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Neuralink and Beyond: Challenges of Creating an Enhanced Human

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Neuralink and Beyond: Challenges of Creating an Enhanced Human*

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ABSTRACT

This article is a literature review of Neuralink, brain-machine interfaces (BMIs) and their applications, followed by future possibilities of BMIs and their potential impacts. Currently, BMIs predominantly have therapeutic applications, such as helping people with spinal cord injury by allowing them to control a computer directly with their brain. However, BMIs can also improve learning, detect emotions, and control basic behaviors. In the future, they could offer many powerful possibilities, such as controlling people and merging our intelligence with artificial intelligence (AI), which may be necessary to mitigate the existential threat of artificial general intelligence (AGI). Simultaneously, they would likely have severe human impacts, such as loss of sense of self, erosion of skills, and privacy issues, creating psychological harm and confusion. This paper shows that BMI research could generate drastic changes with no possible return, thus reinforcing the need to urgently address these critical issues.

CCS CONCEPTS

• **Security and privacy → Social aspects of security and privacy**.

KEYWORDS

Neuralink; brain-machine interface; BMI; BCI; CBI; BBI; transhumanism; ethical issues

1 INTRODUCTION

Since 2017, Elon Musk's project Neuralink and brain-machine interfaces have received a lot of attention [22]. Neuralink is a brain-machine interface (BMI) company that creates devices designed to be implanted in human brains "*to eventually improve memory and interface with computer systems.*" [22]. On August 28, 2020, billionaire entrepreneur Elon Musk presented his pig Gertrude and the chip implanted in the animal's brain. The chip retransmits Gertrude's neurological signals. From this information, a computer can predict at any time where each of Gertrude's members is, giving hope to restore mobility to paraplegic people. Elon Musk is brilliant at marketing his ideas on a large scale and creating enthusiasm and fascination for his various projects. Never short of vivid images, Elon Musk claimed that having the interface is comparable to have a smartwatch in your brain. Science expands and brings new technologies, which leads to benefits, but also threats, as society's relationships are reshaped [23]. For this study, it was of interest to investigate Neuralink, BMIs, and transhumanism, which are both fascinating and frightening. Scientists need to ensure that the benefits are maximized while minimizing the threats [23]. The fusion of human beings and machines naturally raises a plethora of ethical questions. Will a brain-machine interface redesign humanity? What are the impacts?

This study is a literature review, followed by an evaluation of the impacts of brain-machine interfaces on humanity's future. Data types are mostly secondary qualitative data from peer-reviewed scientific papers, which provide a solid basis of knowledge. It gives a well-grounded foundation to my methodological choices. My personal evaluations are also supported by meta-models, such as the *Spiral Dynamics* [3].

The rest of this paper is structured as follows: section 2 shows an overview of brain-machine interfaces (BMIs) and Neuralink. In section 3, we describe Neuralink's showcase application and other therapeutic applications of BMIs. In section 4, we present the current social and cognitive applications of BMIs. Section 5 is devoted to evaluations, where we will explore future possibilities and discuss human impacts, critical issues, transhumanism, and other possible world visions. We conclude this paper in section 6.

2 OVERVIEW OF BRAIN-MACHINE INTERFACES AND NEURALINK

In this section, brain-machines interfaces (BMIs) are presented briefly. Although BMIs have been around for a long time, Musk's Neuralink project intends to bring BMIs to another level and narrow the gap between man and machine, possibly dramatically.

2.1 Brain-Machine Interfaces

Generally, a brain-machine interface is a link between a brain and a machine. The first attempts to translate neuronal activity into commands to control external devices were made in monkeys in the 1960s. [20]. In the 1970s, electroencephalography (EEG) was used to link brain activity with computers directly [19]. The term "brain-computer interface" appeared in the 1970s [20]. Brain-machine interface research and its applications are considered as the most exciting interdisciplinary fields of science [20]. Similar to computers' evolution, neural interfaces will become smaller and more powerful [23]. Today, BMIs allow controlling a cursor on a screen [13]. BMIs are particularly promising for neurorehabilitation of sensory and motor disabilities, neurocommunication, and cognitive state evaluation [20]. Furthermore, better neuronal activity analyses hold out hope for the use of BMIs daily in the future [20]. BMIs can bring huge benefits to society, such as novel therapies, or social

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and cognitive enhancement [23]. Many people already benefit from medical BMIs [23]. Generally, the main goal of BMIs is to repair and/or increase human performance [13].

One could consider that the gap between human and machine needs to be reduced. Our brains are not prepared to deal with the considerable volume of information brought by pervasive technologies and the Internet of Things (IoT) [19]. In addition, the limits of personal and professional life will be increasingly blurred. Niforatos et al. affirm that "*[...], our cognitive capacities cannot simply rely on natural evolution to keep up with the immense advancements in the field of Ubiquitous technologies, which remain largely uninformed about our cognitive states*" [19]. Niforatos et al. have presented a software architecture for developing cognition-aware applications that adjust user presentation to user's current cognitive state (see figure 1) [19]. Generally, there is a will to increase human efficiency by reducing the human-machine gap.

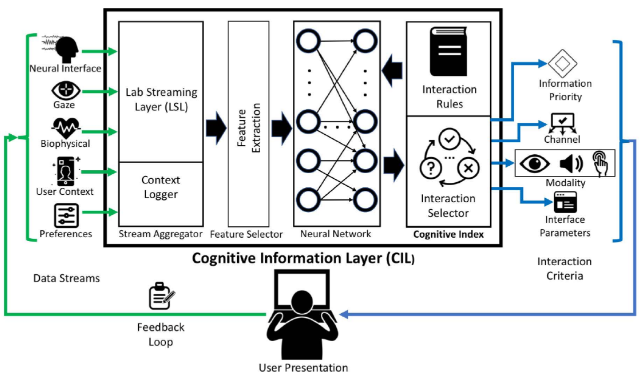

Figure 1: Adaptive user interface [19]

2.1.1 Types of Neural Interfaces. There are two categories of BMIs. Noninvasive approaches do not require opening the skull. The average of millions of neurons can be recorded, but the signal is distorted and nonspecific [17]. In invasive approaches, electrodes are placed directly on the surface of the cortex. Useful signals can be recorded, but they average the activity of thousands of neurons only [17]. Neuralink uses an invasive approach that will be further discussed in section 2.2. We also distinguish recording and stimulating activities. Recording, also mentioned as brain-to-computer interface (BCI), attempts to read brain signals and interpret them. Stimulating, also mentioned as computer-to-brain interface (CBI), goes in the opposite direction and tries to stimulate or control the brain. There are various kinds of invasive/noninvasive and recording/stimulating technologies. Noninvasive technologies are also interesting. Among these, let us cite transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS). TMS produces a changing magnetic field with a coil close to the scalp [23]. It can activate or disrupt activity in the brain, which helps to understand the role of the various brain areas [23]. TMS is also effective in treating drug-resistant depression [23]. As for tDCS, it uses electrodes placed on the head and delivers constant and direct low current impulses [23]. tDCS is used to treat depression and pain. Recently, there is renewed interest in using tDCS to improve cognitive processes and movement in people without health problems. Attempts of tDCS have suggested it helps the brain form connections, but no evidence yet exists [23].

2.2 Neuralink

The approach chosen by Neuralink is invasive and presents a few innovations.

2.2.1 Ultra-fine Polymer Probes. The neural probes employ a variety of biocompatible thin film materials. A thin film array has up to 96 threads, each containing 32 independent electrodes, for a total of 3072 electrode contacts [17]. Thread thickness is nominally 4-6 μm, which includes insulation and conductor layers [17], while thread length is about 20 mm. Surface modifications are used "*[...] to lower the impedance for electrophysiology and increase the effective charge-carrying capacity of the interface*" [17]. A novel alignment and flip-chip bonding process allow to create a package of 23×18.5 mm² [17].

2.2.2 Neurosurgical Robot. The low bending stiffness of electrode probes complicates insertions [17]. Neuralink has developed a robot that allows inserting rapidly and reliably the flexible probes to record scattered brain regions [17]. Custom software enables planning of insertion paths to avoid vasculature [17]. The robot's insertion head holds a quick-swappable "needle-pincher" assembly [17]. "*The tip of the needle is designed both to hook onto insertion loops—for transporting and inserting individual threads—and to penetrate the meninges and brain tissue*" [17]. The pincher acts as a support for the probes during transport and as a guide to ensure that the threads are inserted along the needle's path [17]. The robot can insert up to 192 electrodes per minute, which allows a quick operation [17]. Robotic insertion is an efficient and scalable approach [17].

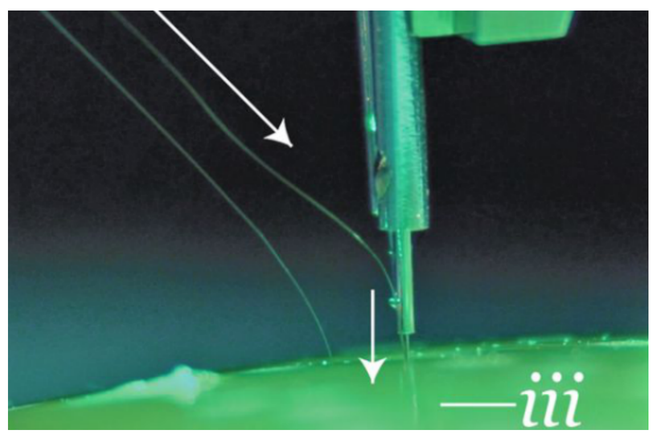

Figure 2: Needle penetrating tissue proxy [17]

2.2.3 Electronics. Recording from thousands of electrode sites presents challenges. "*The density of recording channels necessitates placing the signal amplification and digitization stack within the array assembly*" [17]. "*This recording stack must amplify small neural signals [...] while rejecting out-of-band noise, sample and digitize the amplified signals, and stream out the results for real-time processing*" [17]. Neuralink has built a custom application-specific integrated circuit (ASIC), which consists of amplifiers, on-chip analog-to-digital converters (ADCs), and control circuitry for serializing the digitized outputs [17]. An Ethernet-connected base station converts the data streams, allowing to visualize the data in real time [17].

2.2.4 Electrophysiology. Digitized signals are processed in real time to identify action potentials (spikes). Neuralink uses custom online spike-detection software. The spike detection parameters have to maximize decoding efficacy [17].

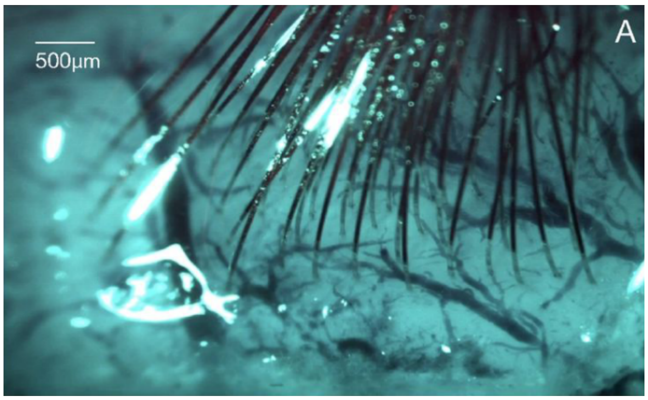

Figure 3: Cortical surface with implanted threads [17]

3 THERAPEUTIC APPLICATIONS

Medical applications are presented, along with a succinct and specific evaluation. We will devote a dedicated, more complete, and more global part to an evaluation in section 5.

3.1 Spinal Cord Injuries

Spinal cord injury is the showcase application of Neuralink. The goal is to help people with spinal cord injury by allowing them to dexterously control a digital mouse and keyboard directly with their brains [17]. Combined with spinal stimulation techniques, it is hoped that this approach could restore motor functions [17]. As mentioned in section 2.1, using BMIs to control a device by thought has been studied since the 1960s [20]. However, Musk's companies benefit from significant fundraising and extensive media coverage.

On the website of Neuralink [18], the latest versions of the project are presented. On figure 4, the link is a sealed and implanted device that processes, stimulates, and transmits neural signals [18]. The Neuralink app (fig. 5) would allow controlling an iOS device, keyboard, and mouse directly with brain activity, just by thinking about it [18].

3.2 Other Applications

Generally, novel therapeutic possibilities are expected with BMIs. We will present some of them here.

3.2.1 Replacement of body parts. Bionic limbs are not new, and the classical approach does not need BMIs. A bionic limb, e.g., an arm, detects small naturally generated signals when the user flexes

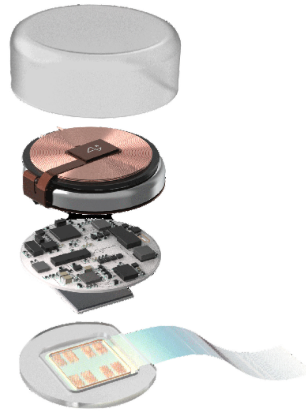

Figure 4: The link [18]

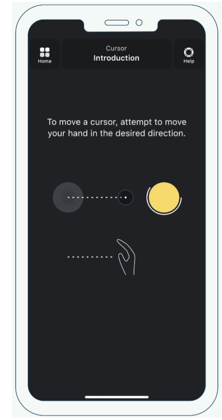

Figure 5: Neuralink app

their residual limb muscles. The bionic limb is then able to convert them into hand movement.

However, BMIs can push this approach a step further and allow to directly use "*the brain to convey our intentions, rather than having an extra, physical step translating those intentions to text, speech, or gestures*" [22]. The interactions can be made easier, faster, and more natural [22].

3.2.2 Epilepsy. BCIs can be used to treat neurological disorders and reveal about brain functions [9]. Karageorgos et al. have presented HALO (Hardware Architecture for LOw-power BCIs), an architecture for implantable BCIs, that allows the treatment of disorders, such as epilepsy [9]. HALO also records/processes data that can be used for a better understanding of the brain [9]. Epilepsy is characterized by epileptic seizures defined by uncontrolled and excessive electrical activity of neurons [27]. Neuronal signals are processed to predict seizures. When an increase in brain excitation occurs, *"the brain needs inhibitory synapses to tone down and regulate the activity of other cells"* [27]. BCIs then electrically stimulate neurons to mitigate the severity of the seizures [9]. However, the time between seizure onset and stimulation must be very short, i.e., tens of milliseconds [9]. Also, low-power hardware is needed for a safe and chronic implantation [9]. HALO is inspired by previous approaches but offers higher bandwidth brain communication in real time at low-power [9]. Noninvasive approaches can also be considered, such as tDCS and TMS [27] (see section 2.1.1).

3.2.3 Parkinson. Parkinson, as well as epilepsy, can be treated by deep brain stimulation (DBS). DBS belongs to invasive BMIs. Surgery is required to implant a thin electrode wire in the part of the brain responsible for abnormal movement [22]. A second surgical intervention is then necessary to implant an impulse generator battery (IPG) in the abdomen or under the collarbone. The IPG can then give electrical impulses to the brain to help control some motor symptoms.

3.2.4 Autism. In recent years, important funding has been allocated to the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) to understand better the origins of cognition and other brain activities. It is hoped that more effective treatments can be found for conditions like autism and mood disorders [22]. With the TMS approach (see section 2.1.1), we were able to show an improvement in social skills in people with autism [23].

3.2.5 Depression. Depression is the most common mental health condition. About one-third of cases of depression are treatment-resistant [23]. BMI therapies are regarded as hope for people that drugs have failed to treat. While drugs could be ineffective because they affect the whole body, BMIs can precisely target relevant regions of the brain [23]. Mental health medications have side-effects, such as weight gain and decreased libido. BMIs can have side-effects as well, but they might be less severe than drugs [23].

3.2.6 Diagnosis of Brain Diseases. In addition, brain diseases that promote dysfunction of the synaptic communication system may be better diagnosed with BMIs [27]. Generally, BMIs can be viewed as alternatives or competing approaches to traditional medicine in specific areas. This trend is expected to intensify in the future.

4 SOCIAL AND COGNITIVE APPLICATIONS

In this section, we address social and cognitive applications. The issues for these applications are more critical than for therapeutic applications. Thus, these issues will be presented in section 5.

4.1 Learning and Enhancement

The brain is a dynamical system that generates spontaneous spatiotemporal patterns even without inputs, movements, or cognitive tasks [10]. For humans, these patterns are called resting state brain activities [10]. The resting state brain activity tells much information about age, mental disorder, and cognitive capability [10]. "*By combining information decoding from brain activity and its neurofeedback in reinforcement learning paradigms, we can unconsciously control brain activity patterns corresponding to specific information*" [10]. This can lead to therapies for psychiatric disorders, but also to increased cognitive abilities [10]. It is expected that this technology will soon be available in much cheaper and lighter devices such as EEG and near infrared spectroscopy [10].

External interfaces are increasingly being used to attempt enhancements of memory and concentration [23]. Headsets using tDCS (see section 2.1.1) could improve memory [23]. Working memory has been improved in older people using a similar technique [23]. US military experiments have suggested that tDCS could sharpen mental skills [23]. tDCS can also enhance physical, as well as mental performance [23]. For example, 20 minutes of exposure to tDCS could improve the peak performance of cyclists [23]. However, other researchers have issued warnings about possible damages to the brain [23].

Studies have shown that brain cognitive functions could be improved through cognitive training interventions, in which learners perform cognitive tasks [25]. However, if the task that the learner is performing is too difficult, motivation and concentration can decrease, resulting in a poor or a lack of improvement in cognitive functions [25]. Taya et al. propose to monitor learners' mental states such as cognitive workload to facilitate and optimize the learning progress [25]. The approach uses objective biomarkers based on spectral properties of EEG signals [25]. To discriminate mental states, extracted features are subjected to mathematical tools based on machine learning [25]. Furthermore, Taya et al. introduced the functional connectome approach, which is based on the graph theory [25]. A connectome is a comprehensive map of neural connections and can be seen as its wiring diagram. The brain connectome approach can provide additional biomarkers for facilitating the learning process. It can be used to understand mechanisms underlying brain cognitive functions, but also to detect mental states [25].

4.2 Alertness Control and Cognitive Load Sharing

Maksimenko et al. could classify the brain activity into two scenarios depending on the degree of attention of the observer, which in turn is affected by the motivation for a task and the task complexity [14]. The two scenarios described different neural oscillations composed of alpha and beta waves. Maksimenko et al. could build a noninvasive BMI to estimate and control the degree of alertness in real time [14]. The device was based on an EEG recorder and a custom developed acquisition software. Controlling the degree of attention was done by a feedback signal using external stimulation. When the subject lost concentration, a sound signal ringed for re-sharpening his attention [14]. Monitoring and controlling human attention and alertness can find essential applications during tasks that require significant attention, such as air traffic control, piloting, and long-distance driving [14].

Also, the cognitive load of a task can be shared among members of a group [13]. In another article, Maksimenko et al. proposed a brain-to-brain interface (BBI) which estimates brain states of the participants and distributes optimally a cognitive load among group members working on a common task, increasing the overall human performance [13]. The workload can be shared among participants depending on their current performance, which is estimated from their electrical brain activity [13]. The BBI uses an EEG recorder and is noninvasive. With human-to-human interaction, it was also found that the subject who initially showed higher degree of alertness, exhibited increased alertness due to the assistance of his/her partner [13]. The efficiency of a team can be increased by giving the most difficult workload on operators who exhibit the best performance [13].

4.3 Reading Thoughts and Emotions

Mind reading has traditionally been linked to science fiction stories. However, the first steps of perceiving thoughts have been taken [11]. Scientists already have the needed mathematical framework, and the only limitations lie in the measurement of brain activity. A study showed that based only on volunteers' brain activity, a computer model was able to produce images of the letters that the volunteers were looking at [11]. Volunteers first looked at handwritten copies of letters, while a functional magnetic resonance imaging (fMRI) machine measured the responses of their brain [11]. Depending on Bayes' Law, patterns of brain activity, and machine learning, the computer model can display an image showing the letter seen by the volunteer [11]. In another experiment, Akbari et al. could reproduce the sounds of numbers listened to by participants, based on their brain activity [1]. In the future, it might be possible to use this type of algorithm to decode thoughts.

Carella et al. have shown that emotions can also be categorized from EEG recordings using the empirical mode decomposition (EMD) method [6]. They observed that emotion detection is possible with an accuracy of over 70%. Zander et al. proposed to fuse cognitive monitoring with BCI technology [30]. Cognitive monitoring uses real-time brain signal decoding for gaining information on the cognitive user state. With the fusion of these technologies, Zander et al. could provide information about the users' intentions, situational interpretations, and emotional states [30]. The study focused on applications for healthy users [30], thus not limiting itself to therapeutic applications.

Generally, the gap between human and machine is narrowing. New systems allow gesture and voice input to create unique and intuitive ways for users to interact with computers [22]. BMIs reduce this gap even further and allow for a glimpse of human-human interaction. Potentially, we could use BMIs to better understand and communicate with each other by clarifying our thoughts and feelings [22].

4.4 Brain Links and Behavior's Control

B. Min explained the approach of using BCIs and low-intensity focused-ultrasound (LIFU) sonication to obtain a brain-to-brain interface (BBI) [16]. The goal is to obtain an interface in which two individual brains communicate by sending signals through computers. A wide range of mental communication can be expected [16].

Yoo et al. could establish functional links between a human's brain and a rat's brain [29]. Transcranial focused ultrasound (FUS) can modulate the neural activity of specific brain regions, playing the role of a stimulating noninvasive CBI. Also, the use of noninvasive BCI techniques, such as EEG acquisition and signal processing, allows to record brain activity and translates it to generate computer commands. A link could be created between two brains by joining these technologies, thus creating a brain-to-brain interface [29]. The implementation could be used to translate the human volunteer's intention to stimulate a rat's brain motor region responsible for tail movement [29]. Thanks to the BBI, the human volunteer was then able to move the rat's tail only by thought. The interface could achieve about 94% accuracy [29].

Rao et al. have presented a direct brain-to-brain interface (BBI) in humans [21]. It was illustrated in a computer game where two humans must cooperate through direct BBI communication. A schematic diagram of the setup can be seen in fig. 6. The goal of the game is to defend a city from enemy rockets by firing a cannon. A friendly airplane also flies across the sky, and should not be shot at. The first user (the sender) sees the game but cannot control the cannon. The second user (the receiver) is located in another building. He does not see the game, but he has a touchpad to fire the cannon. The BBI communication used noninvasive EEG to record the sender's brain signal, and noninvasive TMS for stimulating the receiver's brain. During trials, the sender conveyed the intent to fire the cannon by engaging in right-hand motor imagery [21]. When the receiver's computer received a fire command, a TMS pulse was delivered to the receiver's brain, which caused a movement of the receiver's right hand, and thus operated the touchpad which fired the cannon. Although rudimentary, it provides evidence that information can be transmitted from one human brain to another [21]. This experiment is also a proof of concept to show that a human being can be controlled by another human being.

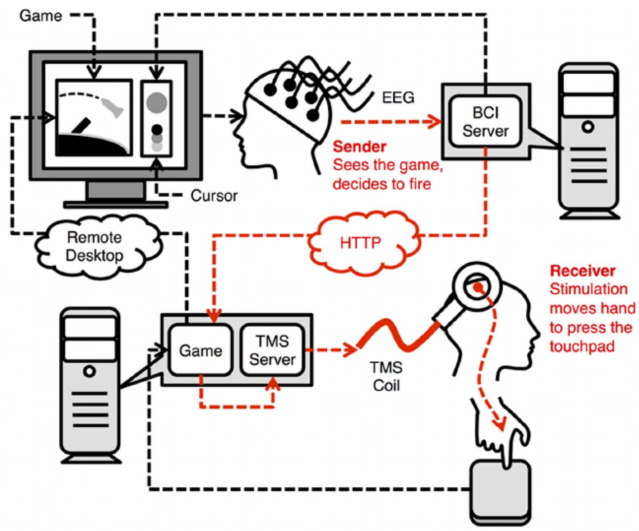

Figure 6: Direct brain-to-brain interface [21]

As explained, mind-to-mind communication remains fictitious for now, but the building blocks have been demonstrated in the laboratory [23].

4.5 Military

With EEG headsets, we can already pilot drones using brain signals only [23]. The Next-Generation Nonsurgical Neurotechnology (N3) program of the US's DARPA aims to develop high-performance and bi-directional BMIs. The main applications are controlling aerial vehicles, cyber defense, or teaming with computers during military missions [23]. Furthermore, as mentioned in section 4.1, noninvasive BMIs such as tDCS could improve mental skills. Military and security applications raise the most significant worries. Enhancing humans mentally and physically could provide some protection but could also be used to organize hostile operations remotely [23]. The following section will explore future possibilities and concerns of BMIs.

5 EVALUATIONS

So far, we have seen state-of-the-art BMI applications, which will allow us to discuss future possibilities. Then, human impacts and ethical issues will be evaluated, as well as transhumanism and its consequences.

5.1 Future Possibilities

BMIs could offer benefits such as better health, better memory, better concentration, and healthier aging. However, they also involve new risks such as thoughts or moods being accessed [23], with a possible drift towards controlling people.

5.1.1 Access to the Brain and Being Controlled. People could become telepathic and be able to communicate without words by accessing thoughts [23]. Beyond thoughts, sensory experiences could be communicated from humans to humans, such as neural postcards, where hearing, seeing, and tasting could be possible. Alternatively, life experiences such as enjoying a meal or taking a parachute jump could be lived virtually and offer sensations as if they were real [23]. More reasonably, it seems possible that we will be able to create pictures of what people are thinking about within the next 20 years [11].

If thoughts could be accessed, companies could use this approach for marketing purposes, and put pop-ups in our heads [23]. Furthermore, George Orwell's thoughtcrime of his dystopian novel *"Nineteen Eighty-Four"* could become a reality, and people could simply be arrested for divergent thinking. Privacy concerns need definitively to be addressed. By accessing thoughts, politicians could recruit people to their causes [23]. In the future, it could be possible that governments will control and manipulate people's behavior not only through mass media but also by directly sending commands or putting ideologies into their brains [20]. Generally, if the human brain can be controlled, it will imply a plethora of consequences. We could imagine that parts of our brain could be deactivated if we have not paid our invoices. We could imagine ransomware applied on a brain, with hackers encrypting the brain and asking for a ransom to decrypt it.

5.1.2 Digital Memory. BMIs will perhaps also offer exciting opportunities to enhance the brain itself. Invasive or noninvasive BMIs could help us remember more and better, learn faster, make better decisions, and solve problems without biases [23]. Instead of hard training, we could simply download a new skill as *Neo* does in the science fiction movie *Matrix*. Neural interfaces could raise educational achievement levels by helping students to learn, remember, and concentrate better [23]. Invasive BMIs could become body parts, as peacemakers are today. Our memory and all its associated knowledge could be securely backed up on digital devices or uploaded to the cloud [23].

5.1.3 Merge our intelligence with AI. Our brain is composed of around 86 billion neurons, and each neuron can make connections without thousands of other neurons via links called synapses [23]. While computers can perform billions of operations per second but are connected to a few neighbors only, the brain's neurons can perform only around 1,000 operations per second, but can communicate with thousands of neighbors [23]. Hence, the comparison between brain and computer is complicated. Additionally, much about the human brain remains unknown, such as the language with which neurons communicate or the brain's propensity to form connections [23].

Today, artificial intelligence (AI) "*is an important technological tool that allows many neural interfaces to function*" [23]. BMIs use AI to convert neural signals into digital data, for example, to interpret instructions from the brain to move a prosthetic arm [23]. In the future, however, a more intricate relationship between BMIs and AI could emerge. As mentioned above, computers and brains are different but can be perceived as complementary. Humans have decision-making capacity and emotional intelligence, while computers are good at processing a considerable number of data quickly. Hence, several technology experts believe that beneficial impacts could arise from linking human and artificial intelligence via BMIs [23]. In general, companies like Neuralink also pursue the goal of linking human brains and AI [23]. Niforatos et al. argue that while sounding like a science fiction scenario, the notion of humans converging with machines not only could be soon a reality, but also a necessity [19]. Niforatos et al. believe "*that the human brain and technology can and should be able to work more closely in tandem for amplifying our cognitive capacities in the era of distractions and information overload*" [19]. Elon Musk said that Neuralink's long-term goal is to achieve "*symbiosis with artificial intelligence*", which is required to compete with an ever more powerful AI, and on which the survival of humanity will depend. Such a form of collaborative intelligence could emerge and bring revolutionary applications, but also raise significant ethical issues [23].

5.2 Human Impacts and Ethical Issues

Talking about the impacts of technology, Paul Virilio said, "*When you invent the ship, you also invent the shipwreck; when you invent the plane you also invent the plane crash; and when you invent electricity, you invent electrocution... Every technology carries its own negativity, which is invented at the same time as technical progress.*" Buruk et al. wrote fictional abstracts about designing children's technologies in the age of transhumanism in 2077 [4]. One of these fictions narrates that, in the year 2065, the Dutch government declared that all new-borns in the Netherlands should undergo a procedure to be equipped with water-breathing implants, due to the impossibility of installing these implants in adults. The fictional paper explores the impacts of this legislation, notably the creation of a new generation of children using the canals of Amsterdam as unsupervised playgrounds [4]. This example shows us that technology always impacts human beings, which seems to be especially true for BMIs, reinforcing the need to consider these issues proactively.

5.2.1 Alter or Loss of Sense of Self. A possible impact of BMIs is the loss of sense of self [24]. For some deaf people, implants can make a vital difference. However, some other people entirely reject the implants, considering deafness to be an identity rather than a disability. They are used to their condition, and sign language provides them with a full and natural communication means [23]. By being augmented, they no longer find themselves [7]. Anita Silvers has considered cochlear implants for deafness as a "tyranny of the normal", designed to adjust deaf people to a world designed by the hearing, assuming the inferiority of deafness [28]. The concept of *self* is challenged: is it us as humans? Or is it the technology [23]? In the end, each human experience is different and has a meaningful value.

5.2.2 Erosion of Skills and Autonomy. If invasive BMIs are making decisions within our bodies, are we still autonomous [23]? By enhancing our bodily functions, we would be replacing them in a way. As our natural bodily functions would no longer be used, we would likely lose our abilities. This would lead to an intimate, dangerous, and significantly increased dependence on technology, reaching the point of no return. We definitively have to ask ourselves if we should be using BMIs to improve the abilities of healthy people [28].

5.2.3 Privacy Issues. BMIs can collect large amounts of physical and neural biodata. In this context, it will be challenging to preserve privacy and control the use of personal data [23]. A portable mind-reading device may not be completely out of reach in the future, and there is a need to establish privacy guidelines now [11]. Generally, people are reluctant to allow systems to understand their intentions, and they do not want their inner thoughts to be read, and revealed [22]. It is also unclear what people believe sensors can reveal, and people rely on existing beliefs about the body to explain what they might disclose [15]. Transparent access to thoughts could modify people's behavior and affect their well-being [23]. *Big Brother's* style of mental surveillance would undoubtedly create psychological harm [23]. Without going so far as to mind-reading, cognitive load's privacy is already an issue. Not only are people unwilling to disclose their cognitive load, but it could also generate significant stress, for example, if their boss knew exactly their current cognitive load for a specific task. Now, as we have seen in section 4.2, cognitive load monitoring and cognitive load sharing between team members is already a reality, strengthening the need for rules now.

5.2.4 Legal Issues. If neural interfaces can intentionally influence individuals' behavior, should they be prescribed by states? [23]. For example, we could imagine that governments would use these technologies to reduce their public health bill by directly influencing people to eat healthier. That power could then be extended in broader contexts, such as sanctions in criminal justice. Conversely, instead of prescribing, some interfaces could be proscribed [23]. We imperatively need to define who should control access to BMIs, for safety reasons. As for privacy issues, regulation and laws will be needed.

5.2.5 Social Issues. The ethical dimensions of the use of BMIs go beyond the contexts of clinical research and patient care, such as economic pressures and regulatory controls associated with commercial availability of BMIs [2]. By having BMIs, more interactions with machines are expected, diminishing social interactions. BMIs will also contribute to widening inequalities, as technology always does, by offering advantages to users who can afford it [23].

5.3 Transhumanism and Philosophical Issues

BMIs challenge the very essence of what it means to be human [12]. As we have seen in section 5.2.1, implants can alter the sense of self. The difference between enhancement and treatment is thin and depends on defining normality and disease [28]. Christopher Boorse "*defines disease as a statistical deviation from species-typical functioning*" [28]. It is questionable whether "enhancement" is an increase or a reduction, or if enhancement is necessary at all. Choices must be made. Another interesting question is whether enhancement can be achieved differently, i.e., without invasive BMIs. For example, we have seen in section 4.1 that cognitive training can improve brain cognitive functions.

Transhumanism is a vision of the world. It sees enhancement as interventions that promote bodily and cognitive characteristics to reach a post-human stage [5], where the human condition itself is transformed. It raises many ethical and philosophical questions, such as the following: How do we want to live as humans? Is such a profound transformation still being human?

Transhumanism could show a productivist view of the human being, instead of a qualitative view of life's experience on earth. However, the debate may not be so trivial when we consider the possibility that *the singularity* could become a reality. The singularity, also known as artificial general intelligence (AGI), can be defined as the point where AI can improve itself faster than humans can. Some argue that AGI will not be realized [8], while AI experts estimate that there is around 50% chance that AGI will occur until 2060 [26]. Personalities such as Stephen Hawking and Elon Musk are also warning about AI. As we have seen in section 5.1.3, Elon Musk and Neuralink advocate BMIs and fusion with AI for the survival of humanity. In its essence, it can be linked to a philosophical question: does consciousness emerge, or is it transcendental?

However, what will the world be like if the AI threat is real, and fusion with the machine becomes a reality? For example, if kids can download school subjects in seconds, instead of slowly learning them over the years, what will childhood be like? Will the time saved be used to enjoy life or to acquire more and more skills? How about social relationships and early friendships built at school? The potential change is so massive that no one can predict with certainty what the outcome would be.

5.3.1 Transhumanism through Spiral Dynamics. Here, we will present transhumanism through the various levels of the model *Spiral Dynamics* [3]. At each level, symbolized by a color, we will show how transhumanism could be used by the system and how it could help foster the characteristics of a level. At *Beige*, transhumanism could be seen as an individual survival tool, against other organisms or against technology itself. At *Purple*, transhumanism could enable a better connection between people through brain-to-brain interfaces, and a better harmony with nature. At *Red*, transhumanism could be used as a domination tool, where people would try to get the best BMIs to dominate others. At *Blue*, transhumanism would be used to reduce people to specific tasks and strengthen the hierarchical structure. At *Orange*, BMIs would be used to reach the top of the hierarchy, thus increasing competition between individuals. At the bottom of the hierarchy, we would equip people with BMIs to increase their productivity. At *Green*, BBIs would allow to understand all languages and cultures, and experiment with full empathy by feeling what others are feeling. With transhumanism, humans would be connected, which would allow for global consciousness and unity. At *Yellow*, transhumanism would make it possible to understand the differences between individuals and integrate all potentials and skills. At *Turquoise*, transhumanism would be used to make people equal both physically and cognitively. At *Coral*, with increased awareness, acceptance, and freedom, would we even need transhumanism? Or would we simply prefer to live without it?

Now suppose that our society currently lies at *Orange*, where the quality of life is not a priority, and efficiency rules the world. This desire for efficiency could fully justify the race for transhumanism. Since transhumanism is irreversible, we would seal the world at *Orange* and stop the evolution of humanity, limiting it to efficiency and competition.

This model is interesting to show that the reasons and uses of transhumanism can be radically different, depending on society's core values. Thus, there is an urgent need to consider the issues of transhumanism globally.

6 CONCLUSION

In summary, this paper first introduced brain-machine interfaces (BMIs), Neuralink, and its technology to produce invasive BMIs. Currently, BMIs mainly have therapeutic applications, such as helping people with spinal cord injury by allowing them to control a computer directly with their brain. Other therapeutic applications include epilepsy, Parkinson's disease, and autism. BMIs also have social and cognitive applications, such as learning, enhancement, behavior control, and reading thoughts. Another objective of this work was to present an evaluation, showing the future possibilities of BMIs, such as brain control, and the fusion of our intelligence with AI. The resulting human impacts and ethical issues were presented, such as loss of sense of self, erosion of skills, and other issues. Finally, this paper explored transhumanism, its potential necessity with the advent of artificial general intelligence, as well as its different reasons for being.

Concerning open issues, BMIs are still in their infancy stage of development, and, therefore, it is still difficult to predict exactly where they are going. Future research should consider more carefully the potential effects of BMIs, particularly the human impacts of current and future BMIs. We have shown that BMI research could generate drastic changes with no possible return, thus reinforcing the need to urgently address these critical issues.

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