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Brain-Computer Interfaces and Their Effects on the Human Species

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Brain-Computer Interfaces and Their Effects on the Human Species

In the future, brain-computer interfaces–implanted or external devices that allow the human brain to directly interface with computer systems and networks–have the potential to create massive shifts in both medical and non-medical fields, as well as have great implications for privacy, human intelligence, and how we interact with technology. This technology could allow people to use prosthetics that give complete feeling and dexterity to their users. It could be a way to cure paralysis and may even be able to remove chronic pain. Further in the future, brain-machine interfaces may give us access to fully immersive virtual worlds that are nearly indistinguishable from reality. In addition, these devices could allow for knowledge to be added directly into the brain in a very rapid manner, allowing humans to become vastly more intelligent. However, there are also risks that come with this technology. Privacy could be threatened, as companies and unscrupulous individuals could retrieve information directly from your brain. This could lead to intrusive and targeted advertising as well as blackmail depending on the nature of the information retrieved. There are also other threats such as hackers who could attempt to use brain-computer interfaces to bring harm to their users. Even the users of these technologies could be a threat as an unregulated and highly immersive virtual world grows and becomes accessible to anyone with an implant. New forms of harassment could appear, as well as abuse and exploitation in the virtual world. And that's all without mentioning the possibility of governments using this technology to monitor their citizen's every thought. While this technology will have a great impact on humanity, it will be up to us to decide whether that impact is positive and beneficial, or negative and potentially even dangerous.

1. Functions and Characteristics of Brain-Computer Interfaces

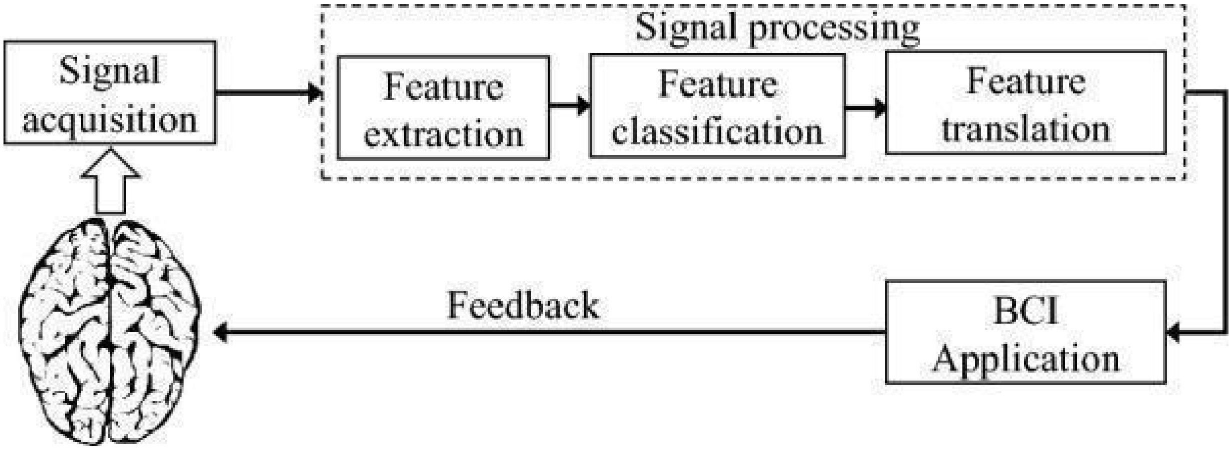

Fig. 1. This figure shows a basic outline of a Brain-Computer Interface as well as its functions and components. Maiseli, Baraka et al.; *National Library of Medicine*; SpringerOpen, 4 Aug. 2023, www.ncbi.nlm.nih.gov/pmc/articles/PMC10403483/.

To work properly with the human nervous system, a brain-computer interface must possess several characteristics. These devices must be able to acquire brain signals and have the ability to process these signals into a usable output. An outline of this process and how it works can be seen in Figure 1 above. A brain-computer interface can also have the capability to stimulate neurons through implanted electrodes and technologies such as transcranial direct current stimulation (tDCS), which uses anodal and cathodal stimulation as a way of modulating neuronal firing in the brain. This modulation of neuronal firing can affect the mental faculties (learning, emotions) of the person on which it is being used. The methods used to collect data from the brain can be split between invasive and non-invasive. Invasive methods, as defined for this paper, are methods of analyzing neuronal activity using a device that is implanted via surgery. Non-invasive methods of measuring neuronal activity do not require surgery and can be used externally. In addition, these methods both have differences in spatial and temporal resolution. Spatial resolution is the ability to link a brain signal to a specific region of the brain. Temporal resolution is the ability to link brain signals to the same time as the occurrence of neuronal activity. Invasive methods typically utilize electrodes placed into the brain with some being placed directly into the surface of the cerebral cortex and other regions of the brain. Invasive systems give a high temporal resolution and strong brain signal that requires less processing, with the downside being that they require surgery and that electrodes will be affected by scar tissue and may damage tissue through slight movement over time. From research discussing this issue, "Because of being implanted into the brain tissue, invasive BCI can damage nerve cells and blood vessels" (Maiseli et al. 9). One invasive implant known as the Stentrode tries to get around this by going through blood vessels in the brain instead, and scientists are researching the possibility of injectable brain implants and electrodes using polymers (Huckins). Moving to non-invasive methods of acquiring signals, these methods include the use of electroencephalography, which utilizes electrodes placed on the scalp to measure electrical activity in the brain and functional near-infrared spectroscopy, which detects signals from the brain by reading the concentrations of oxygenated and non-oxygenated blood as well as blood flow in the brain using near-infrared light and processing that information into data about brain activity. Non-invasive systems acquire weaker and noisier signals that require more processing than invasive systems, and their resolution depends on the type of non-invasive systems used. For example, electroencephalography has a high temporal resolution but a lower spatial resolution. Functional near-infrared spectroscopy, on the other hand, has a low temporal resolution but has high spatial resolution. In some cases, these technologies can be combined to improve signal acquisition.

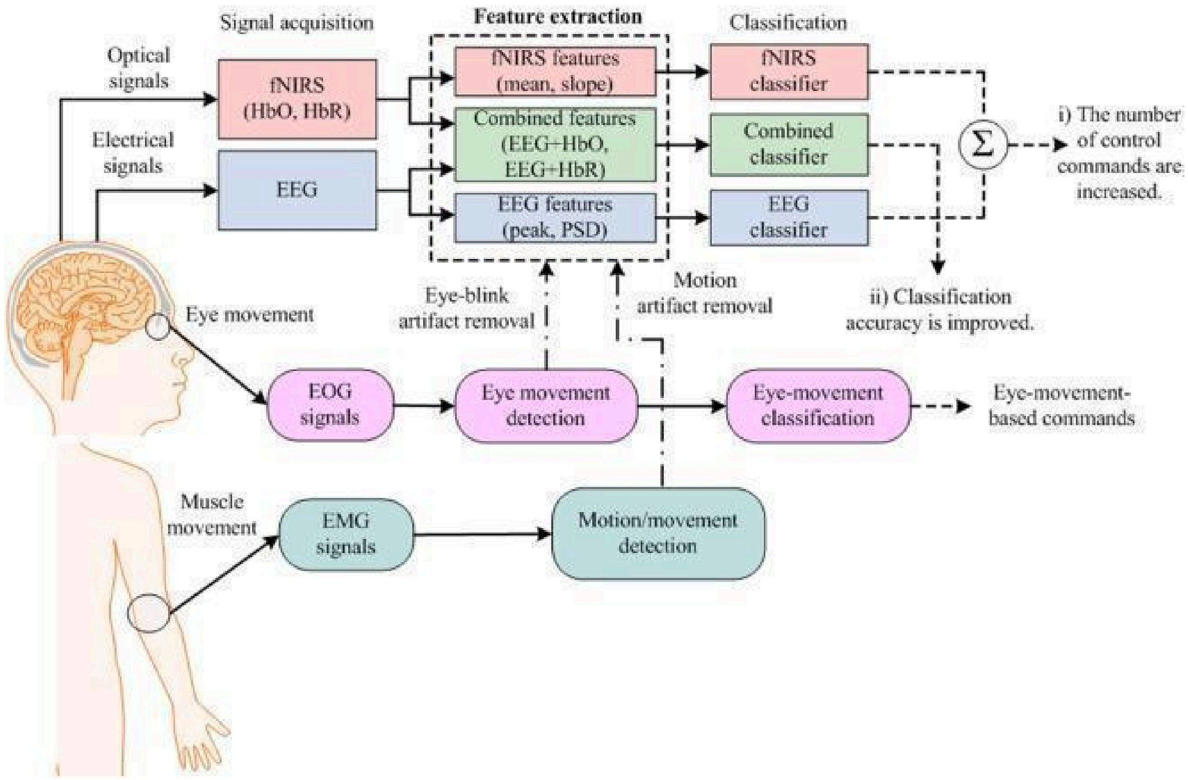

Fig. 2. This figure displays several brain signal acquisition technologies as well as combinations of them and the benefits of those combinations. Hong, Keum-Shik, and Muhammad Jawad Khan. "Hybrid Brain-Computer Interface Techniques for Improved Classification Accuracy and Increased Number of Commands: A Review." National Library of Medicine, U.S. National Library of Medicine, 24 July 2017, www.ncbi.nlm.nih.gov/pmc/articles/PMC5522881/.

One example would be the combination of electroencephalography and functional near-infrared spectroscopy. As seen in Figure 2 above, using both technologies allows for an increase in the number of possible commands as well as better classification of brain signals during signal processing. Using the technologies discussed, brain-computer interfaces have multiple modes of interacting with the human brain and nervous system.

2. Prosthetics with Sensory Output Using Brain-Computer Interfaces

Using Brain-computer interfaces, prosthetics can be given the ability to provide tactile feedback to their users. This is extremely important, as having tactile feedback in places such as our hands allows us to sense the weight of objects that we are holding, as well as determine how much pressure needs to be applied to properly hold an object. The ability to feel would also increase user satisfaction with prosthetic limbs as well as potentially reduce potential psychological issues related to the loss of their limb. A method of doing this involves placing electrode arrays into the somatosensory cortex of the brain, a region that processes sensory data from the body. These arrays are connected to the prosthetic limb, which can then utilize them to electrically stimulate the brain and allow the user to feel physical sensations. Additionally, as the technology improves, users will be able to regain other senses such as feelings of hot and cold. These regained senses will allow the user to be more dexterous and have more control while using a prosthetic limb. In fact, a study has been done regarding this topic and stated, “That artificial tactile sensations substantially improved performance demonstrates that engineered approaches that mimic known sensorimotor circuits–albeit imperfectly at present–will have a major impact on the future performance of BCIs” (Flesher et al. 6). Eventually, those who use prosthetic limbs will be able to feel as if they never lost their original limb in the first place and will be able to live without the loss of a limb having significant effects on their life.

3. Curing Paralysis and Chronic Pain Using Brain-Computer Interfaces

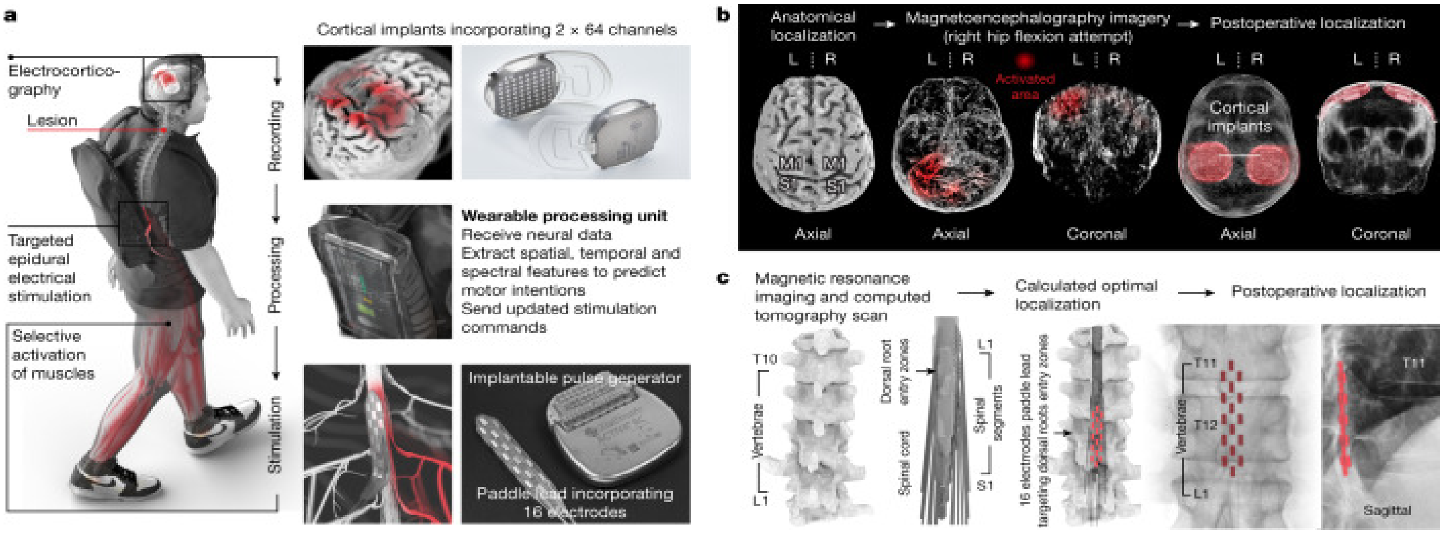

Fig. 3. This figure displays the process of how a Brain-Computer Interface works in a patient with a spinal injury as well as its components. Lorach, Henri et al.; "Design, technology and implantation of the BSI"; *National Library of Medicine*; Nature, 24 May. 2023, www.ncbi.nlm.nih.gov/pmc/articles/PMC10232367/.

Brain-computer interfaces can also be used to cure paralysis in patients with the condition, there is also the possibility that these devices can be used to rid people of chronic pain. To start, curing paralysis can be done by using a brain-computer interface that stimulates nerves in the spinal cord when it receives signals from the sensorimotor cortex of the brain. The implant then responds by stimulating nerves in the desired portion of the body, in many cases, these nerves would be in the spinal cord. Depending on the amplitudes, frequencies, and current of the electrical stimulation used, as well as the configurations of electrodes on the spinal cord, the brain-computer interface can control different muscle groups and allow for control over different limbs. Figure 3 above shows this process in more detail and gives us a greater understanding of how it currently works. Through this, a paralyzed patient can regain the ability to move their limbs and even begin to heal their spinal injury. This has already been done with a real patient to an extent. The patient in question is named Gert-Jan Oskam, and he was paralyzed in his legs and arms due to a cycling accident where he received a partial spinal injury. He originally underwent a procedure where he was implanted with electrodes that were meant to stimulate his spine to induce healing and increase his ability to move his limbs on his own (Lewis and Nature Magazine). However, to further increase his ability to move, he decided to undergo a second procedure that would add additional electrodes that were placed over his brain rather than just his spine. These electrodes were connected to a brain-computer interface inside of a backpack and then calibrated to allow Oskam to control his muscles. After this, the calibrated brain signals were linked to specific types of stimulation on his spine, and he was given control of the amplitude of the stimulation through the implants in his brain. Amazingly, after just 5 minutes of stimulation, Oskam was able to gain a significantly higher degree of control over his leg and hip muscles. Not only that, but he also said that he felt that his movements were more natural thanks to the brain-computer interface. The brain-computer interface also gave him the ability to walk over more complex terrain than he was able to before using the system. Even more amazingly, thanks to his use of the device, he was able to regain the ability to walk while using crutches even without the brain-computer interface being active. The study would note, “These improvements without stimulation translated into a meaningful increase in quality of life, such as walking independently around the house, transiting in and out of a car or drinking a beverage with friends standing at a bar” (Lorach et al. 132). This shows that brain-computer interfaces have the possibility of not only allowing people to regain control of their limbs but also to fully recover from their injuries over time.

3.1 Removing Chronic Pain Through Brain-Computer Interfaces

Chronic pain, according to the CDC, affected 20.9% of the US population in 2021 (Rikard et al. 381). It is a significant issue that can be solved using brain-computer interfaces. However, this isn't the easiest thing to do, as there is not a specific portion of the brain dedicated to processing pain though certain parts of the brain such as the anterior cingulate cortex have been identified as being important for pain processing ("Implantable Brain Device Relieves Pain in Early Study"). This means that its signals can be acquired and read to determine whether pain is being felt and how intense that pain is. Additionally, the prefrontal cortex, which is important for executive functions such as decision-making and planning, has been shown to be able to influence the relief of pain, meaning that it can be stimulated to attempt to recreate this effect. In a study researching the ability to decrease pain using a brain-computer interface the effects above were tested on rats.

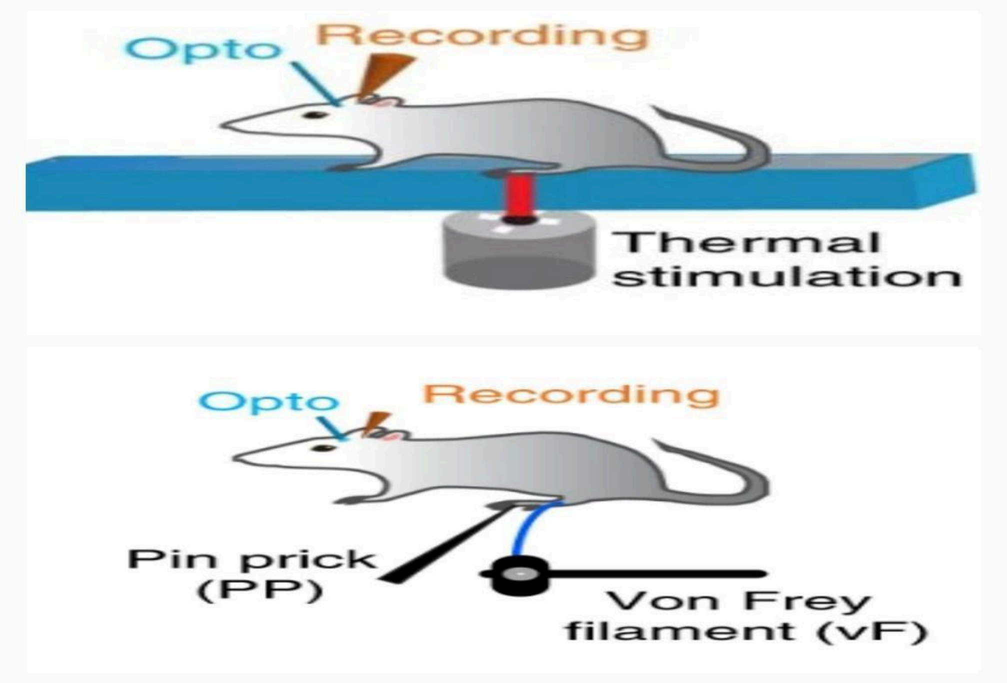

Fig. 4. This figure shows both methods of stimulation tested on rats. Zhang, Qiaosheng, et al. "A Prototype Closed-Loop Brain–Machine Interface for the Study and Treatment of Pain." *Nature News*, Nature Publishing Group, 21 June 2021, www.nature.com/articles/s41551-021-00736-7#Abs1.

In the study, the rats were implanted and then had varying levels of pain inflicted on their hind paws through both IR thermal stimulation, which uses emitted infrared light to heat tissue, and mechanically using a pinprick. A visualization of both methods of stimulation can be seen in Figure 4, above. In the IR experiment, they found that rats that received stimulation from the brain-computer interface took a longer time to move their hind paw away from the IR stimulation compared to rats without the stimulation. In the pinprick experiment, the rats would move their hind paws immediately whether they had the brain-computer interface or not.

However, when placed in chambers that were associated with brain-computer interface stimulation at the detection of pain or random brain-computer interface stimulation and administered the pinprick experiment, the rats would choose the chamber that gave them stimulation when they felt pain (Zhang et al. 537). This means that the system succeeded in reducing the amount of pain felt by the rats to a degree. If such a system could be applied to humans, chronic pain could be managed quickly and easily without the use of addictive or otherwise harmful painkillers. This would mean that patients would no longer be reliant on a constant supply of painkillers and the costs that would come from continuing that supply would also be relieved. However, there should be some research done into the addictive potential of this technology if it were to go mainstream, considering the issues of addiction with some painkillers currently in use and the widely known opioid crisis (Stoicea et al. 4).

4. Enhancing Intelligence and Memory Using Brain-Computer Interfaces

Brain-computer interfaces could be capable of increasing intelligence and the ability to acquire knowledge as well as aid in memorization. To start with, a study has shown that brain-computer interfaces are capable of transferring knowledge between rats. In the study, donor rats with electrodes implanted in their hippocampus, which is an area of the brain responsible for encoding long-term memories, completed a task. When the task was done correctly, the resulting signals generated in the hippocampus of the donor were processed and transmitted to the hippocampus of a different rat that acted as a recipient, which was attempting to complete the same task but had no knowledge of the task beforehand. When this was done, the recipients had an increased ability to complete the task correctly compared to rats that had not received the hippocampal stimulation from a donor (Deadwyler et al. 8-9). However, while the recipient rats had an increased ability to complete the task correctly, they still fell behind the rats that were trained instead of using hippocampal stimulation. Still, these results are promising, and if the stimulation could be improved in a way that allows the recipients to match or beat regularly trained rats it could prove extremely useful. Applying this to humans, it would be useful even if those trained using it didn't match the same level as those who were fully trained in a skill, as it would accelerate the time it would take to learn skills as well as increase competence in the skill in completely inexperienced individuals. The study itself points out some of these possibilities, "Once fabricated into a neural prosthesis for recipients this unique technology could (1) immediately enhance task-specific performance, (2) repair damaged or impaired task-dependent brain circuitry, and possibly even, (3) provide neural encoding of task-relevant information without prior training" (Deadwyler et al. 9). It may even be possible to save patterns of stimulation for later to give a rapid, "crash course", type training in a skill to beginners in a course or other learning situation before moving them to more advanced training.

4.1 Improving Learning and Attention with Brain-Computer Interfaces

Beyond just transferring knowledge, studies have also demonstrated the ability of brain-computer interfaces utilizing brain stimulation to potentially augment the learning process as well as attention. One study used transcranial direct current stimulation (tDCS), to increase the reading abilities of individuals with dyslexia. It was found that individuals who underwent stimulation of the visual cortex in an area known as V5 gained increased reading speed and accuracy. From the study, "Stimulation improved both text reading and reading fluency" (Heth and Lavidor 111). Additionally, these individuals still had increased reading speed a week after the trials had ended, with their reading speed and accuracy having increased even further compared to just after stimulation. In another study, researchers were able to increase the persistence of motor memory from a manipulation task involving a robotic manipulandum, which is a device used to investigate arm movements, that placed resistance on the movement of the arm. They did this by implementing anodal stimulation to the brain across a part of the primary motor cortex. The result was that participants who adapted to the resisted arm movements while using anodal stimulation showed an increase in the development of motor skills related to this adaptation, shown by the increased number of errors made – their muscle memory still anticipating the resistance of the robotic arm – when they had to de-adapt to arm movement without resistance (Hunter et al. 2959). Viewing this result through the lens of rehabilitation and brain-computer interfaces, stimulation could be used in conjunction with an artificial limb. For example, the stimulation could be used to increase motor control skills and overall adaptation. A brain-computer interface would deliver the stimulation required while the user acclimated and connect the user to their new limb, allowing them their senses and better motor capabilities.

4.2 Attention

Sustained attention, referred to as vigilance in the study we'll discuss, has also been shown to be enhanced by brain stimulation of the left and right dorsolateral prefrontal cortex which are both areas of the brain related to attentional control and the ability to switch between tasks. In a study, the loss of vigilance over the course of a single task was reduced by using brain stimulation. The task was to go through a simulation of an air traffic controller and detect possible plane collisions, every time a collision was detected the subject would have to press a spacebar on a keyboard (Nelson et al. 911). Every subject had to do this for 40 minutes, they were also split into two groups that received stimulation 10 minutes into the task or 30 minutes into the task. This was meant to see if stimulation could keep vigilance and performance high while a task was ongoing and if it would increase vigilance and performance if applied after a decline of both during a task. Performance and vigilance were measured through a combination of how many times the subject completed the task correctly by detecting a collision, also called their hit rate, and the number of times they failed the task by incorrectly detecting a collision, called their false-alarm rate. The study found that brain stimulation caused a significant increase in vigilance and performance compared to no stimulation, especially when using anodal stimulation over the left dorsolateral prefrontal cortex and cathodal stimulation over the right dorsolateral prefrontal cortex, with the study stating, “These effects were most prominent in the anodal stimulation type (anodal electrode placed over the left dlPFC), but also visible in many dependent variables for cathodal stimulation” (Nelson et al. 913). Both anodal and cathodal stimulation over the left hemisphere led to a higher sustained level of vigilance and performance compared to no stimulation, and even late use of stimulation allowed subjects to recover their vigilance and performance instead of having it continue to drop. This shows a possible capability of brain-computer interfaces in the future, for example, they could be used to monitor a user's level of engagement and performance and send stimulation to the brain when the performance or engagement level drops below a certain point. Companies have already begun to use these technologies to monitor employee engagement and performance as well as attention. One such product is the SmartCap, which is already being used in 5,000 businesses globally to monitor fatigue. A company could use brain stimulation and monitoring in combination to increase employee productivity (Farahany). Even without direct stimulation into the brain, it is possible that employees could be made more attentive using haptic feedback. Beyond that, the technology is also at the level of being able to discern the type of task being focused on by the employee,

> It's now even possible to use EEG to classify the type of activity an individual is engaged in, according to research funded by the Bavarian State Ministry of Education. As pattern classification of brain-wave data becomes more sophisticated, employers will be able to tell not just whether you are alert or your mind is wandering but also whether you are surfing social media or writing code. (Farahany)

This activity classification technology may lead to privacy concerns in the future.

5. Using Brain-Computer Interfaces to Create Immersive Virtual Worlds

Because of their ability to stimulate the human brain and nervous system, brain-computer interfaces may be capable of creating an immersive virtual experience completely within a user's head. Companies and industry leaders have taken to considering these possible future experiences as part of the Metaverse. To make the experience as immersive as possible, the brain-computer interface would need to recreate the senses of sight, smell, taste, touch, and sound, as well as general somatosensory information such as body position and movement. These additional senses, as well as the immersion gained from involving them in the virtual world, could make the virtual world almost indistinguishable from the real world. While this paper has previously delved into the recreation of tactile senses and touch, we will have to go further to understand how the other senses could be recreated.

5.1 Recreating the Sense of Sight Using a Brain-Computer Interface

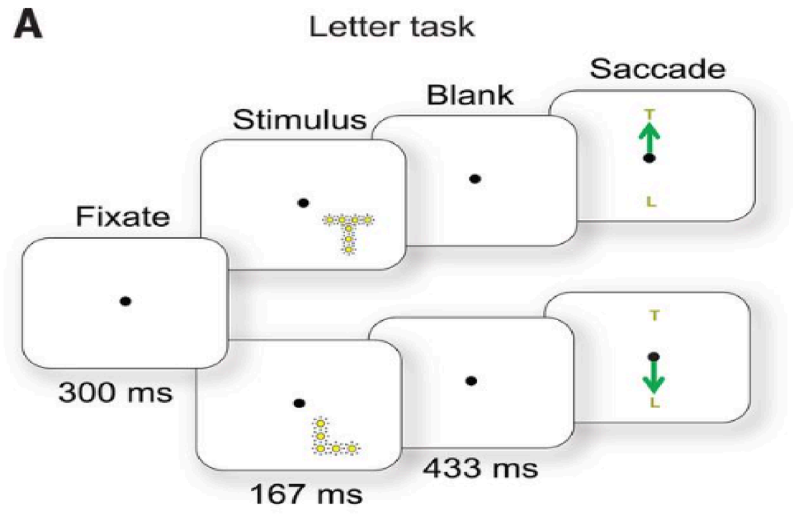

Fig. 5. This figure shows a representation of phosphenes being used to display letters. Chen, Xing, et al. "Shape Perception via a High-Channel-Count Neuroprosthesis in ... - Science." *Science*, Science, 4 Dec. 2020, www.science.org/doi/10.1126/science.abd7435.

The sense of sight would be very important to simulate a fully immersive virtual environment. Without it, there wouldn't be much of a virtual environment to speak of from the perspective of most users. Currently, most development is in the direction of helping the blind be able to see again. This makes sense, as the current approaches to recreating vision are mostly invasive and so are unlikely to be used in healthy people at this time. However, tests that have been done have shown promise with electrical stimulation in the brain leading to the creation of phosphenes, which are little dots of light. Figure 5, above, shows a representation of these phosphenes and their use. As we can see, it is possible that phosphenes could be combined to make shapes and different visuals appear in the vision of a user. A study has already demonstrated this possibility in monkeys. In the study, researchers were able to successfully get the monkeys to see phosphenes as letters, though there were still mistakes due to an overall inability to control the exact characteristics of phosphenes (Chen et al. 6). If the progress with brain-computer interfaces continues, we could one day see systems that can accurately recreate the entire visual experience.

5.2 Recreating the Sense of Sound with Brain-Computer Interfaces

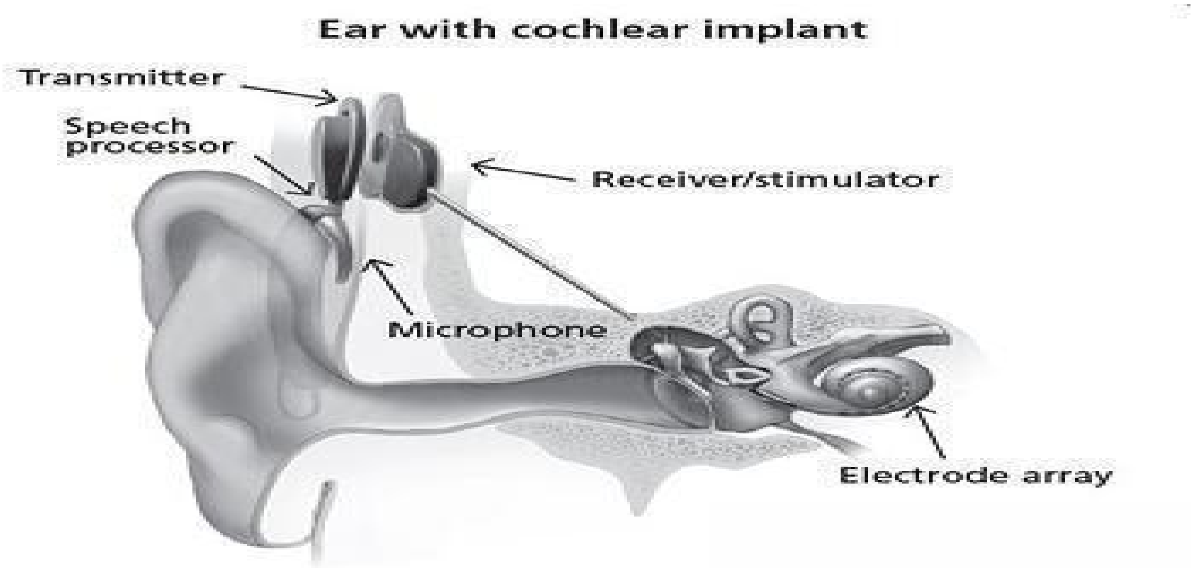

Fig. 6. This figure shows a basic outline of a cochlear implant. NIDCD. "Cochlear Implants." *National Institute of Deafness and Other Communication Disorders*, U.S. Department of Health and Human Services, 24 Mar. 2021, www.nidcd.nih.gov/health/cochlear-implants.

Sound is also important for the creation of an immersive virtual environment. Currently, there is a technology that does this to a degree, called a cochlear implant. It allows people to hear sound by sending electrical signals directly to the auditory nerve of the ear (NIDCD). Above, Figure 6 shows us the components of the device and how they are placed both around and inside of the ear. While these devices are useful for the deaf and hard of hearing, they do not provide the same sensation of hearing that a healthy person would have. Instead, the user gets a representation of sounds that it picks up and must learn how to interpret the signals they get. This creates a barrier, as any user would have to train to understand what they hear if this same technology were used alongside brain-computer interfaces and virtual worlds. The surgery to implant this device can also be expensive, creating another barrier to receiving a device that may not fulfill the requirements of full immersion. However, as research to improve this technology continues, it may be possible that the implant could become more effective with little to no training or that a better mechanism may be found to recreate sound in the brain. In either case, the result would be less or no time being spent learning how to use the implant, as well as a more frictionless experience with a lower barrier to entry that translates to a wider audience being willing to invest their time and money into using this implant.

5.3 Recreating the Senses of Smell and Taste Using Brain-Computer Interfaces

Both smell and taste are senses that would fully bring together a fully immersive virtual world. While not completely necessary, to create the immersive world that a person looking into getting a brain-computer interface would seek, they are needed. The issue with replicating these senses, however, is that they require many more receptors compared to a sense like vision. From an article on the topic, “And smell involves many sensory components. Whereas vision requires interpreting input from three types of receptors, taste involves 40 and olfaction 400” (Weintraub). This additional complexity makes the process of replicating these senses more difficult. While there has been work on these senses, the approaches don’t seem to be close to what a brain-computer interface could be linked with, or their use wouldn’t lead to an immersive enough experience for the user. For example, some systems can induce some flavors on the tongue through electrical and thermal stimulation, but they are also bulky and would require a user to have a potentially uncomfortable device in their mouth to work (Ullah et al.). They are a far cry from what a fully immersive virtual world would require. For now, there will need to be significant amounts of research done on the senses of taste and smell, specifically regarding how these senses could be integrated into an immersive experience through a single brain-computer interface without being cumbersome or difficult to use.

6. Potential Downsides and Dangers of Brain-Computer Interfaces

Despite all the advantages brain-computer interfaces may give humanity in medicine, human enhancement, and entertainment; they also bring forward numerous risks. These risks go broadly from privacy and the possible monitoring of thoughts to hacking and unethical uses of this technology by advertisers and consumers that may lead to serious consequences. Governments could also use brain-computer interfaces to achieve total surveillance. We will be discussing the downsides of this technology and how they could be mitigated.

6.1 Effects of Brain-Computer Interfaces on Privacy and Freedom of Thought

Privacy will be significantly affected by the widespread use of brain-computer interfaces, this is because brain-computer interfaces, by nature, are constantly collecting data from the brain to function as intended. Neuromarketing, which is the use of brain-computer interfaces to determine consumer responses to advertisements and promotions, is an area that may lead to privacy concerns due to its use of brain data. Research has shown that this method allows marketers to attempt to predict the outcomes of marketing campaigns and the likeability of products (Telpaz et al.). Not only that, but the technology also doesn’t require the marketer to question the consumer or for the consumer to do anything other than view the advertisement, "We obtained the EEG measurements used to predict choices while participants were not making actual decisions (or any motor response whatsoever) but simply viewing each product in isolation" (Telpaz et al. 525). It is currently expensive to do neuromarketing research depending on the method of acquiring brain signals, and it is relatively more limited in scale than traditional market research. However, if brain-computer interfaces manage to become as widespread and commonplace as smartphones and other technologies, it would be likely that companies will collect consumer data similarly to the degree they do with common devices today. Unlike that data, however, data collected from the brain could lead to ads that are far more targeted than they are today while also managing to become more personalized and intrusive than ever before. Additionally, because these ads could be able to far more easily convince consumers to make purchases and choices that they otherwise wouldn't make, they could end up being an encroachment on cognitive liberties such as one's right to control their own thoughts and have mental privacy.

6.2 Potential Solution

A lack of transparency as well as a lack of knowledge on how data is used seems to be the greatest issue with neuromarketing and marketing in general, in addition to data protection. One solution could be for companies to adopt better privacy policies for both the gathering and usage of consumer data and allow for more choices of how this data is shared. Companies could also be transparent about how consumer data will be stored and protected. This would allow consumers to make more informed decisions about choosing to share data and give them more control over it. Adding to this, consumers can be willing to share data for some benefit, "Our research shows that, in exchange for saving time or money, customers are willing to share some data. However, they also want to know exactly how it's being used" (Sirich). If this was done, more targeted advertising could be useful by only showing consumers what would be useful to them, making neuromarketing more of a benefit than an issue.

6.3 Privacy of Thought and Belief Under Threat

The thoughts and beliefs of people using brain-computer interfaces may be at risk as the devices become more advanced and widely used. Already, brain-computer interfaces are capable of successfully predicting the political beliefs of people through scans using fMRI. A study researching this found that, after being processed by a deep-learning network, brain activity signals were able to be used to accurately predict the political ideology of subjects and managed to match the prediction capabilities of widely used models that based their predictions on the politics of the subject's parents (Yang et al. 5). When combined with the information gathered from surveys done by the subjects, which included age, sex, education, and income, as well as parental conservatism and the conservatism of their hometown and their current town/city, the results were able to surpass the parental model in their ability to accurately predict the political leanings of a subject (Grabmeier). While research like this is very interesting, it also brings up questions of whether greater use of brain-computer interfaces could be exploited to target and suppress people with different beliefs, political or otherwise. There is also the possibility that a hack of a brain-computer interface could allow someone to discover that someone holds controversial beliefs or beliefs on topics that they wouldn't want those in their social circle to know about and could use this information to blackmail or extort them. Considering that the National Vulnerability Database received 27932 CVEs – identified computer software and hardware vulnerabilities – for 2023 as of December alone ("National Vulnerability Database").

Because these vulnerabilities will likely increase in number in the future, it would be wise to ensure that brain-computer interfaces have proper security measures in place well before they become widely used.

6.4 Potential Solution

The main issues that need to be addressed are the security of brain-computer interfaces as well as the potential for misuse of the technology. To solve the security issues, brain-computer interfaces should implement systems of encryption before sending signals to outside systems and vice versa (Pycroft et al. 458). Any encryption/decryption should be done on-device. Additionally, any data sent to or received by a brain-computer interface should only be what is needed for an operation to be done correctly. If a firmware update is needed for an implant, it should only be done using authentic and signed software after the update has been authorized by the user (Pycroft et al. 458). The potential for misuse of this technology and the data it generates could be mitigated through strong data privacy laws. For example, Chile has amended its constitution regarding the privacy of brain data collected from brain-computer interfaces and made it so that the data could not be sold, trafficked, or manipulated and is also planning another amendment to, "protect the integrity and mental indemnity of the brain from the advances and capacities developed by neurotechnologies" (Guzmán). Laws like this could be used to prevent the misuse of these technologies for the suppression of beliefs – political or otherwise – by the government in countries that adopt them.

6.5 Possible Uses of Brain-Computer Interfaces by Authoritarian Governments

Another possibility is that the technology could be used by authoritarian governments to prevent any competing ideologies or potentially dangerous citizens from rising against them.

Some have considered this to be an existential risk factor for humanity. If brain-computer interfaces become advanced enough to accurately read the intentions, beliefs, and thoughts of a person while also being able to influence them and their mental state, they may be used to have permanent control over the human mind (Rafferty 58). In combination with the use of artificial intelligence flagging certain citizens or changing how their brain is stimulated, it could be ensured that certain thoughts and feelings that would lead to discontent against the state can't occur. The reason this has been seen as a risk factor for humanity overall is that a government using this technology could last indefinitely if capable of protecting against outside threats and these governments would be easier to form as the technology becomes cheaper. In comparison, a democratic country would be less likely to stay stable for as long as a totalitarian brain-computer interface and AI-backed one would. From an article discussing this:

> With BCIs to stabilise themselves from internal resistance and nuclear weapons to stave off invasion, totalitarian countries would almost never fall. They would be secure from internal threats, and secure from external ones. Meanwhile, democratic countries that do not brainwash their citizens could be secure externally but might still at some point degenerate to a more authoritarian form of government. (Rafferty 58)

If a dictatorship was formed in a democratic country, or if a civil war or societal collapse were to fracture it and the separate territories organized themselves into totalitarian states, both would be incentivized to utilize these technologies to ensure their power and authority over the population was permanent. Democracy would be unable to reform such a country, and depending on the amount of such totalitarian states globally and the territories they control, there may not be anywhere a democratic government could be formed, leading to a world where democratic governments that allow for free thought and behavior would be non-existent. Of course, this is an extreme scenario and requires that brain-computer interfaces become more advanced and that there isn't action taken to restrict the access of totalitarian regimes to them, but it could be a real possibility.

6.6 Potential Solutions

There are potential solutions to this problem of brain-computer interfaces being misused in countries with no regard for the freedom of their citizens. One could be the use of international laws and agreements for the use of these technologies (Rafferty). This could reduce the possibility of misuse overall, though governments that refuse to take part in these agreements and laws would still be able to misuse the technology. Another solution could be the fact that, as mentioned previously, brain-computer interfaces are still devices that can have vulnerabilities. This could make it far more difficult for a government to rely solely on them for control of its population without exposing itself to a significant national security risk.

6.7 Brain-Computer Interfaces and the Metaverse

If brain-computer interfaces are one day capable of providing a full virtual environment within the user's mind, there will be a significant impact on how these spaces are used. The greatest factor in this will be the users themselves, specifically users who have malicious intentions. Virtual-reality platforms already have issues with moderation due to the immersive nature of these worlds and how much interaction is occurring. The large amount of data that constantly goes through virtual worlds in verbal and written form, as well as through user actions makes current AI moderation systems insufficient for real-time moderation. From an article on the topic, “Given the immersive nature of the metaverse, many tools built to deal with the billions of potentially harmful words and images in the two-dimensional web don’t work well in VR” (Ryan-Mosley). Currently, human moderators are required to go into these worlds and ensure safety while users can report bad behavior; however, this is still not enough to stop malicious behavior such as child grooming, harassment, and displays of sexually explicit behavior and content (Ryan-Mosley). Additionally, while a user can report these incidents, as previously mentioned, the difficulty of recording all the data of a metaverse as well as the number of reports received – with incidents in the popular VR Chat occurring every 7 minutes – make it hard for moderators to stop malicious users (Frenkel and Browning). There is also the aspect of online anonymity, meaning that malicious users may be more brazen in what they do in the virtual world. When you add the deeper immersion that a brain-computer interface could add to these experiences as well as the additional data, the situation becomes more complex. It may be possible for a malicious user to cause harm to vulnerable users with crimes like sexual assault occurring. Incidents have already occurred, with one woman being groped by a male avatar (Frenkel and Browning). Current issues of child grooming could become issues of virtual child exploitation. And in some cases, this barrier has already been crossed, “Other activists and researchers have similarly reported witnessing children being forced to engage in simulated sexual acts (in VR), as well as a seven-year-old girl encircled by men threatening to rape her” (Homrigh). While there will likely be safeguards in place there could be ways to get around them as there are with current-day internet websites and virtual-reality applications. The CTO of Meta – a company that is attempting to build the Metaverse – has said, “Bosworth said policing user behavior ‘at any meaningful scale is practically impossible” (Robertson). These issues are very worrisome and would not bode well for a fully immersive experience when problems already occur with current VR systems.

6.8 Potential Solutions

While the metaverse and immersive virtual reality may pose a risk in the future, there could be ways to mitigate some of the more significant issues. One solution would be to restrict access to these virtual worlds for minors. This would protect them from potential threats on these platforms, though it could also be difficult to enforce if most minors had access to brain-computer interfaces, so in addition to this measure, there could also be a parental monitoring system. Another solution could be the blacklisting from the metaverse, and other virtual worlds, of brain-computer interface devices associated with harmful users. This could be accompanied by criminal punishment for their actions in the real world. Finally, there could be increased investment in protective systems and Artificial Intelligence used for moderation on these platforms, so that these systems may reach the point where they are capable of moderating large virtual spaces effectively while reducing the burden on and need for human moderators.

7. Conclusion

Throughout this paper, brain-computer interfaces have been shown to have many possible applications. Some, such as those targeting the issues of chronic pain and paralysis, are solely for the field of medicine. Others, such as those involving the possibilities of using this technology to enhance the human mind, were almost a blend of the two with the capability to help both those who are impaired as well as the average person. Furthermore, there were other innovative applications, ranging from improving the capabilities of workers in office environments to usage to create immersive virtual worlds within our heads. Beyond these topics, we delved into the potential downsides of this technology and how those downsides could affect people's lives in significant ways. From the potential for breaches of privacy to the possibilities of these technologies being used by totalitarian governments and even how the average person could be harmed through its use, as well as possible solutions for each problem. It is hoped that this paper will be a push in the right direction to help humanity answer the choice from its beginning. Will this technology be used to benefit us, or will it work to our detriment?

Appendix

This appendix contains the definitions and functions of brain regions referred to within this paper and will aid in the understanding of the topics discussed.

Sensorimotor Cortex: The sensorimotor cortex uses sensory information to coordinate motor commands that are sent to muscles. It coordinates movement in the limbs, trunk, and face (Zhao).

Anterior Cingulate Cortex: This part of the brain plays a role in the regulation of emotions, as well as in the regulation of pain. It is also involved in reward-based decision-making (Jumah).

Prefrontal Cortex: This brain region functions in executive function, behavioral regulation, long-term planning, decision-making, and the ability to focus attention on a specific task (Jawabri).

Hippocampus: This brain region is responsible for memory and learning; it converts short-term memory into long-term memories. It also allows for the memory of your location in an environment, something known as spatial memory. Additionally, it is also responsible for retrieving memories (Fogwe).

Motor Cortex and Primary Motor Cortex: The motor cortex is a region that is responsible for planning, coordinating, and executing voluntary motor movements. Within this region, there is the primary motor cortex, which acts to generate neuronal impulses that get sent to muscles to execute movement (Teka).

Dorsolateral Prefrontal Cortex: This brain region plays a role in emotional control; it also aids in planning and the execution of decisions. Additionally, it works to make social decisions, especially regarding the determination of fairness in social situations. It is also capable of overriding emotional biases in a situation to make a decision (Christian) (Jawabri).

Visual Cortex: This region of the brain processes visual data using sensory information from the eyes. It is made of several subregions (V1, V2, V3, V4, V5), with V1 representing the primary visual cortex. The other subregions play roles in processing components of vision such as motion, color, and orientation (Huff).

Somatosensory Cortex: This region of the brain is involved in nociception (harmful stimuli) and pain processing, as well as the processing of general sensory stimuli such as tactile (touch) stimulation that comes from the skin. Sensory information is also retrieved from receptors that sense muscle movement and temperature changes (Raju).

Cerebral Cortex: This region is sometimes called grey matter, it makes up the outermost layer of the brain, and its surface is covered in many folds that contain most of its surface area. It is responsible for functions such as reasoning, thought, language, intelligence, and consciousness (Jawabri).

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