

The Efficiency and Usability of Human Computer Interactions with a comparison to a Brain Computer Interaction

by

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Project submitted as part of the requirements for the award of Master of Science in Software

Engineering (Web Development)



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For my Mother and Father and the sacrifices you have made for me

Declaration

I, Rhys Callum John Harding declare that I am the sole author of this project; that all references cited have been consulted; that I have conducted all work of which this is a record, and that the finished work lies within the prescribed word limits.

This work has not previously been accepted as part of any other degree submission.

Signed Rhys C. J. Harding

Date 06/02/2020

Form of Consent

I, Rhys Callum John Harding hereby consent that my project, submitted in candidature for the *M.Sc. Software Engineering (Web Development)*, if successful, may be made available for inter-library loan or photocopying (subject to the law of copyright), and that the title and abstract may be made available to outside organisations.

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Date 06/02/2020

Abstract

According to Moore's Law processing power and speeds are increasing with each year. Thus, it can be predicted that technology will continue to advance. Through most recent advances, modern technologies have allowed humans to reach a relatively impressive connective capacity. Although, many can argue we may not be connected enough. Human Computer Interaction (HCI) describes the way in which we communicate through interacting with a given device, an example being the smartphone. This interaction is bound by the speed at which us as a user can interact and how that device can interpret our communication. Here lies a marked potential, whereby the rate of information passed from Human to Computer can be greatly reduced. This reduction is proposed through means of communication via Brain and Computer, thus directly bypassing motor functions – Brain Computer Interaction (BCI). This project investigated the rate of communication through analysis of three HCI methods, keyboard, mouse and speech recognition technology. The results for these methods were compared to the results found for the time taken to communicate via a BCI electroencephalogram (EEG) headset. Further, user experience was analysed by means of Thematic Analysis. Through comparison of both HCI and BCIs, it was found that the more traditional mouse was the most efficient form of communication and the most comfortable input for users. Albeit, though not directly comparable, it has been suggested through the analysis of results, giving evidence to EEG being a potential to produce greater processing speeds, given the correct training, at a compromise of user practicality.

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Abstract

According to Moore's Law processing power and speeds are increasing with each year. Thus, it can be predicted that technology will continue to advance. Through most recent advances, modern technologies have allowed humans to reach a relatively impressive connective capacity. Although, many can argue we may not be connected enough. Human Computer Interaction (HCI) describes the way in which we communicate through interacting with a given device, an example being the smartphone. This interaction is bound by the speed at which us as a user can interact and how that device can interpret our communication. Here lies a marked potential, whereby the rate of information passed from Human to Computer can be greatly reduced. This reduction is proposed through means of communication via Brain and Computer, thus directly bypassing motor functions – Brain Computer Interaction (BCI). This project investigated the rate of communication through analysis of three HCI methods, keyboard, mouse and speech recognition technology. The results for these methods were compared to the results found for the time taken to communicate via a BCI electroencephalogram (EEG) headset. Further, user experience was analysed by means of Thematic Analysis. Through comparison of both HCI and BCIs, it was found that the more traditional mouse was the most efficient form of communication and the most comfortable input for users. Albeit, though not directly comparable, it has been suggested through the analysis of results, giving evidence to EEG being a potential to produce greater processing speeds, given the correct training, at a compromise of user practicality.

1. Introduction

5.4 Background

In recent years advances in technology has been increasing rapidly and technological revolutions have changed the world we live in [1]. Through modern technologies we have seen the world become ever more connected through the internet, and ever more connected to the technology that enables us to do so. In the past decade particularly with the introduction of smartphones, individuals have become more connected to the rest of the world than ever [2]. Smartphones have enabled us to communicate with one another, to check emails, and to browse the internet on the go, without being tethered to a static machine; which itself was only revolutionised in recent years [2], [3]. The majority of the world's population is connected at almost any time and place, through the touch of a few buttons [2], [3], [4]. With that being said, now that so much information and connectivity is at our fingertips, the smartphone has been considered as an extension of one's self. We use planners to keep track of our time, messenger applications to keep communication, search engines to acquire knowledge; on demand, and various other utilities, all of which we rely on our smartphones to assist us in doing. It is easy to comprehend the concept of individuals and their extension of themselves (the smartphone) when you compare the capabilities of someone with and without access to their smartphone. Without, immediately the individual has lost all immediate and possible communication with millions across the globe. Additionally, the individual's knowledge and memory has been limited to the capacity of their own brain. With, the individual has access to the entire internet and the knowledge therein and the memory of the smartphone device. Individuals, therefore, rely on their smartphones for knowledge, memory and communication rather than themselves so it is fair to regard the smartphone as an extension of humans.

Considering this already well-established relationship between humans and their smartphones; connecting us to the world, it might be a surprise to even consider the possibility that we may not be connected enough. Moore's Law states that processing power and speeds increases with every year, so with this in mind one can predict that technology will continue to advance [5]. Whilst all this technological advancement might lead one to argue that we *are* connected enough, it can also be argued that we may not be. Consider the time it usually takes for a device to connect and communicate with another device. These devices can be from two different networks that could possibly be on the other side of the globe. Then, in relative terms, the time taken for a human to communicate with a smartphone (and more generally a computer) is considerably slower. This communication is referred to as Human Computer Interaction (HCI) and includes the most common and traditional methods of mouse and keyboard, touch screen technology, and more recently, speech recognition technology [6]. These methods are bound by the speed at which a user can interact with a device to a very large degree, at least in relative terms compared with the speed of that of computer to computer communication [6]. Mouse and keyboard can be considered one of the easiest ways in which to communicate with a device but require the user to type and click their inputs in order to do so. Likewise, touchscreen technology enables users to interact in a more intuitive way, but compromises in terms of language input. Speech recognition technology is a considerable improvement in terms of communication speed and has potential, but readily available forms are not particularly easy to use or are as accurate as this technology could be [7].

1.1. Brain Computer Interactions

The use of Brain Computer Interactions (BCI) is an alternative interaction which too has become increasingly more popular [8]. Not only has our knowledge and production of powerful computers increased, but more so has our understanding of how the human brain functions.

Utilising this knowledge has allowed the development of various brain-computer interfaces to become the most important technological breakthrough in decades [9].

1.2. The Biology of the Brain

BCI is possible because of the way our electric brain functions [9]. The brain is filled with individual nerve cells called neurons (Figure 1) capable of carrying our bodies electrical activity [9], [10]. These neurons span our body connected to one another through their dendrites and axon terminals (see Figure 1) [9], [10]. Each time we produce movement or thoughts, even when we recall a memory, it is our neurons that are at work [9], [10]. Small electrical signals are emitted through our body with their passage being the neurons. These signals are as fast as 250mph and are generated by the difference in electrical potential carried by the ions located on the neuronal membrane [9], [10]. The speed at which these signals are transmitted are in part due to the insulated axon [9], [10]. A myelin sheath partially covers the axon, this sheath provides insulation blocking any electrical signal to be transmitted there [9], [10]. Due to this, any electrical signal will jump between the sheaths to where a signal can be transmitted, in turn increasing the transmission speed [9], [10]. At these breaks in the sheath signals are capable of escaping and when this happens scientists are capable of detecting their escape, allowing for interpretation of the given electrical signal [9], [10].

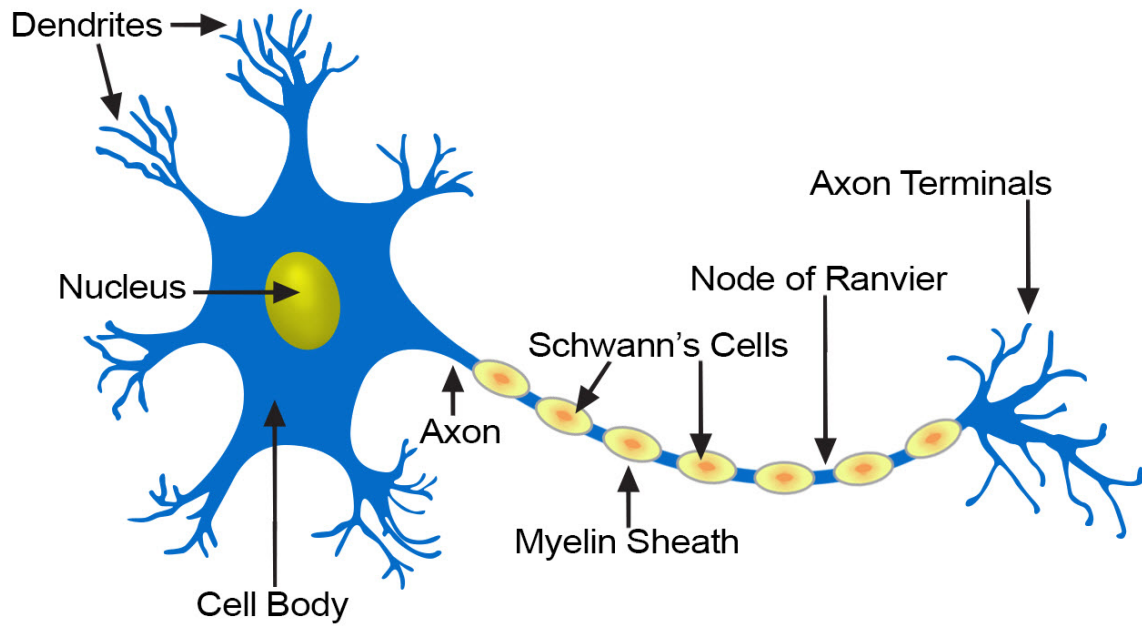


Figure 1: The Structure of a Typical Neuron [9].

1.3. Electroencephalography

The focus of this research project will include a specific BCI, the use of Electroencephalography (EEG) headsets. EEG headsets are devices that use electrodes placed on the head to detect the brain's electrical activity produced by its neurons, they are also considered to be the least invasive BCI method [11], [12]. The activity is then recorded and can be digitally interpreted in order to present wave forms that represent the activity of the person's brain, whom is wearing the device. These wave forms can depict various patterns indicating the user's naturally occurring electrical brain activity for specific body movements, eye fixations and speech [12], [13], [14]. One approach that has been generalised for translating these patterns into control inputs is the technique whereby an algorithm is used to recognise specific patterns relating to body movements, eye gaze or speech of the user [13], [14]. The algorithm attempts to recognise these patterns from a series of preliminary training sessions in which the user exerts these actions in an iterative manner so that the algorithm can 'learn' the

associated patterns. Once the algorithm recognises the induced brain activity, it can then be translated into a system control input [13], [14]. The process of this interaction involves no physical interaction between the user and the computer, rather it uses a more direct ‘brain’ computer interaction. This eradicates the need for such physical interactions that are used in more traditional HCIs and so this research project will investigate whether the effectiveness and speed of BCI from EEG headsets differs from those of traditional inputs.

With technological advancements making us more connected to the internet it seems natural that we also become more connected to the devices that enable us to do so. Although great progress can and has been made in the connectivity of devices, unless the rate of information being communicated between human and computer can be increased, connection speed as a whole will always be hindered. An EEG interface shows promise for adaptive HCI with basic controls already being demonstrated in laboratory systems [12]. Studies suggest that with this technology a substantial amount of peripheral neural and muscle activity could be eliminated [12]. Not only would this be beneficial for most systems requiring input, but there could also be improvements made in the realms of assistive technology such as those with motor impairments [15]. There exists some indication that this is currently being used for those who are physically challenged [15], however there is further potential for assisting those with speech and language impairments (SLI), and possibly those with Autistic Spectrum Disorder (ASD) both of whom may find the traditional methods of inputs challenging. With these regards, BCI and specifically EEG could possibly prove to be a viable alternative not only for human to computer interaction but also for general communication for those individuals.

2. Aims & Objectives

This project will aim to investigate the efficiency and practicality of HCI, specifically a brain computer interface - EEG technology, and make a comparison to more traditional methods, specifically, mouse, keyboard and speech recognition technology. This project will aim to (a) determine whether timed responses to pre-determined questions significantly differ between mouse, keyboard and speech recognition, thus making communication and computer interactions for users more efficient. Additionally, this project will (b) investigate the impact EEG command training has on the time taken to execute that command in a demonstration. A further aspect of this project includes the completion of a post-experimentation questionnaire, upon where thematic analysis will be applied to account for user experience and the usability of HCIs. Ultimately, by determining the most efficient and quickest mode of communication, it is anticipated that this data will benefit a wide variety of individuals. With these regards, the objectives and aims of this research project are as follows:

2.1. Aim

This research study will be conducted to investigate whether there exists a significant difference between the four different input methods with regards to time. Furthermore, it will also be studied how the participants felt using these methods with regards to ease of use and efficiency of communication. It will be hypothesised that there is no difference in time between the three HCI methods. Additionally, it will be hypothesised that the time taken to execute a command using EEG will be reduced with an increase in training. Accompanying this study will be a questionnaire aimed to assist in the evaluation of this HCI method. The studies will be conducted at The University of Wales Trinity Saint David.

2.2. Objectives

- Conduct a literature review that involves detailed and thorough investigation into surrounding and supporting literature of the topic at hand.
- Determine the efficiency of three HCI methods and one BCI method being EEG through the conduction of two experiments -
 1. Efficiency of traditional forms of HCI during a web-based test
 2. Accuracy and Practicality of EEG mental commands as a control input
- Analyse and Evaluate the findings from both experiments and perform a thematic analysis of the follow up questionnaire to provide a response to the proposed hypothesis and, moreover, the objective of this project.

2.3. Expected Outcomes

On the completion of this research project it is expected that the development of software will facilitate the following experiments. It is also expected that a successful experiment and evaluation will lead to the objective being met with supporting evidence being revealed in the findings. It is expected that the project will be conducted such that, surrounding and supporting literature will have been critically considered, and that on a whole, the project and its documentation can testify and support the result presented.

This section has introduced the research topic to be investigated. The objectives and aims have been addressed and the focus has been set for the following section. The following sections will consider existing literature that surrounds and supports the research topic. The technology of EEG will also be briefly introduced and described.

3. Background research / Literature review

3.1. Human Computer Interaction

Human Computer Interaction (HCI) describes the various methods in which humans are able to operate computers, with a design focus reserved for functionality and usability [6]. That is, being able to communicate with computers effectively and efficiently regarding ease of use and the value of the information being conversed [6].

3.1.1. Mouse

The most familiar and standardised forms of HCI are the mouse and keyboard, both of which have seen very little deviation since their initial development in the 1960s [16]. This duo is now used as the most traditional forms of HCI, enabling users to navigate a graphical interface and provide character input, facilitating the use of most end-user software programs [16]. It is most commonly used with most computer desktop scenarios as a well-defined interaction method that allows precision and ease in these interactions [16]. Nonetheless, the mouse has drawn some criticism, including considerations for it being a possible culprit of repetitive strain injury syndrome, due to its repetitive nature [17], [18]. Furthermore, those who are physically challenged, with impaired use of their limbs or reduced motor control experience great difficulty in the use of the mouse and keyboard, since these devices have such precise and steady handed operations [19]. These downfalls have resulted in adaptations of the standard mouse, including those with gesture controls, formulating from attempts to make the control input more intuitive for such individuals unable to benefit from their use [20].

Alternatives to the mouse see the complete eradication of the device in place of technology that interprets hand gestures instead [21]. Evolutions of the keyboard has seen virtual keyboards and speech-to-text technology [22]. Such solutions have been shown to favour the accessibility

for those physically challenged [22]. An example being the utilisation of a Human Computer Interface using Laser Track Pad (LTP), exploring how the reduction of movement needed to operate a developed trackpad allowed for accommodating the specific needs of physically challenged people [22]. It is no wonder however, that the mouse and keyboard have remained mainstream. With regards to the transfer of information from human to computer it is considered relatively accurate. The mouse facilitates the literal pointing, giving an indication of where the user is interested within the interface. Along with the click of a button the user has then selected the area they are interested in. It can be controverted however, that the click has a slightly limited interpretation by the machine. For example, what would happen upon selection, when the user would like to request more information about a certain element in the interface. Some machines utilise tools such as the ability to select a checkbox, a dropdown, or a hyperlink. However, these additional elements with each additional selection option increase the difficulty level of the device being used. A good user interface will do a good job at representing these uncertainties a user might have, by accompanying information along with the element or even styling the element to make the subsequent function seem more obvious. The mouse itself facilitates the act of scrolling through an interface very well, usually with the use of a scrolling wheel. Alternatives to the mouse have been explored, as mentioned above with the LTP [22]. One study analysed the use of Eye Mouse, an input utilising an individual's gaze to operate the cursor [23]. Again, this idea seems beneficial when considering individuals who cannot use their limbs to navigate the conventional mouse. The study by Jin et al. explored actions such as click, double-click, drag and scroll through using eye gaze [23]. However, it was found that Eye Mouse in its current capacity is not the best input device when compared to the mouse [23]. This was due to low accuracy, the effects of tiredness and strain to the eyes after prolonged periods, and the costly software necessary to be able to use Eye Mouse [23]. Whilst, these alternatives to the mouse have not deemed successful when comparing to the

traditional mouse, when it comes to a population unable to use the mouse it is imperative to their needs that these alternatives are accessible.

3.1.2. Keyboard

The keyboard is generally used for text input and in most cases facilitates this very well, this is due to the close link between thought and language [24]. Whilst using the keyboard, individuals are still able to continue honing their words, far beyond what they have previously typed [24]. Specific keys for most used characters allow the precise selection of words, which in most cases accomplishes the desired functionality. However, the keyboard can be considered too precise in the sense that it will fulfil the request of the user by *literally* conveying the selection of keys to the interface, including any mistypes, and incorrect grammar. From the user's perspective the comprehension behind the words keyed is clear; but littered with spelling mistakes and grammar imperfections, the intent from the side of the computer is now unclear. This problem is seen typically in communication and social media interactions whereby the intended communication is unclear and subsequently open to misinterpretation [25], [26]. Interestingly, studies have found the introduction of emoticons a useful method of providing clarity of intent and emotion in such settings [25], [27]. In addition, phrases keyed by the user without good punctuation can then perhaps change the interpretation of the phrase when read by other users. Even in cases where the phrase is keyed as intended, the comprehension of the phrase can be interpreted many different ways; after all the use of a keyboard cannot convey the tone or emphasis in communication between users. In fact, keyboards have been described as "highly unnatural interfaces", due to its unintuitive ability to connect each finger stroke to the final composed message [28]. The problem then is that the keyboard has either partly captured the correct information or not at all. Nonetheless, as a society we have become accustomed to its use, and some individuals are even able to typewrite without looking at their keyboard. Thus, re-designing a more intuitive layout would to some, be like learning a different

language. Although typically this scenario concerns user to user communication, through the use of computer, it is the interaction between human and computer where the capture of information has fallen short.

The keyboard, however, may not be used for key selection alone, it is often used to issue commands that are now instructional rather than text input. In some applications there may be a large number of different commands that are used as a shortcut, facilitated by different combinations of keys selected at once. Examples of these may be ‘Control + F’ to find a given word in a document or ‘Command + Space’ to spotlight search your device. These commands can sometimes be of great use, if the user can remember how to issue them. In these cases, the user can save time but usually, it is the case that a lot of commands exist that are either not used or quickly forgotten. Furthermore, however the command may be used, it fails to be a literal indication of the desired command. Instead it is as like a coded version of the command and if a user wanted to issue, ‘command A’, they would select a combination of keys that would in no sense reflect ‘command A’, instead just adding to the time it takes to execute the user’s desired intention.

3.1.3. Touchscreen Technology

In more recent years, touch screen technology has been developed and popularised as an alternative to the mouse, especially since the development of the smartphone [29]. Touchscreen eliminates the need for an input device, offering a more intuitive way in which users can physically interact with the graphical interface directly. Touchscreen technology has seen uses in mobile smartphones and most other mobile graphical interfaces. However, this technology is also used in settings such as fast food restaurant ordering systems and information services [30]. In addition to being more intuitive than keyboard and mouse, touchscreen in combination with a re-mappable graphical interface allows a software program the ability to customise its

interface dynamically, as oppose to a static keyboard [31]. A host of other commands accompany the basic touch selection such as ‘swipe’ and ‘pinch’. These additional interactions facilitate intuitive gestures that can issue commands such as ‘go-back’ or ‘zoom’. These gestures are more user orientated in their ability to achieve the user’s intentions than a basic mouse click can capture. The user spends less time thinking about ‘how to’, but rather executes the desired command, and so the information passed from human to computer can be portrayed as instantaneous [32]. This can be viewed as a substantial improvement from a keyed-command or multiple clicks of the mouse. The touchscreen is therefore successful in capturing information from the user, and is favoured remarkably well by the user, as it allows the intuitive human nature of using one’s hands to work and use things. Conversely, there are some disadvantages however, as some derivatives of this method have existed which include, low accuracy, reduced input speeds and limited multi-touch functionality [31]. Although these factors are not significant enough to deter from its usage, with touchscreen technology becoming more prevalent, especially in mobile devices. In terms of how well this technology captures the correct information, the touchscreen facilitates the direct selection of elements on an interface much like the mouse, but in this case the selection is more literal and therefore, quicker and more accurate [32].

3.1.4. Human Computer Interaction -Graphical User Interface

Another HCI, which is possibly the most common and useful, is the Graphical User Interface (GUI) [33]. Just as it is important to recognise the methods of which humans can pass information to computers, it is also important to recognise the way in which these computers respond and pass back information to the user. The GUI can be considered as one of the most efficient ways in which we receive information from the devices we use and so, through its display, information and responses are conveyed quickly to the user [33]. Apart from touchscreen technology, these displays have seen very little enhancements. Rather,

enhancements are made in the way in which these displays are used through easier-to-use web designs or programme designs [33]. In terms of how quickly information is conveyed, the display is very close to being instant [32]. The display is one of the quickest ways of achieving its function. It can instantly and dynamically update, containing as much information as it could fit in its 2-Dimensional screen [33]. Where words are displayed, users can read from and extract information and even verify the input of their own keyboard interactions.

Conversely, in this area there are significant limitations when considering those users with specific learning difficulties who may find it difficult to read from the display [34], [35] . However, this can be attributed to how the display and the software installed interact and is potentially not considered a limitation of the capabilities of the display itself. A lot of graphical displays are now used to display notifications in the form of a pop-up. This delivers quick information from which the user can easily capture the information that is being displayed. Not only words, but pictures and graphics can be presented on-screen. These then can be interpreted by the user even quicker. Consider the example of displaying a green tick or using green in the interface in general to indicate success. The display is particularly versatile in terms of accessibility, able to transpose the way it delivers the information in order to make it more accessible for those with deficits or impairments who would otherwise struggle with functions such as high contrast and colour settings [35], [36]. There are limitations however, such as screen size which is usually bound to the size of the device and the practicalities of the setting for which it is being used. In addition, displays are quite costly in comparison to the other HCI methods discussed, particularly considering a high-quality display [37]. Another limitation which may not be particularly appreciated is the fact that the display is 2-Dimensional. In our 3-Dimensional world, we see things and gather information from sources that are 3-Dimensional. With this in mind, it can be argued that, if possible, the use of 3-Dimensional displays may enhance the capabilities of the display even more. There are of course holograms,

however they do not tend to be used in quite the same manner as a display. On the whole, humans take in a lot of information through light and so the display can be considered as one of the better ways for computers to communicate back to us [38].

3.1.4. *Speech Recognition*

A drive for more natural forms of HCI has enthused development into recent applications, with emphasis on these interactions closely imitating the way in which humans communicate with other humans [39], [40]. Hence, from this, methods such as speech recognition technology have emerged as a popular alternative to the traditional forms. Examples of which can be seen in most consumer applications, revolving around personal assistance and dictation [41]. Speech recognition sees technology being able to capture and interpret sound waves as human language, and hence processing the requests or information that is interpreted. This technology is not openly received by some users, who have been documented describing this method as often being frustrating [42], [43]. This is often regarding the accuracy of the interpretation [42], [43]. Understandably, the technology has an incredible task of not only interpreting language, but also the many different accents, dialects and colloquialisms that are to be detected. This difficulty presents itself before the computer even attempts to carry out the command.

However, there is potential, especially since this method eradicates the need for a device from the user's perspective and can be used in favour by those who are physically challenged, whereby use of devices can be difficult [44], [45], [46]. In addition, in comparison to the keyboard, whether it be physical or virtual, the need for accurate spelling and grammar is of the lesser since this is all processed by the technology on the computers side [44]. Furthermore, this method lends itself to being used in a lot more scenarios where the user is otherwise occupied and cannot interact with their hands through the devices already discussed. Hence, it

is easy to see why this method as oppose to others has the potential to be quicker and easier to use, depending on the accuracy of the speech recognition. This method of interaction utilises the most typical form of communication that humans use which can sometimes be the most expressive. However, it is the expression in verbal communication that speech recognition has yet to capture. Although the technology may not be adequate enough to capture the emotion in the user's voice, the information is certainly there for further development. This could potentially lead to the computer having a better understanding of how the user feels interacting with the computer and could possibly adjust accordingly. This could be said for the volume, pitch, emphasis and many other factors that present themselves in someone's voice, which again is all being captured by the microphone of the computer currently. Smart assistants are able to understand our intentions through speech recognition and are generally quite successful in the public market [47], [48], [49]. There are of course however some occasions where these sorts of devices cannot understand the user, which can lead to frustration as dissatisfaction. Communication through speech is quick and mostly efficient as humans tend to express our needs very well in most cases and there are currently many applications where this is utilised. On the contrary, in some cases, speech is not always the best delivery for conveying our thoughts and intentions and for some individuals the art of structuring a well understood sentence can be a difficult task [22]. Furthermore, there may often be occasions where humans tend not to think enough before they speak, or they can get caught up in the words that are spoken resulting in misunderstanding in the receiving parties [50]. Consequently, speech may not be considered the most efficient way of expressing our needs to the computer since there exists the interface of language between the intention and capture of the expression.

3.2. Brain Computer Interaction

An alternative, emerging subset of HCIs fall under the category of Brain-Computer Interactions (BCI). This interaction still describes the method of which humans and computers can communicate, however, more specifically these methods describe how a user can interact more directly, from brain to computer; often bypassing the need for any physical movement [51].

3.2.1. Electroencephalography

One such BCI is through a technology called Electroencephalography (EEG). This BCI method involves recording and interpreting the human's brain activity through a wearable device on the user's head [9]. Until recently, these devices required uncomfortable and unpractical methods of capturing the user's brain activity. Specifically, a cap is used with multiple sets of electrodes in contact with the scalp in conjunction with the use of a gel to aid the recording [9]. More recently, development in this field of technology has seen the advancements of this type of BCI with the introduction of an EEG headset, that uses non-invasive electrodes to measure the brain's activity [52].

The electrodes can be found on various parts of the headset and rest on the user's head. It is through these electrodes where the activity of the brain is detected [52]. The neurons in the brain produce electrical signals which can be measured by the electrodes [9] , [12], [13], [52]. Where EEG is used as a BCI, these signals, once recorded are then interpreted to be associated with particular commands [9] , [12], [13], [52]. Once the headset is able to capture the pattern of a particular electrical signal, it attempts to recognise the pattern to be associated with a pre-disposed command or function [9] , [12], [13], [52]. The technology must undergo a session of training in order to begin deciphering brain activity [9], [12], [13], [52]. Users participate in preliminary questions or training where repetitive techniques are used in order for the commands to be learned. It is common to see machine-learning algorithms being used, whereby

an application is able to identify patterns and familiarities in brain activity during these preliminary sessions, to then be able to later recognise these patterns when exposed to them during operation [9] , [12], [13], [52].

EEG has been most commonly used as a support aid in the medical field, where it has been utilised in individuals with robotic limbs [53], [54]. It is within these systems where EEG is used to recognise physical motion intentions by the user and proceed to carry out these desires with an artificial limb [53], [54]. In such cases, the user either thinks about moving the particular limb or issues a command to move the limb through thought. Through the methods discussed, the technology is able to identify these intentions through brain-computer interface and carry out the operation [53], [54]. EEG provides new and exciting ways to readily communicate with computers through a brain-computer interface eliminating the need for any physical interaction other than issuing a command. The speed at which information can be conveyed from human to computer may then be considered, a lot quicker as it bypasses the need to carry out these intentions. Rather, the technology is aimed to be utilised such that the response from the device is almost instantaneous from the point that the intention manifests in the mind of the user [53], [54].

Currently, there are drawbacks to this technology that prevent its mainstream use to possibly being a distant intervention. Firstly, the technology has to be able to correctly identify the intention of the user through their brain activity [55]. Furthermore, the brain activity detected has to be correctly filtered and identified amongst other, possibly involuntary brain activity that can be recorded, that would otherwise interfere with the identifiable brain patterns [55]. Considering BCI methods alongside HCI ones, BCI has the potential to increase the rate at which information is passed from user to computer [52]. If done successfully, the thought that manifests in mind of the user could be served almost immediately limited only by the speed at

which the BCI method can capture the information and the speed of the computer and relative software [52]. It is fair to establish that the speed on the computers side is negatable when considering the capturing of information that is needed from the HCI, but with BCI bypassing the typical channels of information transfer, the rate overall could be dramatically reduced [52]. In opposition, if BCI were to reach such a potential where thoughts could be actively read from the mind, the user may feel that their privacy could or is being invaded [56], [57]. This particular matter becomes more inappropriate with the fear of malicious intent if the information captured from the BCI is abused [56], [57]. In such instances the user could be exploited to unwanted advertisements or data capture, which could then leave the user feeling vulnerable [56], [57].

3.2.2. BCI End User Experience

Whilst, studies have shown extensive research into BCI usability and feasibility [58] [59], there is little literature studying user experience during such experiments. Especially, since there has been a rapid expansion in BCI use for individuals with physical impairments and also individuals with neurodevelopmental disorders such as Autism, where the vulnerability of such individuals can pose ethical considerations [60], [61], [62] . It can be argued, that such cases involve parties recovering from possible trauma or where capacity is markedly reduced [63]. In such scenarios the importance of assessing user experience during experiments involving BCIs should be considered from an ethical perspective, and is a step in the right direction for providing user appropriate BCI technology [64], [65].

The importance of this is highlighted in a recent systematic review analysing BCI use in social research [66]. The study urged researchers to include user experience as part of experimental work. BCI technology has the ability to improve an individual's quality of life especially for those with physical motor impairments [60], [61], [62]. Conversely, BCIs have also in some

cases lead to user dependency which the researchers regard as leading to “impingements on human autonomy” [67]. In order to bridge this gap between BCI technology and end users, a novel approach – The User-Centered Design (UCD) was utilised in evaluating the usability of BCI controlled applications, adapted by German psychologists [68]. The UCD was designed in hopes that a holistic operation was provided using a simple evaluation process. This process (The UCD framework) is as follows, (1) device effectiveness, (2) device efficiency and (3) satisfaction; which when combined defines device usability [68]. This framework was evaluated in 19 end-users, all of which possessed severe motor impairments [68]. The study demonstrated the use of the UCD framework to inform researchers on BCI tools, specifically regarding end-users with physical impairments [68]. This is useful in matching appropriate BCI technology to end-users, moreover, when such technology will be used by individuals on a daily basis to improve their quality of life. If an appropriate framework such as the UCD is operationalized, technology-user matching could potentially occur in the absence of a professional, such as in-home settings, which could prove cost and time effective [68], [69]. Furthermore, the framework as suggested by [68] is a simple procedure to implement into experiments. Whilst, including participants with severe physical impairments is informative, the study did not include IQ and language capacities of these participants to determine if motor impairments alone were due to effect participant involvement. Further research may be applicable to determine whether the UCD framework is still effective in other scenarios, such as those with neurodevelopmental conditions, whereby restricted attentional capacities and pre-verbal language may affect responses to the questionnaire. Although, verbal abilities are not necessarily affecting BCI use, the presence of any confounding factors such as dyslexia or dyspraxia may lead to possible delays in question understanding causing time differences in end-user responses. Nonetheless, the above studies [66] , [68], [69] highlight the research gap in BCI technology and end-user experience.

This section has analysed the current literature surrounding HCI and BCI technology. Further, a gap in research was identified with regards to BCI end-user experience which will be one focus of the project. The next section will discuss the project planning and the resources required to test the chosen hypotheses.

4. Project planning

4.1. Resources Required

The following resources are needed in order to complete the proposed research project.

- EEG equipment and software (EmotivBCI) – in order to conduct the experiment.
- Laptop/Computer – in order to host the EEG software (EmotivBCI) and the web application design for the project.
- The Learning Support department of the university – in order to assist in the experiment.
- Allocated space within the university – in order to facilitate the experiment.
- Access to an online library – in order to conduct a literature review.

4.2. Gantt Chart

To appropriately manage and plan the time taken for each task that is required to fulfil this project, a Gantt chart has been created and will be used to effectively work to management deadlines.

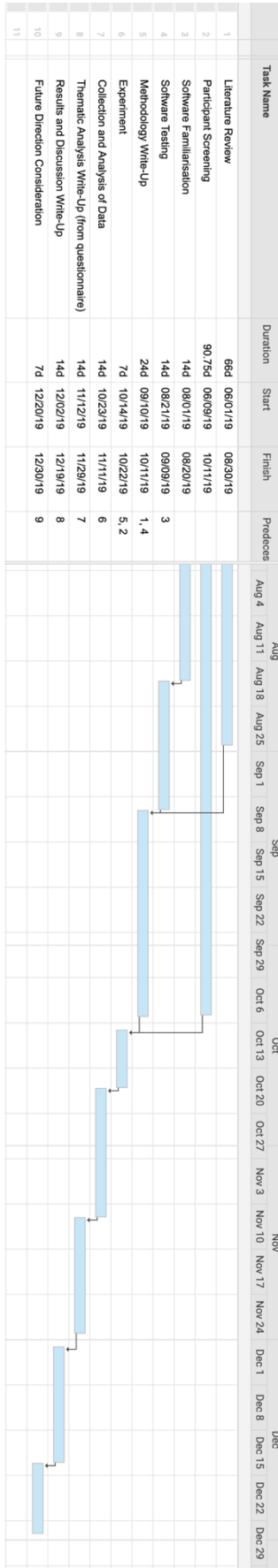
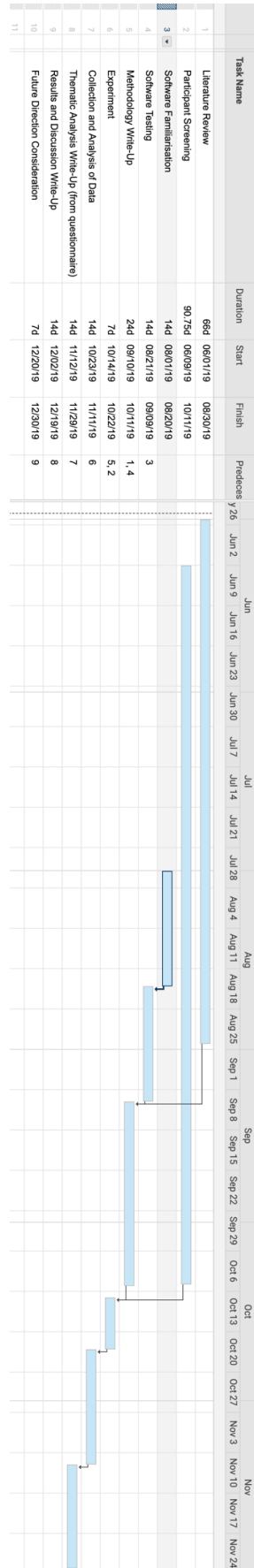


Figure 2: Gantt chart illustrating time management for the project

5. Research Methodology

5.1. Approach, Strategy and Time Horizons

This research project will use a deductive approach where the deduced theory will be hypothesised, and a particular set of three strategies will be used to then triangulate the yielded results in order to test this hypothesis.

The strategy are as follows:

1. Literature Review
2. Experiment
3. Development

This approach has been selected due to the quantitative data, also known as hard data, which will be revealed in its course. Furthermore, it will be the result of exploratory research which involves the collection of preliminary data that will be analysed in order to testify for or against the research topic. As a consequence of the included strategies, the research undertaken will prescribe a ‘snapshot’ of data that will represent the situation for a particular point in time, this is referred to as ‘Cross-sectional’ research.

5.2. Methods

5.2.1. Participants and design

20 participants were recruited to participate in an experiment to compare keyboard, mouse, and speech recognition technology, to determine which is most efficient. The response times of the tests will be recorded within the developed software. Additionally, these participants will also be involved in a second experiment determine the effectiveness and practicality of EEG headsets. The response times of the EEG test were recording using a stopwatch. Post

completion of the experiments, participants were required to answer pre-established questions which can be found in Appendix IV. Participants were recruited via the advertisement poster appended (VII). Posters were handed out around the university directly to interested parties. If interested in participating, individuals were required to email the researcher to receive a participant information sheet (see Appendix I) detailing study inclusion criterion, a participant consent form, study location, date and time. Prior to the day of the experiment, participants were emailed a reminder of the study and given further information on study location.

5.2.2. Procedure and materials

The experiments were conducted in UWTSD IQ building for a duration that roughly spanned the equivalent of 1 working week. Upon arrival participants present will be provided with a hard copy of the participant information sheet and consent form to complete (see Appendix II). When participants are happy to proceed, and consent forms are collected, the participants are allowed to ask any questions prior to the start of the experimenter and the researchers will then commenced the study by introducing the nature of the study.

The first experiment from which the data collection part of this project is concerned was chosen for its ability to test whether a relationship exists between two variables, the independent and dependent variable. The aim of this experiment is to investigate what affect HCI methods have on the time of which a web-based test takes to be answered and specifically the speed of human to computer interaction. This will investigate the comparison between the three different HCI forms. In addition to this, the experiment will investigate this effect with considerations for ease of use and practicality. This was done in the hope to identify any considerable differences in results. The hypothesis of this experiment is: -

The time taken to complete the web-based test is the same for mouse, keyboard and speech recognition.

The independent variable is the form of HCI whilst the dependent variable is the time taken to complete the test. Throughout the experiment, the control variable is the participants involved. This enabled the results to be more valid and doing so enabled us to identify if there exist any alterations in the data. The set questions proposed for the web-based test matched the commands found in the second experiment and are typical movement commands (push, pull, left, right). This test was chosen to best contextualise the considered usage of the HCI methods. Each participant will be timed, using a developed built-in stopwatch from the start to the completion of the last question whilst using the three HCI methods. On completion of the examination, each participant will also be asked to complete a questionnaire on attitudes surrounding the use of the HCIs, allowing my experiment to follow a mixed methods study, including quantitative and qualitative data collection.

The second experiment was designed for its ability to investigate whether the time taken to issue mental commands during a demonstration decreases when the training for the specific command increases. This will aim to help evaluate how efficient and accurate EEG can be considered as a BCI. A follow-up questionnaire will also be used to investigate whether the technology is feasible and practical, taking a particular focus on user experience. The hypothesis experiment is: -

The accuracy of EEG mental commands remains the same with increased training.

As mentioned above, the commands will be push, pull, left and right.

5.2.3. Software Development

For the facilitation of the first experiment, it is required that the researcher develops an application for the integration of the three HCI methods in conjunction with the intended usage. The manner in which the development will be managed and carried out followed

developmental methodology that loosely follows Agile Software Development methods utilising an effective Kanban approach [70], [71], [72], [73]. This includes the gathering of requirements, refinement of those requirements and the compartmentalised execution of each requirement through the creation of specific features that will facilitate the constant and incremental development of the required software. More specifically, the development to be undertaken will be feature-driven meaning that the project is to be divided into tasks whereby each describe an element of the software, often as stand-alone components. These styles of development are to be scheduled around an iterative cycle, whereby requirements were refined, leading to the identification of more features and the development of those features, followed by a review of the product and then the repeat of the cycle re-iterating again with the refinement of requirements. Although these methods of software development each often define their own concept of time-boxing tasks and workflow, the project due to the time constraint nature will roughly follow a workflow similar to that seen in Extreme Programming [74] from which the high-quality work and adaptable iteration values will be chosen to supplement the existing strategies already set out for the development within this project.

5.2.4. Literature Review

Prior to the experimental phase of this project, a literature review was first carried out. This involves detailed and thorough investigation into surrounding and supporting literature of the topic at hand. The document will be created with the objective of identifying the existing research within the field and their corresponding researchers. This strategy will be used to create a comprehensive understanding of what areas have been explored and what factors that may need to be considered for the research being undertaken. The recommendations of any existing literature will be contemplated in order to refine the focus of the research and to help establish and confirm the basis for the remaining strategies and the overarching aims and objectives.

5.3. Ethical Considerations

Ethical approval for this study was granted by the UWTSD (see Appendix III). Participants were made aware of the study during the recruitment process and ensured responses, if they should be involved are anonymous. For interested candidates a participant information sheet outlining the purpose and design of the study were provided along with a participant consent form stating inclusion criteria for the study. Participants were reminded on anonymity of responses on the day of the experiment. After the study, participants were given a debrief form with further information on the study conducted. Each of the aforementioned forms can be located in the Appendix.

5.4. Risks & Limitations

During the collection of data, it will be considered that individuals who have volunteered for the experiments may belong to a vulnerable cohort of students within the university (individuals on the spectrum, individuals with learning and language difficulties or other disabilities) which has a significant proportion of student with such difficulties. Therefore, to safeguard the needs of these individuals testing will be performed with a member of staff present from the student support faculty of the university. Additional considerations are to be made for participants who may not feel comfortable whilst using the headset and so this will be screened for during selection and any of those who consent but still feel uncomfortable will be able to exclude themselves from the study. The experimenter will be blind to any participants who have a disability until after the tests have been performed in order to not bias any results collected. Participants from all aspects are included in the experiment to allow for better generalisability, however certain exclusion criteria have also been selected.

- Must be able to speak English.
- Must not be visually impaired

- Must not be hearing impaired

These exclusion criteria have been identified as being the most likely to impact upon the success or failure of the study. Failure to account for these may have resulted in unreliable or inaccurate results due to these persons not being able to fully participate in all of the tests. Accounting for these characteristics increase the accuracy of the results whilst reducing potential bias [75].

A limitation of the experiment might be that the EEG headsets may not be responsive enough to provide viable results or perhaps even work at all for some participants and so in such instances the result will be marked and will not be included in the analysing of results. These cases, however, will be factored into any conclusions made as to the practicality of the BCI technology.

Another limitation could possibly come as a consequence of ambiguous answers in the follow-up questionnaire and so this limitation will be aimed to be reduced by structuring the questionnaire such that its questions are clear and lead to closed answers where possible and appropriate.

5.5. Data Evaluation

The data collected in the research project is both quantitative and qualitative as a result of the questions and the questionnaire that has been outlined in the strategies. Each of these types of data require different ways in which they are to be evaluated. The data obtained through the test will be collated and analysed using various data analysis methods, investigating any correlation that is present. The gathering of inferential statistics will be used to analyse whether the results have any statistical significance and considerations will be made as to the possibility of any Type I error. The means of the result will be used, and an Analysis of Variance will be performed (ANOVA) [76] in order to help identify statistical significance in a result set.

The answers from the questionnaire will be analysed via Thematic Analysis using Braun & Clarkes (2006) Methodology [77]. Overall, themes will be coded from the data to allow for the emergent of the participant's true feelings towards the use of BCI/HCI technology. In addition to general feelings towards these methods, possible psychological affects experienced from each HCI may also emerge. Ultimately, the careful consideration and analysis of both forms of data will help lead to conclusions to be drawn of the hypothesis of the experiment and, moreover, the aims and objectives of this research project.

5.6. EEG headset selection

A range of different EEG products were considered when purchasing a headset whereby each product was evaluated for ease of use, price and feasibility. It was decided that the equipment to be purchased would be the EMOTIV Insight 5 Channel Brainwear by Emotiv since it appeared to be the better suited for the project being undertaken [78]. In particular, this headset was chosen for its developer support and price which matched the budget for this project.

6. Development

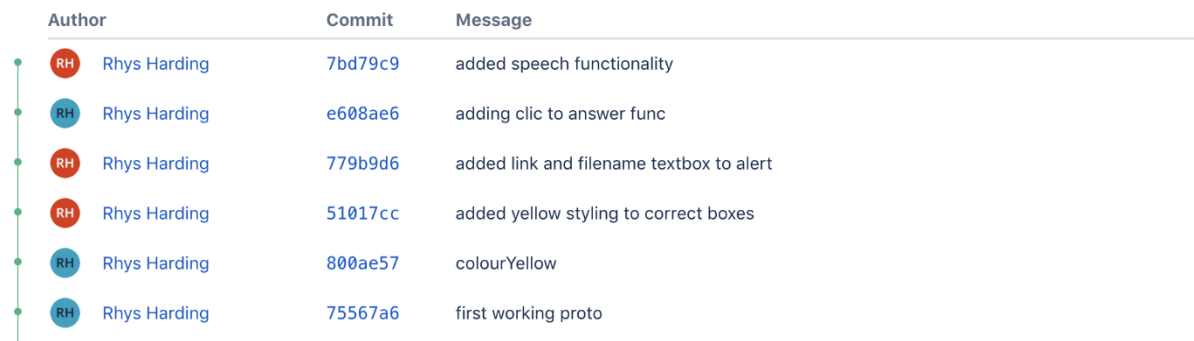
The development for this project consisted of building a React web application to facilitate the experiment and the data capture. React was chosen for the deployment of this application because of its modular structure and how it encourages the separation of components [79]; whereby each component contains the logic for the functionality of the component and how it is styled and designed to look in the application [79]. Initially the application began from React's own 'create-react-app' which contained the essentials for the application to run [79]. The application then implemented some components referenced from a quiz application selected from an online repository [80]. Following this, the development process followed multiple features enabling the iterative and incremental style of development chosen in order to refactor the referenced components and create new ones to suit the needs of the project [70], [71], [72], [73].

These features are as follows:

- Construct basic components and application
- Implement styling to indicate the option the user is to select
- Create text input for keyboard
- Implement functionality to check answer of keyboard entry
- Implement speech to text
- Implement a CSV download link to capture recording

These features were implemented in turn while some were dependant on others consequently having them completed with the highest priority first. Furthermore, each feature was assessed for risk and thus divided accordingly into smaller sub-tasks, in order to easier track the progression and completion of each feature. This style of development was tracked with the aid of a version control tooling that is BitBucket whereby continuous commits were made to

the repository, an example highlighted below [81].



Author	Commit	Message
RH Rhys Harding	7bd79c9	added speech functionality
RH Rhys Harding	e608ae6	adding clic to answer func
RH Rhys Harding	779b9d6	added link and filename textbox to alert
RH Rhys Harding	51017cc	added yellow styling to correct boxes
RH Rhys Harding	800ae57	colourYellow
RH Rhys Harding	75567a6	first working proto

Figure 3: Development tracking and commit history

6.1. Bugs and Issues

```
35 34
36 -   shouldComponentUpdate() {
37 -       this.setState({
38 -           classNames: ['', '', '', '']
39 -       });
40 -       return false;
41 -   }
42 35
```

Figure 4: Code snippet showing removed functionality

Throughout the development multiple bugs presented themselves across the features. For instance, the Answers component of the application had the function ‘shouldComponentUpdate’ (see Figure 3) which was causing the application, when run, to get caught in an infinite loop. After some research into how react components loaded it was discovered that each components follow a lifecycle whereby they can receive props or states and then proceed through a number of different functions that decide ‘if’ and ‘how’ the component should update [82]. This took considerable time, however, after this was understood it was quickly identified that within this method the state was incorrectly changed. It was understood that the state should not be included in such a function, since this code would

reinstate the component lifecycle even before the current one could finish. This would continuously repeat until the application would recognise the infinite loop and crash. The commit history snippet (in Figure 3) shows the code and its removal. This functionality was extracted and used in the parent component and its state was passed through the child component as a prop.

```
26     handleChange = e => {  
-     if (e.key == 'Enter') {  
27 +         let questionAnswered = this.state.questionAnswered;  
28 +         // window.alert(questionAnswered)  
29 +         if (e.key == 'Enter' && questionAnswered == false) {  
30 +             this.setState({  
31 +                 questionAnswered: true  
32 +             });  
33             this.checkAnswer(e.target.value)  
34         }  
35     }
```

Figure 5: Code snippet showing 'handleChange' functionality

Figure 4 code snippet shows the function that can be found within the over-arching test component. Specifically, the code is the functionality behind how the user's selection is submitted once keyed in through the text input. The issue was that the user was able to enter multiple answers for the same round. This was resolved by adding a 'questionAnswered' state which defined whether or not the question had already been attempted. Within this code snippet is an output to the window in the form of an alert which was purely used for debugging purposes and was later taken out. The alert helped identify the state in question and check if it was as expected. Similar implementations of this window alert were used through the application.

To resolve and eliminate many of the issues found throughout the code, alpha testing was undertaken at various points in the development cycle following the test harness, (table 1)

which is a live document utilised in the Kanban approach. As such, as the features develop the document is dynamically added to until all scenarios are passed.

Table 1. Test Harness

Given	When	Then	Pass/Fail
The application is loaded for the first time	The page and its components render	The pop-up alert should be displayed with its relevant information	Pass
The initial pop up alert has rendered	The user clicks the button labelled 'start test'	The alert should disappear, and the test should commence	pass
The initial pop up alert has rendered	The user keys inputs into the text box	The input should be the name of the csv file downloaded at the end of the test	pass
The initial pop up alert has rendered	The user proceeds without inputting into the text field	An alert should appear, and the input field should be styled red and the round should not commence	pass

A round has commenced	The questions are rendered	The correct answer amongst the options will be styled yellow	pass
A round has commenced	The textbox is selected	The user is able to key in characters	pass
A round has commenced	The speech button is clicked	The dictation begins	pass
The speech button is clicked	The user speaks	The interpreted speech is inputted as text in the textbox	pass
A round has commenced	An option is selected	The correct and incorrect answers should be revealed with green and red styling	pass
A question has been answered	The correct answer has been revealed	The continue button should appear	pass
A question has been answered	The question is re-attempted	The options should be unresponsive	pass
A question has been answered	The continue button is clicked	The next round should be rendered	pass
The final round has commenced	The correct answer has been revealed	The 'finish test' button should be revealed	pass

The 'finish test' button is revealed	The button is clicked	The final pop-up alert should appear with its relevant contents	pass
The final pop-up alert has appeared	The 'Download Results' link is clicked	The csv containing the results should be added to downloads	pass
The csv results file has been downloaded	The contents are checked	The fields should contain the correct information	pass

6. Experiment

For the experiments stage of this report 20 participants were selected as volunteers after advertising the experiment and its focus by the means of the poster produced by the author displayed in the University of Wales Trinity St. David's. The experiment took place in the University's Student Services department in a private room containing two chairs, a desk and the equipment described in this report. Once the participants were chosen, they and their results remained entirely anonymous.

In order to test the hypotheses of this project two experiments were undertaken. Both experiments included aspects that analysed quantitative and qualitative measures. The qualitative measures were comprised of thematically analysing the answers provided by each participant on completion of a post-experimentation questionnaire exploring their experiences and feelings during experiments 1 and 2.

6.1. Experiment 1 - Efficiency of traditional forms of HCI during a web-based test

The objective of the first experiment was to test the hypothesis:

H0: The time taken to complete a web-based test is the same for mouse, keyboard and speech recognition.

H1: The time taken to complete a web-based test is not the same for mouse, keyboard and speech recognition.

Furthermore, this experiment will help testament to how well the different methods compare to each other in the setting when considering navigating a web page. The experiment tested the efficiency and time taken using 3 different HCI inputs when taking the web-based test that was developed for this project.

- Mouse
- Keyboard
- Speech recognition

For each method, the time to complete was measured and recorded in order to testify for or against the hypothesis. To measure this time the developed application records the time at the start of the test round and again at the end of the round and calculates the difference before recording all times. The following code (Figure 5) indicates how this was coded.

```
| handleClick() {  
  let {round, numberOfQuestions, times} = this.state;  
  times[round-1][1] = new Date().getTime();  
  this.setState( state: {  
    times: times  
  });  
};
```

Figure 6: Code Snippet showing time capture

In order to carry out this experiment it is necessary to provide a computer with the application running, monitor, mouse, keyboard and microphone. The computer was first set up so that the appropriate control input was connected and functioning and the react application is ready and running on the machine. The participants were then taken through the following set up procedures:

- Made familiar with the set up and surroundings of the quiet and isolated room with no distractions.
- Made clear of the objective and the basic working of the application described.

- Instructed with the aid of visual cues to enter the HCI method used for the particular round along with an assigned candidate number in order to distinguish the results during analysis.

Once the text field was filled with their candidate information the participant clicked the ‘begin test’ button and this marked the commencing of the test. The participant was prompted on screen to select the answer that was highlighted in yellow via the means of the particular HCI method specific to the test round. For mouse, this was done by clicking the answer. For keyboard, this was prompted and done by keying in the answer in the text field provided and pressing enter. For speech, this was prompted and done by clicking the ‘listen’ button followed by the participant expressing their choice by speech followed by the enter key. After each question was answered a button appeared that proceeded onto the next round. The following rounds were completed in the same way as the first and when completed a ‘finish test’ button appeared that was clicked to end the test. The test was finished and was indicated by an alert on-screen indicating the results of the round and a link to download the csv file containing the calculated round times. The participant clicked this, and the results were downloaded. The ‘restart test’ button was then clicked to begin the test for the next HCI method, and the following tests were completed in the same procedure as the first. Once all tests were completed the participant was notified of the end of the test and this marked the end of the data capture.

The Figures below outline the flows for which the experiment was followed in the web application.

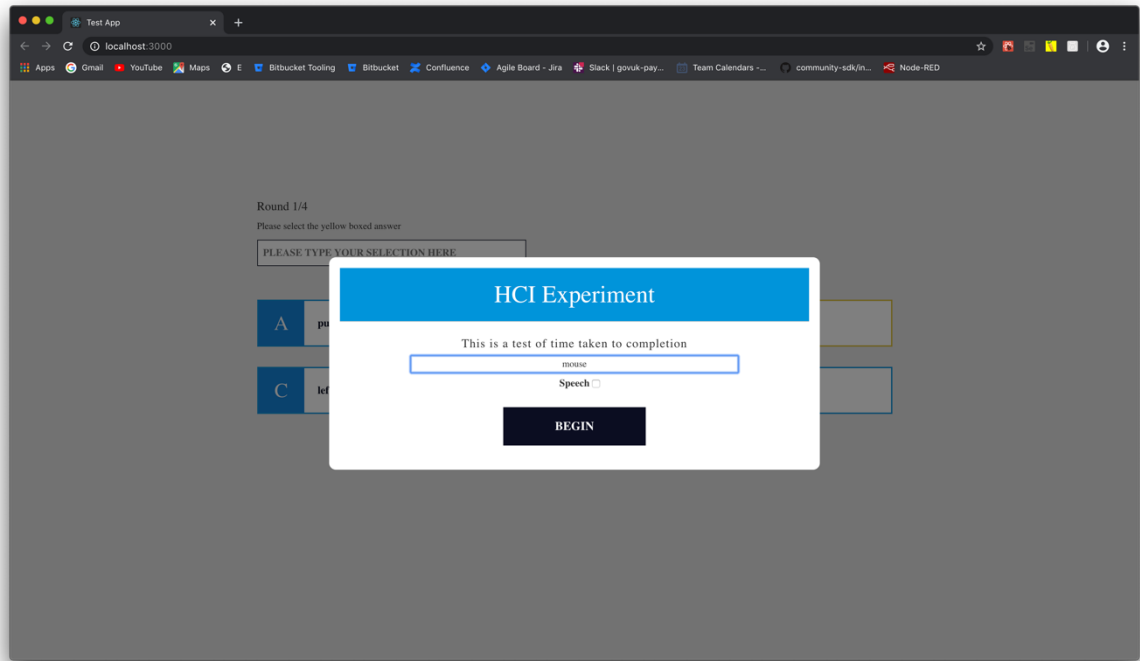


Figure 7: Initiating mouse test

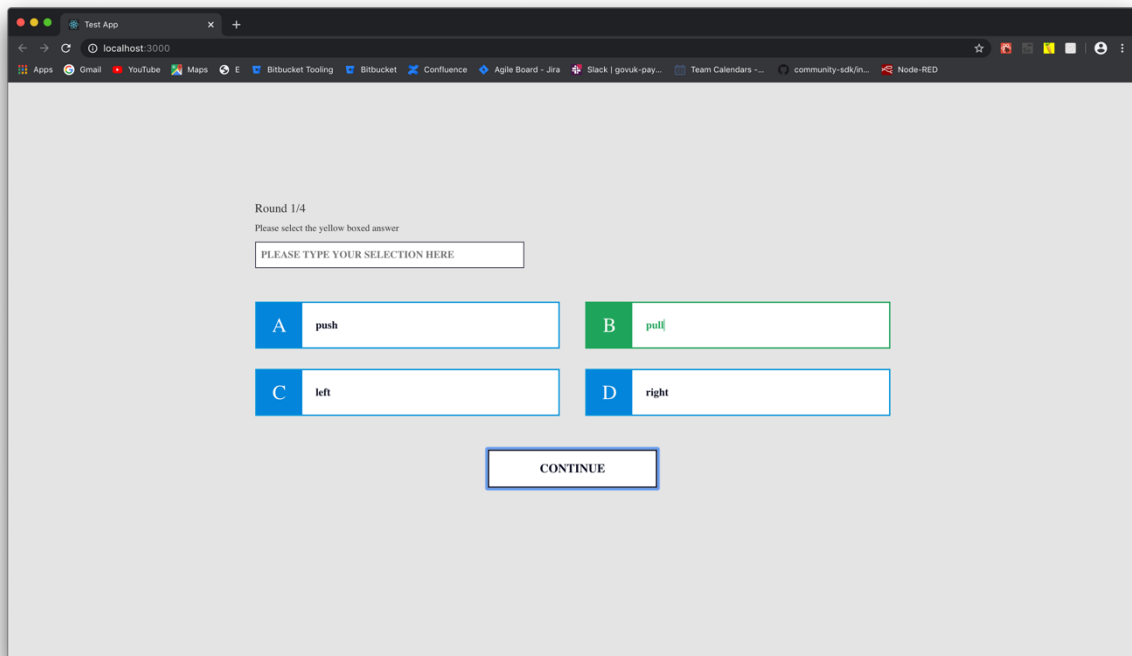


Figure 8: Using mouse during test

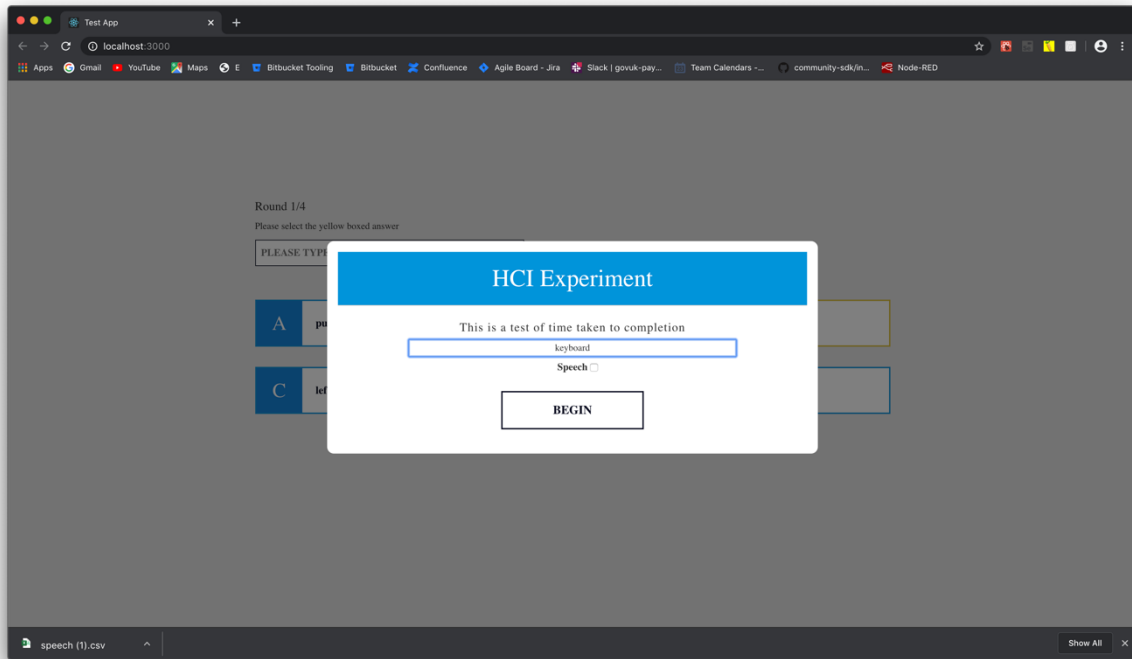


Figure 9: Initiating keyboard test

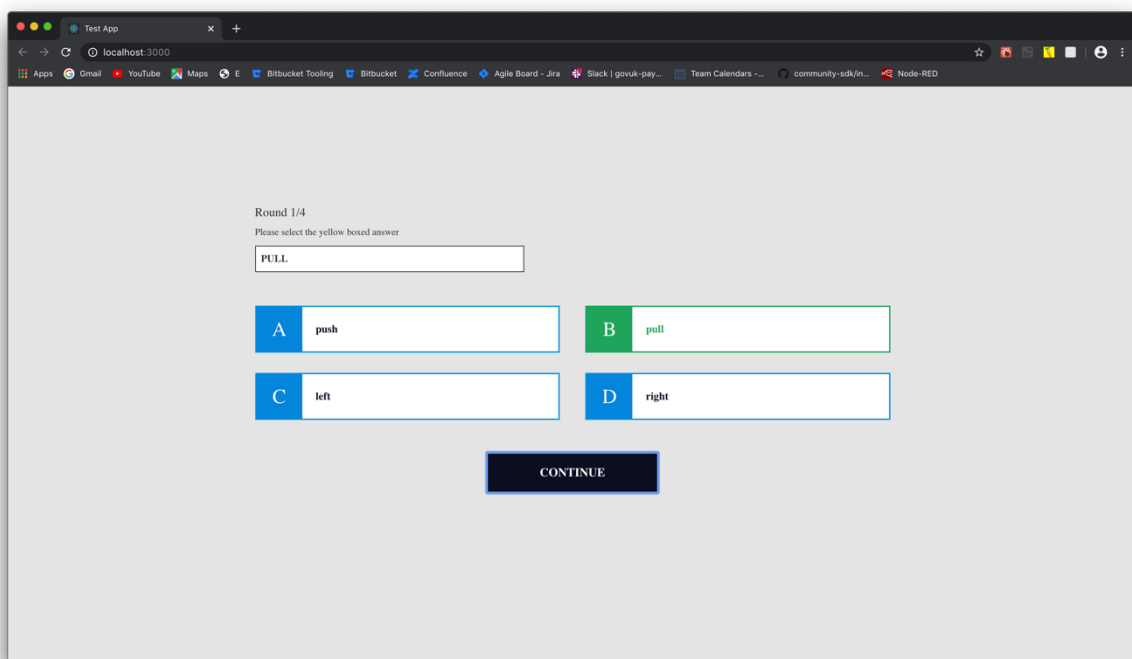


Figure 10: Using keyboard during test

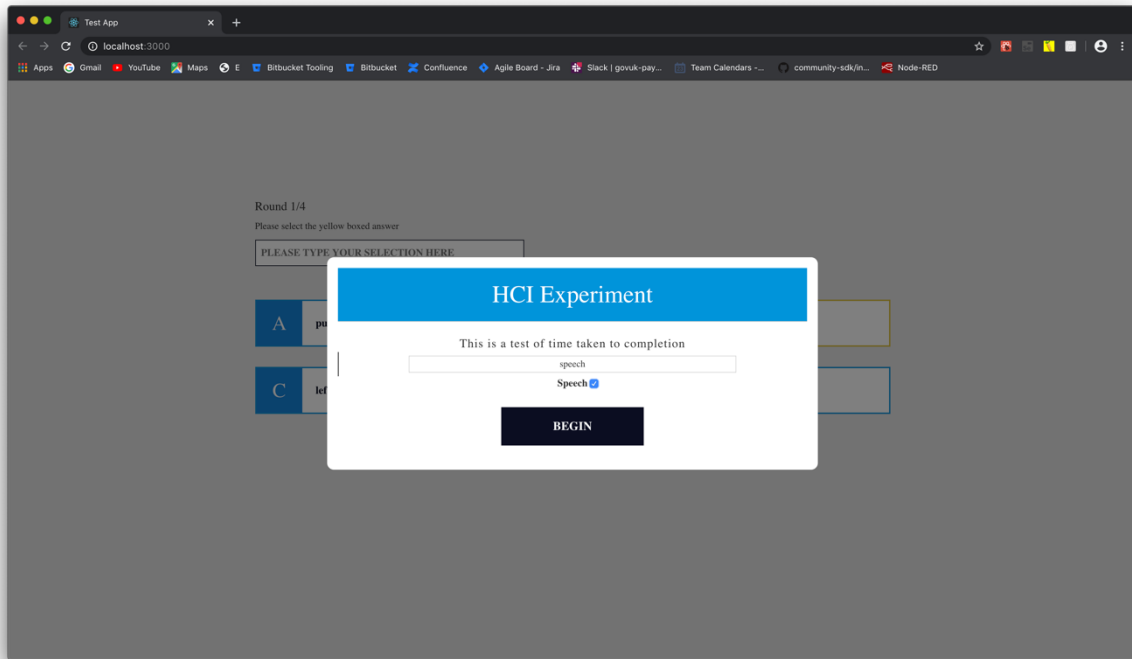


Figure 11: Initiating speech test

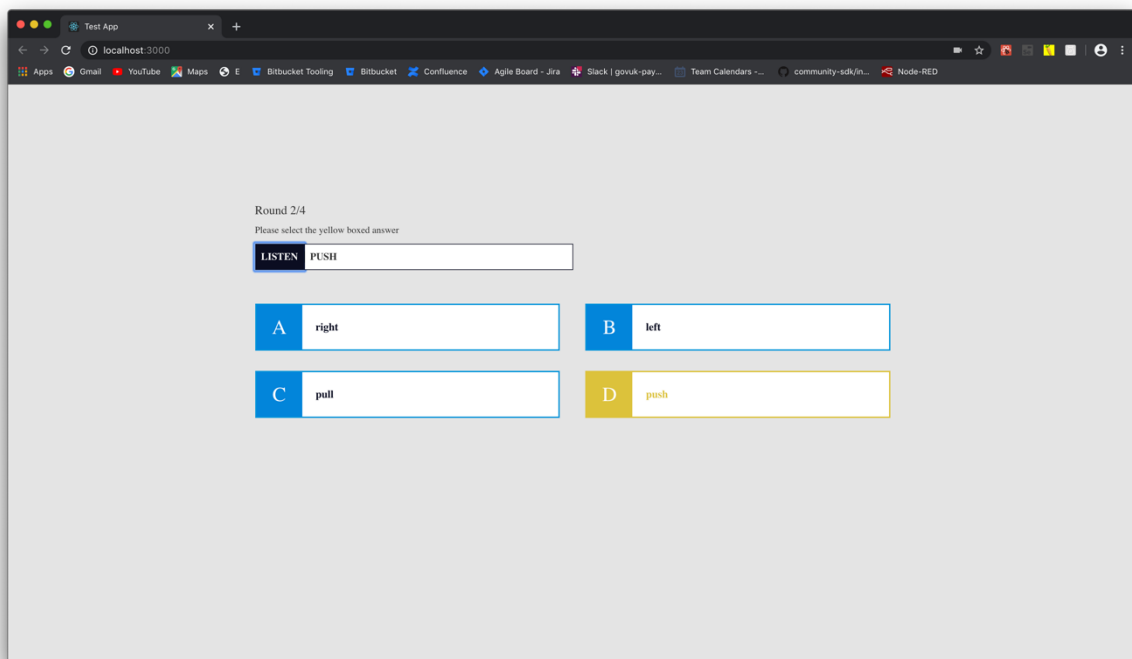


Figure 12: Using speech during test

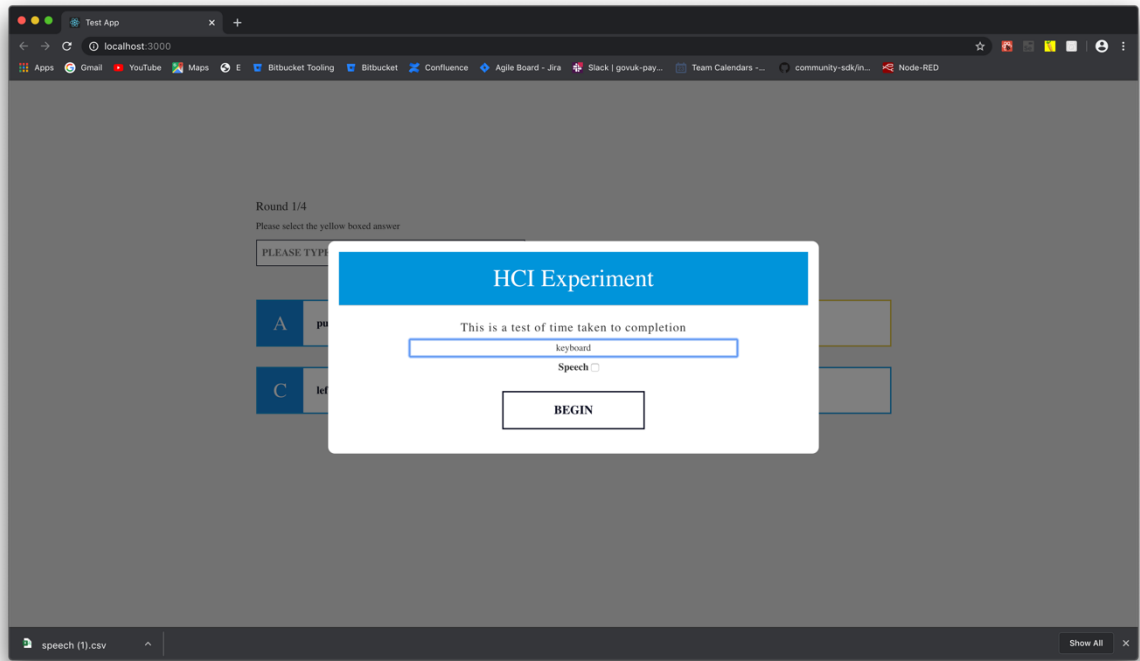


Figure 13: Finishing test and downloading results

6.2. *Experiment 2 - Accuracy and Practicality of EEG mental commands as a control input*

The second part of the experiment tested the following null hypothesis. The objective of this experiment was to test the hypothesis:

H0: the accuracy of EEG mental commands remains the same with increased training.

H1: the accuracy of EEG mental commands remains the same with increased training and presents to be a viable alternative to traditional forms of HCI.

In addition to testing the hypothesis, this experiment is expected to be a testament to the practicality of EEG headsets as an alternative to other HCI methods.

In order to test the null hypothesis, the participant must be supplied with a computer running the EmotivBCI software, monitor, mouse, keyboard, stopwatch and an Emotiv Insight 5 Channel Brainwear headset. The computer was set up so that the software was running, and the headset was successfully connected to the machine and software. The guest profile was chosen for the participant. The participant was prompted to place the headset on their head so that all electrodes provided sufficient contact. This was done with the aid of a visual representation indicating the contact quality of each electrodes. It was a requirement of the test that the contact quality of the electrodes be above 90% as readings below this would cause the headset not to function correctly and so is advised that the contact quality is remained as high as possible.

Once the headset was sufficiently installed the 'train' button was pressed on the main tab of the dashboard of the BCI application. In addition, the command to be trained was selected in the dropdown box. This marked the commencing of the training and when prompted, the participant was instructed to begin training the command by mental thought using whatever technique preferred. It was advised that the command may be thought of as if the participant were performing the action, the word itself was thought of, or any preferred method. Following visual cues, the participant completed the training attempt and persisted to train for a total of 3 attempts re-performing the training steps described. The 'live demonstration' button was then required to be selected which marked the commencing of the demonstration of the trained command where the command was to be exercised on a cube displayed on screen. If successful, the cube would dynamically move according to the nature of the command. A time of 60 seconds was given to complete this before the accuracy demonstration was recorded as being either success or failure. The training was then required to be performed for a total of 5 attempts for the second run through and 10 for the final run through, conducted in the same manner as the first run through. A second command was then attempted with and trained using the same

intervals and conducted in the same manner as the previous command. The process was subsequently followed for each of the four commands push, pull, left and right.

7. Results

7.1 Results 1 - Efficiency of traditional forms of HCI during a web-based test

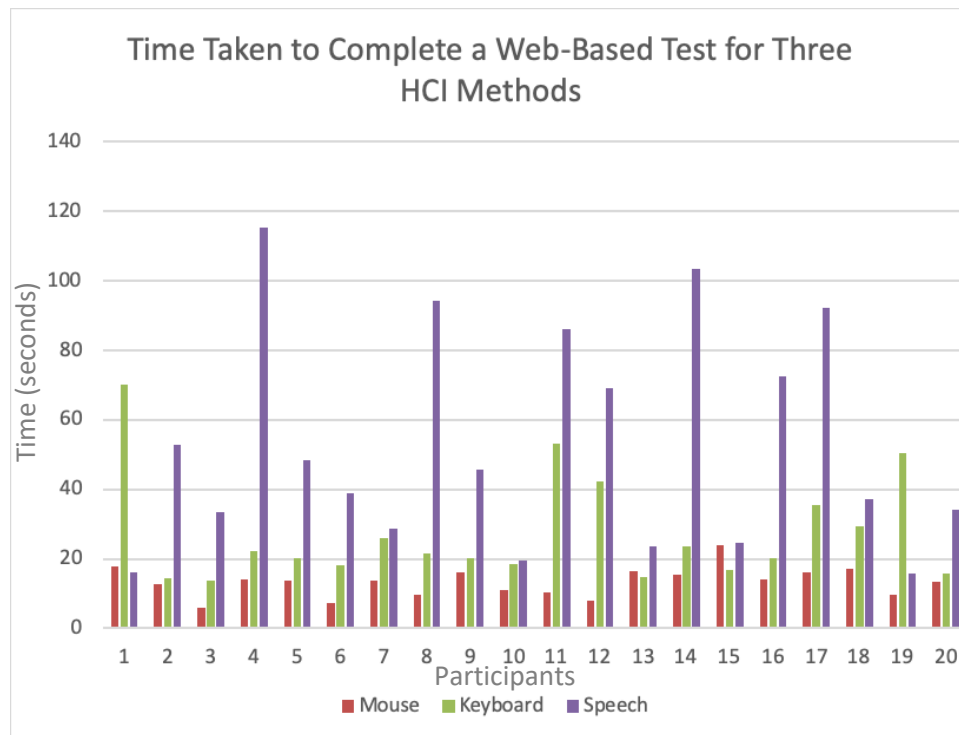


Figure 14: Time taken to complete a web -based test for three HCI methods

The graph in Figure 11 drawn from the result set (see Appendix V) shows the time taken (y-axis) to complete the web-based test developed for this project using three different HCI methods being mouse (red), keyboard (green) and speech recognition (purple) for the 20 candidates that were tested. The use of 3 decimal places was utilised throughout the experiment to allow for consistency with the recorded times on the web application. It can be determined from the graph that mouse method yielded the quickest time with an average of 13.323 seconds to complete the test compared to speech recognition which yielded the slowest average time of 52.551. Keyboard yielded an average time of 27.328. Whilst the results for mouse are similarly placed on the graph, confirmed with a standard deviation of 4.170, keyboard, and speech even

more so show drastic variance between results with standard deviations of 15.303 and 31.399 respectively. The slowest time to complete either of the three tests was that of participant 4 during the speech recognitions test where a time of 115.195 seconds was recorded. The fastest time recorded was during participant 3's mouse round where a value of 5.807 seconds was scored. Participant 4 was recorded as having the greatest variance in times with a standard deviation of 56.128 3dp with participants 8, 11, 12, 14, 16 and 17 yielding similar variances and standard deviations which were above 30 seconds. Most result sets of great standard deviation typically show speech recognition having the most drastic deviation from their mean. However, there are some sets where keyboard presents to be the most drastic from their mean, with some even having low times for speech.

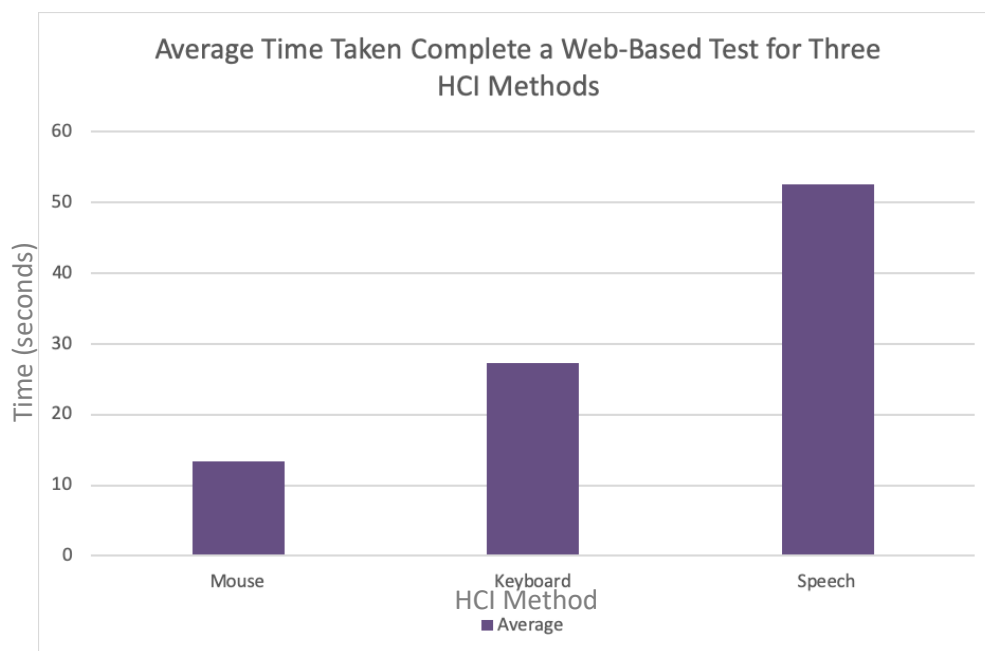


Figure 15: Average time taken to complete a web-based test for three HCI methods

Figure 10 shows the average time taken to complete the test for each HCI method. The clear indication from this visual is that the average time taken keyboard, 27.328 3dp, is greater than

that of mouse which was 13.323 3dp. The average time for speech was greater than that of mouse and keyboard resulting the greatest time of 52.551 3dp. In addition to these statistics, whilst mouse took the least amount of time it was also completed with 100% accuracy. The success of the following HCI methods follow a similar trend to that of the average time with the success rate reducing to 86% for keyboard and 60% for speech. Furthermore, the accuracy statistics of speech methods shows two participants who were unable to score any of the rounds correctly resulting in a success rate of 0%. However, there were still three participants who scored correctly for all rounds. Those who did not score 100% accuracy for the keyboard test typically scored with 75% accuracy with only one participant with 50% and another with 25%.

7.1.1. Statistical Data Analysis

The data set consisted of 3 sets of data, therefore, a one-way Analysis of Variance (ANOVA) test was performed. The conduction of an ANOVA reduced the likelihood of type-I errors and allowed the researcher to identify whether there was a statistically significant difference between the data sets than within the data sets themselves. This is done to testify for or against the null hypothesis for this particular study. The table below shows the results from the ANOVA test.

Table 2: Analysis of Variance Table

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F statistic	P-value
Between Groups	15808.15956	2	7904.07978	19.1616501	4.3178E-07
	23512.19994	57	412.494736		
Total	39320.3595	59			

The ANOVA table above shows the results from the test that was conducted. The F statistic is the ratio for the mean squares between over the mean squares within and is an indication of the variability in these two categories. Also indicated is the p-value for this test is 4.3178×10^{-7} . This probability would suggest that under the assumption of the null hypothesis the probability of the mean squares of between groups is greater or equal to 19.162 times the mean squares within the groups. At a significance level of 0.05, it can be determined that there is highly significant evidence to reject the null hypothesis and hence it can be said that the means of each group of HCI are different.

It is now to be determined where the difference lies between the means and to what magnitude. To do this Tukey's Honestly Significant Difference test will be conducted. This was chosen as it reduces the risk of a Type I error which is to reject a true null hypothesis and does so by using the studentized range. The results for this test are displayed in the table below.

Table 3: Difference in means comparison of table

	MeanX – MeanY	Critical q	Standardised Error	95% confidence interval		Significant at 0.05?
Mouse – Keyboard	-14.00515	3.75	4.541446553	-31.035575	3.02527457	
Mouse - Speech	-39.2284	3.75	4.541446553	-56.258825	-22.197975	YES
Keyboard - Speech	-25.22325	3.75	4.541446553	-42.253675	-8.1928254	YES

In table 3 the first column shows the three different comparisons made between each group. The following column shows the difference in means indicating the estimated difference. Critical q is the critical value of the studentized range drawn from a statistical table that factors for the amount of data, the amount of comparison groups and the degrees of freedom from the previous table. This value is then formulated along with the standardized error in the following column. This calculation is then used to determine the 95% confidence interval using the difference in means from the second column. The confidence intervals can then be interpreted to identify the following:

- It can be said with 95% confidence that on average for a sample size of 60 using mouse takes between 31.04 seconds less and 3.03 seconds more than keyboard. $\left[\frac{L}{SEP} \right]$
- It can be said with 95% confidence that on average for a sample size of 60 using mouse takes between 56.26 to 22.20 seconds less than speech. $\left[\frac{L}{SEP} \right]$
- It can be said with 95% confidence that on average for a sample size of 60 using keyboard takes between 42.25 to 8.19 seconds less than speech. $\left[\frac{L}{SEP} \right]$

From these statements we can infer that between mouse and keyboard on average could possibly be 0 meaning that they could possibly have no difference and take the same time. Consequently, a conclusion cannot be declared regarding this statistic. On the other hand, the remaining statements allows the conclusion to be made that the time taken for mouse and speech, and keyboard and mouse are not equal and that we can say with 95% confidence that a sample of 60 recordings take 56.26 to 22.20 seconds longer for speech than mouse and 42.25 to 8.19 seconds longer for speech than keyboard.

7.1.2. Discussion

Before conduction of the experiment it was predicted that the time taken to perform each test using different HCI methods would decrease when moving from mouse to keyboard and then from keyboard to speech. This was predicted since their perception and intended purpose is to facilitate an easier way to communicate to the computer, thus, also in keeping with the predictions in Moore's Law [5], [83], [84], [44]. The results show distinctively that this is not true, as the average time taken for each technology opposes the initial hypothesis. In fact, the quickest average time was found when participants were using the mouse and the slowest average time when using speech-recognition. However, there was the exception of two occasions where the slowest average time displayed results in keyboard use.

7.1.3. Qualitative results and analysis

After conduction of the HCI experiments each participant completed a short questionnaire. The reason for this facet of the experiment resulted due to the identified gap in the literature review surrounding HCI and user experience. The results gathered from the questionnaire regarding the use of the mouse, keyboard and speech-recognition HCI methods tested during the first experiment would suggest that the participants felt most comfortable using the mouse as a control input and found it easy to use. There were some criticisms, however, with participants finding it difficult at times to navigate the graphical interface, not understanding how to proceed to the next question. This can be considered a criticism to the development and design of the application itself, as oppose to the use of the mouse. With regards to the use of the keyboard most participants expressed how familiar the method was and described very few difficulties. Those who did describe some difficulties however did include the obstacle of accurate spelling and mistypes especially when under pressure in such a test environment. This might have also affected the results gathered in this experiment. Speech input was addressed as being inaccurate in capturing the participants answer and consequently led to the feeling of

frustration. Although some participants commented on how they did not have to think too much about how they were going to answer the question, they did highlight how confusing it was to initiate the speech recognition and how to submit their answers. This again, is partly due to the designed webpage where users ultimately answered using speech recognition but submitted their answer by clicking the enter key and so it is this disparity in control inputs and cross-over between speech and mouse that could have been the cause of this discrepancy and thus possibly affecting the final results. Overall, the general consensus described mouse as being the most comfortable HCI input.

7.2. Results 2 - Accuracy and Practicality of EEG mental commands as a control input

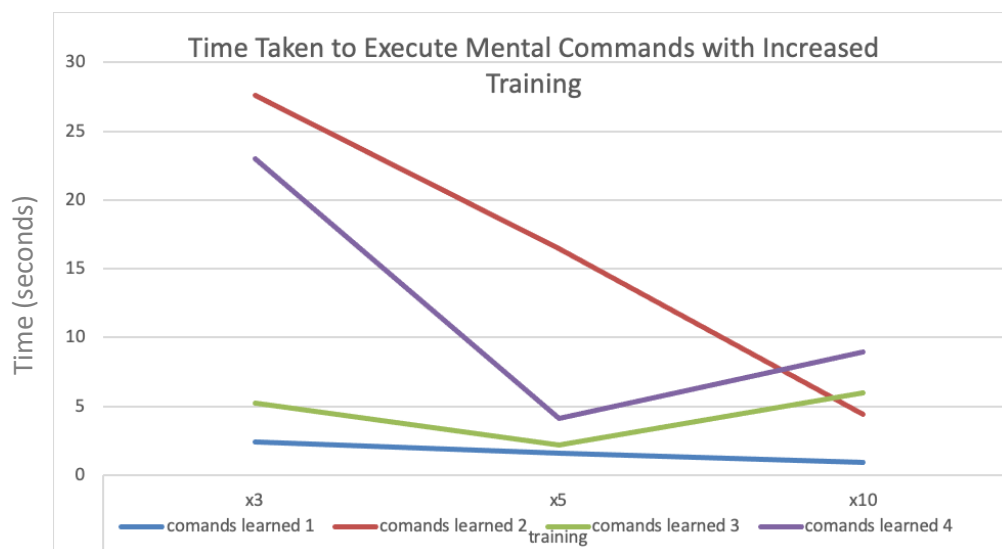


Figure 16: Time taken to execute mental commands with increased training

As can be depicted from the above graph the results identified from commands 1 and 2 revealed that an increase in training sessions resulted in a decrease in the average time taken to execute the trained commands. Conversely, for commands 3 and 4, the average time taken to execute the command reduced upon 5 training session compared to 1 training session, however, after 10 training sessions the average time increased slightly, not following the trend set by

commands 1 and 2. Interestingly, the average time taken to execute the command for command 4 after 10 training sessions were still below the average with only 1 training session. The same is not true for command 3 showing an increase in average time after 10 intervals slightly higher than after 1 training session. Commands were learnt in numerical order with command 1 being learnt first. It is clear to see that both 1 and 2 commands learned have a negative correlation whilst 3 and 4 commands learned are inconclusive. Furthermore, the standard deviations between training intervals calculated show an initial result of 0.91 seconds for 1 command learned but as the commands were learned this raised to 13.77, 6.42 and 12.68 for 2, 3, and 4 commands respectively. Additionally, the standard deviation between each command learned at specific training intervals shows a decrease from 15.13 to 6.32 from 3 to 5 to 10.

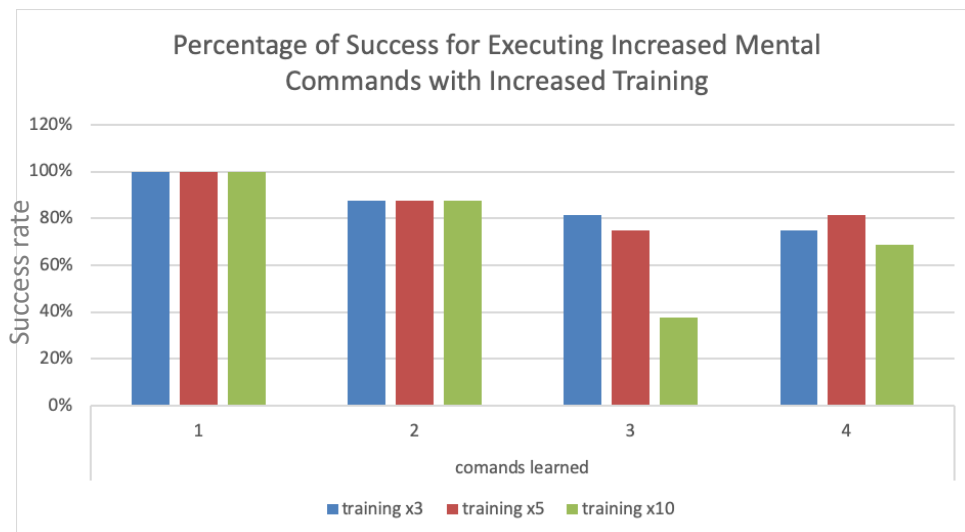


Figure 17: The percentage of success for executing increased mental commands with increased training

Table 4: Accuracy of training

Commands learned	Accuracy of Training (%)		
	3 Training Sessions	5 Training Sessions	10 Training Sessions
1	100	100	100
2	87.50	87.50	87.50
3	81.25	75.00	37.50
4	75.00	81.25	68.75

The accuracy of the EEG headset in producing results were also recorded during the experiment for those participants who were able to do so (see Appendix VI). As seen in Figure 17 and Table x all candidates were able to execute command 1. For command 2, 87.5% of participants were able to produce a reading. Commands 3 and 4 however, found discrepancies in the accuracy of the EEG headset. Command 3 show participants producing a result 81.25%, 75% and 37.5% for the training sessions 1, 5 and 10 respectively. Whilst, command 4 showed accuracy of 75%, 81.25% and 68.75% for training sessions 1, 5 and 10 respectively.

7.2.1. Statistical Data Analysis

A Data Analysis of these results was considered however the failed attempts that exists with high prevalence in the data and the fact that the two variables in this particular study were recorded with the same sample group, an ANOVA test was unable to be carried out.

7.2.2. Discussion

Before conduction of the experiment it was predicted that the time taken to execute each learnt command would decrease whilst training was increased. The mean results indicated this hypothesis to be correct as on average, the time taken to execute a command decreased as the training intervals were increased. Specifically, the average time taken to complete the test after 3 training sessions was 13.96s and this decreased to 6.05s and 4.43s for 5 training sessions and 10 training sessions, respectively. Furthermore, as training increased the standard deviation decreased in parallel ranging from figures of 15.13 – 6.32. This result highlights a decrease in the variation surrounding the mean. Thus, it can be interpreted that with further training, the more accurate the results are. Command 1 (push) was the initial command trained to each participant and the average timing decreased with an increase in training, although the difference was not significant. This may be because the participants were not subject to a lack of focus or tiredness such as when the test progressed, thus, focusing the EEG headset to perform the push action may not have been as challenging as more commands were learned. It can be suggested that the first command is unaffected by any other commands as it is only this command that the headset has been trained to recognise at such point. Such a difference in mental state between neutral thought and command thought may be easier to identify rather than the headset actually recognising the specific thought. This is further supported by the times taken for this first command and the 100% success rate reported, all of which suggest that the participant felt comfortable recalling the 1 command and a small standard deviation would suggest that this was the case for the vast majority of the participants.

Once the participants had already learnt the push command (1), they were subject to learning a new command - pull (2). Results for command 2 highlight a significant difference in the time taken after the 3 initial training sessions, showing times of 0.25 seconds and 28 seconds for command 1 and 2, respectively. This recording in particular shows a greater variance in results

with a significant number of recordings being above the average. This could possibly be caused by an additional command being learned by the participation after only having to learn one command beforehand. Consequently, the participant may have been having trouble tactically thinking of the command in such a way that was sufficiently different from the first. Subsequently, the headset might have taken longer to distinguish between two different thought commands as oppose to just neutral and one command. This is demonstrated in Figure 13, (participant 6), where the pattern of thought converges to portray similar thought processes as oppose to Figure 14, (participant 3), where the pattern is dispersed highlighting the participants use of distinct and different thought patterns being recorded for each command. In Figures 13 and 14 the different colour circles represent the commands and the neutral state which is placed in the centre of the diagram. The distance between the circles represents how different the technology interpreted each command. Interestingly, participant 6 had a success rate of 58.33% whilst participant 3 had a success rate of 100%. This could be attributed to the lack of tactical techniques when training the command to encourage the better placement of each command in terms of how they were imaged, particularly evident since participant 6 specifically expressed how difficult this was.

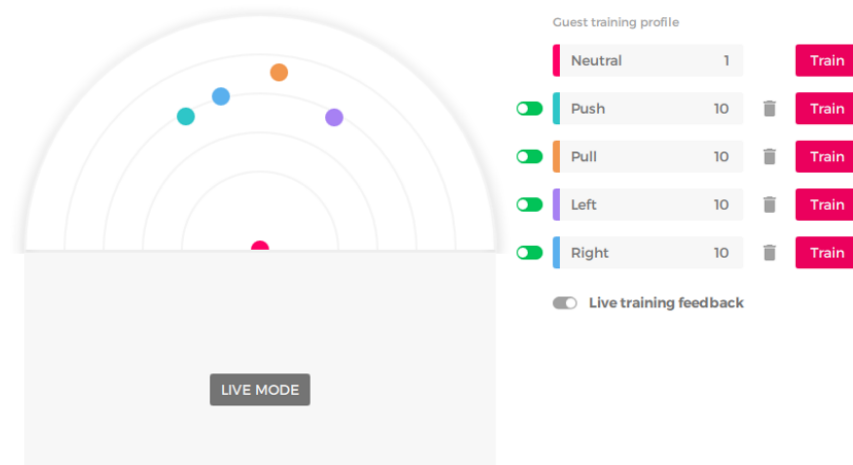


Figure 18: Application depiction of commands for participant 6

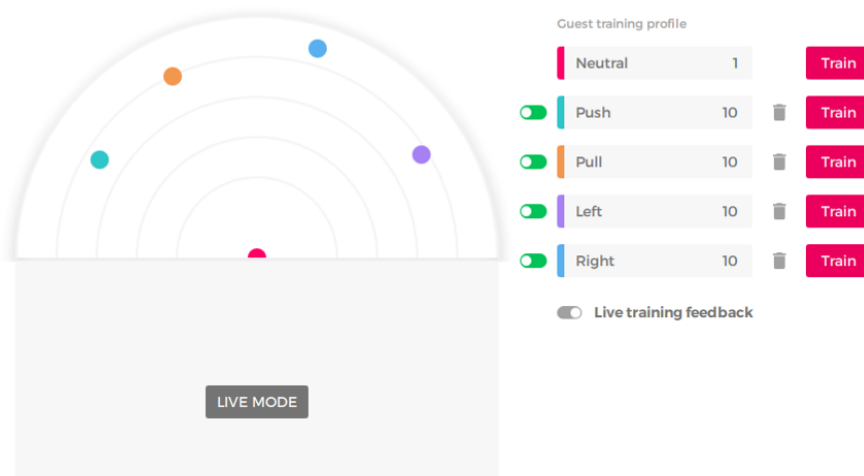


Figure 19: Application depiction of commands for participant 3

Results from the questionnaire also testify to this with the majority of participants describing how they found it difficult to tactically think of a new command in a way which was different from the previous. After the initial recording at 3 training sessions, the time taken to issue command 2 reduced with increased training intervals of 5 and 10 and by 10 training sessions the time taken similarly approached the time for the first command. This could suggest that the

participants could still feel relatively comfortable recalling the two commands learned (push and pull) at a reasonable respective time frame. Overall, the success rate remained positively high, except for 2 participants who were unable to recall the second command for each training interval. This reduction in success rate could be due to multiple confounding factors including the inaccuracy of the headset being able to distinguish between the learned commands, or alternatively, as previously explored a difference in tactical thought patterns. Additionally, another causal factor could be due to the additional commands being learned, causing more stress to the participants who have to learn and perform more tasks.

Conversely, whilst the average time taken showed a decrease with an increase in training, this trend was not as clear for the commands 3 (left) and 4 (right). A reduction in success rate describes the trend for which the third and fourth command follow dropping to as low as 37.5% for command three after 10 training sessions and 68.75% in command four after 10 training sessions. This reduction could also be caused by difficulty and stress as just mentioned for the previous first and second command. Furthermore, the affects would present themselves even more so for the extra commands. Possibly contributing to the decrease is a lack of focus as the experiment took in excess of 20 minutes and so possibly having a negative effect on the participant's attention span.

It is noteworthy to mention however, that the significant different in the success rate for command 3 (left), which is noted as 37.5%. This may be attributed to the fact that all the participants were recorded as being right-handed and that command 3 required participants to move the cube into their inferior position, left. It is speculated then that the participants may have found it difficult to imagine actions with their left hand and other thought techniques due to the possible disconnect for a relatively unfamiliar command in comparison to the command 4 (right). However, this trough in the results was presented after 10 training sessions whereas

the previous intervals presented success rates that were more similar to those of command 4. As discussed before, the increased training could have produced increased stress and may have possibly combined with the reduced ability to tactically think of 'left' associated thoughts. Regarding the times taken to successfully issue command 3, the initial times for interval 3 are a lot less prevalent than that of command 2 whilst being more similar to command 1. This is also true for interval 5 which is concurrent with the trend identified for the first two commands. However, the final interval of 10 displayed higher average times than the previous two intervals and so the results for command 3 do not appear to follow the same correlation as before. Such an increase in average time could suggest similar conclusions as the reduction in success rate as discussed previously and that those who were successful still finding it difficult to issue the command.

The average times for command 4 initially spike above those recorded for command 1 and 3 and mimic those of command 2. Again, this could be caused by an increased in stress and possibly even performance anxiety. The results show an improvement with increased training during interval 5 but, similar to command 3, show a dissimilarity in correlation to the first two commands for interval 10. This could be attributed to participants eager to finish the experiment since some participants did express that they were disinterested and lacked focus towards the later stages of the experiment. However, these results could also be the result of increased demand to perform various different mental commands that could be difficult to do, especially when, as described by participants, the techniques for thinking the mental commands for various commands were difficult and sometimes closely matched techniques for previous commands possibly causing the participant to find the differentiating of commands difficult and thus having them perform poorly.

7.2.3. Qualitative Analysis and Results

In similarity to Experiment 1 after the HCI experiment concluded each participant completed a short questionnaire. The reason for this facet of the experiment resulted due to the identified gap in the literature review surrounding HCI and user experience. Reiterating the previous definition of HCI: the various methods in which humans are able to operate computers, with a design focus reserved for functionality and usability, that is, being able to communicate with computers effectively and efficiently regarding ease of use and the value of the information being conversed. In this definition we see a specific focus on functionality, usability and ease of use. All of which should be considered factors when designing and evaluating HCI and BCI inputs.

For the written answers, thematic analysis was applied to analysis the data further. From initial analyses several key themes became apparent. These were:

1. Frustration
2. Simplicity
3. Efficient Communication

The results gathered from the questionnaire would suggest that overall, participants found it difficult to perform consistently throughout the experiment attributing this to a lack of focus, inability to perform more than one command and frustration when they were not able to successfully issue the mental command. Some participants in particular stated that they were often disheartened when they received negative feedback from the training and performance and so felt this was reflected in their results which could have been the case. Additionally, most participants felt uncomfortable with the feeling of the headset. This could have resulted in the participants having a negative outlook for the duration of the experiment and possibly hindering their capabilities. Furthermore, participants described how concentrating on performing mental

commands resulted in headaches and fatigue. This fatigue could have been the case especially when participants were unsuccessful. Results further suggested that despite a mutual feeling of frustration, the way in which they were communicate to the computer was relatively simple. This simplicity could be attributed to the participant not being required to move and make any physical effort to operate the device for which the EEG was recorded by. Although comments did reflect significant efforts to concentrate and issue the command through various techniques, the participants addressed the ability to not be tethered to the computer through use of a device. Finally, results suggested that participants felt that their intentions were captured efficiently by the headset for the majority of the experiment. This could give testament to the EEG device generally succeeding in interpreting the thought of the participant.

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the participants addressed the ability to not be tethered to the computer through use of a device. Finally, results suggested that participants felt that their intentions were captured efficiently by the headset for the majority of the experiment.

8. Conclusions

The EEG results, whilst varied, did not follow the initial expected outcome. Problems found early on included training times and software acquisition considering the cost of such headsets. Researchers have often cited the control of a BCI system to be an acquired skill; further there is the role of Visual Environments (VE) [51]. As humans, VEs are incredibly important in the 3-Dimensional world we live in. The experiments performed however, were limited to only one sensory pathway, being the visual cortex. Participants visualised the movement of a cube for their desired thought command. This is not characteristic of the five sensory pathways known that shape everyday experiences – vision, hearing, touch, smell and taste; all of which act in a culminative manner to shape our reactions and thoughts [28], [51]. It is therefore difficult to gather generalisable data from the experiments conducted and thus, form conclusions that can explain, and ultimately enhance the use of BCI technology. Further studies may benefit from including additional sensory pathways, which enhance one's perceptual learning [28], [51]. By allowing for this enhancement and subsequently its durability, routes may follow a sensory feedback loop that in turn can help individuals acquire skills to control a BCI system [28], [51]. It is this control, that is currently lacking and inhibiting the capability of how we can use BCI technology [28], [51]. Whilst, these possibilities are plausible; currently, where BCI fall short is the simple use of illusory effects, by means of 3D graphical outputs electronically linked via headsets/goggles/gloves [28], [51]. Rather than utilising the five senses we use to experience day-to-day life.

Nonetheless, with adequate training, the user can convey their intent and have their command interpreted and actioned within seconds, simply through thought [53], [54]. However, there are some issues that could present themselves. Firstly, the training of commands could be quite intensive and, depending on the person, may require a long process of repeat attempts and patience [55]. In addition, the functionality of the headset as a BCI is limited to the commands

that have been trained [55]. Currently, the technology is unable to adapt and learn new commands dynamically and so the user must anticipate the instructions that they may wish to issue when training [55]. Furthermore, the ability to rationalise a thought process and make decisions within one's own mind can be completely misread as a mental command leaving the user infringed upon and possibly unable to feel privacy with their own thoughts [55], [56], [57]. It is understood from this study that the accuracy of the technology is satisfactory but at a compromise to user experience where frustration and intense concentration is evident. The time taken for the headset to interpret the thought command has been shown to be aided by training however it remains unclear as to what extent and possibilities different training techniques impact the time in addition to the number and nature of the additional commands that follow.

The results from the traditional HCI methods show statistical significance evidencing that the times taken for keyboard, mouse and speech recognition do indeed differ with a strong significance in difference between the times of mouse and speech, and keyboard and speech. It was undetermined whether the same significance could be said for mouse and keyboard. Furthermore, the averages discovered from the results set would suggest that using mouse as a control input was the fastest in time. It was identified that this method in particular promotes ease of use and simplicity and was generally the preferred method of choice when compared to keyboard which, although was familiar, often resulted in human error and inefficient communication, and speech which yielded low accuracy scoring and a unfavourable usability.

Although this project involved the conduction of two studies into HCI methods that followed different experimental procedures it is considerable to compare the two result sets in respects that inform and testify to the over-arching aim of this study. In comparison to the three traditional HCI methods tested, EEG poses to be a viable contender in terms of capture and response times of executed commands. However, the ways in which it has been tested to

execute such commands would suggest that EEG could not possibly compare with regards to ease of use and practicality. Whilst the traditional forms of HCI that is the mouse, keyboard and speech are presented as being relatively easy to use and yields relatively low execution times, EEG remains to be a device for which extended training sessions must be undertaken in order to execute the desired command for best results. Nonetheless, this project shows promise for the capabilities of EEG software for future use.

9. Reflection

Due to time constraints this project was limited to testing only a small sample of participants. Further, the complications that came with the EEG headset hindered experimental results. These included the time taken to train participants to learn the given commands and the connectivity problems that came when placing the EEG electrodes on the participants head. For future work, it may be beneficial to plan a longer training period for training each though command. In turn, this may benefit the EEG headset to producing more accurately times results. Additionally, it may be favourable to include a healthy sample size of participants that do not obtain thick, long hair, as the participants who displayed problems in device connectivity reported in the post-experiment questionnaire to having thick, long hair. Moreover, future experimentations will take careful consideration into sampling for age of participants and handwriting orientation as they issues were seen as confounding factors in the speech recognition experiment and the learning of though commands push and pull, respectively. The thematic analysis highlighted flaws in the webpage design especially for the speech recognition technology, participants were subject to confusion when having to move the test along by using the mouse, thus, crossing over from speech-recognition to mouse use. This was made more apparent perhaps, by the design of the keyboard experiment. The researcher designed the keyboard section to automatically focus on the continue button (as seen in Figure 7) once the chosen answer was selected. This meant that the keyboard experiment did not incorporate a mouse technique. It is evident that this discrepancy which generate confusion for participants during the speech-recognition test is a flaw in the researcher's webpage design, this flaw is relatively easy to correct for future studies. It can also highlight a concern when using mouse as a HCI. A subtle assumption was made by the researcher that the user was able to navigate the page well with very little assistance when using the mouse and this could have affected the results from the mouse part of this experiment. To conclude, with hindsight, the software of

the EEG utilised in the experiment (emotive BCI) was not best suited to the needs of the experiment. Not only were there connectivity issues that hindered experimental results, but the inability to work the software tooling provided with the headset changed the course of this project. It was found that certain aspects of the software tooling had been declared end of life and was no longer supported. This subsequently created a barrier for the researcher.

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11. Appendix

11.1. Appendix I: Participant information sheet

With the use of technology increasing rapidly to transform communication and help keep us ever connected. It is important to determine how different aspects of this technology can be utilised. This study will determine how effective brain-computer interaction can be in comparison to speech-recognition technology and how effective they are in terms of speed and usability. Such technology has been successfully employed for the use of individuals in a medical sense who have suffered with motor impairments ...

In the present study, you will be included in an experiment which will assess the speed of both BCI technology (EEG headset) and speech recognition technology. This will be achieved by analysing the time taken to complete a given set of questions. If interested participants will be required to use both a wearable headset and take part in the speech technology. All responses will be anonymous and there will be no way of identifying the responses of any participant.

Participation in this study is voluntary and you have the right to withdraw from this study at any time.

This study has been approved for Standard Ethical Approval by UWTSD.

If you are happy to proceed with this study, please fill in a consent form.

If you have any further questions, please ask the experimenter or e-mail the experimenter at 1809709@student.uwtsd.ac.uk

11.2. Appendix II: Consent Form

	Please tick:
I consent that I am over the age of 18 years old	
I consent that I am proficient in the English language	
I consent that I am not visually impaired	
I consent that I am not hearing impaired	
I understand that all responses given will be made anonymous	
I consent to study participation	

11.3. Appendix III: Ethical approval form

APPLICATION FOR ETHICAL APPROVAL

In order for research to result in benefit and minimise risk of harm, it must be conducted ethically. A researcher may not be covered by the University's insurance if ethical approval has not been obtained prior to commencement.

The University follows the OECD Frascati manual definition of **research activity**: “creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications”. As such this covers activities undertaken by members of staff, postgraduate research students, and both taught postgraduate and undergraduate students working on dissertations/projects.

The individual undertaking the research activity is known as the “principal researcher”.

Ethical approval is not required for routine audits, performance reviews, quality assurance studies, testing within normal educational requirements, and literary or artistic criticism.

Please read the notes for guidance before completing ALL sections of the form.

This form must be completed and approved prior to undertaking any research activity. Please see Checklist for details of process for different categories of application.

Delete the Guidance Notes at the end of the form BEFORE submitting your application

SECTION A: About You (Principal Researcher)

Full Name:	Rhys Harding			
Tick all boxes which apply:	Member of staff:	☐	Honorary research fellow:	☐
Undergraduate Student	☐	Taught Postgraduate Student	☒	Postgraduate Research Student

Faculty/School/Centre:	Faculty Architecture Computing and Engineering: School of Applied Computing
Campus:	SA1 IQ
E-mail address:	1809709@student.uwtsd.ac.uk
Contact Telephone Number:	07954995226
For students:	
Student Number:	1809709
Programme of Study:	Master of Science (Part-time) - Software Engineering (Web Development)

Director of Studies/Supervisor:	Dr Tim Bashford
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SECTION B: Approval for Research Activity

Has the research activity received approval in principle? (please check the Guidance Notes as to the appropriate approval process for different levels of research by different categories of individual)	YES	☐	NO	☒
				<i>Date</i>
If Yes, please indicate source of approval (and date where known): Approval in principle must be obtained from the relevant source prior to seeking ethical approval	Research Degrees Committee	☐		
	Faculty Research Committee	☐		
	Other (write in)	☐		

SECTION C: Internal and External Ethical Guidance Materials

Please list the core ethical guidance documents that have been referred to during the completion of this form (including any discipline-specific codes of research ethics, and also any specific ethical guidance relating to the proposed methodology). Please tick to confirm that your research proposal adheres to these codes and guidelines.	
UWTSD Research Ethics & Integrity Code of Practice 2017-2020	☒
	☐
	☐

SECTION D: External Collaborative Research Activity

Does the research activity involve collaborators outside of the University?	YES	☒	NO	☐		
If Yes, please provide the name of the external organisation and name and contact details for the main contact person:						
Institution	DVLA Swansea					
Contact person name	Mr Craig James					
Contact person e-mail address	craig.james@dvla.gov.uk					
Are you in receipt of a KESS scholarship?	YES	☐	NO	☒		
Is the research funded or non-funded?	Funded	YES	☐	NO	☐	☒
	Non Funded	YES	☒	NO	☐	

Are you specifically employed to undertake this research in either a paid or voluntary capacity?	Voluntary	YES	☒	NO	☐
	Employed	YES	☐	NO	☒
Is the research being undertaken within an existing UWTSD Schools Partnership?	If YES additional information is not required)	YES	☐	NO	☒
Permission to undertake the research has been provided by the partner organisation	If YES attach copy) If NO the application cannot continue	YES	☐	NO	☒

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Where research activity is carried out in collaboration with an external organisation

Does this organisation have its own ethics approval system?	YES	☐	NO	☐
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If Yes, please attach a copy of any final approval (or interim approval) from the organisation

SECTION E: Details of Research Activity

Indicative title:	The effectiveness of Brain-Computer Interaction (BCI) compared to more traditional inputs		
Proposed start date:	31/5/2019	Proposed end date:	01/07/2020
Introduction to the Research (maximum 300 words) Ensure that you write for a <u>Non-Specialist Audience</u> when outlining your response to the three points below: • <i>Purpose of Research Activity</i> • <i>Aims of Research Activity</i> • <i>Objectives of Research Activity</i> Demonstrate, briefly, how <u>Existing Research</u> has informed the proposed activity and explain • <i>What the research activity will add to the body of knowledge</i> • <i>How it addresses an area of importance.</i>			
Purpose of Research Activity This project will aim to investigate the efficiency and practicality of Brain Computer Interaction (BCI), specifically Electroencephalography (EEG) technology, in comparison to more traditional methods, specifically, speech recognition technology. With the use of EEG software, I will aim to determine whether timed responses to pre-determined questions are significantly different to speech recognition, thus making communication and computer interactions for users more efficient. Ultimately, with determining the most efficient and quickest mode of communication a wide variety of individuals can benefit. (this box should expand as you type)			
Aims of Research Activity			

This research study will be conducted to investigate whether there exists a significant correlation between the two different input methods with regards to speed and time. It will be hypothesised that there is a difference in time, with favour being granted to BCI.

(this box should expand as you type)

Objectives of Research Activity

- Conduct a literature review that involves detailed and thorough investigation into surrounding and supporting literature of the topic at hand.
- Construct and adapt the pre-existing EEG software so that it becomes relevant to this piece of research
- Conduct an experiment to investigate whether there is a significant difference between the time taken to complete pre-determined questions for two different Human Computer Interaction methods that are EEG and speech recognition.
- Analyse and Evaluate the findings from the experiment to provide a response to the proposed hypothesis and, moreover, the objective of this project.

(this box should expand as you type)

Proposed methods (maximum 600 words)

Provide a brief summary of all the methods that **may** be used in the research activity, making it clear what specific techniques may be used. If methods other than those listed in this section are deemed appropriate later, additional ethical approval for those methods will be needed.

- The development of and experimentation to investigate whether there is a significant difference between the time taken to complete pre-determined questions for two different Human Computer Interaction methods that are EEG and speech recognition.
- Software development
- Pre-questionnaire

(this box should expand as you type)

Location of research activity

Identify all locations where research activity will take place.

UWTSD

(this box should expand as you type)

Page Break

Research activity outside of the UK

If research activity will take place overseas, you are responsible for ensuring that local ethical considerations are complied with and that the relevant permissions are sought. Specify any local guidelines (e.g. from local professional associations/learned societies/universities) that exist and whether these involve any ethical stipulations beyond those usual in the UK (provide details of any licenses or permissions required). Also specify whether there are any specific ethical issues raised by the local context in which the research activity is taking place, for example, particular cultural sensitivities or vulnerabilities of participants.

<i>(this box should expand as you type)</i>		
Use of documentation not in the public domain: Are any documents NOT publicly available?	NO	☒
	YES	☐
If Yes, please provide details here of how you will gain access to specific documentation that is not in the public domain.		
<i>(this box should expand as you type)</i>		

SECTION F: Scope of Research Activity

Will the research activity include:		YES	NO
Use of a questionnaire or similar research instrument?	☒		☐
Use of interviews?	☒		☐
Use of diaries?	☐		☒
Participant observation with their knowledge?	☒		☐
Participant observation without their knowledge?	☐		☒
Use of video or audio recording?	☐		☒
Access to personal or confidential information without the participants' specific consent?	☐		☒
Administration of any questions, test stimuli, presentation that may be experienced as physically, mentally or emotionally harmful / offensive?	☐		☒
Performance of any acts which may cause embarrassment or affect self-esteem?	☐		☒
Investigation of participants involved in illegal activities?	☐		☒
Use of procedures that involve deception?	☐		☒
Administration of any substance, agent or placebo?	☐		☒
Working with live vertebrate animals?	☐		☒

Other primary data collection methods, please explain in this box Using EEG software to detect the brain's electrical activity produced by its neurons. The activity is recorded in the form of wave forms which can be digitally interpreted to determine the patterns of activity.	☒	☐
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If NO to every question, then the research activity is (ethically) low risk and **may** be exempt from **some** of the following sections (please refer to Guidance Notes).

If YES to any question, then no research activity should be undertaken until full ethical approval has been obtained.

SECTION G: Intended Participants

Who are the intended participants:	YES	NO
Students or staff at the University?	☒	☐
Adults (over the age of 18 and competent to give consent)?	☒	☐
Vulnerable adults?	☒	☐
Children and Young People under the age of 8? (Consent from Parent, Carer or Guardian will be required)	☐	☒
Prisoners?	☐	☒
Young offenders?	☐	☒
Those who could be considered to have a particularly dependent relationship with the investigator or a gatekeeper?	☐	☒
People engaged in illegal activities?	☐	☒
Others (please identify specifically any group who may be unable to give consent) please indicate here and tick the appropriate box.	☐	☒

Participant numbers and source	
Provide an estimate of the expected number of participants. How will you identify participants and how will they be recruited?	
How many participants are expected?	More than 5 less than 10 <i>(this box should expand as you type)</i>
Who will the participants be?	Staff and students <i>(this box should expand as you type)</i>
How will you identify the participants?	Voluntary participants categorised by the pre questionnaire

	<i>(this box should expand as you type)</i>
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Information for participants:	YES	NO	N/A
Will you describe the main research procedures to participants in advance, so that they are informed about what to expect?	☒	☐	☐
Will you tell participants that their participation is voluntary?	☒	☐	☐
Will you obtain written consent for participation?	☒	☐	☐
Will you explain to participants that refusal to participate in the research will not affect their treatment or education (if relevant)?	☒	☐	☐
If the research is observational, will you ask participants for their consent to being observed?	☒	☐	☐
Will you tell participants that they may withdraw from the research at any time and for any reason?	☒	☐	☐
With questionnaires, will you give participants the option of omitting questions they do not want to answer?	☒	☐	☐
Will you tell participants that their data will be treated with full confidentiality and that, if published, it will not be identifiable as theirs?	☒	☐	☐
Will you debrief participants at the end of their participation, in a way appropriate to the type of research undertaken?	☒	☐	☐
If NO to any of above questions, please give an explanation			
<i>(this box should expand as you type)</i>			

Information for participants:	YES	NO	N/A
Will participants be paid?	☐	☒	☐
Is specialist electrical or other equipment to be used with participants?	☒	☐	☐
Are there any financial or other interests to the investigator or University arising from this study?	☐	☒	☐
Will the research activity involve deliberately misleading participants in any way, or the partial or full concealment of the specific study aims?	☐	☒	☐
If YES to any question, please provide full details			
The use of EEG headsets. EEG headsets are devices that use electrodes that are placed on the head to detect the brain's electrical activity produced by its neurons. These are a non-invasive equipment			
<i>(this box should expand as you type)</i>			

SECTION H: Anticipated Risks

Outline any anticipated risks that may adversely affect any of the participants, the researchers and/or the University, and the steps that will be taken to address them.		
If you have completed a full risk assessment (for example as required by a laboratory, or external research collaborator) you may append that to this form.		
Full risk assessment completed and appended?	Yes	☐
	No	☒
Risks to participants		
For example: emotional distress, financial disclosure, physical harm, transfer of personal data, sensitive organisational information		
Risk to Participant: None	How will you mitigate the Risk to Participant	
(this box should expand as you type)	(this box should expand as you type)	
If research activity may include sensitive, embarrassing or upsetting topics (e.g. sexual activity, drug use) or issues likely to disclose information requiring further action (e.g. criminal activity), give details of the procedures to deal with these issues, including any support/advice (e.g. helpline numbers) to be offered to participants. Note that where applicable, consent procedures should make it clear that if something potentially or actually illegal is discovered in the course of a project, it may need to be disclosed to the proper authorities		
(this box should expand as you type)		
Risks to investigator		
For example: personal safety, physical harm, emotional distress, risk of accusation of harm/impropriety, conflict of interest		
Risk to Investigator: None	How will you mitigate the Risk to Investigator:	
(this box should expand as you type)	(this box should expand as you type)	
University/institutional risks		
For example: adverse publicity, financial loss, data protection		
Risk to University: None	How will you mitigate the Risk to University:	
(this box should expand as you type)	(this box should expand as you type)	

Disclosure and Barring Service

If the research activity involves children or vulnerable adults, a Disclosure and Barring Service (DBS) certificate must be obtained before any contact with such participants.	YES	NO	N/A
Does your research require you to hold a current DBS Certificate?	☐	☒	☐

Page Break

SECTION I: Feedback, Consent and Confidentiality

Feedback What de-briefing and feedback will be provided to participants, how will this be done and when? Information for feedback to be designed as part of the project <i>(this box should expand as you type)</i>
Informed consent Describe the arrangements to inform potential participants, before providing consent, of what is involved in participating. Describe the arrangements for participants to provide full consent before data collection begins. If gaining consent in this way is inappropriate, explain how consent will be obtained and recorded. Participants will be informed as part of the selection process <i>(this box should expand as you type)</i>
Confidentiality / Anonymity Set out how anonymity of participants and confidentiality will be ensured in any outputs. If anonymity is not being offered, explain why this is the case. As above <i>(this box should expand as you type)</i>

Page Break

SECTION J: Data Protection and Storage

In completing this section refer to the University's Research Data Management Policy and the extensive resources on the University's Research Data Management web pages (<http://uwtsd.ac.uk/library/research-data-management/>).

Does the research activity involve personal data (as defined by the General Data Protection Regulation)?	YES	NO
"Personal data" means any information relating to an identified or identifiable natural person ('data subject'). An identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.	x	☐
If YES, provide a description of the data and explain why this data needs to be collected:		

Basic personal data in order to identify each participant collected in order to observe the differences between neurotypical and neurotypically diverse persons' results.		
<i>(this box should expand as you type)</i>		
Does it involve special category data (as defined by the General Data Protection Regulation)?	YES	NO
“Special category data” means sensitive personal data consisting of information as to – (a) the racial or ethnic origin of the data subject, (b) his political opinions, (c) his religious beliefs or other beliefs of a similar nature, (d) whether he is a member of a trade union (within the meaning of the Trade Union and Labour Relations (Consolidation) Act 1992), (e) his physical or mental health or condition, (f) his sexual life, (g) his genetics, (h) his biometric data (as used for ID purposes),	x	☐
If YES, provide a description of the data and explain why this data needs to be collected:		
Disability based data		
<i>(this box should expand as you type)</i>		
Will the research activity involve storing personal data and/or special category data on one of the following:	YES	NO
Manual files (i.e. in paper form)?	☒	☐
University computers?	☒	☐
Private company computers?	☒	☐
Home or other personal computers?	☒	☐
Laptop computers/ CDs/ Portable disk-drives/ memory sticks?	☒	☐
“Cloud” storage or websites?	☒	☐
Other – specify:	☐	☒
For all stored data, explain the measures in place to ensure data confidentiality, including details of password protection, encryption, anonymization and pseudonymization:		
All data will be encrypted, and password protected. Use of portable devices will be kept to a minimum with cloud devices taking precedence		
<i>(this box should expand as you type)</i>		
All Data Storage		
Will the research activity involve any of the following activities:	YES	NO
Electronic transfer of data in any form?	☒	☐
Sharing of data with others at the University?	☒	☐

Sharing of data with other organisations?	☐	☒
Export of data outside the European Union or importing of data from outside the UK?	☐	☒
Use of personal addresses, postcodes, faxes, emails or telephone numbers?	☐	☒
Publication of data that might allow identification of individuals?	☐	☒
Use of data management system?	☐	☒
Data archiving?	☐	☒
If YES to any question, please provide full details, explaining how this will be conducted in accordance with the General Data Protection Regulation (and/or any international equivalent):		
Data will be held for the length of the project after which time it will be replaced with the aggregate findings. Organisational cloud storage will be used to ensure the data is safe. Personal data will not be shared outside the university.		
<i>(this box should expand as you type)</i>		
List all who will have access to the data generated by the research activity:		
Student and academic staff		
<i>(this box should expand as you type)</i>		
List who will have control of, and act as custodian(s) for, data generated by the research activity:		
Student and project supervisor		
<i>(this box should expand as you type)</i>		
Give details of data storage arrangements, including where data will be stored, how long for, and in what form. Will data be archived – if so how and if not why not.		
Data will be held for the length of the project after which time it will be replaced with the aggregate findings. Organisational cloud storage will be used to ensure the data is safe. Personal data will not be shared outside the university.		
<i>(this box should expand as you type)</i>		
Confirm that you are aware that you need to keep all data until after your research has completed or the end of your funding	YES	☒
	NO	☐

Page Break

SECTION K: Declaration

The information which I have provided is correct and complete to the best of my knowledge. I have attempted to identify any risks and issues related to the research activity and acknowledge my obligations and the rights of the participants.

In submitting this application I hereby confirm that I undertake to ensure that the above named research activity will meet the University's [Research Ethics and Integrity Code of Practice](#)

Signature of applicant:	R Harding	Date: 31/05/19
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For STUDENT Submissions:

Director of Studies/Supervisor:		Date:
Signature:		

For STAFF Submissions:

Head of School/Assistant Dean:		Date:
Signature:		

Checklist: Please complete the checklist below to ensure that you have completed the form according to the guidelines and attached any required documentation:

☒	I have read the guidance notes supplied before completing the form.
☒	I have completed ALL RELEVANT sections of the form in full.
☐	I confirm that the research activity has received approval in principle
☐	I have attached a copy of final/interim approval from external organisation (where appropriate)
☐	I have attached a full risk assessment (and have NOT completed Section H of this form) (where appropriate) ONLY TICK IF YOU HAVE ATTACHED A FULL RISK ASSESSMENT
☒	I understand that it is my responsibility to ensure that the above named research activity will meet the University's Research Ethics and Integrity Code of Practice.
☒	I understand that before commencing data collection all documents aimed at respondents (including information sheets, consent forms, questionnaires, interview schedules etc.) must be confirmed by the DoS/Supervisor, module tutor or Head of School.
☒	I have deleted the guidance notes before submitting the PG2 for consideration

11.4. *Appendix IV: Participant questionnaire*

Thank you for kindly participating in the testing. I would be very grateful if you could complete the questionnaire below. Your opinions are very important to me and may be used within my report.

Any responses will be held as strictly confidential and will only be reported within the aggregate.

Candidate Information

Candidate Number:

Left-handed / Right-handed (please delete one)

Male / Female (please delete one)

Short hair / Long hair (please delete one)

To which of these groups do you consider you belong (please tick one box only)

White

British

☐

Irish

☐

Any other White background

☐

Asian or Asian British

Indian

☐

Pakistani

☐

Bangladeshi

☐

Other ethnic groups

Chinese

☐

Any other ethnic group

☐

Not stated

☐

Mixed

White and Black Caribbean

☐

White and Black African

☐

White and Asian

☐

Any other mixed background

☐

Black or Black British

Caribbean

☐

African

☐

Testing methods used (please tick all that apply)

Mouse

☒

Keyboard

☒

Speech

☒

Mind (EEG)

☒

On a scale of 1-10 with 1 being the lowest and 10 being the highest, please answer the following questions:

How easy did you find this technology to navigate?

1 2 3 4 5 6 7 8 9 10

How comfortable were you using this technology?

1 2 3 4 5 6 7 8 9 10

How well did you feel the technology captured your intent?

1 2 3 4 5 6 7 8 9 10

What was your preferred mode of communication?

.....
.....

Specific to EEG, what techniques did you employ to practice learning the trained commands, please list each technique if more than one

.....
.....

Would you use this technology again **Yes** ☐ **No** ☐

Other details

Do you consider yourself, as having a disability, if yes and you are happy to disclose this please give further details below:

.....

.....

.....

.....

Further feedback/ comments

.....

.....

.....

.....

Thank you for taking the time to complete this questionnaire. Should the testing or this questionnaire have raised any issues or concerns for you, please contact the university's Learning Support department to arrange an appointment to discuss further.

11.5. Appendix V: Raw Data for Experiment 1

		training		
candidate	commands learned	1	5	10
1	1	2.22	1.06	1.45
	2	44.52	4.85	3.56
	3	2.45	0.45	1.05
	4	8.23	2.75	2.34
2	1	2.75	2.43	1.28
	2	49.85	25.75	4.32
	3	4.77	2.16	
	4			
3	1	3.86	1.76	0.75
	2	2.54	33.75	4.08
	3	1.98	3.14	24.16
	4	6.07	0.64	22.75
4	1			
	2			
	3			
	4			
5	1	1.1	2.08	0.87
	2	6.96	16.23	10.64
	3	0.53		2.54
	4	52.08	1.56	26.28
6	1	1.53	0.59	0.28
	2		2.46	0.43
	3	7.07		
	4			2
7	1			
	2			
	3			
	4			
8	1	2.67	1.68	0.84
	2		15.34	
	3	2.22	2.07	
	4	18.75	1.98	
9	1	1.68	1.58	0.83
	2	34.87	17.21	0.62
	3	4.59		
	4	19.91	1.49	8.34
10	1	2.57	1.5	0.57

	2	29.01		
	3	3.1	1.64	
	4		23.09	
11	1	2.37	1.23	0.67
	2	23.22	14.96	1.42
	3		1.59	
	4	23.17		10.64
12	1	2.47	1.76	1.45
	2	53.02	12.01	2.45
	3	2.86	2.57	1.22
	4	12.56	1.44	2.34
13	1			
	2			
	3			
	4			
14	1	0.48	1.22	0.35
	2	23.89	16.75	1.09
	3	2.92	1.28	0.95
	4	28.48	12.96	12.11
15	1	2.56	1.93	1.22
	2	26.74	18.13	7.35
	3			
	4	43.87	0.97	
16	1	2.07	1.37	0.74
	2	24.32	23.52	5.28
	3		7.59	
	4		1.22	
17	1	2.08	1.01	0.63
	2	18.45	12.97	2.45
	3	29.39	1.57	
	4	20.73	0.76	3.47
18	1			
	2			
	3			
	4			
19	1	3.67	1.61	0.92
	2	36.48		15.28
	3	3.17	1.03	
	4	17.31	1.36	4.21
20	1	4.36	2.67	1.67
	2	12.37	16.24	2.43
	3	2.43	0.75	

	4	24.67	1.09	3.78
--	---	-------	------	------

Accuracy		training		
		x3	x5	x10
commands learned	1	100.00%	100.00%	100.00%
	2	87.50%	87.50%	87.50%
	3	81.25%	75.00%	37.50%
	4	75.00%	81.25%	68.75%

11.6. Appendix VI: Raw Data for Experiment 2

Candidate	Time (seconds)		
	Mouse	Keyboard	Speech
1	17.635	70.034	16.078
2	12.717	14.443	52.863
3	5.807	13.875	33.431
4	14.207	22.251	115.195
5	13.836	20.256	48.471
6	7.43	18.203	38.802
7	13.728	25.864	28.803
8	9.638	21.545	94.092
9	15.997	20.342	45.575
10	11.136	18.349	19.355
11	10.409	53.053	85.983
12	8.003	42.122	68.935
13	16.375	14.674	23.643
14	15.591	23.574	103.362
15	23.743	16.786	24.744
16	13.909	20.053	72.352
17	16.023	35.534	92.21
18	16.983	29.24	37.262
19	9.768	50.443	15.835
20	13.523	15.92	34.035

accuracy		
mouse	keyboard	speech
1	0.75	1
1	1	0.75
1	1	0.25
1	1	0.75
1	0.25	0.5
1	1	0
1	1	0.5
1	1	1
1	0.75	0.75
1	1	0.75
1	1	0.5
1	1	0
1	0.75	0.75
1	1	0.75
1	1	0.75
1	1	0.75
1	0.5	0.25
1	0.75	0.5
1	0.75	0.5
1	0.75	1

11.7. Appendix VII: Recruitment Poster

PARTICIPANTS
NEEDED



A STUDY INTO
BRAIN-COMPUTER INTERACTION

ELECTROENCEPHALOGRAPHY HEADSETS / BRAIN ACTIVITY
INTERPRETATION / THOUGHT INDUCED CONTROL INPUT

I AM LOOKING FOR INDIVIDUALS TO PARTICIPATE IN AN EXPERIMENT AS
PART OF MY STUDY, PLEASE TAKE A FLYER FOR MORE INFORMATION

INTERESTED?

THE PROPOSAL

I am a postgraduate Master's student studying Software Engineering at UWTSD. This project will aim to investigate the efficiency and practicality of brain-computer interaction, specifically electroencephalography technology, in comparison to more traditional methods, specifically speech recognition technology.

THE TECHNOLOGY

Electroencephalography (EEG) headsets use an array of non-invasive electrodes that detect the brain's electrical activity. The technology then uses machine learning algorithms to attempt to decipher the given wave forms which are then translated to a control input.

THE EXPERIMENT

The study will include an experiment to investigate whether there is a significant difference between the time taken to complete pre-determined questions for two different human-computer interaction (HCI) methods that are EEG and speech recognition.

Each participant will initially be made familiar with the headset whilst preliminary tests are carried out. Proceeding this, the participant will complete two sets of pre-determined questions, answering through the means of the two different forms of HCI.

All results and responses will be completely anonymous. For applications of participation please contact the e-mail below for participation forms and further details. Thank you.

GET IN TOUCH

1809709@STUDENT.UWTSD.AC.UK