ROSKILDE UNIVERSITY
AUTUMN 2020
NATURAL SCIENCE DEPARTMENT
3RD SEMESTER PROJECT

Ethical concerns and consequences of Neuralink

Team Members
Nafisa Omar Abdallah Youssef | Vanesa Guia | Filip Walczysko | Suthongchai Suriyasuphapong

Supervisor
Camous Moslemi

Abstract

This paper explores the ethical concerns of Neuralink's intentions in creating a man-machine connection and discusses the possible consequences such technology can have in humanity's development. The purpose of this paper is to shine a light on vital questions such as security, privacy, advantages, risks as well as inequality, issues with human adaptation and evolution, and potential misuse of the technology for political related issues. Neuralink's goal is to have a sensor chip called the Link implanted on the somatosensory section of the brain that will not only establish a connection between the human mind and machines/artificial intelligence, but also have the ability to treat brain diseases such as blindness, and depression. The reflections presented in this paper are not normative, meaning it will not conclude the outcome of the studies as good or bad, but simply explain the meaning, principle, and identity of the questions raised.

Table of Contents

1. Introduction

"We are already a cyborg. We are so well connected with our phones and computers that losing a phone feels like losing a limb" -Elon Musk, 2019

SpaceX and Tesla founder Elon Musk announced a new medical start-up company called Neuralink in 2016. The entrepreneur claims the company will create an association between man, computers and the AI (Artificial Intelligence) as a way to transfer data stored in the brain. In addition, Musk mentioned the company aims to analyse and treat brain disorders such as blindness, deafness and dementia[1]. Neuralink has been open about its processes and objectives, yet concerns have been rising among the general opinion on the ethical aspects of altering the natural process in humans, and the repercussions it might have for future generations. The purpose of this paper is to analyse the different ethical beliefs and concerns of Neuralink technology and explore possible consequences on the future of human evolution. The beliefs explored on this paper will follow the 'common good' and 'rights' ethical views approach.

The technology being discussed is at a very early stage and could potentially become the game-changer tool for the future of humankind. Modern technology has become an essential part of our daily life, and greatly impacted our behaviour, even from a young age. Parents chose to distract their children with phones and tablets, rather than with toys these days.
With this is mind, Neuralink's invention will allegedly be a great way for society to thrive and evolve into a more advanced civilization. On top of that, if the company manages to successfully treat brain disease it will not only greatly influence human life styles, but social engagement, behaviour, medical systems and the economy [2]. Nevertheless, an infant technology such as this is far from perfect, and the public has been open about their concerns about complications arising along with such futuristic dreams.

As exciting as it sounds to surpass AI technology, Neuralink intends to do so is by inserting sensor chips inside the somatosensory area of the brain. Although society has become very dependent on technology, use of external devices differs greatly of that which was been permanently implanted on the brain. Not only can the method of implantation be risky or harmful to the human body, but it might alter the way humans have been adapting and/or respond to the environment. Similarly, the risk of discrimination between those who will carry the chip and those who do not, affect greatly the generations to come. Perhaps the opportunity to control machines at a mere thought will offer somewhat of an advantage when it comes to acceptability and/or job hunting, but the cost of easy access to one's brain carry heavy consequences.

Security and privacy are of great importance when it comes to technology, and for a brain implanted technology such as Neuralink, the stakes are higher than usual. As it is often the case, the majority of software gets hacked and data is leaked; but because information will come directly from our minds, the prospect of direct access to our brain is even more alarming. How much access will Neuralink get when it comes to brain function, and, what happens if it gets hacked? Will the risks be greater than the rewards? Such questions are studied and thoroughly discussed in this paper.

***Research question*:** What would be the potential ethical concerns and consequences of Neuralink for human species?

***Sub-questions*:**

i. How safe is the software of Neuralink and the process of implantation in the brain? Is it hackable? Will it need updating or replacing? Planned obsolescence?
ii. Will individuals who do not have the chip will be put at a disadvantage when it comes to social acceptability and/or job hunting?
iii. Are the risks of brain implantation greater than the rewards?
iv. Is it ethical to use such technology in the military and what are the biggest risks?

2. Methodology

This research was conducted by a qualitative descriptive method by collecting secondary data from online research, literature research and case study. There are three components in our research design: data collection, data processing and critical analysis about possible consequences of Neuralink based on the following two ethical approaches, common-good and rights approach. Scientific news and academic publications are cited in the theory part, while human-technology related articles and studies are mentioned in the ethical discussion section. No specific database was used when collecting reading material. Data was gathered from reliable sources such as interviews, published articles, studies done using similar technology, and discussions from professionals within the engineering and ethics fields.

Data collected needed to be relevant to the topics discussed in this article and valid, whether it is a research paper or a news article, it came from professionals who either quoted Neuralink or brain technology, or studied it themselves. Literature reviews in this articles has been taken from the Neuralink direct source, plus known scientific theories collected in order to explain the processes implicated in the technology. A closer look into the anatomy of the brain and signals implicated with Neuralink's device, as well as brain-computer interaction, is offered during this section of the article to easier comprehension of analysis later on.

Given the infancy of the Neuralink technology, the discussion section includes several speculations, and hypotheses are based on studies performed using similar technology either in the past or present, imagination, and references to science-fiction. An ethical approach was used to analyse the consequences of Neuralink technology in the future of human race in accordance to common- worldviews, greatest benefit for the least amount of discomfort, protection of human rights, peace keeping, and advantages and disadvantages within an optimistic/pessimistic society. Societal impact was also taken into account by analysing the short-long term implications of the technology.

Several ethical approaches have been cited and explained in this article. The two approaches used for the analysis and discussion section of the technology are the common-good and rights theory. The reasoning behind the focus on these two ethical approaches is because they follow normative ethics and fit the desired standard analysis for this article. For the rights theory approach the discussion focused more on the right to free consent, right to due process, and right to freedom of conscience in regard to Neuralink implantation and use. When referring to the common good approach, the discussion focused on whether or not the welfare, social behaviour, institutions, and environments involving Neuralink technology carries the greatest benefits for all.

3. Theory

3.1 ETHICS

What is Ethics?

Derived from the word "ethos", which means character, ethics is a branch of philosophy that is concerned with moral characteristics and how people should generally act or in specific circumstances. Ethics provides a framework for understanding right and wrong as well as define norms within human behavior while simultaneously offering a set of choices for one's own actions. What is considered ethical good or bad varies from individual to individual and societies. For example, codes of conduct express relevant ethical standards for many professions like medicine, law, journalism and business [3].

Furthermore, there are various ways to categorize ethical frameworks. When studying ethics in a theoretical sense it is called meta-ethics. Concurrently, when studying a particular event or circumstance, we refer to this method as applied ethics[4]. Descriptive and normative ethics are among these ethical frameworks used in analysis. Descriptive ethics refers to individual action, and thought process, while normative ethics takes the norms into account and offers a set of actions commonly accepted within these principles [5].

3.1.1 Five ethical approaches

The Utilitarian approach

Utilitarianism is a theory about what is an ultimate value or importance in life. It provides criteria for judging whether any action is morally right or morally wrong based on the end result. This theory focuses on the best possible outcome for the greatest amount of people. It often refers to happiness, and how society should aim to achieve happiness for everyone even through someone else's unhappiness or well-being. For such reason, it is believed utilitarian theory decisions can come across as unethical. Some drawbacks for this theory include making decisions which do not help with the ending result and being exposed to situations where the gain is one-sided at society's expense [5].

The rights approach

The rights theory approach is based on the belief that humans have the ability and right to freely choose what they do with their lives. The most ethical action is the one that best protects and respects the moral right of those involved in the decision making. Rights theory approach can manifest in two categories, negative rights and positive rights. The negative rights refer to rights that should not be obstructed such as freedom, freedom of speech, freedom of movement, the right to remain free of injuries and harm, slavery, etc. Positive rights refer to those entitling a person to something, given it be an object, feeling or action. Some examples discussed in this article include the right to privacy, the right to education, and the right to sue in a court of law.

The fairness or justice approach

The fairness and justice approach deals with fairness and equitability. Everyone is entitled to fair and equal treatment and opportunities. It is one of the most fundamental social and ethical principles when it comes to everyday decisions. For example, justice is one of the most important moral values in law and politics. Legal and political systems can maintain law and order by achieving justice.

The Common Good approach

To pursue the common good means that any actions and/or decisions taken should be beneficial for all members of society. It differs from utilitarian approach in the sense that the ethical standards should cover the entirety of a community, not just the maximum number of people possible. There are three essential elements related to the common good approach. Rights: the public authorities must protect and respect the rights of their people. Need: public authorities should make basic needs accessible. Peace: the common good requires peace and security and protection.

The Virtue approach

The virtue approach originated from Ancient Greek philosophy in the thought of Socrates, Plato and Aristotle. Virtue is essentially someone's character. Virtue comes from a life that seeks truth through the application of reason, for example, our souls and minds contain virtues and passions. Virtues that the Socrates defined include courage, royalty, honesty, temperance, and prudence. These virtues constrain and exalt the soul.

3.2 NEURALINK

What is Neuralink?

In 2015, Professor Pedram Mohseni and Rudolph J. Nudo established a startup company called 'Neuralink'. The main goal of this company was to develop a new way of treatment for disabled patients, eventually inventing a device that could potentially help people suffering from brain injuries[2]. In 2016 they sold the rights to the name Neuralink, for tens of thousands of dollars to investor and entrepreneur Elon Musk. Once the entrepreneur took over, the company expanded its scope and began creating a way for individuals to directly connect their brain into a computer through brain implantation of a tiny electrode for enhancing communication ability[8].

March 2017, Musk announced his BCI bi-directional plan (humans will be able to upload/download directly from computers or others communication devices) in an interview at ISS R&D conference in Washington DC and revealed the ultimate goal of Neuralink was to fuse human intelligence with AI and step up humanities capabilities. He reasoned the shift in goal came due to the dangers advanced AI posed to human race, since computers continue to get smarter exponentially and could one day surpass human intelligence [9]. In 2018 the company made an agreement to fund a research at California National primate research center, University of California Davis [10]. In July 2019, Elon Musk had a presentation on the Neuralink project via live stream, and discussed related scientific improvements related to an integrated brain machine interface platform. The clinical trials were set to start by the end of 2020 with quadriplegic patients as target patients due to spinal cord injury [11].

Neuralink functionality depends on a brain implant and this implant is going to track action potentials or spikes from our brain. The first product will be focused on controlling actions for patients with a mobility disability who would want an ability control device so they can live without a caretaker. Once control is made possible through the implant, the output signals can also be redirected to a computer and function as a mouse and/or keyboard. The main hurdle for Neuralink's technology is getting US Food and Drug Administration (FDA) approval for these implantable devices. Once approved, the future of Neuralink will be in divided into three stages. Stage one would be understanding and treating brain disorders starting with critical patients. Stage two would be to preserve and enhance one's own brain, and the final stage consists of full brain machine interfaces.

Brain Computer Interfaces (BCI)

Brain Computer Interface (BCI) holds impressive amount of promise in rewards to direct communication between brain and internet. BCI technology consist of both input and output devices. Input BCIs are comprised of sensors which acquire electrical brainwave signals. The sensors work together with processing hardware that extracts distinct features and translates it into useful commands. On the other hand, output BCIs translate digital information into electrical signals and then into the users' brain by stimulator hardware. BCI can operate by two approaches, noninvasive BCI and invasive BCI. The noninvasive BCI method uses electroencephalography (EEG) to read brainwave signals from sensors located outside of the skull, and feed electrical signals into the brain using transcranial magnetic stimulation (TMS). The invasive method requires surgery in order to place the sensors into the right position as well as a stimulator inside the skull [6].

Modern BCIs allow disabled patients to control their prosthetic limbs and sensory bionics. Some BCI can now perform real-time speech decoding, translating brainwaves into writing and speech in order to communicate with patients suffering from severe neurodegenerative disorders. A researcher from Sandford University has now built BCIs that allow paralyzed people to type using their brains, by operating an electrode array implanted into the motor cortex of the patient. Scientists have started developing BCIs that let brains talk directly to computers which could open the door to higher possibilities for the human race such as being able to upload your mind into the internet or human immortality [7].

3.3 IMPLANTATION

There are approximately 100 billion million neurons in the brain, whose purpose is to serve as a method of transportation for thoughts and actions. Basically, they are in charge of receiving and sending information. Sensor abilities like sight, smell, touch, taste and sound are the result of neurons processing [1]. Despite the variety of neurons in the brain, their structure consists of mainly three parts: a dendrite, a soma, and an axon. Each of these serve a different purpose in order to make the neuron do its job. Dendrites are in charge of receiving signals, the cell body called a soma (the spherical-like shape in the neuron containing the nucleus) computes signals, and lastly an axon serves to send the signals outside of the neuron [12]. Figure 1, obtained from the official Neuralink webpage, offers a visual representation of a neuron inside the brain. The soma connects to the dendrite spines and the axon. These neurons are able to communicate between one another due to electrical signals.

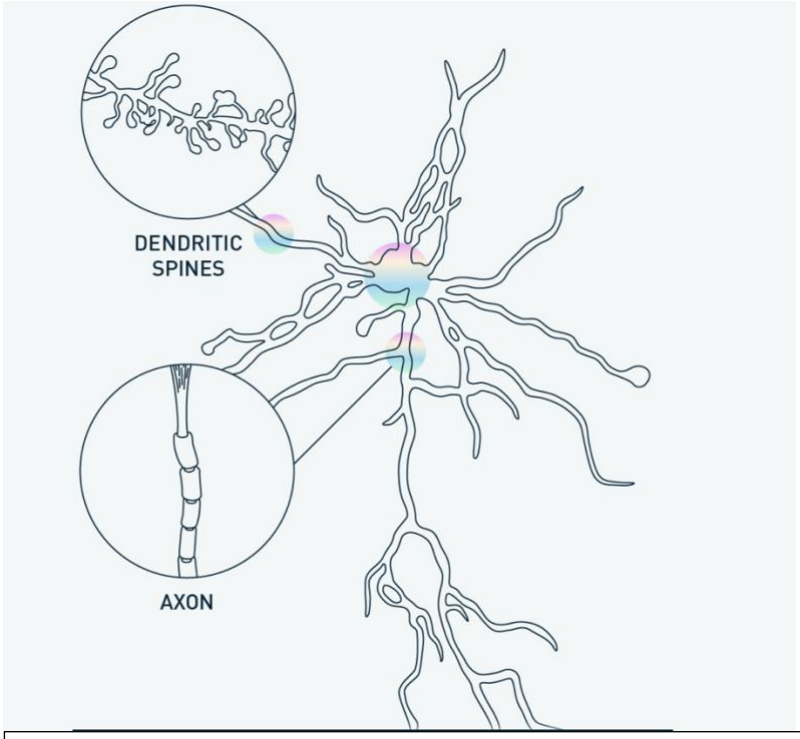

Figure 1. 2D Visual representation of a neuron and it is components. Three sections are highlighted, and two have been enlarged. The latter refers to dendritic spines, and axon / Source: Neuralink Website [1]

Neuralink's approach to men-machine communication is to create a neural implant, which will be able to establish electrodes to read brain activity and allow the user to control a computer or machine at any time. This implant is called 'The Link' and its connected to micro-scale threads which will be implanted in the brain [3]. The threads are extremely thin (4-6 µm) and have a length of approximately 20 µm. These are also flexible in order to adjust to the shifting shape of the brain [1].

Normally, neurosurgeons prefer two methods of implantation, invasive and non-invasive. The invasive method will require to break the tissues in the brain, and a Glial Scar (restore brain tissue) reaction to occur. With the non-invasive method, the damage to the brain tissue is minimal and therefore will not trigger Glial Scar formation.

Since Neuralink's threads are ultra-thin and highly flexible, the company has manufactured a surgical robot that will attach the threads without breaking them and allow neurosurgeons to perform the surgery in a more secure and effective way. The robot structure consists of seven different part, all aiding to implant the threads with the least invasive method. Figure 2 shows the external appearance of the robot, as last mentioned on a conference by Musk. Figure 3 shows the different parts of the robot that will be used for implantation. Each label on figure 3 belongs to a part. Below is a description of each of the parts quoted from a journal

article published in 2019 by the International Conference on Computing, Communication, and Intelligent Systems [1]:

A) Loaded needle pincher cartridge
B) for low-force contact brain position sensor
C) Light modules with multiple independent wavelengths
D) Needle motor.
E) One of the four cameras focused on the needle during insertion.
F) Camera with wide angle view of surgical field.
G) Stereoscopic[1] cameras.

Figure 2. External appearance of Neuralink's automatic Insertion Robot for Link implantation. / Source: Neuralink Website [1]

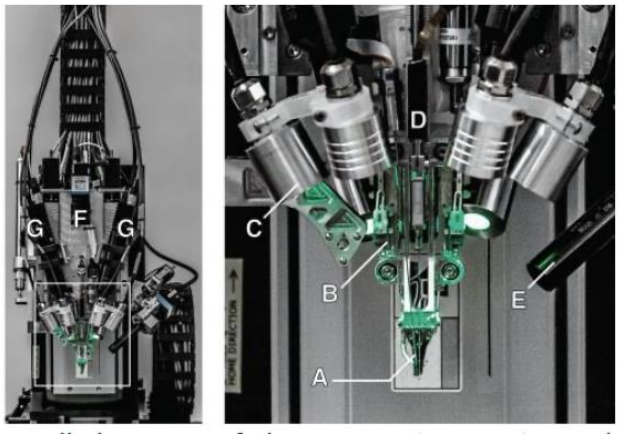

Figure 3. Enlarged view of interior of Neuralink's automatic Insertion Robot for Link implantation. / Source: Neuralink Website [1]

The robot will be able to insert threads into the brain avoiding damage to blood vessels using the "needle pincher" assembly. This procedure consists of a nanoscopic needle injecting the thread, stitching it to the brain and quickly releasing it with the help of multiple cameras aimed to focus on the needle's working area. On one of his presentations, Elon Musk mentioned the process would take less than an hour, can be performed anesthesia free and patients would be able to leave the hospital the same day.

[1] Stereoscopic: pertaining to three-dimensional vision or any of various process and devices for giving the illusion of depth from two-dimensional images.

4. Discussion

4.1 RISK ANALYSIS

In this research we classify the potential Neuralink risks into the following three categories, health risks, social risks and cybersecurity risks. When it comes to placing object inside one's mind, its essential to contemplate the possible risks of such action. For regular surgeries, doctors tend to read the list of complications to their patients even if the likelihood of them happening is low. Therefore, this section will contemplate the severity of Neuralink's technology and whether or not they follow the standard norms for the aforementioned ethical approaches.

An imperative question when analysing the risks of any technology is whether or not the risks would be greater than the rewards? The Link goes directly into the brain; thus, one might repeatedly question if the procedure is worth the hassle and bring the maximum happiness to the majority of people. The purpose of Neuralink implant is to record spike or action potential across many neurons as possible and translate that into a system that will allow for a smooth communication between the brain and any machine. The Link has 10,000 electrodes, while current deep brain stimulation technology is able to only read 10 electrodes. This is a tremendous advantage to Neuralink in the sense that will allow for better reading and translation of brain signalling. Neuralink surgery offers a high change of safety in regard to their brain implantation. The Link's micro threads are about the same size as neurons so the surgery must be performed precisely using the surgical robot's techniques. For safety reasons, Neuralink electrodes are made with biofriendly materials, meaning they will be able to dissolve and become flexible electrodes that the brain can tolerate [13].

Nevertheless, all surgery carries certain risks including a methodically precise one such as Neuralink's. Risk of infection could be around 1-2%, and it may trigger an auto-immune response making the patient's own immune system attack the implant, causing it to lose reliability over time [14].Another possible risk has to do with the positioning of electrodes. There is up to a 3% chance risk of the surgical robot missing its mark and mistakenly positioning the implant on the wrong spot inside the brain. This would not only implicate a surgical complication, but the Link would not be able to properly read brain activity, causing its functionality to decrease tremendously. One of the most concerning risk areas with this technology related to the ½-1% risk of stroke or death. Most patients experience weakness after surgery but given the probability of error and the previously mentioned risks, some patients might experience speech difficulty after Neuralink implant surgery. Under normal circumstances and proper recovery periods, post-surgery symptoms will get better after a few weeks [15]. Older people and people with medical conditions tend to have higher levels of risk, so these numbers might increase depending on the health condition of the patient receiving the transplant.

Additional issues relate to biocompatibility between the Neuralink implant and an individual's brain tissue. It is possible for the brain to reject the implant or recognize it as a possible foreign

object and have the opposite target effect. The electrodes could reorganize and induce some changes in the neural tissue causing some loss of muscle control [17]. There is also a potential risk of BCI affecting responsive behaviour such as decision making as the effects of BCI when it comes to altering cognitive process remains unclear. The uncertainty surrounding BCI on the brain is concerning, because it might lead to undesired long-term effects for their users. Lastly, risk of device malfunction can lead to accidents. For example, a malfunction can misinterpret brain signalling and end up with producing a wrong command. In cases involving people with disability to relay on the technology, this can be dangerous as not only their safety, but that of those surroundings them can be compromised.

Social Risks

On the subject of common-good ethical approach, where the actions taken must benefit the community, Neuralink could potentially have a lot to offer or take when it comes to social risks. Would Neuralink becomes game changer when it comes of work and daily life as we know it? One can imagine a society where all companies, organizations and school systems implement or normalize the use of Neuralink. Let's start contemplating and assume the latter has become a reality. At job interviews, meetings and gatherings people could exchange information directly from their minds into nearby machines, or, if we dare venture farther into the future of this technology, one another. A simple thought between a candidate and its future employer might offer insights on background information, lifestyle preferences, and state of mind. A meeting amongst fellow students or co-workers could be done from a distance by exchanging information through their thoughts and be performed faster than what it is known today. A NASA ex-engineer Marc Rober performed an experiment where he used a home-made machine to try and win every single time, he played at game stores. He tested the machine's precision and compared it humans, realizing that machines are able to perform thing to extreme precision repeatedly as opposed to humans [18]. With Neuralink, not only will job recruiting become more selective and accurate, but humans might be able to replicate the accuracy of machines at the same or greater speed.

But what happens if the Neuralink implant reads out the wrong information, or interprets information wrongly? How much can we trust Neuralink technology to watch out for well-being of society? It is not possible to say what Neuralink will bring to the table yet when it comes to information security, however, error could hurt individuals trying to perform tasks they would normally not fail as well as catch mistakes before it happens. Such decisions fall within the rights theory approach in ethics, in which some individuals will reserve the right to not have the implant or might believe the easy access to their thoughts is a violation to their privacy. To follow up on the previous employment example, there could be the case in which someone decides to work for a company implementing use of Neuralink. Companies may use the implant to monitor employees' attention levels and state of mind, which will bring issues such as discrimination in the workplace. Bosses and employers who are able to access other's thoughts will assign a preferred person, so their team would not suffer from projects that they do not want to do. Focused on their desire to thrive, sympathy might be lost in these sorts of situations.

Neuralink can speed up or obviate annual performance evaluations. Bosses would already know their employees' dedication to the company and their future plans, and whether they want to remain as part of the team or leave if their bosses lack moral character. Conversely,

it would be very easy for employees to run off with employers' intellectual property. Teachers can monitor whether someone in the class is focused or distracted, allowing them to change teaching strategies. It sounds useful to adapt teaching techniques, but when the technology reaches the point that people can download their lessons, perceptions, knowledge and experience directly from the internet to their Neuralink implant, will anyone want to sit in a traditional classroom, and will the traditional teacher role continue to be needed? Additionally, what if pilots and drivers get brain hijacked by terrorists mid-flight, will this lead to horrific tragedy? A solution for this could be to monitor drowsiness and emotions like anger, happiness, depression, desperation, attention level of pilots, bus drivers, taxi drivers, and train drivers using Neuralink technology, so we can make proactive changes. Technology solves problems and creates problems. We would say technology is a two-edged sword.

Cyber Security Risk

Whether we are camping, reading books, cooking, or watching Netflix, our brains are packed with activity. Millions of electro-chemical messages are passing between neurons, this is called brainwave signaling. Scientists study brainwave signals and try to make sense of the brain. Recently they have linked brainwaves to things like consciousness, memory and even certain diseases.

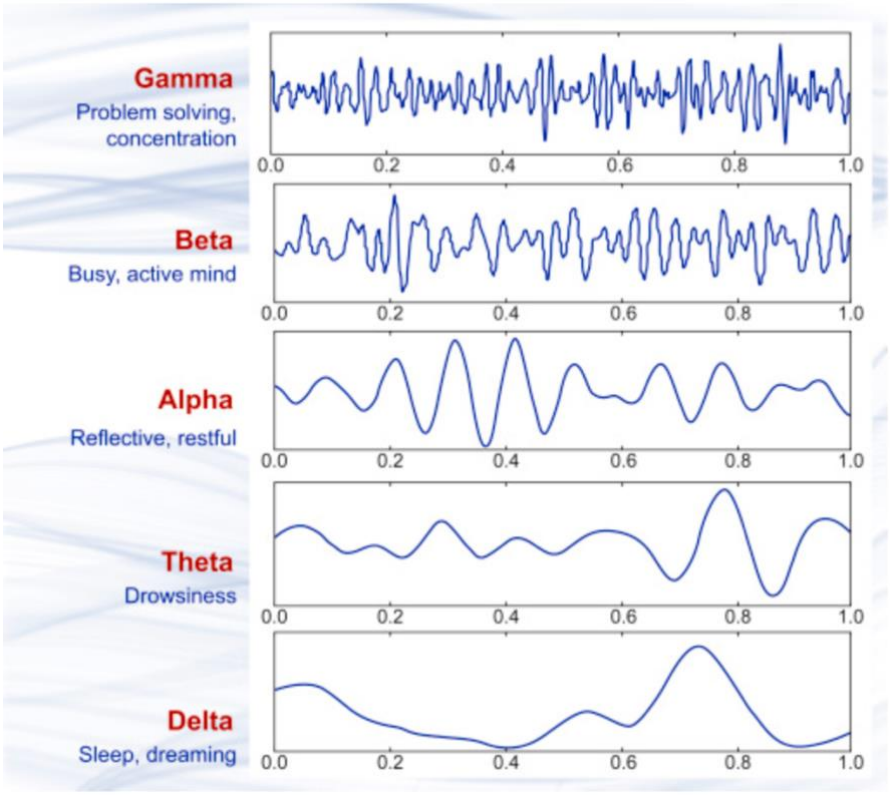

Figure 4. Brain Wave Samples with Dominant Frequencies / Source: [16]

There are 5 main types of brainwave signals. The higher the frequency of the wave, the more alert and awake we are. **Figure 4** illustrates the different brainwave samples. Delta waves are the slowest of brainwave signals, but high amplitude. Delta waves occur in deep sleep and in dream state. Delta waves are around 0.5–4 Hertz. Theta waves are slightly faster, with a frequency of around 4–8 Hertz, which occur in day-dreaming, drowsiness and meditation. Alpha waves are common when we are awake but relaxed. The frequency of Alpha waves is 8–12 Hertz. Beta waves are higher frequency and lower amplitude, and they seem to happen when we are awake, busy and when thinking about something. Beta wave frequency is measured between 12–30 Hertz. Finally, Gamma waves are associated with concentration and problem solving [16]. According to the study we can see that different regions of the brain are more

commonly associated with certain waves. For example, Alpha waves are usually strongest in the occipital lobe in the backs of our heads, where input from our eyes is topographically mapped and processed.

4.2 HOW ARE MEMORIES CREATED AND STORED?

We can classify memories into two main types, the first one is short-term, which we only remember for a few minutes, and the other is long-term, which allows us to keep and retrieve memories over a lifetime. In neuroscience, long-term memory can be divided into two categories— declarative memory which refers to how we handle facts, information, pictures and events, and non-declarative memory which is related to skill development and habit formation [18].

Today we know that memories appear to be stored in different places— our brains pick batches of cells to store memories of things we experience, and those cells are not all in the same area, because parts of our brains specialize in different things. For example, neurons in the visual cortex will store picture that we have seen, and neurons in the amygdala will store how we are feeling. Muscle memory motor tasks are stored in the cerebellum. Memories of facts and events rely on the medial temporal lobe, the thalamus and hypothalamus. When we are going to use memory to do things, the brain activates brain regions all at the same time [19].

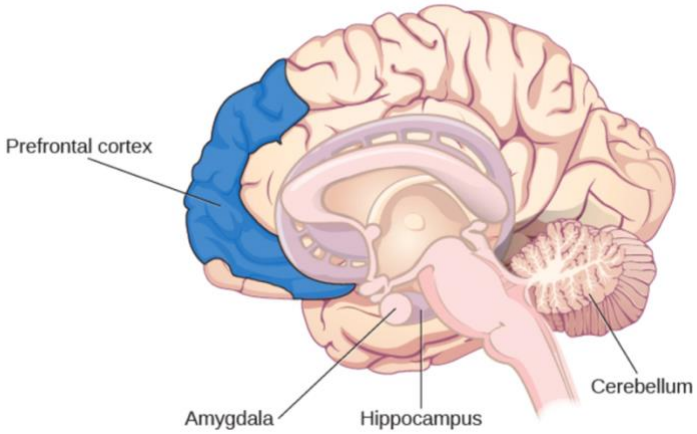

Figure 5. Part of the brain involve in memory /Source: [18]

Manipulate the Memory

There is a scene in a Netflix series named Black Mirror about a memory chip brain implant that allows users to record events they see and hear, then they can replay events. In reality we are getting closer to that state than we realize, since we already understand very well how memories are created and stored in the brain. Recently neuroscientists from MIT found that Beta waves in our brains play a major role in switching between different pieces of a message. The explanation seems to be that Beta rhythms work as a gate, which decides what information will be read out and cleared out, while Gamma rhythms are directly related to storing and retrieving sensory information [20].

Once scientists learned how and where memories are stored, they wanted to know if it could be manipulated. They proved that emotionally important memories were able to be removed in mice. By taking out a set of brain cells in the part of the brain that associates with feeling and emotion (the amygdala) and they could remove a specific memory associated with the fear of receiving an electric shock. In another study, scientists were able to use optogenetics to implant a memory of pain and fear in mice. Optogenetics is a technique combining light and genetic engineering to control brain cells. In the future the ability to manipulate memory will be able to help remember important information and eliminate painful experiences [21]. Some scientists prognosticate that within five years we will be able to record brainwave signals to build memories, edit, expand, and perhaps modify them, and then put them back into our brains. Possibly within 20 years, memory boosting implants and extensive control over memories may be possible with Neuralink [22].

Even though the development of Neuralink will benefit a number of health care devices, it may be an open door for abuse and exploitation. In 2012, a group of researchers, Ivan Martinovic of Oxford University; Doug Davies, Mario Frank, Daniele Perito, and Dawn Song of UC Berkeley; and Tomas Ros of the University of Geneva carried out an experiment on a wearable-brain-computer-interface by using consumer grade headsets. When tracking brainwave signals, P-300 brainwaves (event related potential) can leak out personal data such as passwords, PIN codes and credit card information [23]. P300 refers to a peak latency of a brainwave signal that spikes in activity approximately 300 milliseconds after stimulation, and it occurs only when the subject of the experiment engages in the task [24]. When researchers asked people to recall their Automatic Teller Machine PIN codes, they got the right answer the first time at the rate of 20%. People can guess the correct answers about 30% of the time for questions related to their living area, and even 60% for recalling birthdates. The results suggest that observing P300 brainwaves can leak sensitive information from users. Attacking bank accounts, credit cards and stealing information from companies can leave victims in financial ruin. Now there is a new cybercrime that can lead to physical misery— medical device hacking.

Implanted pacemakers normalize heart rhythms and save many lives. In 2006, pacemaker devices started to have networking capability. Scientists designed them to communicate wirelessly so that patients do not have to undergo surgery when the devices need calibrating [25]. Wireless networking capability can significantly improve health care with implanted medicals devices such as artificial pancreases, insulin pumps, and neurostimulators, but without an understanding of what the attackers can do, and lacking knowledge of security risks, implanted devices can be very dangerous.

In 2016, Marie Moe, a computer security scientist who is also a patient said, “When we add software to a device, we make it hackable and when we connect devices to the internet, we make them exposed.” She started a pacemaker hacking project to hack her own heart, and in so doing, she understood that many fears about technology are true [26]. A hacker can take over all communication of the devices, turn them off and make them malfunction, including falsifying information from the implant to the doctor. In some experiments, the hacker can even drain the battery [22]. In fact, in 2017 the Food and Drug Administration recalled 465,000 implantable cardiac pacemakers due to potential security vulnerabilities they

discovered. Hackers would be able to reprogram the implanted pacemaker, which could result in patient harm from rapid battery depletion and inappropriate pacing [27].

In 2019, the world's first cyborg, Neil Harbisson, an artist who was born with achromatopsia (also known as total colour blindness) underwent surgery to implant an antenna in his head in order to hear colours through vibrations to his skull. On a TV programme called Roundtable, Neil commented that he feels all activities have risks, all sports have risks, cultural events have risks. In the same vein he took a risk, but the results are much more interesting, and the risk is paid off by the exploration of a new sense in his body. He also revealed that one time someone hacked his implant and sent the wrong colour into his head, but he did not find it a bad experience. Maybe this can be regulated by new cyborg laws [28].

Many more speculations can be done in regard to Neuralink, mass manipulation, erasing memories of political events, as well as rewriting thoughts with conflicting information to make people support political views without their knowledge and consent. Criminals could steal memories and sell them, or they could alter them and create a new history. An attacker could possibly seize control of Neuralink users, lock or threaten to destroy them until they pay a ransom, or do something like force them to be a scapegoat, killer, slave etc. Neuralink has just started its long journey of evolution— because of the difficulty of human trials most of the work has been done in the lab, so it is hard to test software vulnerability. All that can be done now is to compare and learn from other already available and approved medical devices.

4.3 SOCIETAL ADVANTAGES OF THE NEURALINK

Before starting this section, it should first be pointed out that these advantages could also pose as disadvantages, depending on the angle from which is analyzed. This section will offer an opposing view to previously discussed topics throughout this article. Other scenarios referring to affordability are not explored in this segment. Most of the scenarios discussed here are based in the longer-term category where it is far in the future where we assume everyone at this point has it.

There are plenty of social advantages related to Neuralink, including many positive outcomes from both long-term and short-term. Long-term advantages that will be listed/mentioned are the advantages that could potentially arise further into the future, whether it is in the nearer future or in a more distant one. The short-term advantages referred to are the immediate outcomes you get right after the procedure and/or in a short period after it or in some years but not too far in the future. Here we are looking at scenarios of possibilities that could happen and could be advantageous from different people's opinions that were found while doing research, plus some that are also based on information already in this report.

Short-term outcomes

Firstly, the short-term outcomes will be discussed. Here the first and most immediate advantageous outcome from the Neuralink's procedure is the same reason that, Elon Musk states, is the purpose of the creation of this device. Elon musk has stated that the purpose for the device is to "Solve important brain and spine problems with a seamlessly implanted device" (Neuralink Progress Update, Summer 2020 on YouTube). This would mean that

problems varying form memory loss, hearing loss and blindness to seizures and even brain damage. As mentioned previously in the section about BCI, the Neuralink will be able to help people with disabilities as well, as mentioned previously in the report in the section about BCI will help with: 1. speech impairment and in paralysis, 2. prosthetic limbs. All mentioned before.

Long-term outcomes

It has already been said that Neuralink will be able to help people with disabilities communicate via technology to have a computer do the speaking or writing of their thought. It is not too far off to also think that with this advancement and the fact that (the technology is also linked to the internet and has many impressive features), that these features could further advance and make verbal communication go extinct. There could be a possibility that these advancements change the way humans communicate all together according to The Oxford Student [32]. This would add to the efficiency of our species and make things a little easier for people and make then use a little less energy from what they would have usually used to use oral speech. This would also greatly benefit the individuals who already have speech impairments and have gotten the procedure done to help aid them with communicating with others. Non-verbal/non-oral communication would also help remove the alienation that might arise towards these individuals.

Answers on Forbes from Quora gave some interesting possibilities for how the Neuralink could affect society in the future, and touched on this saying that it is a possibility to have mind-based communication [33]. To add to this idea, it could even be possible to share emotions more efficiently. Forbes mentioned how it could even lead to people being able to go to school in a different way instead of the traditional way where you are taught and have to read and process that information in your sensory feed. This method is by letting “the interface direct experiences and thought into the consciousness”. This means easier and faster way to get educated and less recourses. This would mean it is efficient for the individuals and also an improvement for the environment[33]. Even before reaching this stage, the rapid information access would improve school for students allowing them to do things easier or better, such as research for school[33].

More of the ideas from the Forbes list based on Quora answers were job related. It makes sense that a device like this would even come to play in this aspect of society in the future.
Firstly, a new profession could be created from. With the mind being more progressive, it could create things such as mind workers, with less training as the information can be sent into our brains[33]. Forbes did not specify what jobs mind-workers would be doing, but since this is all hypothetical/theoretical futuristic thing, no one really knows the actual possibilities, but it very much could be a possibility to work and have a job in this future where all you do and use is your brain and where the only requirement needed is to have the device and with it a high functioning brain.

Another point they made was the fact that with jobs being highly affected by the heightened brain power gained by having the device, there would no longer be an issue of robots taking up jobs from humans but instead make broader employment of humans[33]. The Neuralink could also possibly be able to fix economic problems in the long run, like low levels of productivity and labor market polarization decreasing the inequality to some extent[33].

Lastly, a good point that was made, is also that feelings and thoughts could potentially become products that can be sold and exchanged, creating a new form of entertainment and media[33].

From an ethical standpoint on social advantages of the Neuralink, these all align with the common good approach since they all benefit society as a whole and can be seen as a major improvement for society. The main reason for this is because it is social advantages, and this section mentions positive effects on society and will therefore be good for these approaches. The possible long-term positive outcomes/advantages fit really well with the common good approach, more specifically, because these advantages are more specific to communities by being mostly related to education/jobs and communication and are all about advancing these aspects of the community. Even with these advantages being community focused, they also affect the individuals. They will affect and improve individuals' daily lives and therefore goes well with the rights approach, as these points are about improving these aspects of their lives and making them more efficient.

4.4 ADVANTAGES AND DISADVANTAGES OF NEURALINK FOR THE COMMUNITY

As mentioned before, when it comes to good-common approach ethical views it is imperative to consider the well-being of the community as a whole. Thus, what role will Neuralink play for the community? Will this newly developed technique become the doorway to a new and improved civilization, or the complete downfall of human rights and equality? This section will hypothesize on the possible advantages and disadvantages of Neuralink and the effect it might bring to the individuals and society as a whole. Given that Neuralink is a relatively new technology and, to date, knowledge about its capabilities is still being released, this article intents to describe hypothetical situations that might come to pass with the use of the software, and these might be taken from similar situations in the past.

A common worldview is anthropocentrism, meaning that everything is nature is seen from a human-centered mindset, and therefore considered to be superior to the rest of the organisms. However, with new brain technology such as Neuralink, many questions whether or not humans will continue to remain humans or become cyborgs. If so, would the anthropocentrism theory still apply? Our discussion will begin here, with the need of humans to continue evolving themselves and the implications it brings to do with the use of technology.

For millions of years, humans have been evolving from Australopithecus afarensis[2] to homo sapiens[3] able to stand erect, full critical thinking, and travel the world faster than any other species on Earth. This was made possible with the aid of technology. Though not all has been smooth sailings. Technology has shifted the way humans behave and think throughout history and continues to do so as the years go by. Let’s compare last century humans to the current twenty first century generation. Back in the 1800’s the fastest way of communication was to send handwritten letters or use telegraphs in urgent situations and long- distance recipients. In today’s society, anywhere in the world is reachable thanks to internet connection, and the

[2] Australopithecus afarensis: one of the longest-living and best known early human species in evolutionary history

[3] Homo sapiens: A non-extinct species to which all human being belongs to

smartphone. One might say, today's humans are more advanced thanks to the technological inventions in the past years.

So, how does Neuralink relate to this topic and would using it render natural evolution useless? Today's society humans are carrying some sort of technological device outside of their bodies at most times, such as a cellphone, Bluetooth, pocket wi-fi, an iPad or/ and even a computer. Let's hypothesize and assume Neuralink might replace all of these different devices and the chip implanted inside of the brain would be able to perform all of these functions by a mere thought. Imagine not having to use hands to draw digitally, but it can all be done with the power of the Link and the mind. It would certainly put an end to the whole "how come it is different from what I imagined" argument withing the artist community! This would take human superiority to a whole new level and creating an even bigger gap between human abilities and that of any other species. As a community, a device such as this might be beneficial not only for the accelerated tasks one might be able to perform, but to shift the world to a more equal civilization.

When the word Neuralink comes to mind, one directly thinks of brain implantation and the thought of total control over the human mind. However, before one can begin thinking of total world domination, it is important to know that, to date, Neuralink is meant to be used as a medical tool to help those with mental issues and diseases. Neuralink's objective is to create a means to make basic needs accessible to those who do not have the abilities. This is an extremely gallant move from the company and highly beneficial use of the technology for society. Currently, there are many different technologies, being developed in order to help those with physical and mental disabilities integrate to society better and perform everyday tasks. A great example is how humans have been using technology to create robotic prosthetics that allow those with disabilities to perform regular actions such as walking, climbing stairs, reaching and lifting heavy objects. The human race will always try to push forward and find solutions to their problems; and thus, technology might be just the tool needed to achieve this.

That is Neuralink's intention up to date, but let's venture farther into the future and discuss whether or not its results will be overwhelmingly good or bad. When discussing the beneficial or possible damaging repercussions of a technology that it is at its infancy, imagination is the only limit to the many possible outcomes; and must contemplate the mindset of those receiving such technology. There are two mindsets when approaching a problem, the optimist and pessimist view. While some might choose to look at Neuralink as a problem solvent technology, others might consider it a risk to their customs and way of life. Society, as one, tends to lean towards a more pessimistic approach when it comes to decision making. Thus, things tend to take longer to be released, and multiple check-ins are required when it comes to technology and its usability.

Safety is one of the biggest concerns when it comes to technology, especially one with a direct connection to the brain like Neuralink. For an optimistic society, the aforementioned benefits will weigh out the possible risks as long as the results are as promised. Therefore, the technology is known to flourish greatly and improve faster than in a pessimistic or closed-up society. Optimistic societies often come from democratic countries where the technology can be fully transparent since its beginnings, and the public can openly inquire about it. From a

societal point of view, liberal countries will also protect the users against any abuse in regard to technology like Neuralink through the use of legislation. Though, up to date, governments have not meditated often with issues such as these, in the future it could be possible laws will be created to prevent the abuse of Neuralink technology. Companies might be obliged to hire competent people with or without the Link. The latter can pave the way for a generation who opted to divorce from their biological roots and of advanced professionals, able to perform tasks faster and accurately.

Subsequently, in a pessimistic and authoritarian society, the results can vary greatly. The community will tend to question the validity of the product, and be more sensitive to the cons. A pessimistic society will be more cautions towards their approach and contemplate whether or not the benefits of Neuralink truly benefit the community as one. For example, while Neuralink can offer a solution to mental disabilities, the stability of the product becomes a key concern. Would the technology hold in the long term? It might be difficult to compromise to something that will lose its effect, or malfunction often as it will bring more discomfort to the user than comfort. Previously, the risk of implantation has been discussed, but what about the maintenance of the Link? Current health risks can change in the future, so would Neuralink be able to keep up? Unpredicted head trauma aside, if Neuralink is not able to maintain itself remotely, users might be subjected to unnecessary brain surgery. If Neuralink gives hearing ability to those with a hear impairment, but the user refuses to undergo such severe maintenance in fear of the risks, then they will lose their hearing again. This could pose as a threat in a society where the majority are Neuralink users, as not only those with disabilities would lose their benefits, but have been left with less options than before as the community matured around something they can no longer use.

Rights play a big role in authoritarian societies, as it gives additional opening for the technology to be abused by those in power. Organizations can use the software to spy on their people in a more closely matter, disrespecting their privacy. As its now known, memories can be altered, and Neuralink could potentially become a tool for brain hacking domination, and the spread of false information, creating a future controlled by hackers, and those with access to the technology. It can also become a preference issue, where all children must have the Link implanted since birth as it is common for non-Jewish parents to perform a circumcision on their sons.

Neuralink can also play an important role in the economics status of a country. It is difficult to speculate where the money would come from or create a cost analysis with the information we have. However, if we postulate further and imagine Neuralink has been established beyond its medical uses, what stops the company and/or government itself to use it for an economical advantage? Given that the implantation method is extremely intricate, and a surgical robot will be used instead of a neurosurgeon, implanting the Link will be costly. For the same reason, would this procedure be considered a medical one and be covered by medical insurance (in non-universal healthcare systems)? Most likely, the procedure will be treated as an aesthetic one and will either fall under some special branch of medical insurance, or a loan system will be used. It is a known issue, some big technological countries abuse their popularity to increase their value. This is common in the smartphone industry, where planned obsolescence plays a role. The devices have been purposely made to last a certain amount of time and need replacement just when a new product comes into the

market. Neuralink could be no exception to this. As the technology matures, and different companies mirror the Link, Neuralink could purposely come up with new and improved versions of the Link every certain time to remain relevant and increase revenue. Planned obsolescence within Neuralink will be specially damaging to its users given the device is already inside their bodies.

So far, social repercussions and safety, either health or cyber related, have been discussed within the limits of the imagination for the future of this technology. There are some essential points for which we will hypothesize using results from past and current research, data manipulation and social engagement. One imagines Neuralink will bring a utopian world capable of reforming modern thinking individuals, and this was also thought with the development of internet and media in 1990 [29]. Yet, humans turned more vulnerable to the mass of information and instead of evolving into smarter individuals, they have become easily manipulated and defensive. There is a Korean series names “Fiery Priest” which plays out a similar situation. In short, after the assassination of a priest and a threat of information about the murder getting out to the media, the responsible partly decided to use the public’s opinion in their favour. By using one truth, covered by many lies they managed to turn the public against the innocent party and sympathize with them instead. On one of the episodes the prosecutor talked about the maneuverer and it roughly translates to: “Even when they (the public) are informed of the truth later on, they never admit that they were fooled. Why? Because it is humiliating. They go even further than that and attack the truth instead.” [30] Neuralink would have a direct access to the user brain, meaning that the vulnerability humans experience now with their phones as an accessory could become overwhelmingly worse if the data is fed directly into their brain. Data could be manipulated into a target audience given their likes, dislikes, and social patterns; possibly affecting the overall critical thinking of Neuralink’s users and rational behaviour of future generations.

With the maturity of media, internet, and smartphones there has been a growing trend amongst society, allowing them to be physically present yet mentally away called “absent presence”. This is due to the ability to use technology at any moment during any situation. A study by Georgetown University’s Psychology department researched the decrease of smiles between strangers when introducing themselves, or in regular conversations due to constant access to smartphones [30]. Since Neuralink offers a direct man-machine connection, society could risk losing basic behaviours needed in social interactions. When placed in a room together or faced with uncomfortable/boring situations, instead of sparking a conversation among each other, Neuralink users might opt to access their phones and un-attach themselves from the environment they are in. The 21st century generations are considered to be more “distant” and unattached from each other than the previous generations. If Neuralink works as a means to a more technologically driven environment, the gap between human behaviour and social conduct will continue to expand.

4.5 ETHICAL DILEMMAS OF USAGE OF NEURALINK OR SIMILAR TECHNOLOGY FOR MILITARY/SECURITY PURPOSES

Privacy is a much-discussed topic not only in connection with the internet and computers in general. Nowadays, people value privacy, especially on the internet. Misuse or theft of

sensitive data has been and remains a big problem, that is why EU made "The General Data Protection Regulation", more commonly known as GDPR back in April 2016 (fully implemented May 2018) [34]. Even though it was a huge step towards data protection/user protection some things still remain undefined or undone. Bigger problem for everyday user can occur in regards with military usage and/or security purposes.

As mentioned in *"Brain-computer interfaces: military, neurosurgical, and ethical perspective"* paper published by Ivan S. Kotchetkov B.A. and collective in May 2010 [34], the implementation of BCI into military sector is already in progress. Researchers pointed at Pentagon's DARPA (The Defense Advanced Research Projects Agency) projects which are based on noninvasive BCI's and its use as "Silent Talk" that aims to develop user-to-user communication on the battlefield through EEG signals of "intended speech" or enhancements of soldiers' perception and control of vehicles or heavy machinery with BCIs are also within the realm of possibilities.

Even though researchers point out few ethical concerns as well as concerns which are related with its implementation (surgery, while talking about invasive BCI's) the research and development of such technology is still going, according to DARPA's publicly available documents.

Military vs. Common goods approach

Speaking entirely from definition of Common good approach [35], BCI is a completely valid and useful technology as long as all members of the community/society will benefit from it. More specifically we can speculate security advantages will be significantly higher on scale of importance and therefore it will be just logical to implement such technology to society for security reasons. In military, as mentioned in the ***"****Brain-computer interfaces: military, neurosurgical, and ethical perspective****"*** [36] paper, the advantages are very obvious and therefore we can see that organizations such as DARPA are already trying to use this technology to get tactical or overall military advantage. This can be seen as very relevant and important for whole community and so from the approach point of view this can be taken positively.

Problems will most likely take place when people begin disagreeing with this approach. The common-good approach does not acknowledge freedom to choose for individuals, therefore at some point it could become mandatory for everyone to have such device. This could be due to whole society is benefiting from it, but in some cases, it might not be on board with the idea and/or potentially refuse Neuralink technology altogether. Similar effects we can be observed today on similar problems like vaccination. Many people refuse to get vaccinated themselves or their children due to beliefs of government manipulation with their bodies. It is believed in these cases that the government is purposely implanting micro-chips, and in some cases, individuals simply refuse to believe that the vaccination is meant for immunity purposes and nothing else. Thus, we can realistically assume that similar things will eventually be happening with BCI's.

Military vs. Right approach

On the other side of the scope the rights approach focuses on human dignity and dignity is based on our ability to freely choose how to live our lives [37]. As discussed in previous sub-

chapter about common-good approach, many people can have more individualistic point of view on usage of BCI's. This will most certainly effects military/security sector as well. The implications of usage of BCI's may be frightening. While talking about invasive BCI's some may point its dangerous surgery or even unknown psychical consequences.

This approach still has some positives. First, people can choose if they want such device or not. Furthermore, in security/military this approach may ensure more honorable approach towards its people and therefore lower moral obligations. Let us imagine for a moment following possible future scenario. In a not far future might majority of people have some kind of BCI device implemented, for reference with today's world we can think of smartphones. In military we could see various types of different BCI's which will correspond to different tasks. It will definitely have big tactical, medical or other benefits which we can already see today in published documents, for example from DARPA. On the other side, question remains if this is the future we want to live in? The negative effects of usage and implementation are very severe. For example psychological trauma, medical threats, potential of damage after "hacking" someone's brain and of course the ethical implications of usage such technology from which some might point if it will not be misused on civilians for tracking, monitoring and other frauds against privacy of citizens.

On the end note the common good approach will be more logical approach for military usage in comparison with the rights approach but it all depends on future development and standpoint of governments and other instances.

5. Conclusion

There are a number of interesting points to take into consideration when we look at the ethical concerns and consequences of Neuralink. The main goal of Neuralink's Link was to read brain activity and allow its user to control a computer or machine at any time. In this article, the possible outcomes of Neuralink technology have been discussed through a normative ethical approach and areas such as health risks, social risks, cybersecurity risks including advantages/disadvantages to community. The potential abuse of the technology when it comes to the military sector, and government branch were also studied. Given the infancy of the technology, analysis and, therefore, the following conclusions were based on speculation and possible hypothesis.

Even in its infancy, it is agreed that Neuralink technology will become a gateway to a future in which generations can perform tasks as accurately as machines. Subsequently, there are societal outcomes which will affect the different aspects of lifestyle, such as individual's health, rights to privacy and equal treatment, and safety. Even though there is some percentage of health risk, the advancement of medical technology can lower the risk of brain surgery for people without pre-existing medical conditions. In the future, we can expect robot performed surgeries to heal faster and be the least minimally invasive, so, though important, health risks will most likely not be amongst the biggest concerns of Neuralink.

It is possible that Neuralink technology will create inequality within society, as it has happened with similar technology like computers, smartphones, and electric cars. Early adopters tend to be within the first people to obtain and afford technology. Therefore, given the ambiguity of economic cost for Neuralink, it is possible the latter will be the first ones who can access it. As time goes similar technology will be released and the price could either decrease or increase depending on the popularity of the technology and the company.

Everything that is connected to the internet can be hacked, when technology advances, cybersecurity needs to be uncompromised, data encryption is required, implants need to have software backdoors and override capabilities in case of medical emergency. Healthcare professionals who work with implants need to have a good understanding and awareness of cybersecurity practices, and we need as yet unparalleled collaboration between healthcare and IT security to build security into medical technology as it develops, or we may experience unparalleled disaster.

For the societal advantages and disadvantages of Neuralink for the community, it looks like there could be both amazing improvements to society and also concerns related to communities. For the individuals, the link could possibly make more aspects of society more efficient and even contribute to it further. Things such as school and work will become easier and more advanced as well as new type of jobs could be created making higher employment for people. Even things like communication will become more efficient and take less energy. Overall, looking at the communities as a whole, whether Neuralink is good or bad for the society depends on whether it is an optimistic or pessimistic society. Pessimistic/authoritarian societies will be more cautious and things such as if it needs continuous maintenance and how people of authority or power could possibly abuse it, could be a concern. In general,

these society concerns are based on physical safety of the implanted device and the non – physical concerns such as socialization decrease between humans with the increased use of the Neuralink.

We cannot say with certainty that Neuralink or any other similar BCI device will or will not be misused for military and security purposes but from our research we can conclude that the usage of BCI's have very severe implications in near as well as in the far future which can be inappropriate or, worse, completely wrong and against human rights. Looking at how things are going right now we can tell how the immediate outcomes will be, which is that individuals who need the device for medical reasons and works with the rights approach. For long term effects, it will all depend on how the people of the future apply this device in ways other than the medical one and how people handle it in reference to things like hacking.

Looking at these form an ethical standpoint would show that individuals would be benefiting in some aspects, however, even looking from different possible applications of Neuralink, there could be many repercussions alongside these benefits and improvements. Therefore, in some cases, the Neuralink being applied in communities will comply rather with the rights approach, not necessarily with the common-good approach. Looking at the societal advantages, individuals benefit significantly meaning it complies with the rights approach and common good approach but focusing on the points of the advantages and disadvantages of Neuralink for the community, it will not comply with the either of the ethical approaches. From how the device is planned on being used currently for the near future, it both works with the common good approach and the rights approach. It allows people with disabilities to overcome the disability while the surgery seem safe enough to be done.

6. Bibliography

[1] A. Kulshreshth, Abhinav & Anand, Abhineet & Lakanpal, "Neuralink- An Elon Musk Start-up Achieve symbiosis with Artificial Intelligence," pp. 105–109, 2019.

[2] J. Miśkiewicz, "The Merger of Natural Intelligence with Artificial Intelligence, with a Focus on Neuralink Company," *Virtual Econ. 2*, no. 3, pp. 22–29, 2019.

[3] M. J. M. Manuel Velasquez, Claire Andre, Thomas Shanks, S.J., "What is Ethics?," *Markula center*. .

[4] "Type of Ethics," *Internet Encyclopedia of Philosophy*. [Online]. Available: https://iep.utm.edu/ethics/.

[5] Khemka, Pradyumn. (2020). Contemporary Ethical Theories A comparison between decision making and ethical decision making. 10.13140/RG.2.2.18971.41762.

[6] J. R. Wolpaw, "Brain-Computer Interface," *Encycl. Neurosci.*, pp. 429–437, 2009.

[7] M. Vilela and L. R. Hochberg, *Applications of brain-computer interfaces to the control of robotic and prosthetic arms*, 1st ed., vol. 168. Elsevier B.V., 2020.

[8] A. R. Page, "Meet the Guys Who Sold 'Neuralink' to Elon Musk without Even Realizing It," *MIT Technology review*, 2017.

[9] D. Mckissen, "How Elon Musk's Neuralink could end up hurting average Americans," *Scipol*, 2017.

[10] A. Roger, "Here's How Elon Musk Plans to Stitch a Computer into Your Brain," *WIRED*, 2018.

[10] "Neuralink Launch Event live stream," 2019.

[11] N.d., "Science-Neural link," 2020. .

[12] J. Agorelius, F. Tsanakalis, A. Friberg, P. T. Thorbergsson, L. M. E. Pettersson, and J. Schouenborg, "An array of highly flexible electrodes with a tailored configuration locked by gelatin during implantation-initial evaluation in cortex cerebri of awake rats," *Front. Neurosci.*, vol. 9, no. SEP, pp. 1–12, 2015.

[13] V. S. Polikov, P. A. Tresco, and W. M. Reichert, "Response of brain tissue to chronically implanted neural electrodes," *J. Neurosci. Methods*, vol. 148, no. 1, pp. 1–18, 2005.

[14] A. J. Fenoy and R. K. Simpson, "Risks of common complications in deep brain stimulation surgery: Management and avoidance - Clinical article," *J. Neurosurg.*, vol. 120, no. 1, pp. 132–139, 2014.

[15] W. Glannon, "Ethical issues with brain-computer interfaces," *Front. Syst. Neurosci.*, vol. 8, no. JULY, pp. 1–3, 2014.

[16] P. A. Abhang, B. W. Gawali, and S. C. Mehrotra, *Technological Basics of EEG Recording and Operation of Apparatus*. 2016.

[17] "How are memories formed?," *The university of queensland*. .

[18] Rober, M. (2018, January 03). ARCADE SCAM SCIENCE (not clickbait). Retrieved December 17, 2020, from https://www.youtube.com/watch?v=vXBfwgwT1nQ

[19] M. P. Kathryn Dumper, William Jenkins, Arlene Lacombe, Marilyn Lovett, "Parts of the Brain Involved in Memory," in *Introductory pschycology*, .

[20] A. Trafton, "New study reveals how brain waves control working memory | MIT News," *MIT News*, pp. 2018–2021, 2018.

[21] D. Noonan, "Meet the Two Scientists Who Implanted a False Memory Into a Mouse," *smithsonian magazine*, 2014. [Online]. Available: https://www.smithsonianmag.com/innovation/meet-two-scientists-who-implanted-

false-memory-mouse-180953045/.
[22] “The Memory Market : Preparing for a future where cyberthreats target your past,” no. October, 2018.
[23] I. Martinovic, D. Davies, M. Frank, D. Perito, T. Ros, and D. Song, “On the feasibility of side-channel attacks with brain-computer interfaces,” *Proc. 21st USENIX Secur. Symp.*, pp. 143–158, 2012.
[24] T. W. Picton, “The P300 wave of the human event-related potential,” *J. Clin. Neurophysiol.*, vol. 9, no. 4, pp. 456–479, 1992.
[25] H. Burri and D. Senouf, “Remote monitoring and follow-up of pacemakers and implantable cardioverter defibrillators,” *Europace*, vol. 11, no. 6, pp. 701–709, 2009.
[26] “This woman hacked her own pacemaker to show how vulnerable we are to cyberattacks,” *world economics forum*, 2020.
[27] “Firmware Update to Address Cybersecurity Vulnerabilities Identified in Abbott’s (formerly St. Jude Medical’s) Implantable Cardiac Pacemakers: FDA Safety Communication,” 2017. [Online]. Available: https://www.fda.gov/medical-devices/safety-communications/firmware-update-address-cybersecurity-vulnerabilities-identified-abbotts-formerly-st-jude-medicals.
[28] B. Coulson, “BRAIN IMPLANTS: What next for neurotechnology?,” United Kindon, 2019.
[29] Andrews, Evan. “Who Invented the Internet?,” December 18, 2013. https://www.history.com/news/who-invented-the-internet.
[30] “열혈사제.” SBS. Accessed December 17, 2020. https://programs.sbs.co.kr/drama/fierypriest/main.
[31] Kushlev, Kostadin, John F. Hunter, Jason Proulx, Sarah D. Pressman, and Elizabeth Dunn. 2019. “Smartphones Reduce Smiles between Strangers.” *Computers in Human Behavior* 91 (June 2018): 12–16. https://doi.org/10.1016/j.chb.2018.09.023.
[32] A. Lahiry, “Will Elon Musk’s Neuralink Shape The Future Of Humanity?,” 2020.
[33] Victor Xing, “How Might Elon Musk’s New Neuralink Business Affect Society?,” *Forbes*, 2017. .
[34] GDPR Archives. (n.d.). Retrieved December 17, 2020, from https://gdpr.eu/tag/gdpr/
[35] Kotchetkov, I., Hwang, B., Appelboom, G., Kellner, C., & Jr., E. (2010, May 01). Brain-computer interfaces: Military, neurosurgical, and ethical perspective. Retrieved December 17, 2020, from https://thejns.org/focus/view/journals/neurosurg-focus/28/5/2010.2.focus1027.xml
[36] University, S. (n.d.). Ethical Decision Making. Retrieved December 17, 2020, from https://www.scu.edu/ethics/ethics-resources/ethical-decision-making/
[37] Brown University. (n.d.). Retrieved December 17, 2020, from https://www.brown.edu/academics/science-and-technology-studies/framework-making-ethical-decisions