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| Brain Computer Interfaces |
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# Introduction

This report will be on the emerging technology Brain Computer Interface (BCI) [1]. BCI is the direct communication pathway between the brain and an external device. This is a research and development technology that aims to create applications and solutions to improve the quality of life of human beings, specifically those with disabilities. This report will cover what BCI is, what makes the technology successful, rival technologies and the implication of this technology on everyday life.

# What is BCI?

BCI is an emerging technology that uses the brain to have a direct communication with computer devices, usually connecting through the brain or nervous system. The signals that are used for BCI are; EEG [2], ECoG [3], LFP [4], Single Units [5]. EEG (Electroencephalography), which is the most common signal, is the recording of electrical activity along the scalp. This is the signal which is used in most of the devices this report will talk about. ECoG (Electrocorticography) is the recording of electrical activity from the cerebral by placing electrodes on the surface of the brain. LFP (Local Field Potential) is a particular class of electrophysiological signals. Single Units is a method to measure the electrophysiological responses of a single neuron using microelectrode systems. LFP and Single Units however are more commonly used on animals such as mice therefore the technology in this report will be using mainly EEG or possible ECoG.

There are four types of BCI; Invasive BCI [6], Non-invasive BCI [7], Partially-invasive BCI [8] and Neuroprosthetics [9]. Invasive BCI is a BCI that is directly implanted into the grey matter of a subject's brain via neurosurgery. These produce the highest quality signals but are prone to scar tissue. Non-invasive BCI is a BCI that does not require surgical implantation; this is usually done with an EEG cap or headset. Partially-invasive BCI is a BCI implanted into the skull but not into the brain. Neuroprosthetics are implanted devices that are designed to improve or replace a certain function of the central nervous system. Neuroprosthetics applications aim at restoring damaged hearing, sight and movement. Due to the brains cortical plasticity signals from implanted prostheses can be handled by the brain like a natural sensor.

As well as being an interface between the brain and a computer it can be used to relay signals from the world straight to the brain. An example of this is with disabilities such as blindness. BCI will allow the person to see like any other person through the use of a camera device. The way this works is the scientists find the specific signal for each colour. Then for the BCI technology to work the person will need to have a chip implanted to their brain which will relay the signal from a camera device straight to their brain in the same way their eyes would. This type of BCI is not to be confused with the similar neuroprosthetics. Neuroprosthetics and BCI have similar devices and many neuroprosthetics are a type of computer interface however the difference is in the way the computer device connects with the user; Neuroprosthetics connects to the nervous system only whereas BCI mainly uses the brain itself. Another difference is their purpose; neuroprosthetics’ purpose is to aid or return a sensory function through devices e.g. a person’s hearing has decreased severely and through a device called a cochlear implant, which is similar to a hearing aid but is implanted in the cochlear itself, which provides a sense of sound to a person who they can resume normal life. BCI would look for the specific signals the brain receives and whenever a hearing aid type device pick up those sounds it would tell the persons brain the signal replacing the ears completely.

# Objective of BCI

The objective of BCI is the creation of applications and solutions to improve the quality of life of human beings. BCIs are often aimed at assisting, augmenting, or repairing human cognitive or sensory-motor functions. There are many examples of the different methods used such as; Deep Brain Stimulators [10], BrainGate [11], Cochlear Implant [12], Cursor Control [13]. Deep Brain Stimulation (DBS) is a surgical treatment where a device called ‘Brain Pacemaker’ is implanted into the brain. In select brain regions DBS provides therapeutic benefits to treatment resistant movement disorders such as; Chronic Pain, Parkinson’s Disease, Tremor and Dystonia, through the use of electrical impulses. DBS directly changes brain activity in a controlled manor and its effects are reversible. BrainGate is a brain implant designed to aid those with loss of limb control or other bodily functions. A computer chip is implanted into the brain and converts the thoughts or intention of the user into computer commands. A Cochlear Implant is an electronic device that provides a sense of sound through a surgical implant. The Cochlear Implant is implanted into the Cochlear itself. Although this is a neuroprosthetic, it still follows the objectives of BCI. Cursor Control is the ability to control cursor movement on a computer through the use of EEG either with a non-invasive devices over the scalp or to get better results and responses they user can have invasive BCI implants into the grey matter. Cursor control can be used for games, spelling applications or allow people with disabilities to communicate.

# What makes BCI an emerging technology?

I believe that this is an emerging technology as it is creating new ways to interact with computer devices and could be the new generation for interfaces, removing the need for physical interaction and allowing use to a wider public such as those with disabilities.

BCI started research in 1970 with 'Real-Time Detection of Brain Events in EEG' which was the first report by Jacques J. Vidal[14], the man who coined the expression 'Brain Computer Interface' for his research in biocybernetics and human-machine interface. BCI research that was then spurred on by DARPA (Defence Advancement Research Projects Agency) [15].

However BCI did not make a major advancement for humans until 2005 when a 25 year old quadriplegic named Matthew Nagel was the first person to be fitted with the BrainGate [11] Neural Interface. This advance would allow disabled people regain some freedom to their lives through the aid of the BrainGate. The next steps in BCI advancement were in 2009 with much advancement that would aid the disabled, the military and towards the commercial market. The first step for the disabled users came from a University of Wisconsin-Madison [16] student Adam Wilson who successfully posted a message on Twitter using a BCI. This showed that BCI could be used by disabled users on modern day communication tools.

Later that year Honda's ASIMO [17] robot was able to be controlled by thought and perform four actions. The demonstration first showed that this technology could be used by the military to have robotic soldiers that were controlled through BCI by actual soldiers or precision tasks such as bomb diffusions. This demonstration also showed the possibility of basic commands being incorporated into daily life situations e.g. changing TV channels or tuning on and off light switches.

Another step was the use of BCI to control a wheelchair from Nissan and EPFL [18]. The aim is to further wheelchair technology and hopefully incorporate the technology into cars. Another military view is from DARPA who initiated the 'Silent Talk' program [19] which had the goal to "Allow user to user communication on the battle field without the use of vocalized speech through analysis of neural signals". This is a similar research from the University of Southampton [20]. Conducted by Dr Christopher James the aim was to expand the limits of Brain-to-Brain (B2B), which allows a person to transmit their thoughts through the internet to another person. The technology however is not at a level where the person receiving the message can interpret the message without the aid of computer software.

On a commercial side there are a few different devices that can be used for games both real world and video based. On a real world based game a BCI headset or similar devices have been used to monitor the athlete to find new ways to improve them. One of the main consumer BCI products for video based games is from the company NeuroSky [21]. They are a BCI based company that currently have two headsets and many different applications. The main headset, MindWave [22], measures brainwave signals and monitors the attention levels of the user so that the user can perform mental tasks or computer games with their mind. The applications vary but all revolve around a meditation and concentration theme.

# Will BCI be successful?

Although BCI has been in research and development stage since 1970, there has only recently been an interest in university PhD students and BCI related companies. And even though BCI is currently a niche market, BCI does hold a large potential to be a successful product with many areas of the market to go in; gaming, vehicles, medical, military and other minor daily life activities. There are many large companies and organisations that are backing this new research which helps the advancement. Large companies such as Honda and Nissan, which are backing this technology for their vehicles or for their robotic research and DARPA, who want the technology for military purposes, will have a major influence on the success of this technology.

As gaming is advancing there are many new devices that can be used to enhance the game play and the immersion into the game. If BCI can be implemented into the gaming community then I believe this would give BCI a substantial boost to its progress and move it out of the niche market it is currently in.

I believe the technology will have the largest effect of the medical sector as BCI can be and is being incorporated into devices that will help to change the lifestyle of those with disabilities, giving them a new found freedom to their lives or returning the freedom the once had. Having BCI controlled wheelchairs has already been mentioned but there are many different prototype devices that could be used instead. Honda has not only focused about putting the technology into robots but has created other innovations towards mobility in humans. These innovations, which were developed for their ASIMO robot, such as the ‘Stride Management Assist’ [23] which are aimed towards those that can still walk but have weakened muscles. This innovation regulates walking pace and lengthens the users stride. Another innovation from Honda is the 'Bodyweight Support Assist'[23] which is used for those who encounter long periods standing or have repetitious lower body tasks. These innovations are aimed at user who can walk however if they were to be developed to be used by those who can't walk using BCI then this will be a very useful mode of transport or even be used to rehabilitate. Another medical innovations from Japanese scientists of Cyberdine Corporation and Professor Sankai of Tsukuba University is their development, HAL (Hybrid Assist Limb) [24], this is a solution to the handicapped, aging and for leisure activities such as hiking. There has been a significant demonstration from José del R. Millán, a professor at the Federal Polytechnic School of Lausanne [25], of a robot being controlled by a paraplegic man 37miles away using a non-invasive EEG cap. This shows a glimpse at the success BCI can have in the future.

For the military the organisation which will influence BCI the most is DARPA, they want this technology for their 'Silent Talking' program. Technology that would allow for a telepathy type communication would give an advantage that the military would not want to let slip through their hands.

As for a daily life situation, if BCI could be advanced to a point where everyone could get a simple chip in their head and remotely control devices around them such as TV remotes and light switches however BCI would have to first advance to the stage were anyone can have a simple chip and freely control devices.

I believe that having a product that can be used across multiple platforms and multiple devices such as smart phones, will allow a BCI company to achieve a successful product. The company could also create a product that could be used for different purposes such as industry, education, military or even leisure. For military training or leisure activities the device would have to be unrestricted.

The best current device at this time that relates to a successful product is the BodyWave with its multiple platform possibilities and it wide range of uses both mental and physical. It is also being used in education and the military as well as improving the lives of people with disabilities like Attention Deficit Hyperactivity Disorder (ADHD). Another reason that this product in particular differs from other similar product is that the company offer software that can help improve the user, which some of the headsets do, but Freer Logic includes free access to Attention Specialists who through telephone tutorials will provide help with the software and help analyse the user's data. The final point that this company even whilst having a newly created product have already started improving upon it and redesigning it in the form of a wristwatch which I believe will be popular as it would be a device design people would be used to and would be more comfortable than the current device.

# What are the rival technologies?

There are a few current BCI devices being sold that could be considered as rival technologies. The first is an America product from the company NeuroSky which aiming to develop non-invasive BCI for multiple applications such as gaming controllers to the games themselves as well as medical and education uses. The current peripheral devices they have can be used across multiple platforms. The design is simple with one dry sensor positioned on the forehead. Currently it is sold at $99.95 which is cheaper than most rivals and the multiple platform use is a persuasive factor.

A rival from an Australia company called Emotiv Systems which is also focused on non-invasive BCI and they created a peripheral for gaming on Windows PC’s called Emotiv EPOC [26]. This device is similar to the American product but varies in its design with more focus on the multiple sensors that are placed around the forehead. The cost is also more expensive than the MindWave at $300.

Another rival device is called Indendix [27] from the company G-Tec. This is a consumer product that is being tested to be used to control a Second Life [28] avatar, play a game of pong or make music in an orchestral setting. The product is at €9000 which is the most expensive out in the market.

A similar designed headset to NeuroSky's MindWave is XWave [29] by PLX Devices, which is a headset that is used on Apple's iphone, giving it a larger market than pc users. It cost is $89.95 which is cheaper than the pc type headsets.

A new BCI device release January 13th 2012 called BodyWave [30] from the company Freer Logic [31] is the first of its kind, measuring brainwave activity through the body instead of the scalp. Due to this new unrestricted technology the device can be place on the arms or legs unlike the EEG headset currently sold. The device uses three dry sensors that rest directly on the skin. It is used on both pc and mobile phones and used for more physical actives such as sport or military training. It is however more expensive than most headsets at $1,795 but with technology that isn’t bound to the head it could be the most successful on the market.

# Can BCI be implemented into daily life?

Although significant progress has been made in researching BCI technologies in recent years, the applications controlled by these interfaces have largely been designed for training or demonstration purposes and would not be too effective in real-world applications. The problems that would affect personal and work life overall are; information transfer rates, high error rate, autonomy and cognitive load. Information transfer rate or 'bandwidth' refers to the rate a message can be sent in BCI communication. The amount of words that can be typed is around three words a minute which will make communication very difficult and unnatural. If this could be increased to match or be faster than typing speed for the use on the internet side such as email. On a more face to face type of communication DARPA's “Silent Talk” project could potentially replace verbal communication with a telepathic type communication. High error rate refers to the brain signals the BCI would be uses which are highly variable and would cause lapses in the orders. This would make the BCI which should make certain activities easier unreliable. A situation where this would be bad is Honda's idea of combining BCI and vehicles. If I were to be driving a car with the aid of BCI and I am distracted then that could cause a car accident. Autonomy refers to the BCI system itself and how it requires more than the user to operate. BCI's original aim is to improve the lives of those with disabilities however when the system needs to be controlled by another it isn't making life easier. Even if the system could be controlled through BCI, if it is turned off the user wouldn't be able to turn it back on which is a large issue with current BCI. The last problem is cognitive load, an issue that relate to having daily life. Because BCI is tested in quiet laboratory environments where the user will be able to concentrate the result with differ from the real world where there are more complex situations that will affect the cognitive load of the task being performed, the emotional responses and interactions with others.

Due to these issues current BCI technology is not at a level where it can be implemented into daily life; however it is one of the most promising developments that could change how we live our lives. BCI can aid the personal and work related lifestyles in many ways. For personal lifestyles BCI currently offers a large range of headsets that offer relaxation/meditation type software and concentration type games. There could also be adverse affect from using these types of software as in some parts it forces the user to slow down their brain waves in order to achieve a task and cause trouble with focusing their attention. There is also the question of how BCI other than non-invasive affect the user. Although invasive BCI can rehabilitate with conditions that would be unresponsive to medical treatments such as Parkinson's Disease it could also have negative effects on the body like creating conditions the user didn't have before such as paranoia from the new feedback from their environment and their daily lives.

In work places BCI can allow the user to control the computer via the brain which could potentially improve the work output and reduce the errors created from typing however this could create more errors from fatigue and poor concentration from whilst working. How the user would be connected to the devices would also change how well it benefits the compatibility and usability. Whilst non-invasive BCI are able to be used the user would have a more improved compatibility and a more responsive work when using invasive or even partially invasive. This means that if BCI were to be incorporated into work the performance and quality of the piece of work itself.

# How will it affect daily life?

BCI can expand or improve many leisure activities both physical and non-physical. On the physical side there is now the use of BodyWave which can be used in sports to monitor the user's conditions throughout the activity, monitoring the mental stability and how certain organs e.g. heart, are reacting whilst training. Information such as this could help to improve the user or show where there is a problem.

On the virtual side games could advance in a way that allows the user to have a more real-time experience then this would open up the possibilities for BCI going from a headset to another peripheral device and possible even virtual reality. This would allow for an all new experience to games turning them into a simulation type/role playing game, and allowing the user to have a more immersive and enjoyable experience. This could however have negative effects on the users. The experience could be so realistic that it causes a neurological effect on the body such as heightened blood pressure. The immersion itself could cause the body to react as if it were in that exact situation.

Depending on how advanced BCI become it could have a large impact on society. For example if the devices instead of a headset or an armband become more invasive such as a chip that could be implanted into anyone then that could be both an improvement and a threat. It would be an improvement because it could have many different applications such as opening up the ability to do menial everyday tasks e.g. turning on and off light switches. On a more threatening side the chip, if inserted into the grey matter as most invasive BCI are, could be used as a weapon. If it were to be used as a weapon then it could be a very effective way. The chip, which normally controlled by the user, could be overridden by another users chip and cause harm or influence thoughts.

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