Brain-Computer Interfaces: The Technology of Our Future

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Abstract

A Brain-Computer Interface (BCI) is a promising technology that has received increased attention in recent years. BCIs create a direct link from your brain to a computer. This technology has applications to many industries and sectors of our life. BCIs redefine how we approach medical treatment and communication for individuals with various conditions or injuries. BCIs also have applications in entertainment, specifically video games and VR. From being able to control a prosthetic limb with your mind, to being able to play a video game with your mind—the potential of BCIs are endless. However, as with any new innovative technology, ethical concerns are raised.

Keywords: Brain-Computer Interfaces; BCI; Brain-Computer Interaction; Technology Ethics; Cognitive Enhancement; Prosthetics

INTRODUCTION

A Brain-Computer Interface (BCI) is a promising technology that can send and receive signals from the brain while translating these signals into commands readily interpreted by an output device. BCIs create a direct link from our brain to a computer, opening up a new realm of possibilities for future advancement. The advancements in brain-machine interfaces and neural engineering technologies represent transformative tools that will come to shape our future. One day, we will not need to manually enter input to our devices via our hands or other peripherals. With this technology, we will link to our devices where input is fed directly to the device with little to no need for manual and direct interaction. We will also be able to control the machines around us using our thoughts and walk around with augmented body parts as though they were a part of our body. When we wake up in the morning, we will be able to turn off our alarm, play a song on Alexa, and turn on the coffee maker, all with our thoughts.

BCIs carry revolutionary implications for populations suffering from neurodegenerative diseases and neuromuscular injuries. A woman with paralysis named Cathy drank coffee through a straw on her own for the first time in 15 years by directing a robotic arm with her thoughts (Ehrenberg, 2012). Through BCIs, people can successfully move robotic limbs with their thoughts while receiving sensory feedback in the process to complete tasks and other functions. It is also possible to augment intelligence, memories, and other features. Abilities previously regarded as impossible are now in the realm of possibility. Despite these exciting prospects, there are still significant ethical concerns attached to this innovative technology. Will a person's thoughts and memories be accessible to anyone else? If so, how can we safeguard this sensitive data from possible hackers or even companies seeking our data for advertising? Additionally, will our identities become further complicated by our new relationship with technology (Klein et al., 2015). Expanding research and development of BCIs will reveal the role they play in our future as efforts toward safety and availability are made.

EVOLUTION OF BRAIN COMPUTER INTERFACES

The BCI was first proposed around the 1970s when a patient was able to move a cursor on a screen with their mind. Since then, an exploration into BCI applications progressed in other fields and industries. Apart from medicine, BCI research has expanded more into the realms of entertainment and education. In video games, BCIs increase player immersion by giving the player the ability to control their character with their thoughts (see Figure 1). In education, we will see BCI technology grant us the ability to download knowledge or transfer memories from one another.

Figure 1. Early Brain-Computer Interface Gaming. Source: https://www.emotiv.com/bci-guide/

A big turning point for early BCIs was the discovery that EEGs could allow a user to control a cursor on their screen by thinking alone (Li, 2020). EEGs are the signal acquisition technology that non-invasive BCIs primarily utilize to monitor the brain's function. Non-invasive

BCIs, due to their consumer-friendly and low-risk nature, received more research attention from laboratories. On the other hand, research is still being conducted for invasive BCI technologies due to their precise accuracy. One type of BCI might serve to function better depending on the purposes of its use.

Early invasive BCI research consisted of electrodes implanted into a monkey's brain and other animals to give them the ability to control things on a computer screen (Li, 2020). One of the first breakthroughs of this technology happened in 1998 by scientists who placed a glass electrode on the brain of a 57-year-old who became paralyzed after a stroke. By reading signals from the man's brain, the electrode allowed the man to move a cursor on a computer screen with his thoughts (Kaku, 2012, p. 59). More recently, big strides are being made with invasive BCIs under Elon Musk's new company, Neuralink. Another leading invasive BCI implant company and competitor to Neuralink, Synchron, received FDA approval in 2020 and is cleared to work with human participants. As a result of current innovations, many people are now discussing the implications of such a technology and what it could mean for our privacy and security. As these technologies progress, the impact they will have is still up in the air. Only time can tell what impact such a technology will have when everyone has a chip wired into their brain connecting them to the internet.

NON-INVASIVE BRAIN COMPUTER INTERFACES

Non-invasive technologies receive more focus from researchers across the world due to their low cost and low-risk nature, making it easier for them to receive recognition from government health institutions and receive research funding. There is little risk when utilizing and applying them; however, there is a loss of accuracy when looking at the activity of single neurons. Additionally, there can be noise when analyzing the brain signals externally. Therefore, the application of non-invasive BCIs are still limited compared to invasive EEGs, which are more accurate. Non-invasive BCIs use signal acquisition techniques such as EEGs. EEG headsets can turn data from the brain into commands that are readable by a computer. Companies such as EMOTIV and NeuroSky produce wearable EEG technology at the consumer level (see Figure 2). They advertise these devices to promote health, education, and recreational use. Alternatively, TMS, or transcranial magnetic stimulation, can non-invasively deliver information into the brain (Jiang et al., 2019). TMS stimulates the brain by applying magnetic fields to certain parts of the brain; combined with EEGs, the areas of application for this form of BCI are endless. TMS is already being researched to treat depression, as there are no harmful side effects associated with the stimulation (Stern, 2018).

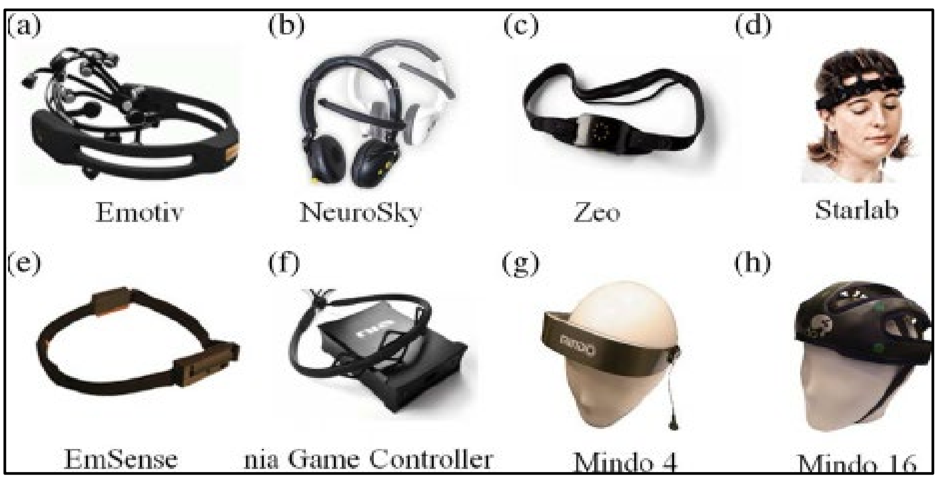

Figure 2. Wearable EEG devices. Source: https://www.researchgate.net/figure/Wearable-EEG-devices-a-Emotiv-b-NeuroSky-c-Zeo_fig3_236894398

There are two types of non-invasive BCIs, one based on motion perception and the other on event-related potential (ERP). ERPs have multiple sensory types, such as visual and auditory (Li, 2020). Motion non-invasive BCIs require a participant to imagine performing a motion while an EEG records their brain signal, which then results in the targeted object moving in the way the participant perceived.

INVASIVE BRAIN COMPUTER INTERFACES

Invasive BCI technologies are far more precise than non-invasive ones. The directness of invasive BCIs allows for a precise spatial resolution that simply cannot be achieved by peering into the brain via its signals from a distance. Invasive approaches to BCI technologies include placing electrodes or computer chips directly on one's brain where they are then connected to a computer or a mechanical limb. Ray Kurzweil is a world-leading inventor and futurist known for his technologically sophisticated predictions of the future. Kurzweil predicts computers to be as small as blood cells, foregoing the need for surgery when directly applying them to neurons (Kurzweil, 2011). There are also some compelling disadvantages with invasive means of BCIs– that is, as of now, it is difficult to apply them and there is an inherent risk when performing the procedure to implant them. Invasive BCIs are also more costly than non-invasive ones. Therefore, it will be a long process to gain future support from official institutions to increase the accessibility of this technology to the public and for active medical use. However, we are one step closer with the company Synchron, receiving FDA approval for its implantable BCI device and soon to follow will be Neuralink.

BIDIRECTIONAL BRAIN COMPUTER INTERFACES

A new approach to invasive BCIs are bidirectional BCIs, which can grant the user sensory feedback. Bidirectional refers to the information going both ways between the signals from the participant's brain to the computer. When a participant touches something with a mechanical limb for example, the feeling of touching that object is sent back via electric signals to the brain that stimulate the somatosensory cortex, which accounts for the participants' brain area that processes sensory information. This is seen most prominently in topics revolving around limb rehabilitation–the ability to feel artificial limbs makes controlling them feel natural. In the future, we may be able to feel objects and surfaces in our Virtual Reality surroundings as we transverse through the environment using our thoughts.

MOTOR AND MOOD DISORDERS

Already, it is becoming increasingly common for brain implants to be used in treating motor and mood disorders (Lipsman & Glannon, 2013). Such is the case with Deep Brain Stimulation (DBS) technology. DBS can modify brain function; specifically, it can replace abnormal electrical signals in the brain with pre-programmed ones. As a result, mood and behavior can change–whether intentional or an unintended consequence of a DBS surgery. This raises questions about the nature of identity and what the impact of being able to deliberately alter one's thoughts and behaviors will have on one's sense of self. In most cases, the patient is not aware of their behavioral change, or they misinterpret the change to be a positive one.

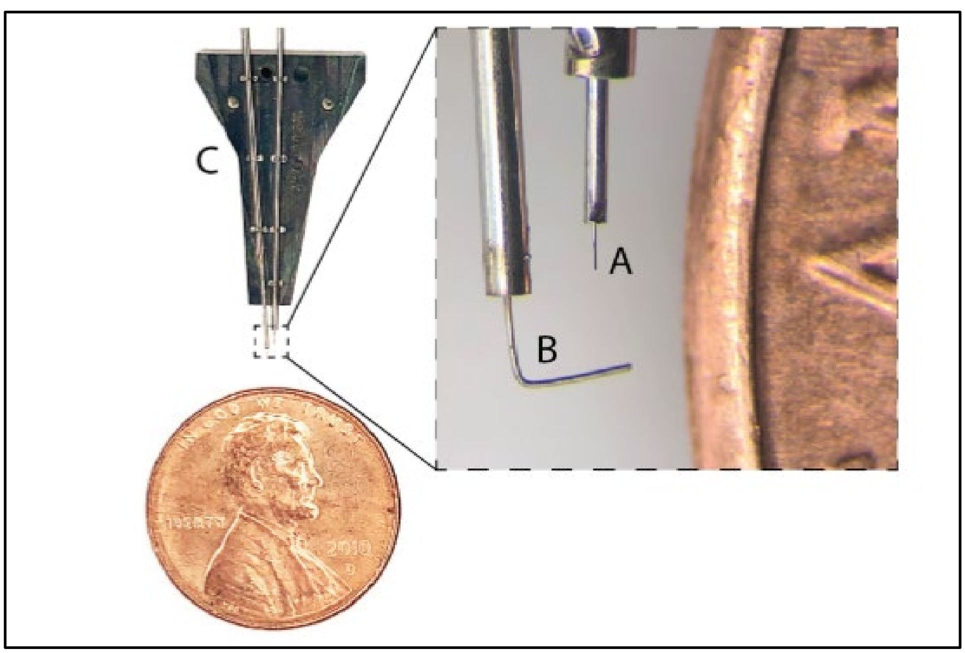

Figure 3. Scale of needle pincher cartridge compared to a penny. Source:

https://doi.org/10.1101/703801

LEADING COMPANIES

In 2017, Elon Musk announced Neuralink–a company aimed at innovating the use of BCIs to connect humans with computers. Neuralink has taken its first steps in developing a high-bandwidth BCI system that takes an invasive approach. The procedure for the device can be done by a robot with precision and efficiency, creating an incision no larger than 8-millimeters (see Figure 3). The scale needle pincher cartridge (NPC) is part of an inserter head on the robotic electrode inserter. The needle (Figure. 3A), is 40 micrometers in diameter, and the pincher (Figure. 3B), is 50 micrometers. The NPC (Figure. 3C) is the inserter head that contacts the brain tissue during the procedure (Musk & Neuralink, 2019, p. 3-4). The early attention received by Neuralink continues to raise unprecedented questions about the impact this technology will have on us in the future. Another leading company and rival to Neuralink is Synchron–the first BCI company to receive FDA approval for IDE clinical trials with human participants (Synchron, 2021). In one of Synchron's latest studies, BCI implants were used to improve motor function in two participants with upper limb paralysis caused by amyotrophic lateral sclerosis (ALS). Eye-tracking was also used in the minimally invasive implant (Oxley et al., 2021). Neuralink and Synchron both contribute to a future that BCI technology benefits. With Sychron's human clinical trials now underway for the first time, it will not be long before others soon follow. This will lead to rapid developments in BCI tech with exciting prospects to come. With different technology companies developing these devices, the matter of safety will become the single factor that determines success. We see this already with Synchron taking the lead given FDA approval–as their devices are less invasive compared to Neuralink.

HEALTH AND REHABILITATION

BCI technology has major implications for people with rare conditions that make them unable to move, such as amputated limbs or spinal cord injuries. In the future, this technology will impact more than just a small percentage of people with these conditions. By constantly monitoring brain patterns, BCIs have the potential to redefine current medical treatments and detect signs of many deadly diseases early on. Following the detection of an abnormality, the internal or external BCI could warn the user and give them information regarding the abnormality detected–in which case, the user could seek out medical treatment immediately. In critical situations, an ambulance could be alerted immediately in response to a user falling unconscious, bleeding out, or having a stroke. Eventually, these technologies will be able to correct certain brain signals on their own–without our intervention.

MEDICAL TREATMENT

BCIs are redefining current medical treatments and opening new pathways for their clinical application. This can make medical care more accessible and efficient by drastically reducing the number of doctor visits a person might make on average. In those with a chip implant, their medical condition can be monitored constantly and accessed for any warning signs that may lead to a stroke or seizure. Sleep patterns can also be monitored. Life threatening conditions, such as sleep apnea, can be detected earlier to prevent long-term health consequences.

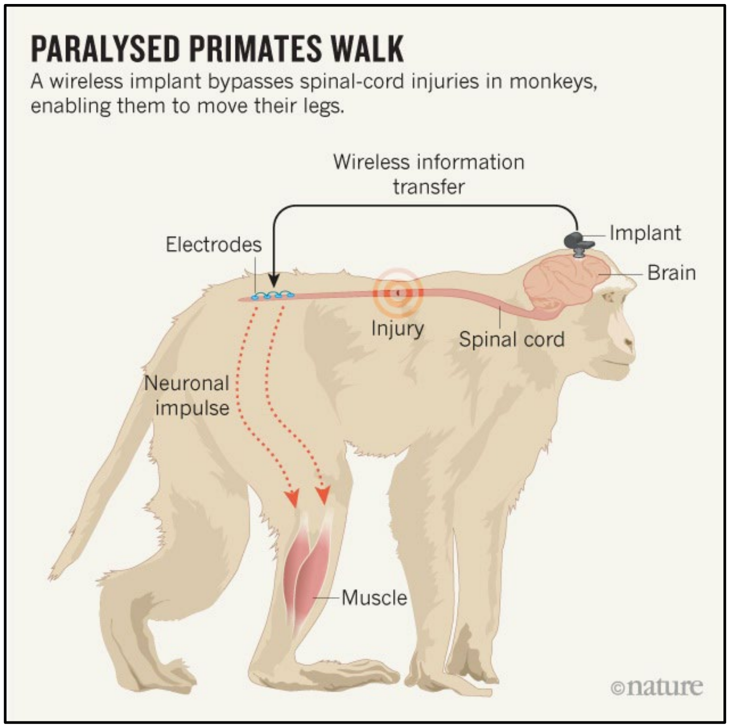

Figure 4. Brain Implant Correcting Spinal Cord Injury in Monkeys. Source:

www.nature.com/news/brain-implants-allow-paralysed-monkeys-to-walk-1.20967.

One of the most promising medical applications of BCIs implants is their ability to correct paralysis. A spinal injury that left a previously paralyzed monkey was corrected by a wireless chip implanted in the monkey's brain. The implant recreates brain signals which then stimulate electrodes in the monkey's leg–as a result, the muscles in the monkey's leg are mobilized (Cyranoski, 2016). Because the implant is wireless, information is transferred to bypass the spinal cord injury (see Figure 4). Synchron is a leading company currently conducting research on human participants with paralysis. It looks hopeful that this technology will allow us to grant mobility to paralyzed patients in the near future.

PROSTHETICS

BCIs have proven to be a promising tool for limb rehabilitation. In 2006, the Defense Advanced Research Project Agency's (DARPA) Revolutionizing Prosthetics program funded two research teams to create more advanced mechanical arm options for wounded warriors (Emondi). This led to the advancement of early mechanical arms and revealed BCIs to be a promising rehabilitation tool. Patients with amputated or paralyzed limbs can imagine moving their arm, and the signal acquisition device would record their brain activity (see Figure 5). The signal would then be processed and decoded by a computer to translate into control commands for the robotic limb. The signals are decoded based on an initial calibration stage that records the activity of the brain while imagining certain movements. The computer will then recognize the movement when it is reimagined by the patient (Lopez-Larraz et al., 2018).

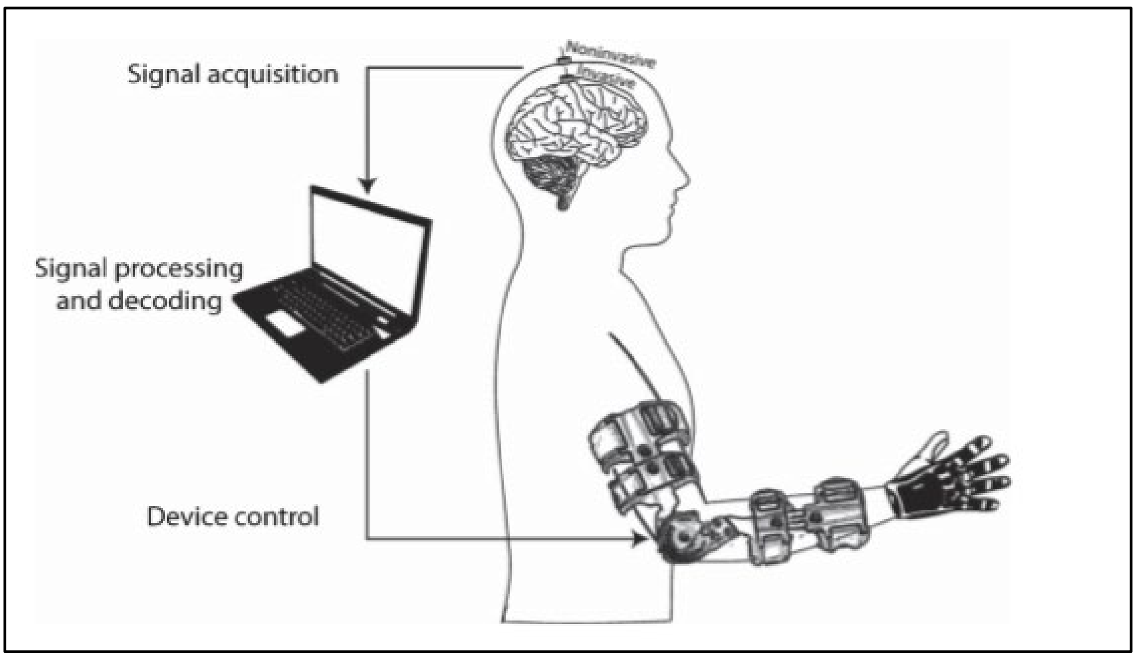

Figure 5. Standard Brain-Computer Interface for limb rehabilitation

The sense of touch can also be simulated through the robotic limb. A group of researchers at the University of Chicago led by Robert Gaunt, an assistant professor in the Department of

Physical Medicine and Rehabilitation at the University of Pittsburgh, created the innovative BCI that was implanted in 28-year-old Nathan Copeland in 2014 (Wood, 2016) (see Figure 6). Copeland was paralyzed from the chest down as a result of a car accident in 2004. This BCI allowed him to control a robotic limb that allowed him to play video games via brain implants and allowed him to eat a taco on his own for the first time. Copeland was the first one to receive sensory signals from his robotic arm which enabled a sense of touch (Mabe, 2017).

Figure 6. Image of Nathan Copeland Source:

https://www.theatlantic.com/science/archive/2017/04/mind-controlled-robot-arm/522315/

COMMUNICATION

Another popular application of BCI is to give a voice to those who lost the ability to speak by converting thoughts into speech. Research in the past has shown that distinct brain patterns are produced when we speak or listen to someone speak. The next generation of speech

BCI systems are beginning to emerge. Speech synthesizers and AI are used to detect and translate these brain patterns into understandable speech (Glenny, 2020). We see this technology used in AI systems such as Siri, which respond to user voice input. Researchers from Columbia University have built a system that turns thoughts into dialogue using a deep neural network. The goal was to create a direct communication pathway to the brain that would produce speech based on the brain patterns of the person who was imagining speaking (Akbari et al., 2019). This technology is promising to those with communication disabilities caused by rare conditions or accidents. This could also help recovering patients who suffer from temporary speech impairments. For example, BCIs devices are being studied to help ALS patients communicate effectively. Stephen Hawking relied on forms of communication that utilized his finger and later cheek muscles to select words he wanted to use. This slower form of communication can be improved to help ALS patients communicate quicker in real-time.

THE FUTURE: COGNITIVE ENHANCEMENT

BCIs provide many possibilities for human enhancement in the future–from being able to download knowledge, alter response times, record dreams, and read minds. These applications, while they may have years to come, are still in the scope of what can be accomplished with this technology.

AUGMENTED INTELLIGENCE

In the future, BCI technology will allow us to access our minds similar to how we access the file explorer on our computers. We can add, move, and delete data completely of our own volition–giving us the ability to install knowledge directly into our brains. If it is possible to skip the learning curve by augmenting intelligence and memory, this will impose a major change in the structure of learning institutions. The way in which information is exchanged will be entirely redefined. Additionally, response times and other brain patterns can be augmented to enhance our behavior and thinking processes.

MIND READING

Brain-to-brain interfaces are an emerging line of research that could grant us telepathic abilities in the future. The ability to share motor and sensory information with brain-to-brain interfaces is possible. Miguel Nicolelis, a neuroscientist from Duke University, led a research team that allowed rats to communicate through brain chips. The brain activity of one rat was recorded and translated into electrical pulses sent to the other rat which would push a certain lever in response to the electrical pulses stimulated in its brain (Rojahn, 2020). As Nicolelis states, "If you put brains together, you could create a more powerful non-Turing machine, an organic computer that computes by experience, by heuristic, that could be a very interesting architecture to explore." (Rojahn, 2020) This will help create a new way of computing and advance future AI systems.

When giving participants various stimulus categories, such as faces, houses, and other objects, researchers were able to classify which category a participant viewed with 96% accuracy by seeing the patient's brain images (Farah & Wolpe, 2004). The brain activation in subjects who lied versus ones who told the truth were distinguishably different in terms of brain images from fMRIs (Farah & Wolpe, 2004). Therefore, brain imaging can become a more accurate method of lie detection. In the future, thoughts may be readable by a computer or individual when portable brain imaging devices become a reality. Similar to how the Vulcan mind-meld works in Star Trek; minds could be connected, and two individuals could share consciousnesses. As a result, advancements in brain imaging will affect the way we exchange information.

VIDEO GAMES AND ENTERTAINMENT

Toy companies have been early adopters of EEG technology to advertise games which allow you to move objects with your mind. In 2009, NeuroSky used an EEG headband which allowed the wearer to move a foam ball through an obstacle course by controlling air streams via brain signals picked up by the headband (NeuroSky, 2004). The use of BCIs in the video game industry can revolutionize user engagement and experience. As portrayed in one episode of the TV series, *Black Mirror*, adaptive gameplay is a likely application of BCIs in this industry. For example, horror games with adaptive gameplay could read into your deepest memories and fears to create a gameplay experience tailored toward you. Combined with advancements in VR technology, user engagement in video games will be at an unprecedented revolutionary stage. Which will then pave the way for artificial worlds to popularize, similar to Second Life–a massive online virtual network where people can interact. With BCIs able to grant sensory feedback and the ability to read your thoughts, it would be possible to receive sensory feeling from the things you interact with in VR and be able to move through the virtual space without the need for a controller. Already, it is possible to play Tetris with your thoughts. BCIs would eliminate the need for a third-party peripheral device to input your intentions. If you want to walk forward in a game or access a menu, you will simply think it.

ETHICAL ISSUES

Once we begin merging technology into ourselves, the impossible starts to appear seemingly more possible. Considering the endless possibilities of these technologies, some unanswered questions and concerns may arise around data privacy, security, equity of access, identity, and legal implications. Will thoughts and memories be accessible to others in any capacity–how might we safeguard this from those with malicious intent? Will invasive advertising be permitted within this technology? Or should valuable data from this technology–

that is our brain activity–be legally sold between companies, similar to social media and website data. How can we protect users of these devices and their data? Once brain imaging systems become more accurate, extracting one's thoughts will become easier and could likely be done by a computer. But even with the high accuracy of such a technology, there are still concerns about ethics, human rights, and privacy. Is it ethical to use memories for or against someone in court–or is this a violation of privacy? Other ethical concerns are still pending for future progress, while others may be dissolved over time through the advancement of BCIs.

SAFETY AND ETHICAL TESTING

One of the main concerns with invasive BCIs are the high risks associated with implanting this technology directly into the brain. While invasive approaches have many benefits, the implantation of a device into the brain has left many people skeptical of the procedure. To be an early adopter of this technology comes with many risks. As of now, only people with rare conditions are utilizing invasive BCI technology and undergoing its early testing. More is at stake with this approach; therefore, it will take many years of refining BCI devices along with approval from health institutions before they are at the consumer or medical grade.

Figure 7. A rat with a brain-signal recording implant. Source: https://www.technologyreview.com/2013/02/28/16532/rats-communicate-through-brain-chips/.

On the other hand, testing this technology still raises ethical concerns. With any new drug, vaccine, or technology, early testing is often conducted on animals to assess safety and effectiveness. Within invasive BCI research, the procedure for brain implants is first tested on monkeys or mice (see Figure 7). While the animals do not feel the pain during their surgery or procedure, many people are skeptical of animal testing given the cases of mistreatment toward the animals. With human test subjects now ready for implants–notably under Synchron–these animal trials have contributed to the success and safety of human participant trials that are ongoing today.

PRIVACY AND SECURITY

Today it is easier than expected to hack cars, voting machines, home devices, or even power plants (Rainie & Anderson, 2019). With the rise of BCI technology, hacking into someone's brain will become a future security and privacy concern. More is at stake with the security of neurological devices than computer systems alone. For example, users who rely on implants to control prosthetics implemented with wireless technology, face a risk of being hacked, having these devices controlled against their will (Klein et al. 2015). With invasive BCI technologies, personality traits, preferences, moral attitudes, and specific thoughts can all be deduced by brain imaging alone. However, brain imaging has not yet reached the point where it can deliver reliable enough information to pose a threat to one's privacy. However, brain imaging is believed to one day become portable as opposed to requiring an entire room (Kaku, 2012, p. 68). As a result, private information that was previously obtained in a lab by looking at brain images would then be accessible to others with a portable device. While this area advances, the idea of mind-reading will become more plausible–and with it a plethora of ethical dilemmas. For non-invasive BCIs, since most utilize EEG, specific areas of the brain where brain activation occurred cannot be pinpointed–due to EEGs lack of spatial resolution. This makes them less decipherable for personal information at this stage.

How BCI data should be treated raises further questions. For example, should BCI data be treated as medical or commercial data? (Emotiv, 2022). Additionally, companies could access this information to create ads tailored to their findings within your data without your awareness. People are skeptical enough of their mobile devices picking up on conversations or the sharing of their personal data among websites. Companies having access to your brain's data is more of an intrusion on one's privacy and has serious implications with the handling of our data. As we tread further into the future, we may have the capacity to record our experiences. The possibility of someone maliciously getting a hold of our experiences without our knowledge is something to be cautious of going forward.

PERSONAL IDENTITY

The new relationship with this technology causes our identities to become further complicated. Neural devices will soon become a part of us, in terms of our social identity as well as how we subconsciously view ourselves. Already we extend our bodies using tools through embodied cognition (Spivey, 2020, p. 133-136). For example, when a blind person uses a cane to walk, the cane temporarily becomes part of that person and their receptive field. And in most cases, smartphones act as an “extended mind”, granting us readily accessible information. With the introduction of BCIs, our conception of body schema will change with positive and negative implications (Klein et al. 2015). In the case of BCIs used for mood regulation, what does it mean to be yourself if what is considered to be abnormal brain signals are replaced with “pre-programmed” ones? A “normal” state must first be defined to correct what is to be considered abnormal signals (Lipsman & Glannon, 2012).

EQUITABLE ACCESS

While in its early stages, this technology is inevitably going to be expensive and less accessible to the public, particularly with invasive BCIs. The cost for initial BCI implantation estimates to be at least $5,000-$10,000, not including continued technical support of the device (Shih et al. 2012). On the other hand, non-invasive devices would be significantly cheaper since they do not require a procedure or as many resources. Current users of BCI technology have special circumstances that require specialized solutions that utilize BCIs. There is also the threat of those with different socioeconomic backgrounds having an unfair advantage with this technology and consequently widening the social gap.

Proper distribution and economic evolution of these technologies will thus be crucial to the positive impact and success of these technologies. On a similar note, due to these risks, there are many legalities this technology must go through before being considered for typical consumer use.

POTENTIAL SOLUTIONS

Many problems with BCIs can be solved by further research, regulations, and through other evolving technologies. Future advancements in encryption systems may answer some security concerns regarding BCIs. Technology is rapidly innovating, and other clever innovations in data security will certainly come forth. Due to the complexity involved in engineering the brain, some people believe there are unintended consequences involved. However, futurists such as Michio Kaku and Ray Kurzweil believe that through the exponential growth we see in technology and science, the complexity of this task will not matter long term. Additionally, the ethical concerns attached to such a technology will gradually diminish as it becomes more understood and thoroughly tested. The way we apply this technology will also become safer. With today's invasive research, we are currently placing small needles into the scalp to implant electrodes in the brain. In the future, we might utilize nanobots in the bloodstream to monitor the brain and send signals. The process of getting a BCI implant may be no different from getting a small shot during a doctor's visit. Overall, the procedure will become less daunting to prospective users of BCI technology and will set the stage for consumer and medical grade BCIs. There have also been significant strides in non-invasive BCI research. Researchers from Carnegie Mellon University have made great progress in the field of robotic device control via non-invasive BCIs, developing the first non-invasive mind-controlled robotic arm. Bin He, Trustee Professor at Carnegie Mellon University, believes that non-invasive BCIs are the ultimate goal leading to the development of non-invasive BCIs in neurorobotics (Durham, 2019).

ETHICAL TESTING OVER TIME

Ethical testing, however, remains a current concern–specifically with the invasive implant procedures. In most cases, the procedure for these implants is very quick, with incisions no larger than 8-millimeters (see Figure 3). For example, the Neuralink device can be implanted painlessly with a procedure done by a robot (Dadia & Greenbaum, 2019). The device at Synchron is even less invasive than Neuralink and has been approved for clinical IDE testing. Currently, most research regarding this technology has been done on animals or users with rare conditions. However, animal testing alone can be a controversial topic for some. In some cases, BCI animal research seeks to improve the quality of life of an animal by correcting paralysis or other disabling conditions. Further regulations would ensure that animal testing remains ethical. For example, the Animal Welfare Act ensures humane handling, treatment, and care for animals in research (National Research Council). However, as technology becomes more complex, and contemporary research methods and procedures are introduced, regulations will need to be amended to accommodate. As this technology evolves, the testing conditions will become safer and ideally less invasive.

ROBOT CONTROL

BCIs can also bring about a solution to concerns raised with other technologies. Since we can control a mechanical limb with this technology, it is not outside the realm of possibility that we might be able to control other complex machines with our thoughts in the future. For instance, a robot controlled by your thoughts rather than a deep learning AI system, will act as an empty vessel which you can use to carry out functions. In this case, we need not worry about robots gaining consciousness–as we would be if we placed our ‘consciousness’ in the robot temporarily to carry out a purpose. More practical applications could include emergency response robots that are controlled via non-invasive BCI. Eliminating peripheral controls as well as AI provides responders with multiple options for emergencies and simulates the presence of the responder. Controlling a robot with your brain in real-time can prove to be effective and save lives.

PRIVACY AND DATA SECURITY

The implications that arise once BCIs become part of the user are another major ethical concern regarding this device. With current encryption technologies, the safety of users' data on websites can be assured under cryptosystems such as RSA–which work through computational complexity caused by inverse mathematical operation. However, when quantum computers become a reality, encryption will need to advance to accommodate the abilities of these powerful computers. To ensure data privacy, it is crucial for the companies pioneering these technologies to maintain transparency and trust with their consumers. This can be safeguarded by laws protecting consumers. Just as the food industry in the U.S. was once regulated as a result of negative media attention, this industry will take time to become regulated as it gradually evolves to meet the demands and concerns of consumers.

CONCLUSION

Brain-Computer Interfaces generate excitement for their many possibilities within numerous industries. BCIs can revolutionize our approach to medical treatment, increase user engagement with digital media, grant us enhanced cognitive capabilities, and redefine information exchange as a versatile medium for many applications. BCIs will directly link us with technology and the internet, revolutionizing the way we approach current problems. The way we interact with technology and the world around us will also begin to change. This future can only come about if advancements are made to the hardware and application of BCIs.

Promising steps have already been taken to create more reliable non-invasive BCIs and safer procedures for invasive BCIs. Technology that was previously considered science fiction is possible with BCIs. Today, our collective accomplishments have surpassed the imaginations of those before us. Already, disabled people are benefiting from this technology and in the future, we can expect it to benefit the public.

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