Bridging Minds and Machines: Exploring the Capabilities of Brain-Computer Interfaces

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An Informal Survey

***Abstract*—Brain-Computer Interfaces (BCIs) are an emerging technology with the potential to fundamentally change our daily lives. This paper explores the background behind BCIs, including how they came to be, and how they work. Additionally, this paper examines current applications of BCIs, primarily in research, and covers the many ways they will impact our lives, following further much-needed research, discussing the many fields BCIs can influence such as medicine/healthcare, communication, and entertainment. Furthermore, this paper introduces theoretical future applications to highlight the potential BCIs have to enhance human capabilities. Finally, this paper will offer a discussion of the ethical challenges and societal ramifications that will emerge alongside this new technology as BCIs become intertwined with our daily lives in the same way smartphones have over the past couple of decades. In offering this discussion of the challenges and complexities of introducing BCIs into society, this paper aims to spark further conversation on the responsible development and deployment of BCIs.**

***Index Terms*—BCI, Brain-Computer Interface, EEG, Electroencephalography, BCI Technology, Hardware, Software, Software Engineering, Biomedical Engineering, Computer Science**

NOMENCLATURE

BCI	Brain-Computer Interface.
ECoG	Electrocorticography.
EEG	Electroencephalography.
fMRI	Functional Magnetic Resonance Imaging.
fNIRS	Functional Near-Infrared Spectroscopy.
fUS	Functional Ultrasound.

I. INTRODUCTION

CONSIDER your friends, your family, and every person you've ever met in your entire life; how many of them wear glasses or contacts? Vision problems affect at least 2.2 billion people globally, [1] yet having to wear glasses or contacts has become so common in our world that it has stopped being an issue of curing or solving this issue but instead finding ways around it, a 'band-aid' fix so to speak. A temporary and fragile solution like glasses or contacts is not sustainable and in most cases, due to this fragile and disposable nature, is not affordable either.

Contacts are completely disposable and, depending on many factors, can cost between $250 and $960 annually not including added costs like saline solution and protective cases. [2] Glasses, on the other hand, are not disposable like contacts but are incredibly fragile and, depending on the type of lens and frame, can cost around $200 up to over $1,000. [3]

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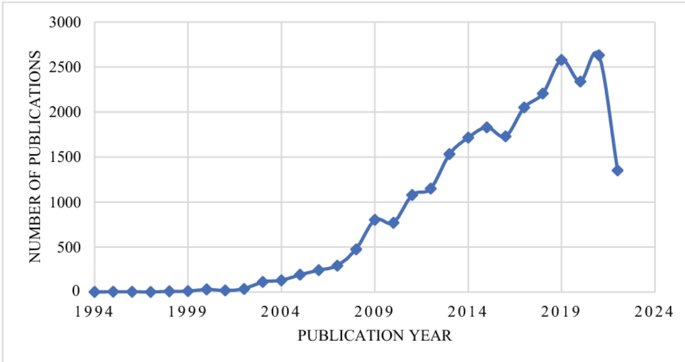
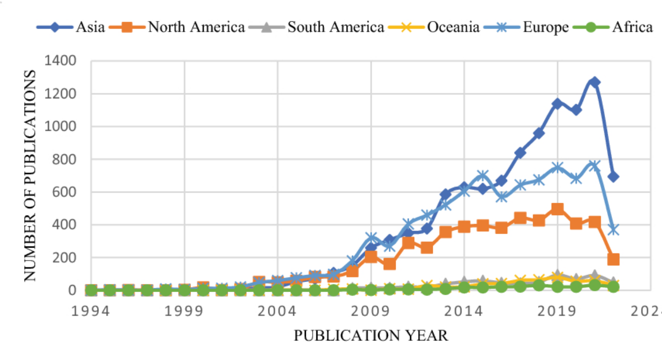
As far as assistive technology, one current simple, yet bulky and expensive, solution is to use some current AR devices such as the *Meta Quest 3* or the *Apple Vision Pro* which have already been cited to drastically improve vision in at least one legally blind individual. [4] Because these devices display the world on a screen right in front of your eyes, nearsighted users are able to focus only on seeing right in front of them without having to strain to see far away, letting the device do all the work of depth perception. This can be further facilitated by taking advantage of the *Apple Vision Pro*'s accessibility features which allow the user to zoom in on the world. Still, both these devices come with a hefty price tag; starting at $499 for *Meta*'s device and $3,499 for *Apple*'s. Plus, they're pretty bulky and awkward to carry around on your face all day every day; not to mention the short battery life that would only let you see for a few hours a day.

Another seemingly simple, yet theoretical, solution could be to develop a prosthetic eye, similar to a glass eye, that can capture digital visual data in place of a less functional eye and transmit that data directly to the brain, a Brain-Computer Interface (BCI). Unfortunately, the closest technology we have to this today could be the *Argus II Retinal Prosthesis System* which relies on an external camera mounted to a pair of sunglasses, but this device only stimulates the eye–instead of directly communicating with the brain–to discern light, movement, and shapes without significantly restoring sight to the user; and still, this device and surgical procedures add up to nearly $150,000. On top of all that, it is also only available to people who have no vision or almost no vision due to advanced retinitis pigmentosa which affects about 1 in 50,000 people. [5] Furthermore, the implant can lead to many detrimental side effects including bacterial infection at the very least and retinal detachments. [6] That is to say, there is still plenty of research to be done on BCIs before they can be affordable and accessible.

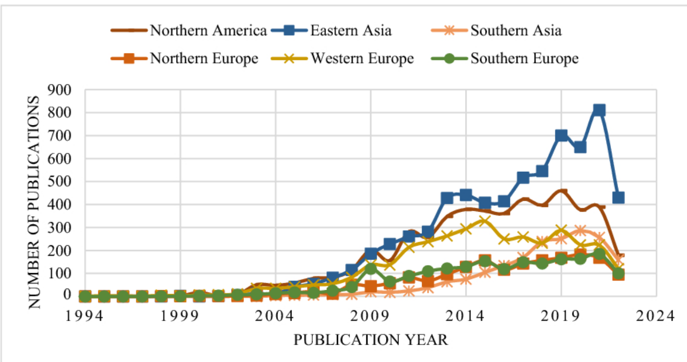
Vision impairment is just one of the many problems researching Brain-Computer Interfaces can open the door towards solving. Today, BCI research is still emerging, and not much is out there; this is the reason we can't yet create a ”bionic glass eye” like previously described, but hopefully, one day, this will be a cheap and permanent prosthetic solution, unlike the previously discussed temporary solutions. Additionally, because of the interdisciplinary nature of BCIs, interconnecting fields of Neuroscience, Engineering, Psychology, and Computer Science, paired with the human and animal testing required by BCIs, it is very difficult to research BCIs. Vision impairment falls under 'Medicine' as one of the many fields of research relevant to BCIs, other common fields include



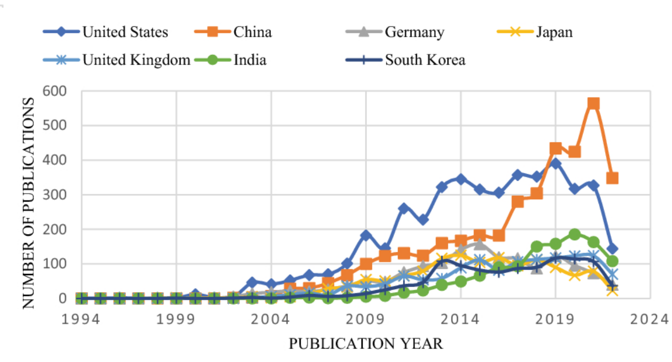
(a) Overall publication trend



(b) Continental publication trend



(c) Regional publication trend



(d) Publication trend per top countries

Fig. 1. "Evolution of brain-computer interface publications." [8]

'Communication and Control' and 'Entertainment,' [7] all of which will be covered in the following sections.

In section II, this paper will touch on some basic background information regarding BCIs followed by section III which will discuss the different types of BCIs along with their advantages and disadvantages; then, in section IV, this paper will discuss each field that BCIs impact and in what ways they do so. Finally, in section V, this paper will open a discussion of ethical considerations.

II. Background

A Brain-Computer Interface, generally defined, is any technology that bridges the brain with an external device. The goal of most BCIs is to decode the human's intention to directly control some device, like a computer, without physically interacting with it. [9] The term 'Brain-Computer Interface' was initially coined by *Jacques Vidal* in 1973 [9] in his paper "*Toward Direct Brain-Computer Communication*" [10] in which he developed a system that determined the direction of eye gaze in humans to determine the direction in which they intended to move a computer cursor.

In modern times, to decode human intention from the brain, BCIs must first be used to interface with data analysis software so that researchers can detect common patterns in brain signals in a controlled environment. First, to detect brain signals, BCIs take advantage of several neural signal recording methods such as, most commonly, electroencephalography (EEG) [11], or, less commonly, electrocorticography (ECoG) [12], and, rarely, Functional Magnetic Resonance Imaging (fMRI) [13], or Functional Ultrasound (fUS) [14]. Then, using machine learning, they can decipher the signals into usable data such as words in the case of decoding speech. [15]

The primary motivation behind BCIs is to create a direct means of communication between the brain and devices like computers or prosthetics; specifically, the primary goal is to assist those with disabilities that make it difficult to move or communicate.

The current state of BCIs leaves much to be desired as, although research stems as far back as 1875 [16], there is still not much known about how the brain processes information and, subsequently, how to take advantage of the brain's electrical impulses. However, research is actively being conducted across the globe and has seen a significant increase in the past two decades as seen in Figure 1 which originates from an article analyzing trends in BCI research by researchers from the University of Dar es Salaam in Tanzania. [8] Additionally, most of the research is coming from Eastern Asia–more specifically, China–, followed closely by Europe and Northern America.

As this research trend continues, we can expect to see this topic appear more and more in mainstream media and news outlets as it has recently with Neuralink in popular sources like Forbes [17] or CNBC. [18] Furthermore, we may begin to see public access being given to BCIs like what Neuralink has been doing by allowing U.S. and Canadian residents to partake in their first rounds of clinical trials. [19] In the coming decades, we can specifically expect to see devices like the *Meta Quest* being advertised to be controlled with the mind, and many devices geared towards facilitating control of prosthetic devices for quadriplegia, paraplegia, and other impairments impeding movement and control of limbs. We may even see that disabilities such as paralysis, blindness, and deafness may be completely overcome.

III. Types of BCIs

Most, if not all, BCIs can be placed into three categories: Completely Non-Invasive, Partially Invasive, or Totally Invasive. These categories represent the medium over which the device acquires its data, also referred to as the signal acquisition method used. Different signal acquisition methods offer several advantages and disadvantages compared to other methods, the most important of which is the signal-to-noise ratio; this dictates how precisely the BCI can detect neural activity. Having a higher signal-to-noise ratio is preferred as it defines clearer signal acquisition, allowing the interface to more precisely collect data. For example, an EEG headset has a fairly low signal-to-noise ratio because it has to detect neural activity through the scalp and skull whereas Intracortical Microelectrodes reach deep into the brain tissue and acquire signals directly from small groups of or individual neurons. Each category reaches further into the human head as portrayed in Figure 2. Non-Invasive generally does not penetrate the scalp whereas Partially Invasive does–and often the skull as well–while Totally Invasive will penetrate through the Dura and into the Cortex. Due to the risk associated with more invasive methods, there has been a strong trend in research towards non-invasive devices in recent years.

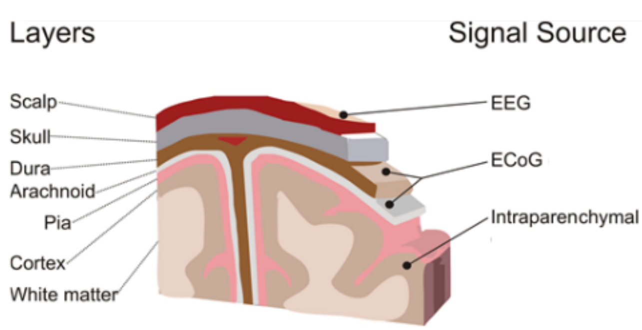


Fig. 2. Layers of the brain [20]

A. Non-Invasive BCIs

See Figure 2, Signal Source → EEG Layer

A non-invasive BCI is one that can acquire neural signals completely independently of the human body, generally placed on the scalp. The most common non-invasive BCIs take advantage of EEG technology (hence why it is referred to as the EEG layer). Commonly, these take the form of a headset [21] which can easily be worn to acquire data, then removed when done. Other examples include Functional Near-Infrared Spectroscopy (fNIRS) [22] and Functional Magnetic Resonance Imaging (fMRI). [23] fNIRS constructs images of the brain using near-infrared light to analyze the concentration of blood throughout the brain and uses these images to estimate brain activities. [22] fMRI is similar in that it also analyzes blood flow in the brain, however, this method is much bulkier as it requires a full-size MRI machine. [23] The most obvious advantage of a non-invasive BCI is the non-invasive part; the lack of surgery and ease of deployment/removal make this the most advantageous method more many researchers, especially for smaller studies like pilot studies. However, as previously mentioned, non-invasive BCIs tend to offer a low signal-to-noise ratio; this means that these devices have a harder time recording clear and accurate signals from the brain because of the extra noise generated by recording through the skull and scalp. This low signal-to-noise ratio is much less of an issue for fMRI, however, as this technology can "visualize activity in all areas of the brain, not just those close to the surface." [23] The true disadvantage of fMRI comes in the enormous size and inaccessibility of an MRI machine.

B. Partially Invasive BCIs

See Figure 2, Signal Source → ECoG Layer

Partially invasive refers to a device that only requires minimal surgery. These BCIs combine some advantages from non-invasive methods and some advantages from invasive methods making these relatively easily removable while still having a high signal-to-noise ratio. The downside is that, in most cases, these include performing a craniectomy to remove part of the skull to temporarily place the BCI on the *surface* of the brain or dura, the protective layer between the brain and the skull. The keyword there is *surface*; as in, the device does not directly penetrate brain tissue, which is much less risky than most invasive methods. Additionally, this method shares the same disadvantage as most non-invasive methods in that it generally records close to the surface of the brain and not deep within it. Examples of partially invasive BCIs include Functional Ultrasound (fUS) [14] and Electrocorticography (ECoG). [12] fUS is very similar to fNIRS and fMRI in that it images the brain to "sense changes in cerebral blood volume (CBV) from multiple brain regions" [14] however, this method requires a craniectomy to see into the skull which fNIRS and fMRI do not need. ECoG offers the strongest signal quality since it directly measures the electricity flowing through neurons on the surface of the brain, but it similarly suffers from poor signal depth as it solely records on the surface. [20]

C. Invasive BCIs

See Figure 2, Signal Source → Intraparenchymal Layer

An invasive BCI is a surgically implanted BCI, generally in the skull. Sometimes, these may be implanted at the base of the skull to interact with the brainstem–where the brain connects with the spine–in the case of BCIs aimed towards rehabilitating a loss of muscular ability or paralysis. Other times, these are implanted directly onto the surface of the brain and, in the case of technologies such as intracortical microelectrodes, have electrodes extending into the grey matter for deeper signal acquisition. The major advantage of invasive BCIs is the high signal-to-noise ratio. Similar to ECoG, this directly records electrical impulses in neurons throughout the brain. However, this direct connection to the brain limits the breadth of signals it can acquire; measuring the entire brain invasively would require a large quantity of sensors which would greatly irritate the brain tissue. Regardless of the number of electrodes, invasive BCIs pose a great risk due to the surgery required; brain tissue is incredibly sensitive and the presence of any electrodes can irritate and inflame the brain.

IV. Current and Future Applications of BCIs

As shown in Figure 1, BCI research is on the rise, having a 1.5 times increase in just five years, between 2016 and 2021. [8] As shown in Figure 3, research conducted by researchers at Tomas Bata University in Zlin, Zlin, Czech Republic tells us that the majority of current applications of BCIs can be categorized as medical, followed by control which is very closely linked to medicine. Additionally, of the applications surveyed, entertainment is the least research application. [7]

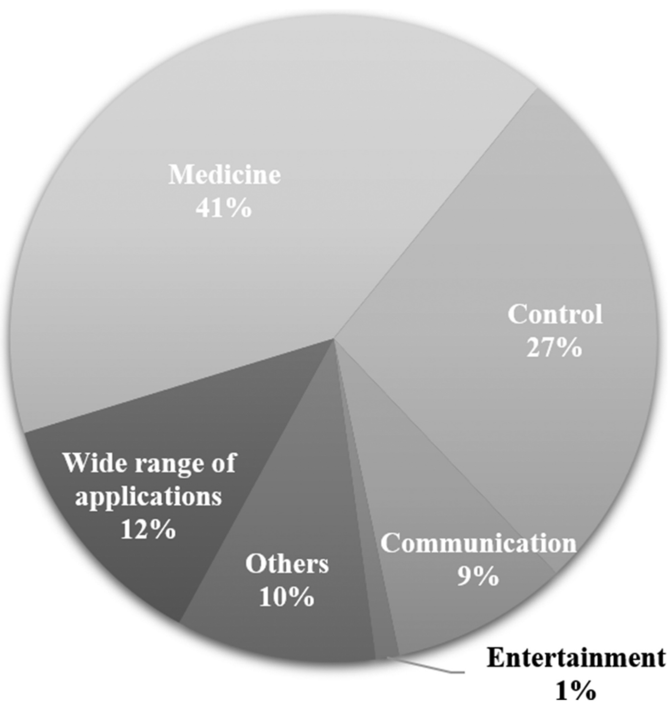


Fig. 3. The most common applications in brain-computer interface (BCI) research in the period from 2016 to 2020 [7]

A. Medical and Healthcare Applications

Medical and Healthcare applications include "improving the quality of life for individuals with disabilities, illnesses, impairment, and paralysis." [7] The hope is that one day this technology will enhance accessibility, bringing equality to those who are medically disadvantaged like the blind, deaf, paralyzed, etc. This can be done, for example, by enabling communication for those who are nonverbal or restoring mobility for those who are paralyzed.

1) Current: After experiencing a stroke, it can be difficult for a person to relearn motor functions such as moving limbs. In an article published in Nature Communications, researchers discuss using BCIs in stroke recovery efforts "to translate brain signals into intended movements of the paralyzed limb." [24] In this research, 27 patients with a weakness or inability to move one side of the body following a stroke were split into two groups, one group with a EEG based BCI that assisted the patient by electrically stimulating the patient's muscles based on the detected intention, and the other "sham" group essentially receiving placebo electrical stimulation of the muscles. The success was quantified using the Fugl-Meyer Assessment for upper extremity (FMA-UE) test and the researchers discovered a statistically significant difference in patient FMA-UE scores after BCI treatment compared to those in the sham group. In tests moving the wrist and hand, the BCI group improved from 1.3 to 3.2 points and 2.9 to 4.7 points respectively, whereas the sham groups only improved from 2.0 to 2.6 points and 3.4 to 3.7 points respectively. [24]

Their research shows that BCIs can offer a significant improvement in those who are otherwise impaired by detecting their intention and assisting the damaged and healing body in stimulating the muscles. This can also be applied to those who have other forms of paralysis not caused by stroke. In another study, a patient with a spinal-cord injury received two intracortical microelectrode BCIs in the hand area of his motor cortex alongside "36 implanted percutaneous electrodes in his right upper and lower arm to electrically stimulate his hand, elbow, and shoulder muscles." [25] As part of his treatment, the patient used the BCI to control a virtual 3D arm and make movements that would then translate to a device which stimulated the muscles in his arm to make the same movements. After 463 days, the patient was able to successfully reach for and drink out of a mug of coffee and after 717 days, the patient was able to feed himself, both things he could not do before. [25]

Furthermore, those suffering from *any* kind of muscular disability like paralysis as previously discussed or those with missing limbs can benefit from BCIs. Although it falls more strongly into the Communication and Control category rather than medicine, BCIs can enable people to directly operate robotic limbs either in the form of prosthetics or limbs not attached to the human body rather than electrically stimulating the limbs they already have; this may be beneficial in cases of severe muscle atrophy in which a patient has been impaired for such an extended period that the muscles in the desired limb are beyond the point at which stimulating may be viable.

There are many other ways BCIs can be used in the field of medicine, although BCIs that restore movement are the most recurrently researched. BCIs can also be used in therapies and other treatments for diseases such as borderline personality disorder (BPD), depression, schizophrenia, attention deficit hyperactivity disorder (ADHD), or autism and can also be used to treat issues in the brain that lead to epilepsy or Parkinson's disease

2) Future: In the future, we may see improvements in technologies like cochlear implants, further improving the quality of sound wearers of these implants can hear; currently, cochlear implants struggle to correctly convey pitch without training or experience with the device [26]. Furthermore, we may see devices that allow the blind to see in the same way that these new cochlear implants will allow the deaf to hear like normal. Some of the previously mentioned current applications are still very early in development and could technically also be considered future applications due to the significant gap before these devices are ready to fully cure diseases like Parkinson's or epilepsy. This would be significant because current pharmacological treatments for such diseases are accompanied by heavy risk of side effects.

B. Entertainment Applications

Entertainment encompasses any application that doesn't affect the real world; that is to say, it is limited to direct digital interactions. This can include forms of media like games and movies. These applications are setting the stage to shake up the gaming peripheral debate; traditionally, there is a strong contention in the gaming world arguing whether mouse/keyboard or controller is the superior peripheral for gaming.

1) Current: For entertainment, BCIs are principally being used in the realm of video games. BCIs have been seen controlling simple games like pong or pinball; [27] these games are perfect for BCIs as there are really only two buttons you need to press. As a consequence of the complexity of the brain, it is difficult to train BCIs to move in more than a couple directions; especially with EEG devices that have such a low signal-to-noise ratio. A polish computer engineering student at the Opole University of Technology published a paper outlining his efforts to use the EMOTIV EPOC+ Neuro Headset as a controller for a more complex game, Dragon Age II, a 3D "Role Playing Game (RPG) that includes a complex combat system. The player uses a lot of skills and spells by pressing specific keys and shortcuts." [28] In his paper, the student trained the headset to recognize four unique patterns which he mapped to unique key presses in order to control the game. Initially, he tried to map those four patterns his headset detected to the W, A, S, and D keys which are used in the game to move forward, left, backwards, and right respectively. Given that a key must be pressed and held down to move in a direction, it was difficult to maintain the brainwave pattern longer than 2 seconds at a time causing inconsistent movement in the game.

After this discouraging outcome, the student then tried mapping the four patterns to other keys which corresponded to certain spells which would only need to be pressed once to activate. This led to a much more encouraging result in which he was successfully able to activate his spells in combat using his mind. [28] This research shows that, although it may be complicated for the brain to recognize several patterns, and games have more interactions than there are completely unique brain patterns, it is possible to use BCIs for complex games, we just need to find the most efficient way to leverage the capabilities of BCIs. Using more invasive devices may facilitate using BCIs for gaming, however the risks associated with invasive devices *heavily* outweigh what we may gain from implanting devices in our brains to play video games.

2) Future: Soon, we may see Augmented Reality (AR), Mixed Reality (MR), and Extended Reality (XR) devices taking advantage of BCI technologies to facilitate interaction with digital elements. Similarly, we may see technologies like TV remotes adapt to this technology, allowing us to pick and choose our movies and TV shows even more easily than before. When this technology develops far enough, you can imagine furniture makers implementing something like an EEG headset, directly into the headrest of a couch.

Thinking even further into the future, BCIs could be used to overlay images directly onto your sight, fully immersing the user into AR/MR/XR and allowing the user to do things like surf the web or lock their car without an external device. One day, we may even see media that is specifically targeted to us based on our current emotional state. Although, all this could be abused by overlaying advertisements into your world and possibly even completely blocking your sight with advertisements, effectively making you blind.

C. Communication and Control Applications

The category of Communication and Control differs from the previous two in that they allow users to interact with their environment. Although this can intersect with entertainment (i.e., interacting with a television or gaming console) and medicine (i.e., using a BCI to control a prosthetic), this specifically includes BCIs that intend to allow a person to interact with the world, usually when they could not otherwise.

1) Current: Thanks to extensive research in control supported by BCIs, humans have shown to be able to control prosthetic limbs and independent robotic arms, becoming capable of performing complex movements such as typing, making gestures (like a peace sign or a fist bump), and gripping objects of various shapes, sizes, and strengths (for example, grabbing something soft, such as an egg, without crushing it). This is incredibly beneficial for amputees and individuals with varying degrees of paralysis, crucially restoring their personal autonomy. Unfortunately, this also come with a fair share of challenges. According to a paper published in a 2008 edition of IEEE Computer Magazine, these types of robotic arms often have seven or more degrees of freedom whereas the human hand and arm have many more; this makes these devices difficult to control with a BCI because, at the time of this articles publishing in 2008, only three dimensions of movement control had been achieved alongside grasp control with invasive methods, and less for noninvasive methods. Of course, sixteen years in the future, we have progressed a little bit with this technology, but there's still more dimensions of movement in a real human hand and arm than we can currently control in a robotic one. [29]

Furthermore, BCIs are also enabling some to regain a sense of touch alongside the freedom of movement. As mentioned in ”Bypassing Paralysis” published in the Feb. 2021 edition of IEEE Spectrum, researchers place a thin film on the persons hand or fingers which register the sensory information and, in turn, send that information through a processor which finally sends stimulation instructions to implanted electrode arrays in the sensory cortex, allowing the person to “feel” the object and adjust his grip if necessary. [30]

2) Future: Eventually, we may see BCIs used a lot in communication. Telepathic or brain-to-brain communication is many people’s science fiction fantasy and, with the continuation of research in speech decoding via BCI, may soon be a reality. This method of communication would completely overhaul the way humans interact with BCIs being used instead of smartphones to text and call people over long distances. The rate at which we can communicate is entirely limited by how fast we can move our fingers or our mouths; with direct brain-to-brain communication, we can altogether bypass these physical limitations and share our thoughts, experiences, and emotions directly. In the same way that it is normal to see people talking to themselves when they’re actually wearing a Bluetooth headset, we may see people staring off into space when they’re actually telepathically on the phone using their BCI.

Furthermore, in the realm of control, we may see people fully controlling robots (or twelve foot tall blue aliens who are better suited for surviving on the alien moon of Pandora where you’re mining unobtainium), allowing humans to perform tasks in hazardous environments remotely, without actually taking the risk themselves and thus reducing the danger to human life. For instance, in deep-sea exploration, space missions, or disaster response scenarios, robots controlled by BCIs could undertake tasks that would otherwise be much more dangerous for humans. Thinking of other possibilities, we may also see people controlling smart home devices; imagine adjusting lighting, temperature, or entertainment systems simply by thinking about your preferences!

D. Other Applications

The category of ”other” is infinitely vague, however so is the human imagination; there are so many other possible applications for directly interfacing a computer with your brain. The most exciting prospect might be the likelihood that we could download other people’s memories and experiences; although, we would have to understand how the human mind processes and stores memories, which is probably not going to happen anytime soon. With this ability, we could learn new things in an instant, completely revolutionizing how we perceive and handle education. Moreover, we could download memories of thrilling activities like skydiving without actually having to take the risk of skydiving ourselves; this would unquestionably lead to a heated debate of whether you actually did the activity though.

V. Discussion of Ethical Considerations

One large consideration to be made in researching this technology is the potential privacy concerns, ethical implications, and societal impact of BCIs. If research trends continue as they have over the past two decades, BCIs may change our lives in the same way the smartphone fundamentally changed our lives over the past twenty years.

A. Privacy Concerns

A major concern with having a BCI on your person as often as you carry your smartphone, especially with how much more connected a BCI can be to your thoughts, is that your BCI can become compromised and share your thoughts and memories (such as passwords and banking information) with third parties without your consent. Thankfully, with what we know now, this is purely science fiction. Although research is actively being conducted to interpret words and natural language from your brain, primarily for those affected by conditions like locked-in syndrome, a BCI cannot directly read your mind. to interpret words from your the electrical impulses in your neurons, a lot of training is required by both the user and the BCI; so, unless you wear a BCI with the specific intent to use it to speak, you should never need to be concerned by this. Every person’s brain is unique, so even if researchers find a way to generally train a BCI with the necessary information it needs to read thoughts, it would have a difficult time reading your specific thoughts compared to somebody else. In the distant future, when BCIs become more all-purpose, and it becomes more difficult to separate your communication from your BCI, like how it is difficult to communicate with distant family without your smartphone, this will be a very real challenge that researchers and engineers will have to seriously consider as they work on this technology.

Alongside the potential breach of your device, there is also the possibility of the misuse of data you have consented to share by governments or corporations. In the same way that cookies track you across the web and the government can influence social media content moderation, it is entirely feasible that your data will be taken advantage of, or the content you are fed by your BCI will be manipulated. This BCI data is an entirely new kind of data so it will be slow to start profiting off of it, but, as we have seen many times before, someone will find a way.

B. Philosophical/Ethical Implications

A common question with BCIs is that of your humanity. Does having this technology implanted in your head make you any less human? Does it make you a cyborg or even a full-on robot? This is simply a question of perspective; although this may feel like it will turn you into a cold unfeeling cyborg, think of yourself compared to what you would have been like if you had been born even just a couple of decades earlier; you already are a cyborg, relatively speaking. As time goes on and the generations keep coming, we forget how lucky we are to have such easy access to information, we forget what it was like to have to go out and ask someone, or worse, a book when we had a question instead of immediately being able to pull out our phones and google the answer. As Tim Urban put it in his 2017 blog post, ”We don’t feel like cyborgs. We feel like humans who use devices to do things. But think about your digital self—you when you’re interacting with someone on the internet or over FaceTime or when you’re in a YouTube video. Digital you is fully you—as much as in-person you is you—right? The only difference is that you’re not there in person—you’re using magic powers to send yourself to somewhere far away, at light speed, through wires and satellites and electromagnetic waves. *The difference is the medium*.” [31] So this new medium, although scary now, is going to change our lives in many of the same ways smartphones already have.

C. Societal Impact

The question of humanity leads to another question, does this technology make you superior and those without it inferior? Unfortunately, in the early days of BCIs, there may very well be a distinction between social classes. As BCIs are just starting to be developed, they may be expensive, leading them to only be accessible to those who are better off financially, and, if BCIs offer frequently used or significant improvements to humans, this will further increase the gap between social classes; the upper class, who can afford the new BCIs, will have stronger control over their devices like phones and computers alongside some new or augmented abilities, while the lower class will get left behind and possibly even insulted for being ”inferior.” Of course, a similar argument could have been made about smartphones, allowing the ”rich” to be better connected to the internet and better informed because they could afford an iPhone whereas the ”poor” couldn’t afford it and would subsequently become dumber; however, this never happened. Although it may have taken a few years to get here, everyone has a smartphone nowadays, regardless of class or wealth.

If you go out in public today and you spot someone talking to no one in particular, you just assume they have some form of bluetooth earbuds in and are talking on the phone; however, seeing the same thing even just a decade ago, you would’ve steered clear of the weirdo talking to themselves. We may see a similar shift in public behavior with the advent of BCIs, especially if BCIs can start immersing people in AR/MR/XR like previously discussed. Eventually we might see people staring at us when in reality they’re paying attention to something only they can see; this may lead to people sitting in public looking like zombies staring into the void instead of staring at their phones like today.

VI. Conclusion

In the year 2024, researchers still have a lot of work to do before BCIs can be ready for consumer purchase and use in everyday life; however, humanity has taken a fantastic first step towards realizing this technology. . In the future, humans may be able to lock their cars from a distance using only their minds or surf the web as if they had a mouse and keyboard built into their brains. Even further down the line, BCI researchers can bring their knowledge to engineers working in AR, XR, and VR and collaborate on technologies that extend human capabilities without us having to move a single muscle; we could navigate a map and get directions overlaid directly on our eyes just by thinking about it, or we could even simply send texts or emails. These are just examples of entertainment, communication, and control; BCIs will open doors in many more fields like medicine and healthcare as well.

The advent of this technology may be scary to many but it is merely a matter of perspective. How much more of a cyborg are you today than your parents were at your age? Humans today have a heavy reliance on the internet and smartphones, helping us communicate with others and learn new information, in the same way that humans may one day rely on BCIs. This technology is one to look forward to; although it may have many implications for our future, we have every reason to remain hopeful the benefits will heavily outweigh the shortcomings and drawbacks.

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