/10.1002/hbe2.179.
12. Kim, Tammy D., et al. "Cognitive enhancement in neurological and psychiatric disorders using transcranial magnetic stimulation (TMS): A review of modalities, potential mechanisms and future implications." Experimental Neurobiology, vol. 28, no. 1, 2019, pp. 1–16, https://doi.org/10.5607/en.2019.28.1.1.
13. Pilitsis, Julie G, et al. "Deep Brain Stimulation." AANS, www.aans.org/en/Patients/Neurosurgical-Conditions-and-Treatments/Deep-Brain-Stimulation#:~:text=Deep%20brain%20stimulation%20(DBS)%20is,that%20control%20abnormal%20brain%20activity. Accessed 4 Dec. 2023.
14. Angelakis, Efthymios, et al. "EEG Neurofeedback: A brief overview and an example of peak alpha frequency training for cognitive enhancement in the elderly." The Clinical Neuropsychologist, vol. 21, no. 1, 2007, pp. 110–129, https://doi.org/10.1080/13854040600744839
15. Marzbani, H., et al. "Methodological note: Neurofeedback: A comprehensive review on system design, methodology and clinical applications." Basic and Clinical Neuroscience Journal, vol. 7, no. 2, 2016, https://doi.org/10.15412/j.bcn.03070208.
16. Adam P. Stern, MD. "Transcranial Magnetic Stimulation (TMS): Hope for Stubborn Depression." Harvard Health, 27 Oct. 2020, www.health.harvard.edu/blog/transcranial-magnetic-stimulation-for-depression-2018022313335.
17. "Brain Stimulation Therapy: The Past, Present, and Future of Treatment through Brain Stimulation." IEEE Brain, 2022, brain.ieee.org/topics/brain-stimulation-therapy-the-past-present-and-future-of-treatment-through-brain-stimulation/.
18. Camacho-Conde, Jose Antonio, et al. "Therapeutic potential of brain stimulation techniques in the treatment of mental, psychiatric, and cognitive disorders." CNS Neuroscience & Therapeutics, vol. 29, no. 1, 2022, pp. 8–23, https://doi.org/10.1111/cns.13971.
19. Cinel, Caterina, et al. "Neurotechnologies for human cognitive augmentation: Current state of the art and future prospects." Frontiers in Human Neuroscience, vol. 13, 2019, https://doi.org/10.3389/fnhum.2019.00013.
20. Suthana, Nanthia, and Itzhak Fried. "Deep brain stimulation for enhancement of learning and memory." NeuroImage, vol. 85, 2014, pp. 996–1002, https://doi.org/10.1016/j.neuroimage.2013.07.066.
21. Puderbaugh, Matt, and Prabhu D Emmady. "Neuroplasticity - Statpearls - NCBI Bookshelf." National Library of Medicine, 1 May 2023, www.ncbi.nlm.nih.gov/books/NBK557811/.
22. "What Happens to the Brain in Alzheimer's Disease?" National Institute on Aging, U.S. Department of Health and Human Services, 2017, www.nia.nih.gov/health/alzheimers-causes-and-risk-factors/what-happens-brain-alzheimers-disease#:~:text=How%20does%20Alzheimer's%20disease%20affect,with%20other%20neurons%2C%20and%20die.
23. Šimko, Patrik, et al. "Is non-invasive brain stimulation effective for cognitive enhancement in alzheimer's disease? an updated meta-analysis." Clinical Neurophysiology, vol. 144, 2022, pp. 23–40, https://doi.org/10.1016/j.clinph.2022.09.010.
24. Hampson, Robert E, et al. "Developing a hippocampal neural prosthetic to facilitate human memory encoding and recall." Journal of Neural Engineering, vol. 15, no. 3, 2018, p. 036014, https://doi.org/10.1088/1741-2552/aaaed7.
25. Zhdanava, Maryia, et al. "The prevalence and national burden of treatment-resistant depression and major depressive disorder in the United States." The Journal of Clinical Psychiatry, vol. 82, no. 2, 2021, https://doi.org/10.4088/jcp.20m13699.
26. Mayberg, Helen S., et al. "Deep brain stimulation for treatment-resistant depression." Neuron, vol. 45, no. 5, 2005, pp. 651–660, https://doi.org/10.1016/j.neuron.2005.02.014.
27. Gruzelier, John H. "EEG-neurofeedback for optimising performance. II: Creativity, the performing arts and ecological validity." Neuroscience & Biobehavioral Reviews, vol. 44, 2014, pp. 142–158, https://doi.org/10.1016/j.neubiorev.2013.11.004.
28. Ferrucci, Roberta, and Alberto Priori. "Transcranial cerebellar direct current stimulation (tcdcs): Motor Control, cognition, learning and emotions." NeuroImage, vol. 85, 2014, pp. 918–923, https://doi.org/10.1016/j.neuroimage.2013.04.122.

INSIDE THE MIND: A GLIMPSE INTO SUFFERERS OF NON-SUICIDAL SELF-INJURY

1. American Psychiatric Association. (2013). Diagnostic and