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PERSPECTIVES AND CHALLENGES IN COGNITIVE ENHANCEMENT BASED ON THE NEUROTECHNOLOGY APPROACH

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Abstract: *Cognitive enhancement or neuroenhancement implies any action or intervention that improves performance related to cognitive abilities such as learning, memory, attention, or vigilance. The whole approach is based on an understanding of the underlying neurobiology of cognitive functions and interventions through conventional methods (environmental enrichment, adequate sleep, optimized diet, physical activity, etc.), pharmacological methods (nootropics and drugs used for treating patients with neurological disorders) and neurostimulation.*

Due to the latest developments in the field of technology, the possibility to enhance cognitive function using computer chip implants in the brain is opened. Such devices that interface with the neural system are presently in development and engaged only for those with a therapeutic requirement. On the other hand, as for all methods of cognitive enhancement, it is really hard to draw the line between their approved and non-approved usage. Therefore, the upcoming application of brain chip implants could expand brain performance for individuals even without therapeutic prerequisite, although both the public and scientists already anticipate some negative impacts.

This paper discusses perspectives and challenges in the latest development of the neurotechnology approach used to improve cognitive performance.

Keywords: Cognitive Enhancement, Neurotechnology, Brain Chip Implants.

1. INTRODUCTION

Cognition refers to mental processes that comprise attention, memory, making decisions, solving problems, producing and understanding language, reasoning, etc. Demand for memorising facts, learning new operations and skills, and performing complex analytics is on a constant rise in contemporary society. Modern humans are facing a huge amount of information on a daily basis, especially in certain technology-based professions. Keeping and improving mental capabilities might be crucial in daily life, but especially in some professions. For example, enhancing procedural memory may upgrade task competency in many job positions. Besides the high demand for improving cognitive skills of healthy population several disorders, for instance, attention deficit hyperactivity disorder (ADHD), Alzheimer's, Parkinson's and Huntington's diseases, schizophrenia, etc. are characterized by cognitive impairments. Such patients regularly fight with numerous everyday activities demanding focusing, memory, problem-solving and planning. The probable public health benefit of improving treatments for such patients is more than obvious. Cognitive skills are regularly and traditionally acquired through slow, step by step, effortful, and expensive procedures of education and training. Therefore, several approaches to augment brain function have been proposed. These different strategies of brain functioning improvement are usually termed cognitive enhancement or neuroenhancement (Table 1). Cognitive enhancement techniques are classified whether they are

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conventional or unconventional, but also if they are external or internal to the user, and whether they are hardware/software based [1]. Unconventional techniques of direct nervous system stimulation are here presented as a special category known as neurostimulation.

Table 1. Different approaches to cognitive enhancement
Source: presented data are acquired through literature review and appropriate references cited in the table

COGNITIVE ENHANCEMENT	**Conventional methods**	**Education**: formal, informal and non-formal types [1]; **Enriched Environment**: physical stimulation (nutrition, sleep, exercise…), social stimulation and cognitive challenges [2]; **Mental Training**: learning strategies, general mental activity, rhyming, recalling colourful or emotional scenes, recalling number series or letters, yoga, martial arts, meditation, video gaming [2]; **Use of external information processing devices**: cognitive training, neurofeedback [3].
	Pharmacological methods	**Nootropics**: classical nootropic compounds, substances increasing brain metabolism, cholinergic drugs, plants and their extracts with nootropic effects [4]; **Drugs for treating neurological disorders** [5].
	Neurostimulation	**Transcranial electric stimulation** (i.e., tDCS, tACS, tRNS) [6]; **Transcranial magnetic stimulation** (i.e., single, dual pulse, and rTMS) [6]; **Focused ultrasound** [7]; **Electrical vestibular stimulation (EVS)** [6]; **Vagus nerve stimulation (VNS)** [6].

Cognitive enhancement embraces three steps [1]. Assessment of cognitive abilities is the first step. It is followed by intervention aimed at cognitive abilities improvement. Final step is the validation of improvement that takes place by evaluating the cognitive abilities upon intervention. If the intervention is used to correct a certain pathological conditions or impairments of cognition, then it is stated as a therapy. However, drawing the line between intervention and therapy is not that easy in certain cases.

Conventional means of enhancing cognition embrace education, enriched environment, mental training, and the use of external information processing devices (Table 1). Education could be defined as any experience that has effects on the way one thinks, feels, or acts. Clearly, education is approached through formal and unformal programs and forms and affects how our "biological software" in the brain collects, preserves, and analyse information. Enriched environment is the stimulus for the brain by its social and physical surroundings, or by cognitive challenges [2]. Any stimulus which represents positive experience enhance cognitive flexibility through the process of neuroplasticity. Neuroplasticity is biological capability of the brain to constantly modifies in concordant to stimuli from the environment. In addition, there is a huge number of different forms of mental trainings through which cognitive enhancement is possible to achieve. Usually, these are learning strategies to memorize information, methods for general mental activity, use of rhyming, recalling colourful or emotional scenes, recalling number series or letters, yoga, martial arts, meditation, video gaming, etc. The list of mental trainings is constantly expanding. External information processing devices are applied in modern versions of "mental gym programs". They are often used in conjunction, such as neurofeedback and cognitive training. Cognitive training is a conventional method transformed into modern virtual game-like format of mental exercises. Neurofeedback is a technique to monitor brain signals with either visual or auditory feedback [3].

The use of pharmacological methods in cognitive enhancement is associated with the treatment of medical disorders such as dementia and ADHD, but there are considerations that certain medicines are also taken in non-clinically prescribed circumstances. Nootropics, also known as "smart drugs" are an assorted collection of medicinal substances whose action advances human mental activities, particularly in cases where these functions are impaired [4]. A heterogeneous group of nootropics has been divided into four subgroups according to their nature and effects: classical nootropic compounds, substances increasing brain metabolism, cholinergic drugs, and plants and their extracts with nootropic effects. Nootropics are used in acute or subacute conditions for treating memory, consciousness, and learning disorders.

Neurostimulation embraces group of non-invasive technologies such as; transcranial electric stimulation (tES), transcranial magnetic stimulation (tMS), electrical vestibular stimulation, vagus nerve stimulation (VNS), and focused ultrasound; as well as invasive technologies as deep brain stimulation. All neurostimulation technologies are all grounded on the usage of electrical or magnetic stimuli to alter the electrophysiology of the central and peripheral nervous systems. Transcranial direct-current stimulation (tDCS) is a movable, wearable electric brain stimulation technique that delivers a low electric current to the scalp. In transcranial alternating current stimulation (tACS) a low-intensity sinusoidal electrical current is applied to the brain through electrodes on the scalp. Transcranial random noise stimulation (tRNS) is a method that involves the application of a low-intensity alternating current whose intensity and frequency change in a randomised way. Deep brain stimulation involves inserting neuro-stimulators in precise fragments of the brain, which direct electrical pulses that interfere with neural activity at the target sites. This technology is mainly used for the treatment of movement and memory disorders [7].

2. NEUROTECHNOLOGY IN COGNITIVE ENHANCEMENT

Until recently, deep brain stimulation and other invasive technologies based on the insertion of electrodes and devices were used in humans only due to medical interventions (e.g. epilepsy and Parkinson's disease). Research on cognitive augmentation in humans was limited to medically approved cases as learning enhancement and visual prosthesis. The development of brain-computer interfaces (BCIs) opened a new era for the implementation of technologies for brain recording and brain stimulation. Brain-computer interfaces obtain brain signals, analyse them, and decode them into instructions that are transmitted to output devices that perform wanted actions. The BCI includes hardware that records brain signals (electrical or magnetic signals made by brain neurons) and software that analyses and converts them into specific commands. The brain comprises of almost 100 billion neurons, each making thousands of synapses (connections) with other neurons. Therefore, interpreting the collected signals is quite a complex problem. Hopefully, it is expected that machine-learning algorithms will increase the capacity of BCIs to interpret brain activity in real time.

The main goal of BCI in medicine is to replace or restore useful functions to disabled people. BCI technology may permit individuals unable to speak or use their limbs to once again communicate or operate devices for walking and object manipulation. In other words, brain-computer interfaces are systems that allow communication between the brain and various machines like a computer, smartphone, or robotic limb. Looking from more general view, BCI might be used as an approach to cognitive enhancement not only in patients with medical diagnosis but also in healthy populations.

The term brain-machine interface is commonly used as a synonym to the described term brain-computer interface. Anyway, brain-machine interface (BMI) refers to the definite interface between nervous system tissue and a device (usually an electrode); accordingly, BMI is invasive. Many researchers assume that BCI encompasses the entire BMI field since brain-machine interface is focused on refining the electrodes themselves for recording or stimulating brain activity. The term neurotechnology is another term often used as a synonym, but more precisely it includes any method or electronic device which interfaces with the nervous system to screen or control neural activity [8]. Neurotechnology incorporates the use of brain chips, neural implants, and BCI technology.

2.1 Brain Implants

In April 2021, Neuralink, the tech startup co-founded by Elon Musk, demonstrated how a chip-implanted monkey could play the video game Pong with its mind. This demonstration opened the possibility for human brain implants. Neuralink announced in May 2023 approval from the USA Food and Drug Administration to begin trials to implant brain chips into humans. Most probably, many years will pass before patients get the Neuralink treatment, but that isn't stopping investors from

boosting the company. Neuralink aims to ultimately enable a patient suffering from paralysis to use devices such as computers or phones with their brain activity alone. It is presumed that their implant contains multiple chips, a wireless battery, and other electronics that are hermetically closed inside a small device (the size of a large coin). Ultra-thin threads will protrude from the implant directly into the brain tissue, and signals will be sent via Bluetooth to, and decoded by, BCI. As a result, a patient will be able to, for example, control an onscreen cursor or move a robotic limb. Neuralink already created a surgical robot to embed the implant and its 64 ultra-thin flexible connected threads upon which are 1,024 electrodes that record neural activity. The robot uses optical coherence tomography for non-invasive imaging of the brain and the needle as thin as a human hair to insert the "threads.
Neuralnik is not the only company in the field of inserting brain implants into humans. Synchron is a company financially supported by Bill Gates and Jeff Bezos and they already tested brain-computer interface (BCI) in humans. The same company also reported the insertion of Stentrode through the blood vessels into the brain's motor cortex.
According to some sources, more than 150,000 people from the USA have a type of brain implant known as a deep brain stimulator to treat tremors caused by movement disorders such as Parkinson's. One forthcoming practice of brain chip implants could be to expand brain functioning for people even without therapeutic requirements. A brain implant might work by transferring pulses of electricity straight into neurons that help rule a particular skill of interest or to improve memorizing facts. The chip might also give the brain some extra memory and subsequently knowledge could be kept externally.

3. PERSPECTIVES

Practically, neurotechnology can be applied to permit mind-controlled prostheses, improve cognitive abilities, and cure neurological dysfunction. The use of BCIs to enhance motor and cognitive recovery within neurorehabilitation settings is more than expected and approved by scientists and by public. In research published in 2019 Widge and associates determined that electrical stimulation of the ventral internal capsule/ventral striatum brain areas enhances cognitive control. They also found that upon deep brain stimulation of this area, specific neural biomarkers that correspond with clinical improvements could be observed and followed [10]. The almost identical framework could also be applied to further cognitive or emotional difficulties, for example, monitoring and enhancement of learning or emotion dysregulation, thus opening the possibility for some type of “cosmetical cognitive enhancement” approach.
In both cases from the point of technology, there are several critical segments to be improved. Implanting electrodes into brain tissue comes with certain risks. Therefore, it would be ideal to attach them outside of the brain entirely and specifically outside of the dura mater, the brain’s protective membrane. Currently, chip arrays record data from maybe a couple of hundred neurons at a time. Expanding this feature to record electrical signals instead from hundreds to hundred thousand of neurons opens much bigger possibilities around the type of fidelity keeping in mind almost 100 billion brain neurons, each having a couple of thousand synapses. Furthermore, an open question is do we need chip technology that is limited concerning the size of the implant and invasive surgical approach? The next step in brain chip development could be the creation of nanomaterials that move through the body and specifically through the bran. Injecting nano-sensors that would be deployed throughout the brain could be followed by their control by magnets or radio signals. Additionally, the technology of nanoparticles could be combined with genetic and molecular engineering. Huge number of such nanoparticles would substitute one or a few implants. As a result, instead of sensing broad signal from multiple neurons nanoparticles would detect specific signals from single cells of various cell types finally allowing us to associate them with specific neurological diseases or specific cognitive domains and functions. Another additional step in improving the usage of neurotechnology

in cognitive enhancement could be refining the connection between brains and machines. This would beef up our senses and allow us to control robots from a distance.

Neurotechnology that is based on non-invasive neurostimulation is at certain preference compared to invasive technology that uses brain implants. For example, transcranial direct current stimulation works by sending electricity through the scalp. Some scientists believe that this method could be further improved thus helping in the enhancement of skills such as learning and memory. Similarly, the transfer of electrical signals through the vagus and other nerves may prompt the brain to release neurotransmitters and metabolites that alter connections between different neural cells. The natural process of memorizing and learning is based on the same neurobiological mechanism. Thus, further stimulation and direction of the same neurobiological process via electrical stimulation of the vagus may “tune” the brain to recognize important details with less practice which might be of interest to both, patients and healthy population. Moreover, recent studies have revealed the prospect of using neurotechnological methods to assess the cognitive processes associated with individual and group decision making, memory enhancement, attention enhancement, different aspects of perception and awareness, and social interaction [7].

Lately, scientists have started exploring the option of brain-to-brain communication. This would be possibility to physically and directly connect two or more brains permitting straight and shortest exchanges of information between people. In several studies combination of electroencephalography and transcranial magnetic stimulation was used in brain-to-brain communication to spread information between individuals in a collaborative task [7]. Although described brain-to brain communication is currently characterized with lot of limitations achievements in this field represent an important proof-of-concept, and further development might potentially lead to future upgraded and more functional systems of brain-to-brain communication.

4. CHALLANGES

The usage of neurotechnology raises concerns in first place about free will and privacy of individuals. The potential ability to “read” or “assess” someone's thoughts, emotions, states, or attitudes opens the possibility of its misuse. Nowadays, many neuroscientists are worried about the latest consent for insertion of brain chips into humans that Food and Drug Administration approved. A logical question is whether the private company Neuralink will have admission to the neuro data of the people that they implant devices in.

As expected, different investigations on public attitudes demonstrated negative views across the whole population about using brain chip implants for enhancement. Most the people recognize usage of brain chip implants to improve cognitive processing as interfering with nature and passing a line. In this line, they are mostly bothered about potential economic inequality in brain implants application and cybersecurity. Most people claim higher standard to guarantee the safety of brain chip implants, especially if they are used in the cosmetic cognitive enhancement practice. In contrast, most people support the use of brain chips for medically approved therapeutic purposes in patients [11].

Neuroscientists are afraid that the application of BCI technology in humans will cause mental changes that are unpredictable and little understood. Most probably some changes might entirely modify someone's identity and sense of self. In some particular cases, patients have stated back feelings of estrangement, or even that the implant makes them feel unlike themselves. Consequently, the main questions are what kinds of changes does BCI-based cognitive enhancement cause, and how much changes matter to individuals and whole human society? Clearly, notions of personality, individuality, independence, and self are quite compact, obscure, and opaque dimensions. Therefore, all criticisms are well based and reasonable.

5. CONCLUSION

At present time, methods of cognitive enhancement based on neurotechnology approach look quite promising, but at the same time frightening. That is the step that all new technology passes on their path to approval and usage. Helping other people in their fight against neurodegenerative diseases and other types of handicaps is beyond any doubt something we should persist. Opening the gates for cosmetic neurology that will allow anyone with enough money in the pocket to "expand mind" is something different. Both practices are based on the same neurotechnology approach. In both cases at the moment, we are not able to predict all side effects, particularly ones that may affect someone's personality. Consequently, our attitude towards cognitive enhancement must be carefully determined and balanced.

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