Interaction Paradigms for Brain-Body Interfaces for Computer Users with Brain Injuries

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To my Creator Jesus who makes all things beautiful in His time. To my first baby who I never cuddled, never carried, never kissed but was my inspiration to work with the brain-injured and the people around them. I will always love you.

To all participants who strive to communicate against all odds. To all the researchers around the world who work tirelessly to enhance the lives of individuals not counting the cost.

Yea doubtless, and I count all things but loss for the Excellency of the knowledge of Christ Jesus my Lord: for whom I have suffered the loss of all things, and do count them but dung, that I may win Christ – Phil. 3:8

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Abstract

In comparison to all types of injury, those to the brain are among the most likely to result in death or permanent disability. Some of these brain-injured people cannot communicate, recreate, or control their environment due to severe motor impairment. This group of individuals with severe head injury have received limited help from assistive technology. Brain-Computer Interfaces have opened up a spectrum of assistive technologies, which are particularly appropriate for people with traumatic brain injury, especially those who suffer from “locked-in” syndrome. The research challenge here is to develop novel interaction paradigms that suit brain-injured individuals, who could then use it for everyday communications. The developed interaction paradigms should require minimum training, reconfigurable and minimum effort to use.

This thesis reports on the development of novel interaction paradigms for Brain-Body Interfaces to help brain-injured people to communicate better, recreate and control their environment using computers despite the severity of their brain injury. The investigation was carried out in three phases. Phase one was an exploratory study where a first novel interaction paradigm was developed and evaluated with able-bodied and disabled participants. Results obtained were fed into the next phase of the investigation. Phase two was carried out with able participants who acted as development group for the second novel interaction paradigm. This second novel interaction paradigm was evaluated with non-verbal participants with severe brain injury in phase three. An iterative design research methodology was chosen to develop the interaction paradigms. A non-invasive assistive technology device named Cyberlink™ was chosen as the Brain-Body Interface. This research improved previous work in this area by developing new interaction paradigms of personalised tiling and discrete acceleration in Brain-Body Interfaces. The research hypothesis of this study ‘*that the performance of the Brain-Body Interface can be improved by the use of novel interaction paradigms’* was successfully demonstrated.

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Chapter 1 – Introduction

As medical technology not only extends our natural life span, but also leads to increased survival from illness and accidents, the number of people with disabilities is constantly increasing. The World Health Organization (WHO, 2005) estimates that there are more than 600 million people in the world who are disabled as a consequence of mental, physical or sensory impairment, thus creating one of the world's largest minorities. It has been estimated that 80 to 120 million European citizens have a form of disability, exceeding the population of almost every European state (Council of Europe, 2002). In comparison to all types of injury, those to the brain are among the most likely to result in death or permanent disability. In the European Union, brain injury accounts for one million hospital admissions per year (NABIS, 2005). Injury is the leading cause of death for children in Europe (Vincenten, 2001). For every child that dies from injuries, another 160 children are admitted to a hospital for a severe traumatic injury (Vincenten, 2001). Each year in the United States, an estimated, 1.4 million people sustain a brain injury (Langlois *et al.*, 2004). Studies have reported personality changes attributed to traumatic brain injury, which contribute to the perception of those with brain injury as social misfits. As a result of this, individuals with traumatic brain injury often face difficulty in adjusting to their injuries, causing extreme isolation and loneliness (DeHope & Finegan, 1999, Dumont *et al.*, 2004). Brain-injured patients typically exhibit deficiency in memory, attention, concentration, analysing information, perception, language abilities, emotional and behavioural areas (Serra & Muzio, 2002). In the UK, out of every 100,000 of the population, between 100 and 150 people suffer a severe head injury (Tyrer, 2005). Some cannot communicate, recreate, or control their environment due to severe motor impairment. This group of severe head injured people are cared for by nursing homes that cater for their well being in every possible way. Their loved ones also play a major role in the well being of this group.

A Brain-Body Interface is a real-time communication system designed to allow a user to voluntarily send messages without sending them through the brain's normal output pathways such as speech, gestures or other motor functions, but only using bio-signals from the brain. This type of communication system is needed by brain-injured individuals who have parts of their brain active but have no means of communicating with the outside world. There are two types of Brain-Body Interfaces, namely *invasive* (signals obtained by surgically inserting probes inside the brain), and *non-invasive* (electrodes placed externally on part of the body). This thesis reports on an investigation carried out on the use of novel interaction paradigms for non-invasive Brain-Body Interfaces so that this group of brain-injured people can communicate more reliably and more effectively in their environment using computers, despite the severity of their brain injury.

1.1. Motivation

The World Programme of Action Concerning Disabled Persons states that people with a disability:

> *"are entitled to the same rights as all other human beings and to equal opportunities. Too often their lives are handicapped by physical and social barriers in society, which hamper their full participation. Because of this, millions of children and adults in all parts of the world often face a life that is segregated and debased."* (United Nations, 1982).

In a statement presented to the 56th Session of the UN Commission on Human Rights in Geneva, in early April 2000, Bengt Lindqvist stated: "It will take a long time to change this pattern of behaviour, which is deeply rooted in prejudice, fear, shame and lack of understanding of what it really means to live with a disability" (Lindqvist, 2000). At the 52nd meeting of the Third Committee, on 29 November 2001, the representative of Mexico introduced a draft resolution on an international convention on the rights of persons with disabilities, which the Committee recommended for adoption by the General Assembly. General Assembly resolution 56/168, entitled "Comprehensive and integral international convention to promote and protect the rights and dignity of persons with disabilities", was adopted on 19 December 2001. There are also eEurope 2002 and eEurope 2005 initiatives, which show how the European Union also wants to improve the accessibility of the disabled in Europe (Council of the European Union, 2003, Bühler & Stephanidis, 2004).

Assistive technologies have done much to improve the quality of life of individuals with impairments (Salem & Zhai, 1997, Cleveland, 1994, Scargle, 1998, Zafar *et al.*, 1999, WebAim, 2005). However, the group of individuals with severe head injury has received very limited benefit to date from assistive technology to communicate, recreate, or control their environment in any way (Marik *et al.*, 2002, Thornhill *et al.*, 2000). Brain-Body Interfaces have opened up an entirely new spectrum of assistive technologies (Doherty *et al.*, 1999, 2000, 2002, Gnanayutham, 2005, Gnanayutham *et al.*, 2005), which are particularly appropriate for people with traumatic brain injury, especially those who suffer from 'locked-in' syndrome, and appear to be comatose but are actually sentient (Chatrian *et al.*, 1996). Locked-in syndrome patients are completely paralysed, unable to speak or respond to anything, but are cognitively intact. This group of people do not receive further assessments, after their initial head injury and classification as locked-in syndrome, to find individual channels for communication with the outside world. Research has been carried out successfully in laboratory environment in the past, but the results had not filtered through to brain-injured individuals at large. This study aims to take the Brain-Body Interface assistive technology to the field, develop novel interaction paradigms and evaluate with the brain-injured community, so that brain-injured individuals can use a communication system as part of their routine communication, in real time without the need for any off-line data processing.

Although medical technology has advanced immensely in the last forty years, assessing the brain-injured is still very challenging. Medical personnel find it hard to establish the appropriate medical classification with this group of disabled individuals (Roy, 2004). This further complicates matters in performing research with such participants, since it is not known if some of these people are aware but unable to respond, or are really comatose (Berkow *et al.*, 1997, Iskowitz, 1999). One such individual whose capabilities went unrecognised for many years (Gnanayutham *et al.*, 2003, 2005), and was classified as locked-in, with no ability to respond to any instruction, became a valuable contributor to this study. This individual was able to utilise the novel interaction paradigms developed in this study to communicate and control the environment for the first time since suffering traumatic brain injury. Although feedback from the participants of this study was limited at times, the effort made by some to communicate was a great motivating force to carry on in this study. This group of people possess the right to communicate their feelings to the outside world, without all their decisions being made by others on their behalf.

1.2. Research Approach

A non-invasive assistive technology device named Cyberlink™ was chosen as the Brain-Body Interface for this research. Cyberlink™ combines eye-movement, facial muscle and brain wave bio-potentials detected at the user's forehead to generate input via the mouse port. It is also relatively easy to set up. A novel interaction paradigm, was developed and evaluated first with able-bodied, and then with disabled participants. An interaction paradigm can be defined as a pattern underlying an open family of interaction techniques that exploit common knowledge of effective user interface features, whereby optimisation methods can be used to select the most effective technique within a paradigm. An interaction paradigm is characterised by the abstract task that users follow to achieve an interaction goal. Task steps are described in a manner that allows variations of design features and user interface parameters. Nevertheless, the paradigm has a coherence based on key distinguishing user interface features.

Interfaces using brain waves to navigate a cursor around a computer screen to reach specific targets were developed and evaluated in this phase of the research. The investigation was carried out in three phases. Phase one was an exploratory study using two interfaces. The interaction paradigm for the first, used techniques from previous research by Doherty (2001). The second used a novel interaction paradigm developed at this stage of the research. The data obtained in phase one was used in phase two to develop a second new hybrid interaction paradigm. The phase two investigations were carried out with able participants who acted as the development group for the development of the interaction paradigm. In phase three, the developed interaction paradigm was evaluated in a field study with non-verbal participants with severe brain injury. Various research methodologies were considered before the choosing the appropriate one for this investigation. It was an iterative development process. Formative research and empirical summative research methodologies were chosen to evaluate the interaction paradigms (Burns & Grove, 1997). The approach used here was one of developing a prototype interface (Abowd *et al.*, 1989) using non-disabled people as test subjects, then evaluating the interface with brain-injured participants. This allowed better feedback for faster development. The ethics boards at each of the institutions approved this research.

1.3. The Hypothesis

This research attempts to improve on the existing work of Doherty (Doherty *et al.*, 1999, 2000, 2001, 2002) by developing a new interaction paradigm. It is intended to extend the scope of Brain-Body Interfaces, in terms of both the population who can operate them (both as carers and users) and in terms of what (some) users can do with them. The developed interaction paradigm is to be used for everyday communication by brain-injured individuals. Doherty's success was limited and inconsistent. It was clear that improved control over the cursor would extend the population of brain-injured who could use Brain-Body Interfaces, as well as the functionality that could be accessed through it.

The research hypothesis is thus:

> *That the performance of the Brain-Body Interface can be improved by the use of novel interaction paradigms.*

1.4.Original contribution to knowledge

The interaction paradigms developed in this research used hybrid techniques to improve control over the cursor. The application of these novel interaction paradigms to Brain-Body Interfaces is an original contribution to knowledge. The previous work in this area had limited success, but the user interaction paradigm developed in this research improves on the previous one by developing an individually configurable interaction technique thus creating a more inclusive interface (Keates & Clarkson, 2002).

1.5. Structure of the remainder of the thesis

Chapter two surveys the research conducted in the area of Brain-Body Interface devices. The chapter begins by looking at the structure of the brain, brain injury and the bio-potentials that could be taken from the brain and used for Brain-Body Interfaces. Thereafter it deals with its main focus, which is devices for the severely brain-injured. The latter part of the chapter focuses on the choice of bio-potential device for this research and the previous research done using Cyberlink™ as a Brain-Body Interface. The chapter concludes by identifying the most suitable bio-potential, the Brain-Body Interface with the best success rate, the challenges faced by this area of research and the need for further research, in the area of Brain-Body Interface. Chapter three describes the overall research methodology that was used for this study. The chapter begins with the challenges involved in researching in the area of Brain-Body Interfaces and goes onto describe the chosen methodology and the structure of the investigation.

Chapters four, five and six report on the first, second and third phases of this research. An interaction paradigm was developed, and experiments were carried out in the first phase. In the second phase, a further novel hybrid interaction paradigm was developed, experiments carried out, and parameters refined, to obtain an optimised interface for phase three. Phase three used the optimised hybrid paradigm, to carry out experiments with brain-injured participants. Each chapter starts with a local hypothesis to be tested in each phase and goes on to report details of each experiment, time span, interface design/development, participants and experimental methods and results obtained. Chapters four and five conclude with what was accomplished in phase one and two of the research, and what is to be investigated in the following phase. Chapter six concludes with what was accomplished in phase three of the research and relates the results to the overall hypothesis of this research.

Chapter seven summarises the work undertaken in this study. It also discusses the contributions made to Human Computer Interaction and assistive technology. It concludes by discussing future work that could be carried out in this area.

Chapter 2 – Literature Survey

The chapter begins by looking at the structure of the brain, brain injury and the bio-potentials that could be taken from the brain and used for Brain-Body Interfaces. Thereafter it deals with research carried out in both non-invasive and invasive Brain-Body Interfaces. The chapter concludes by focusing on the choice of Brain-Body Interface for this research and opportunity relative to existing research.

Jagacinski and Monk (1985) described muscle tremors, angle of head rotation, and other biological concepts that influenced a user's performance using a joystick or a helmet mounted sight in target acquisition experiments, but said little about the brain (Cooper *et al.,* 2006). Auletta (1997) argued for the need for more computer interfaces and recording devices that require a variety of biological and environmental inputs. An improvement in understanding of how they can work together efficiently can benefit persons with or without a disability. It is therefore important to include some information about basic brain anatomy and physiology.

Allanson and her team (1999, 2002) said that the computer interface developer should have a tool kit available that will allow the addition of biological inputs as an alternative means of control. In addition, Picard (2000) describes how a user may control a computer with signals generated by the movements of eyes, the contraction of muscles, the changing of skin resistance, the creation of intense thoughts, or by the regulation of respiration. It is becoming evident that more computer interface designers, users, and those who wish to assist persons in using alternate methods of controlling a computer need some understanding in human biology if they do not already have it.

2.1. Structure of Brain

The brain is the centre of the central nervous system in humans as well as the primary control centre for the peripheral nervous system (Figure 2.1). The building blocks of the brain are special cells called neurons. The human brain has approximately a hundred billion neurons. Neurons are the brain cells responsible for storing and transmitting information from a brain cell. The adult brain weighs three pounds and is suspended in cerebrospinal fluid. This fluid protects the brain from shock. The brain is also protected by a set of bones called the cranium or a skull.

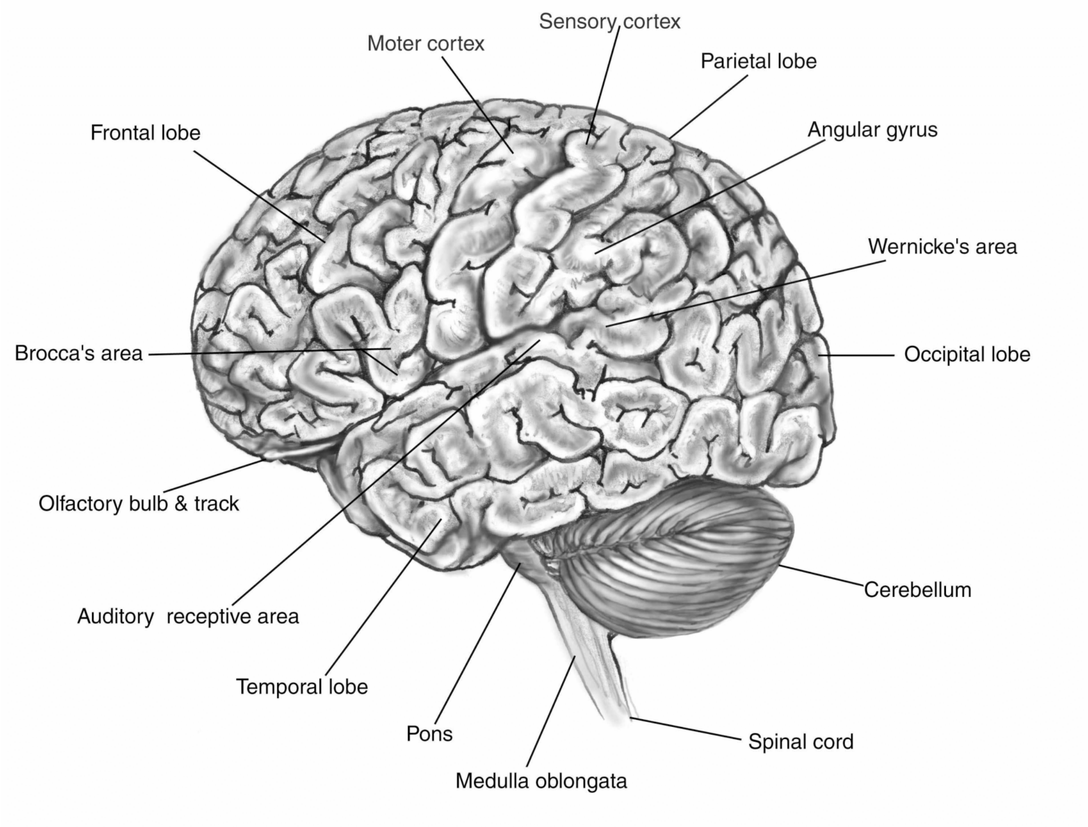


Figure 2.1 – Brain Map (Courtesy of www.headinjury.com)

The three main components of the brain are the cerebellum, cerebrum and brainstem (pons and medulla oblongata). The cerebellum is located between the brainstem and the cerebrum. The cerebellum controls facial muscle co-ordination and damage to this area affects the ability to control facial muscles thus affecting signals (eye movements and muscle movements) needed by Brain-Body Interfaces.

The cerebrum is the largest part of the brain and sits on top of the cerebellum and contains large folds of brain matter in grooves (Kalat, 1995). The cerebrum is divided into two hemispheres, the right and the left. The dividing point is a deep groove called the longitudal cerebral fissure. The left hemisphere controls the right side of the body while the right side controls the left side of the body. The cerebrum is the section where thoughts are created and memory is stored. The associated brain waves may be used in Brain-Body Interfaces. The cerebrum also has five lobes which are the frontal lobe, occipital lobe, temporal lobe, parietal lobe and insular lobe. Injury to the cerebrum can leave a person fully aware of their surroundings but unable to react to any events happening in the surroundings (Berkow *et al.*, 1997). The frontal lobe contains the motor cortex, which creates alpha brain waves. The occipital lobe contains the visual cortex. The visual cortex effects the visual perception, which creates brain waves (Schmolesky, 2006). The temporal lobe contains the cranial nerve and auditory cortex (Berkow *et al.*, 1997). Damage to this region may affect a person's hearing. The parietal lobe contains the primary somatosensory cortex. Damage to this area of the brain affects the ability to use bio-potentials to manipulate a Brain-Body Interface. The insular lobe affects emotion and damage to this region may affect a person's ability to relax when using a Brain-Body Interface.

The brainstem controls basic functions such as eating, respiration, heart rate (Fridlund, 1994) and also controls cognition (Berkow *et al.*, 1997). It is connected to the spinal chord and covered by a small flap of brain tissue known as the dura. The cranial nerves that carry the signals to control facial movements also originate in the brainstem, hence the brainstem is of interest when using Brain-Body Interfaces.

There are two stages in traumatic brain injury, the primary and the secondary. The secondary brain injury occurs as a response to the primary injury. Primary brain injury is caused initially by:

- Trauma - an acquired injury to the brain caused by an external physical force;
- Amyotrophic lateral sclerosis - a degenerative disorder affecting upper motor neurons in the brain and lower motor neurons in the brain stem and spinal cord;
- Brain stem stroke - A stroke affecting the area of the brain control functions such as breathing, instructing the heart to beat. Brain stem stroke may also cause double vision, nausea, loss of coordination and loss of speech.

Secondary brain injury refers to the changes that evolve over a period of time (from hours to days) following the primary brain injury and includes complications such as damage caused by lack of oxygen, rising pressure and swelling in the brain. A brain injury can be seen as a chain of events beginning with the first injury which occurs in seconds after the accident and being made worse by a second injury which happens in minutes and hours after this, depending on when skilled medical intervention occurs. There are three types of primary brain injury - Closed, Open and Crush. Closed head injuries are the most common type, and are so called because no break of the skin or open wound is visible. Open head injuries are not so common. In this type of injury the skull is opened and the brain exposed and damaged. In crush injuries the head might be caught between two hard objects. This is the least common type of injury, and often damages the base of the skull and nerves of the brain stem rather than the brain itself.

Individuals with brain injury require frequent assessments and diagnostic tests (Sears & Young, 2003). Most hospitals use the Glasgow Coma Scale for predicting early outcome from a head injury, for example, whether the person will survive; or Rancho Levels of Cognitive Functioning for predicting later outcomes of head injuries (Roy, 2004). See Appendix 4 for full details of brain injury assessments and diagnostic tests.

A few people sustain a head injury so severe that they remain in a state of coma for months and years. They may have sleeping and waking cycles allowing them to be fed, but they do not speak or follow commands. Such a person may be described as being in a persistent vegetative state or PVS. There are typically just less than 100 people in the UK in PVS at any one time (Headway, 2005). There is also another category of people who are alert and cognitively intact but cannot move or speak. This phenomenon is called locked-in syndrome. This group faces a great challenge in trying to communicate using eyes, muscle movements and brain waves (Kennedy *et al.*, 2000, Moore, 2003). This group of people do not receive further assessments after their initial head injury and classification as locked-in syndrome, but this could find individual channels for communication with the outside world. Open/close eyelids, movement of eyebrows, movement of toes/fingers and use of bio-potentials are some examples of how individual channels can be used for basic communication by the locked-in syndrome individuals (Doherty, 2001). There are various recommendations and standards for monitoring comatose and other unresponsive states (Chatrian *et al.*, 1996), especially for those who suffer from locked-in syndrome, and appear to be comatose but are actually sentient. See Appendix 5 for full details of recommendations and standards for monitoring comatose and other unresponsive states.

2.2. Bio-potentials for Brain-Body Interfaces

This section describes the bio-potentials that can be used in Brain-Body Interfaces. Bio-potentials are electrical signals from the brain which can be obtained from skull, forehead or other parts of the body (the skull and forehead are predominantly used because of the richness of bio-potentials in these areas). Each bio-potential has its own unique characteristics, such as amplitude, frequency, method of extraction and time of occurrence. Each brain-injured patient (apart from persistive vegetative state patients) can produce one or more of these bio-potentials with differing degrees of consistency. Brain-injured patients can operate Brain-Body Interfaces depending on the reliability of the bio-potential which they can produce. There are various definitions for data transfer rate in Brain-Body Interfaces. This thesis will use bits/second as defined by Farwell and Donchin (Kronegg *et al.*, 2005). This thesis will use bits/second as defined by Farwell and Donchin (Kronegg *et al.*, 2005). Farwell and Donchin law states,

$$B = V \cdot R$$

where V is bit-rate (bits/second), V being the classification speed (in symbols/second) and R the information carried by one symbol (in bits/symbol). The current Brain-Body Interfaces can transfer data up to 1.13 bits/second (Gao *et al.*, 2003).

2.2.1. Electroencephalalography (EEG)

Electroencephalalography measures electrical brain activity that results from thoughts or imagined movements (Kalcher *et al.*, 1994, Guger *et al.,* 2001). Electroencephalalographic signals can be collected by electrodes placed on the scalp or forehead (Berkow *et al*., 1997). The amplitude can vary between 10 - 100 μV when measured on the scalp or forehead. Electroencephalalography covers a frequency spectrum of 1 - 30 Hz and is divided into five classes. Authorities on electroencephalalography dispute the exact frequency demarcation points of the five classes (Berg *et al.,* 1998). Robinson sampled electroencephalalographic signals from ninety-three participants and classified them as delta, theta, alpha, beta, and high beta (Robinson, 1999). Robinson's classification will be used throughout this thesis. Some classes of electroencephalalographic signals can be used as bio-potentials for Brain-Body Interfaces.

2.2.2. Delta Waves

Delta waves are slow waves that are formed in deep sleep and have a frequency range of 0 - 4 Hz. Eye movements often produce strong signals that also affect electrical activity in the delta range (Berg *et al*., 1998). Brown (2006) states that the 3 Hz component of the delta wave can bring back experiences from the past, which could be psychologically traumatic for the patients. Hence it is desirable to avoid electroencephalalographic activity in the 3 Hz region. Tortora and Derrickson (2006) state that the presence of delta waves in an awaske adult indicates brain damage, since the presence of delta waves in a patient who is awake indicates unconsciousness or deep sleep.

2.2.3. Theta Waves

Theta waves have a frequency range of 4 - 8 Hz. Theta waves are associated with daydreaming, emotions and sensations. This component of electroencephalalographic signals reflects a state of wakefulness and sleep at the same time (Robinson, 1999). Eye movements can also affect electrical activity in the theta range since they occur between 1.1 - 6.25 Hz (Berg *et al.*, 1998). Brown (2006) states that the 5 Hz component of the delta wave is directly tied to physical trauma and/or structural changes to cortical regions that are frequently damaged in traumatic brain injury. Hence it is desirable to avoid electroencephalalographic activity in the 5 Hz region. Tortora and Derrickson (2006) state that the presence of theta waves in a patient who is awake indicates stress.

2.2.4. Alpha Waves /Mu Waves

Alpha waves, also known as Mu waves, have a frequency range of 8 -12 Hz. The alpha wave is collected through electrodes placed over a large fold in the brain known as the central sulcus (Kozelka, 1990) or at the forehead (Berg *et al.*, 1998). Eye closures often produce strong signals that also affect electrical activity in the alpha range. Kalcher and his team (1994) say that movement of a limb or imagined movement of a limb also affects alpha waves.

2.2.5. Beta Waves

Beta waves have a frequency range of 12 - 20 Hz. Berg (1998) says that those with brain lesions have diminished capabilities to manipulate beta waves. In Berg’s work, military pilots used a Brain-Body Interface with beta settings to control one axis of the cursor in a flight simulator thus creating a Brain-Body Interface.

2.2.6. High Beta Waves

High beta waves have a frequency range of 20 - 30 Hz. Facial movements often produce strong signals at approximately 45 Hz that also affect electrical activity in both the beta and high beta ranges (Berg *et al.*, 1998). High beta waves have not been used for controlling Brain-Body Interfaces.

2.2.7. Electromyography (EMG)

Electromyography measures an electrical signal resulting from a contracted muscle (Berkow *et al.*, 1997). The moving of an eyebrow, for example, is a muscle contraction that produces waves at 18 Hz, but which resonate throughout the electroencephalalographic spectrum (Berg *et. al.*, 1998). Electromyographic signals can be collected on the arms, legs, or face because muscle contractions may occur there. Electromyographic signals have an amplitude range of 0.2 - 2000 μV.

2.2.8. Electrooculargraphy (EOG)

Electrooculargraphic signals are low frequency signals derived from the resting potential (Corneal-Retinal Potential) by ocular or eyeball movements (Knapp *et al.*, 1995). Eyeball movements affect the electroencephalalographic spectrum in the delta and theta regions between 1.1 - 6.25 Hz (Berg, 1998). Electrooculargraphic signals have an amplitude range of 1 - 4 mV.

2.2.9. Slow Cortical Potentials (SCP)

Slow cortical potentials (SCPs) are signals of the cerebral cortex, which can be collected from the scalp surface. They are electroencephalalographic oscillations in the frequency range 1 - 2 Hz (Kotchoubey *et al.*, 1997) and can be positive or negative. The signals can be 5 - 8 μV and a person may be trained to change the amplitude of slow potential signals to indicate a selection such as for a spelling device (Birbaumer *et al.*, 1999, Hinterberger *et al.*, 2003).

2.2.10. Evoked Potential (EP)

Another signal detected in the electroencephalalographic range is the evoked potential, also known as an event related brain potential (ERP). Evoked potential can be a positive or negative signal and can occur at various times after visual or auditory stimuli. Evoked potentials occur when a person concentrates on an object. Evoked potentials are of relatively low amplitude signals with a range of 1 - 10 μV in comparison with electroencephalalographic signals (10 - 100 μV). When someone sees or hears anything that is especially meaningful to them then a special response is produced such as steady-state visual evoked potential, P300 and N400 (these signals are described in Sections 2.2.12 and 2.2.13). Electroencephalalography measures all brain activity at any point in time, while the evoked potential is that part of the activity associated with the processing of a specific event (post stimuli).

2.2.11. Steady-State Visual Evoked Potential (SSVEP)/ Steady State Visual Evoked Responses (SSVER)

Steady-State Visual Evoked Potentials (SSVEPs), also known as Steady State Visual Evoked Responses (SSVERs) are obtained when users can indicate their interest in specific stimuli by choosing to attend or ignore it (Cheng, 2002, Gao, 2003). This allows a user to send information by voluntarily modulating their attention, through SSVEP (e.g. choosing buttons flashing at different rates, on a virtual telephone keypad to make a phone call). SSVEP uses the 4 to 35 Hz frequency range. SSVEPs transfer data at high data transfer rates (1.13 bits/s) and occur at 100 - 1000 ms after the stimuli.

2.2.12. P300

The P300 (also called P3) is a component of the evoked potential range of brain waves. P300 displays a brain wave with positive amplitude, peaking at around 300 ms after task-relevant stimuli. This signal occurs in the delta (0.5 - 4 Hz) and theta (4 - 7 Hz) frequency range. Kotchoubey and his team (2001, 2002) investigated bio-potentials in patients with severe brain damage. They used oddball tasks (two stimuli with different probabilities e.g. 80/20) using signals such as sine tones, complex tones or vowel sounds o and i, to elicit P300 waves from twenty five out of thirty three patients. The P300 is perhaps the most studied evoked potentials component in investigations of selective attention and information processing (e.g. for choosing letters on a computer screen to communicate) in comparison to the other components of the evoked potentials (Patel & Azzam, 2005, Farwell & Donchin, 1988, Donchin *et al.*, 2000), further details in Section 2.4.5. The key stroke level model gives an average of 200-280 ms for an average typist to type a character or press a key on a keyboard (Kieras, 2005, Card *et al.*, 1983). The times given by key stroke level model, compares favourably with the P300 task-relevant stimuli but, the participants using the P300 will have problems processing the letters on screen at this slow speed since our brain processes information in chunks (Kirschner, 2002, Kalyuga *et al.*, 1999, Hinterberger *et al.,* 2005).

2.2.13. N400

The N400 is a component of the evoked potential range of brain waves. N400 displays a brain wave with negative amplitude, peaking at around 400 ms triggered by unexpected linguistic stimuli. The N400 is most pronounced over centro-parietal regions of the scalp and tends to be larger over the right than the left hemisphere. This brain wave is mainly used for speech and gesture comprehension (Spencer *et el.*, 2004, Debruille *et al.*, 1996).

2.2.14. Electrocochleography (ECoG)

Electrocorticographic (ECoG) signals are obtained by recording brain surface signals with electrodes located on the surface of the cortex (invasive method). It is an alternative to data taken non-invasively by electrodes outside the brain on the skull such as in electroencephalalography, electromyography and evoked potential. Electrocochleography records at 300 - 1000 µV amplitude and has a frequency of 40 Hz (Tran *et al.*, 1997, Lal *et al.*, 2005).

2.2.15. Low Frequency Asynchronous Switch Design (LF-ASD)

The low-frequency asynchronous switch design (LF-ASD) was introduced as an invasive Brain-Body Interface technology for asynchronous control applications. The low-frequency asynchronous switch design operates as an asynchronous brain switch (ABS) which is activated only when a user intends to control. The switch is placed on a scalp, it maintains an inactive state output when the user is not meaning to control the device (i.e., they may be idle, thinking about a problem, or performing some other action). The low-frequency asynchronous switch design is based on electroencephalalographic signals in the 1 - 4 Hz frequency range (Borisoff *et al.*, 2004) with an amplitude of 10 - 100 μV.

2.2.16. Local Field Potential (LFP)

Signals can be recorded in a human frontal cortex using implanted microwires in the sensorimotor regions of the neocortex which exhibit synchronous oscillations in the 15 - 30 Hz frequency range and have an amplitude of 6 μV. These signals are also prominent in the cerebellum and brainstem sensorimotor regions. These signals are called local field potentials. Multiple electrodes can be used to record these local field potentials, which can be synchronised with the execution of trained and untrained movements of limbs. Local field potentials provide an excellent source of information about the cognitive state of the subject and can be used for neural prosthetic applications (Kennedy *et al.*, 2004, Harrison *et al.*, 2004).

2.3. Brain-Body Interface Devices

Assistive devices are essential for enhancing quality of life for individuals with severe disabilities such as quadriplegia, amyotrophic lateral sclerosis (ALS, commonly referred to as Lou Gehrig's disease), brainstem strokes or traumatic brain injuries (TBIs). Research has been carried out on the brain's electrical activities since 1925 (Kozelka & Pedley, 1990). Brain-Computer Interfaces (BCIs), also called Brain-Body Interfaces or Brain-Machine Interfaces (BMI) provide new augmentative communications channels for those with severe motor impairments. BBI will be used as the acronym for Brain-Computer Interfaces, Brain-Body Interfaces and Brain-Machine Interfaces from this point onwards.

In 1995 there were no more than six active BBI research groups, in 2000 there were more than twenty (Birbaumer *et al.*, 2000a) and now more than thirty laboratories are actively researching in BBIs (Vaughan *et al.*, 2003). A BBI is a communication system that does not depend on the brain's normal output pathways such as speech or gestures, but uses electrophysiological signals from the brain, as defined by Wolpaw and his colleagues (2000). There are two types of BBIs namely invasive (signals obtained by surgically inserting probes inside the brain) and non-invasive (electrodes placed externally on part of the body). Allison (2003) states that a BBI may even transfer data faster than conventional interfaces because it is possible to determine a user's intent to move from the electroencephalalography before that information is actually sent to the spinal cord. Although the above statement is true in theory, in practice it is much harder to control and process brain waves in order to make BBIs work faster than conventional interfaces (Gnanayutham *et al.*, 2005). Most non-invasive BBI devices use bio-potentials taken from skull/forehead as signals for communications instead of functional imaging approaches such as Functional Magnetic Resonance Imaging (fMRI) and Positron Emission Tomography (PET) as illustrated in the next section.

2.3.1. Mechanism of Brain-Computer Interfaces

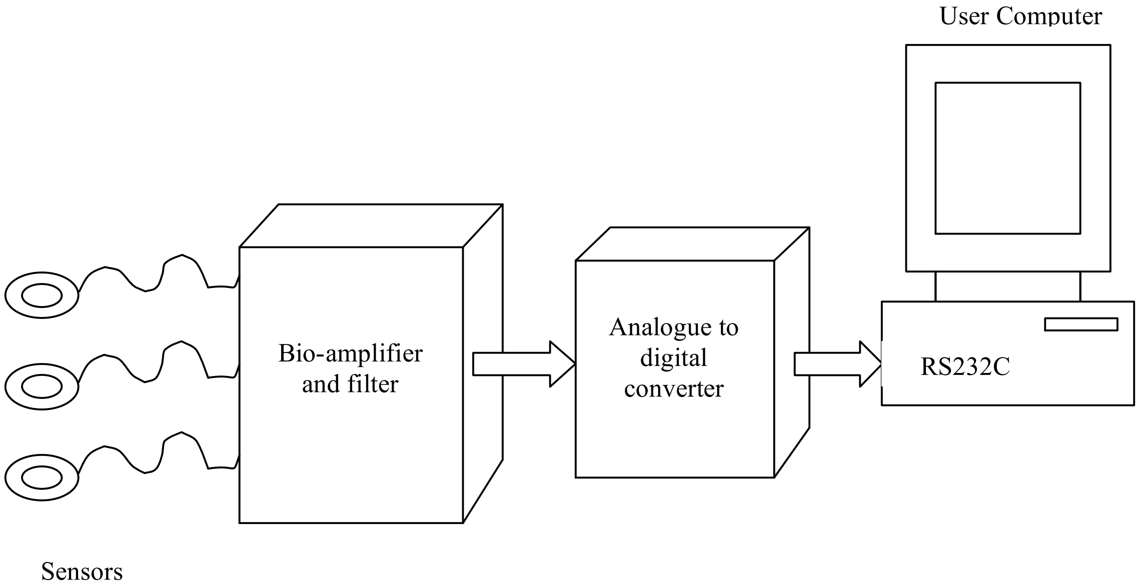


Figure 2.2 – Non-Invasive Brain-Computer Interface

Non-invasive technology involves the collection of control signals for the BBI without the use of any surgical techniques, with electrodes placed on the face, skull or other parts of their body. The signals obtained are first amplified, then filtered and thereafter converted from an analogue to a digital signal (Figure 2.2). Various electrode positions are chosen by the developers, who choose electrode caps, electrode headbands with different positions and number of electrodes or the International 10-20 System (Pregenzer, 1994, Coyle *et al.,* 2007). Authorities dispute the number of electrodes needed for collection of usable bio-potentials (Berg *et al.*, 1998). Junker recommends using three electrodes for collecting signals (Junker, 1997) while Keirn and Aunon (Keirn & Aunon, 1990) recommend using six electrodes. Chatrian claim at least twenty electrodes are needed (Chatrian *et al*., 1996). The caps may contain as many as 256 electrodes, though typical caps use 16, 32, 64 or 128 positions, each cap has its own potential sources of error. High-density caps can yield more information, but in practice they are hard to utilise for real time communications (Nunez *et al.*, 1999). The bio-potentials obtained from these large numbers of electrodes need extensive off-line processing to make any sense of what the user is trying to express. There is only one agreed standard for the positions and number of electrodes, the International 10-20 System of electrodes (Jasper, 1958) shown in Appendix 1.

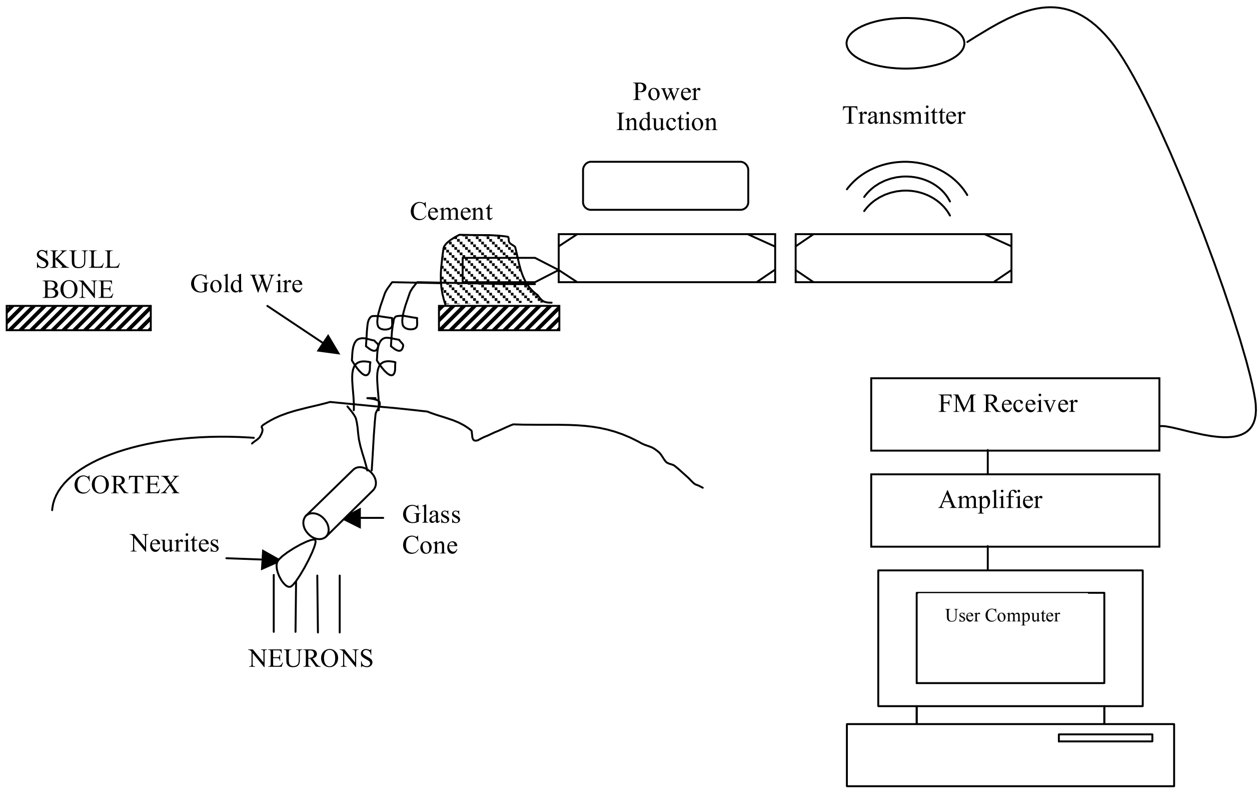


Figure 2.3 – Invasive Brain-Computer Interface

Invasive electrodes can give better noise to signal ratio and obtain signals from a single or small number of neurons (Figure 2.3). Signals collected from the brain require expensive and dangerous surgical measures. There are two types of electrodes used for invasive BBIs. If signals need to be obtained with the least noise and from one or few neurons, Neurotrophic Electrodes are used (Siuru, 1999, Kennedy *et al.*, 1999, 2000). The other choice is the Utah Intracranial Electrode Array (UIEA), which contains 100 penetrating silicon electrodes, placed on the surface of cortex with needles penetrating into the brain, which can be used for recording and simulating neurons (Maynard *et al.*, 1997, Spiers *et al.*, 2005). Neuron discrimination (choice of single or a group of neurons) does not play any part in the processing of signals in BBIs (Sanchez *et al.,* 2005).

2.4. Non-invasive Brain-Body Interface devices

Brain activity produces electrical signals that can be read by electrodes placed on the skull, forehead or other part of the body (the skull and forehead are predominantly used because of the richness of bio-potentials in these areas). These bio-potentials are then translated into instructions to direct the computer, so people with brain injury have a channel to communicate without using the normal channels. Various research groups have developed many BBIs and the following is a survey of the non-invasive category of BBIs.

2.4.1. Alpha Wave Based

Alpha wave based experiments were conducted by Craig and his teams (1997, 1999) with 21 non-disabled and 16 spinal cord injured participants. They used a 19 electrode BBI device to show how the alpha wave increases (between 200 - 400%) in the 8-12 Hz range in posterior, central and anterior regions of the brain following eye closure. They established that a majority of persons (95% of non-disabled and 93% of spinal cord injury individuals) could operate hands free control of devices using eye closure. The experiment also demonstrated that alpha waves increased when the electromyographic bio-potential was reduced by closing the eyes. This BBI did give the opportunity to switch electronic devices hands free, but had no further use. Hence it was never used outside the labs on a brain-injured population.

2.4.2. Electroencephalalography Based

Kostov and Polak (1997a, 1997b) achieved one dimensional up - down movement on a computer screen using electroencephalalographic signals with a cap of twenty eight gel filled electrodes. This BBI was evaluated by three able-bodied participants, the results obtained showed significant differences between the participants' generation of electroencephalalographic signals, and hence this device was not developed further. However Kostov and Polak (2000) went on to develop a new parallel man-machine approach, using electroencephalalographic signals with relatively short practice, with parallel learning process. This process involved an operator sitting with the participants and recording the relevant electrodes in a hard disk and using offline and online processing to communicate in real-time. The object of the exercise was to achieve up-down-left-right precise cursor positioning. Two subjects (one able-bodied and the other disabled) achieved 70 to 85% success rates using this BBI. This was an improvement on the previous BBI (Kostov & Polak, 1997a, 1997b), with less training and cursor movement in all directions but there were still problems in controlling the cursor, hence it was not used beyond the laboratory exercise.

An electroencephalalography based raw data acquisition system was developed by Malina and colleagues (2002). The BBI developed here aimed to acquire data in real time. Electroencephalalographic (alpha waves) signals using thirty-two scalp electrodes and standard amplification were recorded in this experiment. Limited computing power and signal delay caused them to discontinue this line of research.

Electroencephalalography based research was also carried out by Wolpaw and colleagues (1991), who performed a group of experiments with a BBI that used the 8 - 12 Hz alpha waves to move a cursor along one axis to targets marked yes or no. Five participants were instructed to respond to a series of questions directed at them. This BBI had two major flaws. Firstly, the BBI could not cater for the inconsistent amplitude of the signal created by each participant. Secondly, speed and accuracy of the selection and voltage ranges gave inconsistent results in relation to real-time online processing of the signals. The BBI was later improved to allow the cursor to move simultaneously in both vertical and horizontal directions. Success for the five participants was in the range of 41 - 70%, which needed further improvement (Wolpaw & McFarland, 1994). This device was further improved to an accuracy of greater than 90% using digital signal processing techniques and a sixty-four electrode data acquiring system. Wolpaw and his team used five able-bodied participants, with 90% accuracy, to show that humans can learn to control the amplitude of electroencephalalographic activity at specific frequency bands and use it to move a cursor to a target (Wolpaw *et al*., 1997, McFarland *et al.*, 1997, Miner *et al.*, 1998). The main disadvantage of this BBI was the time taken for training, which was in the range of 26 - 81 one-hour sessions. This team has now gone on to develop a general purpose standard (BCI-2000) to share with other research groups (Wolpaw *et al.*, 2003). BCI-2000 is an Application Programming Interface (API) that can incorporate any brain signal (individual or in combination), signal processing methods, output devices, and operating protocols. This standard is meant to cater for the future researchers and computer manufactures who will be able to integrate BBIs into mainstream hardware and software, thus making this research available in greater numbers to the brain-injured public.

Experiments in which participants imagined limb movements to manipulate their electroencephalalographic signals in order to choose one of six letters were developed by Keirn and Aunon (1990). The five able-bodied participants were able to control their electroencephalalographic signals to select required combinations of letters about 90% of the time. Kalcher and his team performed experiments similar to Aunon with a success rate in the 25 - 35% range (Kalcher *et al.*, 1994). This area of research needs further work in order to improve the success rate.

2.4.3. Electroencephalalography and Electromyography Based

One of the well known applications for electromyography as a BBI is HaWCoS: The ‘Hands-free’ Wheelchair Control System developed at the University of Siegen in Germany (Felzer, 2002). A non-invasive electroencephalalography and electromyography based BBI system was developed by Barreto and his team (1999). This device used four electrodes placed above pericranial muscles and above the occipital lobe of the cerebrum. The electrodes were made of Ag/AgCl and were adhered to the scalp using a headband or baseball cap. The computer interactions obtained were up, down, left, right and left mouse click. This real-time system was tested on six healthy subjects who verified the successful operation of the system. This BBI suffered from electromyographic contamination such as any eye movements and eye blinks. This system remains a laboratory experiment and the research is yet to be utilised by the brain-injured community.

2.4.4. Electroencephalalography, Electromyography and Electrooculargraphy Based

Knapp and Lusted (1990) developed a BBI device called the "Biomuse" for their organisation called BioControl Systems. Electroencephalalographic, electromyographic and electrooculargraphic signals were obtained from seven electrodes and then sent to the signal-processing unit. The device's only recorded use as an assistive technology consisted of an instance in which a paralysed boy used electromyographic signals to move a cursor (Lusted & Knapp, 1996). This device was used mainly as a computer music application. It was concluded that these bio signals did not carry enough data nor were they controllable enough to make a usable BBI. Knapp and Lusted are now developing a wireless system for acquiring bio-signals for applications such as interactive computer gaming, simulation environments and music/audio control (Lusted, 2005, Knapp, 2005). Knapp and colleagues used a four channel (horizontal and vertical for each eye) electrooculargraphic signal acquisition headband, on six subjects over three trials to obtain both accuracy and speed. The test was to reach a target on the screen using Electrooculargraphic signals. The average response time was 0.25 seconds with an average success rate of 65%. Electrooculargraphic signals have also been used to control a wheelchair (Barea *et al.*, 2000).

Only a limited amount of research has been done using Cyberlink™ as a BBI. The Cyberlink™ was developed at US Air Force Armstrong Laboratory, Wright-Patterson Air Force Base, as a future technology for the US Air Force (Furness, 1986, Nelson *et al.*, 1996, Junker, 1997). It was studied as an alternative method of control in a flight simulator and evaluated using seven able-bodied participants. Cyberlink™ is a BBI that uses bio-potentials from the user’s facial contractions, eye movements, and thoughts (Metz & Hoffman, 1997) to produce discrete and continuous signals. The signals obtained from the forehead are digitised, filtered, amplified and sent via the computer's serial port (Berg *et al.*, 1998). Junker (1997) divided the signals in the 0.5 - 45 Hz range into ten bands for which he had coined the term ‘brainfinger’. The ten brainfingers were divided into theta, alpha, and beta bands of the electroencephalalographic spectrum. Investigations of the use of Cyberlink™ up to 1997 were of a military nature and involved pilot’s physiological monitoring and aircraft control (Haas, 1995) and relieving them of mundane tasks. In separate studies, the Cyberlink™ was tested with non-impaired adults to switch menu screens and control an aircraft along one axis of flight (Nelson *et al*., 1996).

Doherty investigated whether the Cyberlink™ could be used as an assistive technology for communications by the disabled (Doherty *et al.*, 1999, 2000, 2001, 2002). Doherty's research question was *can severely motor-impaired non-verbal persons use the Cyberlink™ as an assistive technology to communicate and recreate?* He investigated whether Cyberlink™ could be used by all the participants, which tasks could be performed with the device, and also observed how the use of the Cyberlink™ performed in comparison to other assistive technology devices and common input devices such as Mouse, Track Ball, Eyegaze Communication Device and Head Pointer. Experiments were carried out in four phases using forty-four participants from five institutions with various mental and physical impairments. This was a fifteen month longitudal study. The participants were organised into five groups. These groups comprised:

- Ten traumatic brain-injured participants;
- Fourteen participants with cerebral palsy, cognitive disability and with/without sensory deprivation participants;
- Two highly spastic, cerebral palsy and cognitively disabled participants;
- Eleven able-bodied participants;
- Seven miscellaneous participants who died or otherwise left the investigation.

The participants tested the Cyberlink™ and other assistive technology devices to reach targets and play games. Target acquisition was chosen as a pointing and clicking exercise to simulate the windows environment. Game scores, completion times, communication tasks and other such metrics were recorded by Doherty for later collation. From the results obtained through games and target acquisition, Doherty chose participants who could use no assistive device other than Cyberlink™ to communicate or recreate. The final focus group consisted of three participants who were severely motor impaired and not thought to be sentient due to their inability to respond to the environment (Doherty *et al.*, 1999, 2000, 2002). The other participants were able to use other devices, which were much easier to use in comparison to Cyberlink™.

Doherty developed a 'Yes/No, program that worked with Cyberlink™ for these three participants to communicate. The participants had to navigate the cursor through a small maze to reach Yes and No targets. The concept of reaching the target through navigating through a maze was developed as requested by physicians responsible for disabled participants. Having had disappointing results up to version five of the program, fifteen able-bodied participants were recruited by Doherty to improve the previous versions of the 'Yes/No' program. The data obtained using this new group of participants showed that targets at certain angles took longer to reach and also needed to be kept at optimum distances from the starting point.

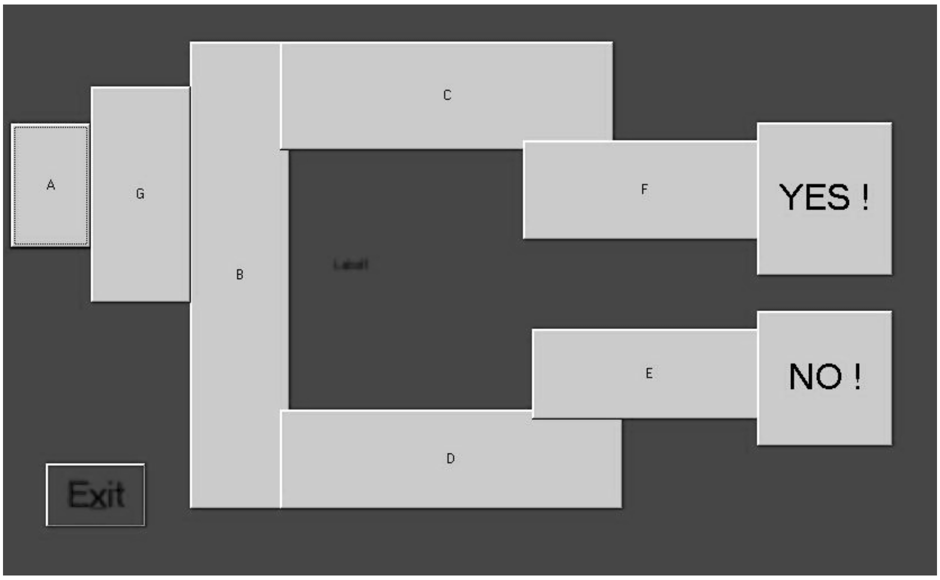


Figure 2.4 – Doherty's Interface

Doherty included these changes in version six of the program (Figure 2.4) and achieved a success rate of 60% (without any time limit restriction to reach a target). The number of experiments conducted with each participant was also limited (average three sessions per participant). The average number of targets reached successfully per session was 2.5.

BBIs cannot necessarily exploit existing input device research. Menu pointing can be seen as a goal directed process, where an input device can be configured so that the distance to the target or size of the target can be changed in an orderly predictable way.

Common input devices obey Fitt's Law (Doherty, 2001, Accot & Zhai, 2003). The standard mouse and other pointing devices operate using this rule. Larger targets with shorter distances to reach are easily achieved in comparison to smaller targets with longer distances. Cyberlink™ does not obey this law. These results obtained by Doherty indicated a limited amount of conformity, but were inconclusive. Hence there remains a need for more research to be done in this area (Doherty, 2001).

BBI systems using changes in alpha waves were developed at Graz University of Technology by Pfurtscheller and colleagues (Kalcher *et al.*, 1994). This team conducted two studies to demonstrate how human beings could learn to regulate electrocortical activity (electroencephalalography, electromyography and electroocularography activities) over the sensorimotor cortex. The International 10-20 System was used to record the results. The first study was a one-dimensional cursor control system, which could discriminate between left and right hand movement planning. This study was conducted with four able-bodied participants and obtained an average success rate of 50% with almost no training. This second version was evaluated with four able-bodied volunteers. The task was to extend a bar on a screen to the left or right boundary using electroencephalalographic, electromyographic and electroocularographic signals. The experiments' results indicated 85- 90% success rate (Neuper *et al.*, 1999). The main difference between the two studies was the use of online feedback processing. In previous studies, discrete feedback was used which presented delay. These studies indicated how electrocortical activity could be regulated in future BBIs to use a pathway for communication. This team also developed a BBI which uses rapid prototyping (Guger *et al.*, 2001) to enable fast transaction for real-time implementation that can be controlled using the Internet, Local Area Network or modem via a standard PC. The system was tested with three subjects with 70% - 95% success rate. This team also used motor imagery (e.g. imaginations of left-hand, right-hand movements) to train a tetraplegic patient to use electroencephalalographic signals, with an array of electrodes to control an artificial hand with almost 100% accuracy (Pfurtscheller & Neuper, 2001).

Takahashi and colleagues (2006) investigated the possibility of a gesture recognition interface system for non-verbal users. They used electromyographic and electroocularegraphic signals to recognise the intended gestures and electroencephalalographic signals to evaluate the user's emotion. The bio-potentials for this system were obtained using Cyberlink™ as the BBI. This system was evaluated successfully using five able-bodied participants, but is yet to be evaluated with disabled participants.

2.4.5. P300 Based

Donchin and his colleagues, using four able-bodied individuals, tested the feasibility of using P300 based BBI devices (Farwell & Donchin, 1988). Users were presented with a matrix of 6 x 6 cells, each cell containing one letter of the alphabet. The user focused his or her attention on a cell to indicate selection using the P300 signal. The results obtained indicated that P300 signals can be used as an effective communication switch but the data rate was rather slow at one character every twenty six seconds. This team went onto improve the previous work by using higher quality signal filters and faster computers. Ten able-bodied participants and four disabled participants evaluated this device. The results obtained showed that the able-bodied participants selected the letters at a speed of six to eight characters per minute, while disabled participants were able to select approximately three letters per minute (Donchin *et al.*, 2000). The experiment proved that it was feasible to use P300 signals for BBI devices, but needed more work with the brain-injured participants.

Bayliss and Ballard (1998, 2000) built on the previous work of Donchin and colleagues (2000) by developing a real-time BBI using virtual reality and electroencephalalography. Five participants were asked to do virtual driving using P300 evoked potential. These participants achieved commands successfully at 60 - 90% rate. Although P300 signals are robust and can be used in any real-time environment (Bayliss, 2003, Hinterberger *et al.,* 2005).), they need evaluation with brain-injured participants before final conclusions on its usage are made for real-time BBIs.

2.4.6. Slow Cortical Potentials Based

Birbaumer and his colleagues (1999, 2000b) developed a spelling device named 'The Thought Translation Device' as a means of communication using slow cortical potentials (SCPs) of the electroencephalogram (Hinterberger *et al.*, 2003). This spelling device was tested on two locked-in patients, who were able to spell simple words although it took a long time for them to write a sentence. This device was then improved to cater for the two main errors, missing the correct symbol and choosing the wrong symbol. These adjustments gave a success rate of 75% (Perelmouter *et al.*, 1999). This device was further improved to BCI-2000 standard, based on alpha waves and slow cortical potentials (Birbaumer, 2003a, Schalk *et al.*, 2004). This BCI-2000 standard device was successfully tested with five amyotrophic lateral sclerosis (ALS) participants who were able to spell and select words at more than 75% success rate, further to extensive training (35 sessions of forty minutes per session). Training locked-in patients on using slow cortical potential for BBIs takes a lot of effort and time, hence only eleven disabled participants had been trained up to 2003 (Neumann & Birbaumer, 2003, Neumann & Kübler, 2003). Hence Neumann and his team (2004) stated that more research needed to be done in the area of slow cortical potentials before it can be accepted as possible bio-potential to control BBIs. Birbaumer and his colleagues have also developed a Brain Web Surfer for the quadriplegic community (Mellinger *et al.*, 2003), which has been successfully evaluated with able-bodied participants. Evaluation with disabled participants needs to be completed before any form of conclusions can be drawn about this as an assistive technology.

2.4.7. Electroencephalalography, magnetic resonance imaging and slow cortical potentials Based

Birbaumer and his colleagues (2003b) worked on combining an electroencephalalographic driven BBI with Functional Magnetic Resonance Imaging (fMRI) with the intention of increasing transfer rates and improving control of slow cortical potentials. They used Magnetic Resonance Imaging and Transcranial Magnetic Stimulation (TMS) in five healthy participants and in six disabled participants to evaluate the Thought Translation Device (TTD). The average selection speed obtained was one letter per minute. More research needs to be done before this set-up could be used as a BBI.

2.4.8. Low-frequency asynchronous switch design (LF-ASD) Based

The Low-Frequency Asynchronous Switch Design (LF-ASD) was introduced as a direct BBI technology for asynchronous control applications. The LF-ASD operates as an Asynchronous Brain Switch (ABS) which is activated only when a user intends control and maintains an inactive state output when the user is not meaning to control the device (i.e., they may be idle, thinking about a problem, or performing some other action). An asynchronous signal detector was developed and tested with five able-bodied subjects by Birch and Mason (2000). The results gave a success rate of 78%. The system was then tested with two disabled participant who obtained a success rate of 50%. Further work is being done with able and disabled individuals to improve this BBI.

Research is being done at present to improve Low Frequency Asynchronous Switch Design (LF-ASD) using direct BBI for asynchronous applications. The switch is activated only when the user intends to, giving an opportunity for the user to be idle, thinking or performing some other task (Borisoff *et al.,* 2004).

2.4.9. Steady State Visual Evoked Response Based

Calhoun and her team (1995) carried out initial experiments on Steady State Visual Evoked Response (SSVER) or Steady State Visual Evoked Potential (SSVEP) with three able-bodied participants to indicate how potentials from surface electrodes could be used to modify the SSVEP in order to generate control signals. Cheng and colleagues (2002) used SSVEP based BCIs and achieved transfer of 0.45 bits per second. Eight out of thirteen participants used virtual keypad and International 10:20 Standard electrode system to send information successfully to a computer. This team went on to improve the transfer rate to 1.13 bits per second using a new environment controller (Gao *et al*., 2003). SSVEP based research is also being carried out to show that the training can be minimised using SSVEP and P300 based BBIs (Beverina *et al.,* 2003). This area of research shows great potential for future BBIs.

2.4.10. Functional Magnetic Resonance Imaging based

Functional Magnetic Resonance Imaging (fMRI) is also being researched for real-time BBIs (Weiskopf *et al.,* 2003). This set-up lets participants observe and control changes of their blood oxygen level dependant response. The data obtained is processed and used for communicating. More work needs to be done in this area before firm conclusions can be drawn about the performance of this set-up for BBIs.

2.4.11. Summary of Non-Invasive BBIs

A summary of this survey of the non-invasive category of BBIs is given in Tables 2.1-2.3. The tables show that the developed BBIs had a success rate ranging between 41- 95%. All the experiments except the one by Doherty's team were evaluated in the laboratory environment and not in the field. The table also shows that some BBIs were evaluated only with able-bodied participants and not with brain-injured individuals. Most of the BBIs also needed computer processing power and extensive training.

Table 2.1 – Summary of non-invasive Brain Body Interfaces (Part 1)

Dates	Researcher /Research Group	BBI	Participants	Location	Achievements	Comments
1997 - 1999	Craig and his team	Alpha wave based	21 able-bodied and 16 disabled	Laboratory	95% able and 93% disabled, used eye closure to switch devices	Laboratory exercise only
1997 - 2000	Kostov and Polak	EEG based	1 able-bodied and 1 disabled	Laboratory	70 - 85% success in moving a cursor in real-time	Laboratory exercise only, Needed online and offline processing
1991 - 1998	Wolpaw and team	EEG based	5 able-bodied	Laboratory	41 - 90% success in moving a cursor around a screen	Laboratory exercise only. Needed extensive training sessions
1990	Keirn and Aunon	EEG based	5 able-bodied	Laboratory	90% success in choosing one out of six letters on a screen	Laboratory exercise only
1990	Barreto and team	EEG and EMG based	6 able-bodied	Laboratory	Moving a cursor around a screen and also mouse clicks. Success rate not given	Laboratory exercise. Any eye movement caused this system to give wrong results

Table 2.2 – Summary of non-invasive Brain Body Interfaces (Part 2)

Dates	Researcher /Research Group	BBI	Participants	Location	Achievements	Comments
1990	Knapp and Lusted	EEG, EMG and EOG based	1 disabled	Laboratory	Move a cursor. No other data available	Laboratory exercise. Now used a computer music application
1996	Knapp and Lusted	EEG, EMG and EOG based	6 able-bodied	Laboratory	65% success in hitting a target on screen	Laboratory exercise only
1999 - 2002	Doherty and team	EEG, EMG and EOG	3 disabled	Field	60% success in hitting a target on screen	A field exercise with limited success
1994	Pfurtscheller and team	EEG, EMG and EOG based	4 able-bodied	Laboratory	50% success in Extend a bar on screen	Laboratory exercise only.
1999	Pfurtscheller and team	EEG, EMG and EOG based	4 able-bodied	Laboratory	87% success in Extend a bar on screen	Laboratory exercise. Needed online processing
2001	Pfurtscheller and team	EEG, EMG and EOG based	3 able-bodied	Laboratory	70 - 95% success in Extend a bar on screen	Laboratory exercise using internet control Needed online processing
1988 - 2000	Donchin and team	P300 based	10 able-bodied and 4 disabled	Laboratory	Able-bodied selected 6 - 8 letters per minute while disabled selected 3 per minute	Laboratory exercise only
1998 - 2003	Bayliss and Bollard	P300 based	5 able-bodied	Laboratory	50 - 90% success in completing virtual driving	Laboratory exercise only
1999 - 2003	Birbaumer and team	SCP based	5 disabled	Laboratory	75% success in using the developed spelling device.	Laboratory exercise. Needed extensive training
2003	Birbaumer and team	EEG, fMRI, SCP based	5 able-bodied and 6 disabled	Laboratory	Average one letter per minute	Laboratory exercise only

Table 2.3 – Summary of non-invasive Brain Body Interfaces (Part 3)

Dates	Researcher /Research Group	BBI	Participants	Location	Achievements	Comments
2002	Birch and Mason	LF-ASD Based	5 able-bodied and 2 disabled	Laboratory	78% able and 50% disabled, success in producing signals	Laboratory exercise only
2002 - 2003	Cheng and team	SSVER based	13 able-bodied	Laboratory	62% success in sending information to a computer.	Laboratory exercise only
2003	Weiskopf and team	fMRI,	No data available	Laboratory	Not data available.	No data to comment

2.5. Invasive Brain-Body Interface devices

Various protective tissues, the skull, blood flow and other brain matter between the scalp and area of the brain generating the signal can distort the bio-potentials drawn from the outside of the scalp. Hence invasive electrodes can give better signal to noise ratio and obtain signals from a single or small number of neurons. Vidal (1973) first mentioned an invasive or direct BBI. Huggins and his team planted the first direct brain interface, as reported by Levine (Levine *et al.*, 1996). It was found that participants with epilepsy who had electrodes placed under their dura during surgery could operate a switch on command by thought. The following is a survey of the invasive category of BBIs.

2.5.1. Electroencephalalography and Electromyography Based

An invasive brain interface was developed by Kennedy and colleagues (1999). They used two participants where they planted neurotrophic electrodes which are electrodes coated with a chemical to promote nerve growth (Siuru, 1999) into their skull in two different positions (as X and Y coordinates). These electrodes pick up action potential to specify location, and neural firing rate changes to speed up cursor travel (Adams *et al.*, 1999). The studies showed that the users had difficulty in controlling both electrodes at the same time. Hence one electrode was left in the skull and two more electrodes were placed on the participants, one on the foot and the other one on the arm to pick up electromyographic signals to use as the other coordinate and for mouse click.

This study had limited success since the signals obtained were weak**.** Following this, Kennedy and colleagues went on to produce an improved invasive BBI device. In this instance neurotrophic electrodes were implanted in two locked-in patient neo-cortices. Nerves had to be grown in the electrodes for approximately two months before the person was able to operate the interface. This interface was tested with a rat and a monkey for sixteen months before being used on two participants. The first participant, who was an Amyotrophic Lateral Sclerosis patient, died 76 days after the implant. The second participant was able to control a computer cursor for seventeen months (Kennedy *et al.*, 1999, 2000). Kennedy and his team (2004) have gone on to develop a system using conductive screws to access cortical local field potentials (LFPs) to communicate without entering the brain itself. A single Amyotrophic Lateral Sclerosis participant was able to use local field potentials to successfully communicate. Further tests are being done in this area.

2.5.2. Electrocochleography Based

Electroencephalographic signals have limited resolution and require extensive training, while single-neuron recording entails significant clinical risks and has limited stability. Levine and his colleagues (1999) collected data from seventeen epilepsy patients who had electrodes implanted on the surface of their cerebral cortex to record seizure activities. Patients were instructed to move their face, tongue, hand and foot. electrocochleographic signals (ECoG) recorded showed that the patients produced signals successfully at the rate of 50 - 90%, which could be used in BBIs.

Birbaumer's non-invasive slow cortical potentials device offered potential for communication and controlling the environment (details in Section 2.4.6.). This encouraged Birbaumer's team to go on to invasive BBI research. Three participants with epilepsy had electrodes placed on to the cortex as well as deeper into the brain, with the skull over the interested regions having been removed. Electrocochleographic signals were recorded over a period of five to fourteen days. The participants were asked repeatedly to imagine two different movements that are represented at the primary cortex; a tongue and little finger movements. The average success rate was between 77 - 82% (Lal *et al.*, 2005). Electrocochleography based BBIs could provide the brain-injured individuals a potentially stable communicating device for the future in comparison to electroencephalalography based and less traumatic than BBIs that use electrodes penetrating the brain (Leuthardt *et al*., 2004).

2.5.3. Neuroprosthetic Based

Research is being done in Stanford University on neuroprosthetic (brain activities related to intended movements) BBIs that translate neural activities from the brain into control signals for prosthetic devices to assist disabled patients. The signals from the pre-motor cortex of a rhesus monkey enabled it to move computer icons solely by activating neural arm movements (Yu *et al.*, 2004). The success of the human motor prosthetics will largely depend on increasing systems performance by maximising movement related information that can be recorded from cortical neurons (Shenoy *et al.*, 2004). Local field potentials (LFP) in the brain area are an important source of information for neuroprosthetic applications. In the near future implantable devices will need to transmit neural information from hundreds of microelectrodes to make human neural prosthetic motor systems possible (Harrison *et al.*, 2004). More research needs to be done in this area before neuroprosthetic BBIs can be implemented.

2.5.4. Motor Function Based

Research was done using primates to show that signals from imaginary motor functions can produce signals that can be used in BBIs. Experiments are being carried out with monkeys being implanted with electrodes to prove this phenomenon (Taylor *et al.*, 2002, Musallam *et al*., 2004). Primates learnt to reach and grasp virtual objects by controlling a robotic arm, using their brain signals to create imaginary motor functions. The monkeys succeeded in reach and grasp movements even when they did not move their arms. More research is being done to extend such closed loop methods for humans in future BBIs (Carmena *et al.*, 2003).

Research on neural prosthetics has focused mainly in activities related to hands. Recorded data has been taken from motor cortical areas. Researchers are looking for other signals such as local field potentials, which can be used for controlling devices. New movable probe technologies are also being tried to seek the best signals for the electrodes automatically (Anderson *et al.*, 2004). This research uses monkeys and is yet to be tried on humans.

2.5.5. Summary of Invasive BBIs

A summary of the survey of the invasive category of BBIs is shown in Table 2.4. Fewer teams have been involved in this type of BBI development than the non-invasive category due to the complicated setup needed. The signals obtained can be accurate and less noisy than non-invasive BBIs, but the success rate still ranges between 50- 90%. All the experiments were conducted in the laboratory environment and evaluated with disabled participants due to the medical intervention needed. The procedures for implanting an invasive BBI, the risks involved, and the skilled personnel required makes non-invasive BBIs the preferred choice as a communication tool for brain-injured individuals.

Table 2.4 – Summary of invasive Brain Body Interfaces

Dates	Researcher/ Research Group	BBI	Participants	Location	Achievements	Comments
1999 - 2000	Kennedy and team	EEG and EMG based	2 disabled	Laboratory	One participant died, the other one communicated for 17 months.	Limited available data to make any conclusions.
1999	Levine and team	ECoG based	17 disabled	Laboratory	50 – 90% success in producing signals	Laboratory exercise only
2005	Birbaumer and team	ECoG based	3 disabled	Laboratory	77 – 82% success in producing signals	Laboratory exercise only
2004	Stanford University	Neuroprosthetic Based	No humans	Laboratory	Not data available	No data to comment
2002 - 2004	Tsinghua University	Motor Functions Based	No humans	Laboratory	Not data available	No data to comment

2.6. Current Research in Brain Body Interfaces

Artificial Intelligence at the level of the user interface is currently being supported through number of strands such as adaptive user interfaces and interface agents (Akoumianakis *et al.*, 2000). Much research is being done in the use of agent technology in areas such as networking but not much is done in interface agents (Brown, 1999) for the disabled. Use of interface agents to closely monitor user trends and change configuration parameters of the interface where the bio-potentials of a user is altered to such an extent that, changes need to be made to improve the performance.

The problem with intelligent user interface is that it may violate many good usability principles by not being transparent, predictable and taking control. One way to provide user control is to provide the user with choices for adaptability. Proper analysis will show individual differences (Friedman *et al,* 2007). Scalability should be included (Höök, 2000). Is the adaptive user interface going to take the emerging technology of agent based interaction in the future specialising in intelligent help, intelligent hypermedia and intelligent filtering (Benyon & Murray, 2000)?

There is a possibility that interfaces can be extended to include data such as location, presence of objects, people, temperature and blood pressure of the user (Pascoe, 1997) when the interface is being used. The bio-potentials generated by the individual might be monitored to observe any adverse or pleasant reaction to the environment. This will give any additional data that can be used to indicate any unwanted stress caused to the participants when using BBIs. It can also indicate any stimulus that takes place when using BBIs.

Research is being done by Kaiser and team (2001) to create a portable BBI for severely paralysed patients to voluntarily generate bio-potentials at anytime. This work is done to create a BBI which will be used to communicate continuously rather than at a time set by the personnel around a brain-injured individual. Research is also being done in wearable wireless BBIs where technology such as bluetooth is proposed for transmitting and receiving signals from the participant (Navarro, 2004) so that a BBI wearing individual can move around without the need for apparatus to be attached when moving from place to place.

Work is also being carried out where an invasive BBI will not only receive signals but also introduce information into the brain. The Defence Advanced Research Projects Agency (DARPA) has awarded $26 million to improve its implanted BBI techniques towards this research (Wickelgren, 2003).

Interfaces could be standardised in future to a standard like BCI2000 (a General-Purpose Brain-Body Interface Application), this type of design could be used with any BBI thus increasing the usage of any BBI to a much higher level without tying to a particular technology.

2.7. Choosing a Design and Development Strategy

Many experimental psychology (McCarthy, 1995) and scientific methodologies can be applied to the study of computer tools and how humans interact with tools (Hawthorn, 2000, MacKenzie *et al* 2001). There are various models and techniques for specifying user interfaces such as psychological and soft computer science notations, user models, graphical/diagrammatic approaches, abstract mathematical models and user interface management systems (Abowd *et al.*, 1989).

A user interface consists of an input language for the user, an output language for the machine and a protocol for interaction (Chi, 1985). Wang and MacKenzie (1999) state that there is consistent human bias when objects are manipulated in an interface. This meant there was an optimum setting that needs to be addressed when developing interfaces. The design and development task faced here was not an engineering problem but an iterative problem that needed an optimised design. Various technologies, design and development strategies and guidelines were considered and discarded, such as:

- Contextual Inquiry (Beyer & Holtzblatt, 1998, Clarke & Cockton, 1999, Dekker *et al.,* 2003) – This research followed on from the previous work on using Cyberlink™ as a BBI (Doherty, 2001) and is not an inquiry to find out whether Cyberlink™ could be used as a BBI;
- Task and Domain Models (Burmester & Machate 2003) – Not enough common tasks are known to be carried out by brain-injured users in order to create domain design models;
- Layered Approach (Furtado *et al.*, 2003) – Not enough common features exist between brain-injured users or Brain Body Interfaces, to use this design methodology;
- Heuristic Evaluation (Baker *et al.*, 2002, Kleinig & Witt, 2000, Nielsen, 1995) – The usability heuristics needed for this research were not known at this stage of

the research, hence this evaluation was found not to be flexible enough for carrying out studies with brain-injured participants (Holzinger, 2005);

- Fitt's Law predicts the time required to move from a starting position to a final target area (Bertelson, 1994, Card *et al.*, 1983) – The chosen BBI, Cyberlink™, does not obey this mathematical law since bio-potentials cannot give a consistent input to a BBI as demonstrated by Doherty and his team (2003);
- Design space of input devices (MacKinlay *et al.*, 1990) – The participants of this research could not use the standard input devices covered in this model;
- User Centred Design (Bevan, 2003) – Participants with severe brain injury could not be used as the central source of information since each of their abilities were very different and could not be generalised for the development of an interface;
- Haptic Brain-Body Interfaces (Műnch & Dillimann, 1997, Beckhaus & Ernst, 2004) – The disabled participants in this research were quadriplegic hence this type of interface was not considered;
- Artificial Intelligent User Interfaces (Höök,1998, Friedman *et al.,* 2007) – The usability issues connected with using bio-potentials as inputs took precedence in the choice of interface design concepts at this stage of the research. This research could not find an area to accommodate concepts from artificial intelligence.

A specific research development strategy is evolved in Chapter 3.

2.8. Conclusions and Research Directions

The potential of various bio-potentials used in BBIs was discussed in this chapter. Electroencephalography gives access to one bio-potential (brain waves) that can be found on every brain-injured patient, but the amplitude of this signal is rather small (10 - 100 μV). However in the absence of any other signal, electroencephalography can be used in BBIs. Electromyographic signals (muscle movements) and electrooculargraphic signals (eye movements) are two bio-potentials with high amplitude (1- 4 mV) that can be used in BBIs, but patients must be able to move their muscles and eyes in a controlled manner to apply these two bio-potentials. These two bio-potentials also could be used to operate other assistive devices such as an eye tracker or switch. There are other bio-potentials, positive and negative, which occur after a period of a stimulus to indicate selection, such as slow cortical potentials, steady-state visual evoked potential, P300 and N400. Researchers have tried to use these bio-potentials for spelling devices and other information processing BBIs, with limited success.

We can deduce that electromyographic and electroocular graphic signals will be the two front runners for the most suitable bio-potentials for non-invasive BBIs because they are high amplitude bio-potentials which be easily produced by a patient in comparison to other bio-potentials. Tables 2.1 - 2.3 show that the BBIs had a success rate ranging between 41- 95%, albeit with a lack of consistency. All the experiments except one by Doherty's team were evaluated in the laboratory environment, and not in the field. Most BBIs also needed extensive computer processing power and extensive training. Experiments with bio-potentials obtained by invasive means are limited in comparison to non-invasive bio-potentials, due to the medical intervention needed to access the neurons, and the risks involved in opening the skull. The signals obtained are noise free in comparison with the non-invasive bio-potentials. Electroencephalographic signals, electromyographic signals and electrocochleographic signals are three examples of bio-potentials obtained by invasive technology. From these three bio-potentials, electrocochleographic signals offer the highest amplitude (300 - 1000 μV), and becomes the strongest contender using invasive technology. Tables 2.1-2.3 and 2.4, indicated that the number of teams involved in invasive BBI development were fewer than the non-invasive category. The success rate was between 50 - 90%, albeit again with a lack of consistency. All the experiments were conducted in a laboratory environment. The risks involved, and the personnel need for setting up an invasive BBI system, made the non-invasive BBIs the preferred choice for a communication tool for the brain-injured individuals.

The survey included BBIs with various success rates. The overall success rates of BBIs had a range of 41 - 95%. Hybrid systems could be implemented with more than one type of bio-potential to complement BBIs, as shown by Pfurtscheller and colleagues. The most successful non-invasive BBI was the device that combined electroencephalalographic, electromyographic and electrooculargraphic bio-potentials at Graz University of Technology by Pfurtscheller and colleagues. As for the invasive BBIs, the number of tests carried out with brain-injured participants was too small to identify the most successful BBI.

Diagnostics and measurements of brain injuries have progressed, but medical personnel working in the rehabilitation area (further to a brain injury) need accessible reliable BBIs to make progress in rehabilitating brain-injured patients. BBIs have not been shown to be dependable enough for main software manufactures to integrate them into mainstream operating systems and applications. This trend is likely to continue unless computer manufacturers see a need to invest in this area of special needs.

The pace of research is increasing, and good progress is being made in the area of assistive technology. The last ten years have seen more than thirty research groups working on developing BBIs, both invasive and non-invasive types. The researchers have carried out extensive work and created many applications such as spelling, surfing the net, operating robots and controlling wheel chairs, and real-time manipulation of bio-potentials obtained from the brain. Many BBI research applications are laboratory implementations, with limited test results obtained from the brain-injured community. Hence slow progress has been made in the use of these devices for the brain-injured population at large (Gnanayutham, 2004, 2006). Despite the potential shown by many of BBI devices in this chapter, limited use is made by the brain-injured community. This is due to the cost of BBI systems and the lack of evaluation with participants outside research laboratories. Hence there is a clear need to take this technology outside the laboratory and into the field to nursing homes and hospitals.

Doherty's research achieved a limited amount of success. Doherty tested assistive devices and showed that the traditional assistive devices (mouth stick, switch, eye tracker, voice recognition software, head tracker, head mouse and head pointer) could not be used by severe brain-injured patients since they could not:

- Control the movements of their mouth for mouth stick (Heyer, 1991);
- Control parts of their body consistently for switches (Terrell, 1985);
- Control their breath for sip and puff devices (Marsden, 2000);
- Control their eyes for eye tracking (Ohno & Mukawa, 2003);

- Speak or will have slurred speech for voice recognition (Zafar *et al.*, 1999);
- Have precise positioning and control of the head for head movement devices (Anson *et al.*, 2003, Scargle, 1998).

Doherty had only one interface for all users. If a particular user could not move along the predefined route, no communication was possible. Hence this interface was not inclusive of all users. An inclusive interface is needed to overcome this. Inclusive design implies (for this research), inclusion of any brain-injured (or able-bodied) user who can respond. The exceptions to this are individuals who are comatose, visually impaired, or suffer adverse effects of daily medicine intake.

Participants can create unwanted signals (e.g. a twitch), so there is a need to ignore unwanted signals (noise) due to certain components of the bio-potentials. Research needs to improve cursor control, while giving the user the opportunity to move around a screen without any predefined route, a personalised route with targets which suit an individual. Doherty's participants took different times to reach the targets Yes or No. Could individuals be allocated a pre-defined time to reach a target to suit their ability? Could a group interface be developed to suit a particular disability, or an individual interface to suit a person?

Doherty concluded from his thesis that Cyberlink™ appeared to be a useful assistive technology for some disabled persons (Doherty *et al.*, 2001, 2003). It was unfortunate that participants could not always operate the Cyberlink™ to select a response because of their fatigue, their injury and their responses to medications taken. He also stated that usable settings could be found and used for persons operating a Cyberlink™, but it was not known how close to optimal these were without a rigorous study involving medical personnel. Doherty also stated that with usable settings, Cyberlink™ does often allow participants a means to recreate and communicate to some degree, albeit with limited reliability. This is much better than the option of no communication or recreation being possible. Participants often navigated difficult mazes to completion, but could not consistently perform this task due to the extent of their injuries. Doherty claimed that it was logical that, given the above mentioned impairments, the Cyberlink™ had a definite but limited value as an assistive technology for severely motor impaired persons. Doherty's success was limited and inconsistent, although three participants could use no other computer input device other than Cyberlink™. Could research be carried out to optimise the interface parameters in order to minimise training? Moving the cursor across a computer screen using bio-potentials is a slow process. Hence there was a challenge to accelerate the cursor in the direction of travel to minimise the effort needed by the users. Is there any technique to push the cursor along the route to enable the user to reach the target easily, thus minimising the effort needed, thus reducing frustration? This research reported in this thesis addresses all above questions.

Chapter 3 – Research Methodology

This chapter describes the challenges involved in developing and evaluating novel interaction paradigms for BBIs, the methodology chosen for this research and the resulting plan. Many scientific methodologies can be applied to the study of computer tools and how humans interact with these tools (e.g., Hawthorn, 2000, Höök, 2000, MacKenzie *et al.*, 2001). Research development methods can draw on engineering design approaches to optimise designs, but the broader design context in HCI must embrace usability issues (Nielsen, 1993). One such approach of particular relevance would be Gould and Lewis's (1985) three principles of system design: early focus on users and tasks, empirical measurement and iterative design whereby the interface is modified, tested, modified again, tested again, and the cycle is repeated again and again.

The research hypothesis proposes that the performance of the BBI can be improved by the use of novel interaction paradigms, to the benefit of brain-injured individuals. Gould and Lewis' principles are central for testing this hypothesis. The literature survey carried out for this investigation showed that all non-invasive BBI experiments (except Doherty's) were laboratory experiments completed mainly with able-bodied participants. Invasive BBI exercises were laboratory experiments carried out with a small number of disabled participants. Tables 2.1-2.3 and 2.4 show that participants needed extensive training in many cases before a BBI could be used for communication. This meant a better design is needed, with emphasis on usability considerations, as well as brain injury and BBI issues. Severely brain-injured participants could not be expected to go through extensive training in order to use an interface. Hence learning should be considered when developing interfaces for this group of individuals. Minimum learning effort should be expected from this group of users. The training needed is to last no more than an hour, and should involve participants being instructed on how to use their eyes (look left and right), forehead (frown and relax) and their brain waves (imaginations) to move a cursor around a blank screen using a BBI.

This research proposes to develop an interface that can be used for everyday communications in the field and not in a laboratory setting, with evolutions being guided by field evaluation. Testing must therefore be carried out in the field. McDonald and her colleagues (2006) state field methods for usability evaluation reveal a broad and a very different range of problems that could not be achieved through lab testing. They also provide a better basis for understanding the causes of usability problems.

3.1. Challenges with Brain-Body Interfaces

Various challenges needed to be addressed by this investigation. Firstly the challenge of access to brain-injured individual needed to be addressed. Permissions and informed consents from the rehabilitation institutions, participants and/or their parents or guardians had to be obtained before research began (Friedman & Kahn, 2003, p.1189). A medical practitioner would be needed to assess each disabled participant for suitability for this research. The ethics boards at each institution had to approve this research. The validity and usefulness of this research had to be emphasised.

There could be various problems associated when working with this group of participants such as:

- Individual disabilities and abilities;
- Effect of medication on individual participants (or change of medication in the middle of the investigation);
- The best time for visiting a participant (e.g. ‘night person’ or ‘morning person’);
- Attention span of an individual;
- Emotions and frustrations when research is being carried out. Will this research bring back any flash backs from the past that could effect an individual?
- Medical assessments further to existing ones will have to be carried out. Organs such as eyes might be functioning, but the brain might not process any information from the eyes.

Another challenge is the qualities and features of novel interaction paradigms. There were various design issues to be address here:

- Can this study develop an inclusive interface that can be used by any brain-injured user (except comatose, severely visual impaired or an individual with adverse effect of daily medicine intake)?

- Can a universal access (Stephanidis, 2001) interface be developed? If not, can we identify similarities to see whether group interfaces could be developed according the classification of the brain injury, e.g. one for cerebro vascular accident (stroke), another one for locked in syndrome etc,. From initial experience of various categories of brain injury, this study considered developing interfaces to cater for specific disability groups;
- If neither universal nor group interfaces can be developed, can we design a personalised interface to cater for each brain-injured participant?
- Should personalisation involve choice from a group of novel interaction paradigms, or one novel interaction paradigm that can be personalised?
- Can the developed interface offer a facility to re-configure the interface at any time, if the medical or physical condition of the user changes?

Doherty's encouraging achievements in field testing lead to the choice of the Cyberlink™ as the BBI for this research. However, background noise (unwanted bio-potentials) can cause the Cyberlink™ to behave in an erratic way when a user tries to control a cursor on a computer screen, regardless of the distance to the target or size of the target. Various background noise can be picked up by Cyberlink™, which moves the cursor to unwanted parts of the computer screen (where there are no targets), causing erratic movements that could not be controlled, producing frustration and fatigue. Bringing the cursor back under control also takes a lot of effort. Such problems mean that we must improve cursor navigation.

Doherty created a generic solution, having considered quite a range of geometries (Figure 2.4), by restricting the path of the cursor by creating a predefined maze (Doherty, 2001). This did not prevent the cursor becoming stuck in a corner for an indefinite period of time, frustrating users of the BBI. Research needs to find a technique for the cursor to be navigated in a controlled way on a computer screen to reach the intended targets, and also to come back to the starting point if the cursor does not reach the target in a given time interval. Moving the cursor across a computer screen using low voltage bio-potentials (0 to 10 μV) is a slow process, hence there could be advantages in accelerating the cursor in the direction of travel to minimise effort from users.

Therefore this research had to investigate strategies for:

1. Minimising the effort needed by brain-injured users to reach a target, using an enhancement for cursor control of the BBI that can improve user performance;
2. Avoiding user ineffectiveness when using the developed interfaces, e.g. by ensuring the cursor does not get stuck in an unwanted area of the computer screen for an indefinite period of time when attempting a task;
3. Optimising the interface before being used by brain-injured users to minimise configuration and learning;
4. Designing interfaces which will be robust in, and portable to, the field and not just used in laboratory experiments;
5. Designing interfaces that will give realistic daily usage for communication;
6. Designing interfaces that can facilitate independent usage at user's care home.

3.2. Chosen Approach

Having considered research methodologies (Freeman & Tyrer, 1998, Matthews, 2002, Preece *et al.*, 2002), an appropriate one was chosen to deal with the challenges of this research. This is not to be a classic engineering design approach, which would not cater for usability issues (different disabilities), but an iterative HCI approach with appropriate optimisation for some iterations. It combines field usage of prototypes with field evaluation, and is an example of a design research approach.

Design methods used in 1960s and 1970s did not deliver hoped for scientific standards (Cross, 2001). However, science can and does underpin design. This research thus draws on brain and behavioural sciences. The steps to be taken for this research are thus:

1. Select a research paradigm and select research methods (Kennedy, 1999) comparable with selected paradigm;
2. Design an algorithm that can let the user navigate the screen in a controlled manner, enhancing cursor control of the BBI to improve the time to reach a target;
3. Can a universal access interface be developed? If not, can we design an interface that can group disabled participants together, when developing

interfaces iteratively, e.g. one for cerebro vascular accident (stroke), another one for locked in syndrome etc.?

4. If group interfaces are not possible, can we design personalised interfaces that can be compared with the group interfaces?
5. Can the final interface be an inclusive interface that can be used by any brain-injured user (except comatose, severely visual impaired or an individual with adverse effects of daily medicine intake)?
6. Develop interfaces that can facilitate independent usage at user's care homes;
7. To evaluate all BBIs and design controlled studies.

For step 7 above:

1. Refine methods and approaches for each study;
2. Obtain ethical approval for each study;
3. Recruit participants both able and disabled;
4. Choose participants both able and disabled;
5. Obtain optimised values for design parameters, through engineering design approaches;
6. Measure values for usage variables (time taken to reach the target, route taken to reach a target and success rate);
7. Use formative (for development) and summative (to show robustness and validity) evaluation, based on quantitative and qualitative results.

Principles from iterative user interface design thus underpin the methodology for this research (Gould & Lewis, 1985). This methodology uses iterative methods to refine the interface design. Lessons learnt from previous user evaluations are used for refinement in the next iteration.

The chosen approach is shown in diagrammatic form in Figure 3.1. The diagram shows an oval shape with an inner and outer area. The inner shows initial development and evaluation process carried out with able-bodied participants, while the outer shows the main evaluation process carried out with disabled participants. Evaluating with able-bodied participants could give data for optimising interfaces before they are used with the disabled participants. It also enabled optimising the settings for each novel interaction paradigm before it can be used with brain-injured participants. These optimised settings were used as the starting point when experiments were concluded with the disabled participants. Iteration drove the formative and summative evaluations (Munhall, 1989, Omery, 1987). Iteration also gave the opportunity for building artefacts that evolved into refined, tried and tested prototypes (Alexander, 1986, Abowd *et al.*, 1989).

Formative and summative methodologies were chosen to evaluate the paradigms being developed in this research (Kerlinger, 1986**,** Nogueira & Garcia, 2003). Formative evaluation is to be conducted before summative evaluation at each phase of research (Figure 3.1). Prototypes to be formatively evaluated based on users' preferences and its implications for interface design, which could suggest possible re-designs. The participants for the formative evaluations are to be medical professionals, attending personnel and relatives of brain injured individuals. Focus groups are also expected to be setup for formative and summative evaluations during the development stages of the research. Summative evaluation is to be used to assess the interface designs refined through formative evaluation. Formative and summative evaluations are to complement each other when developing interaction paradigms.

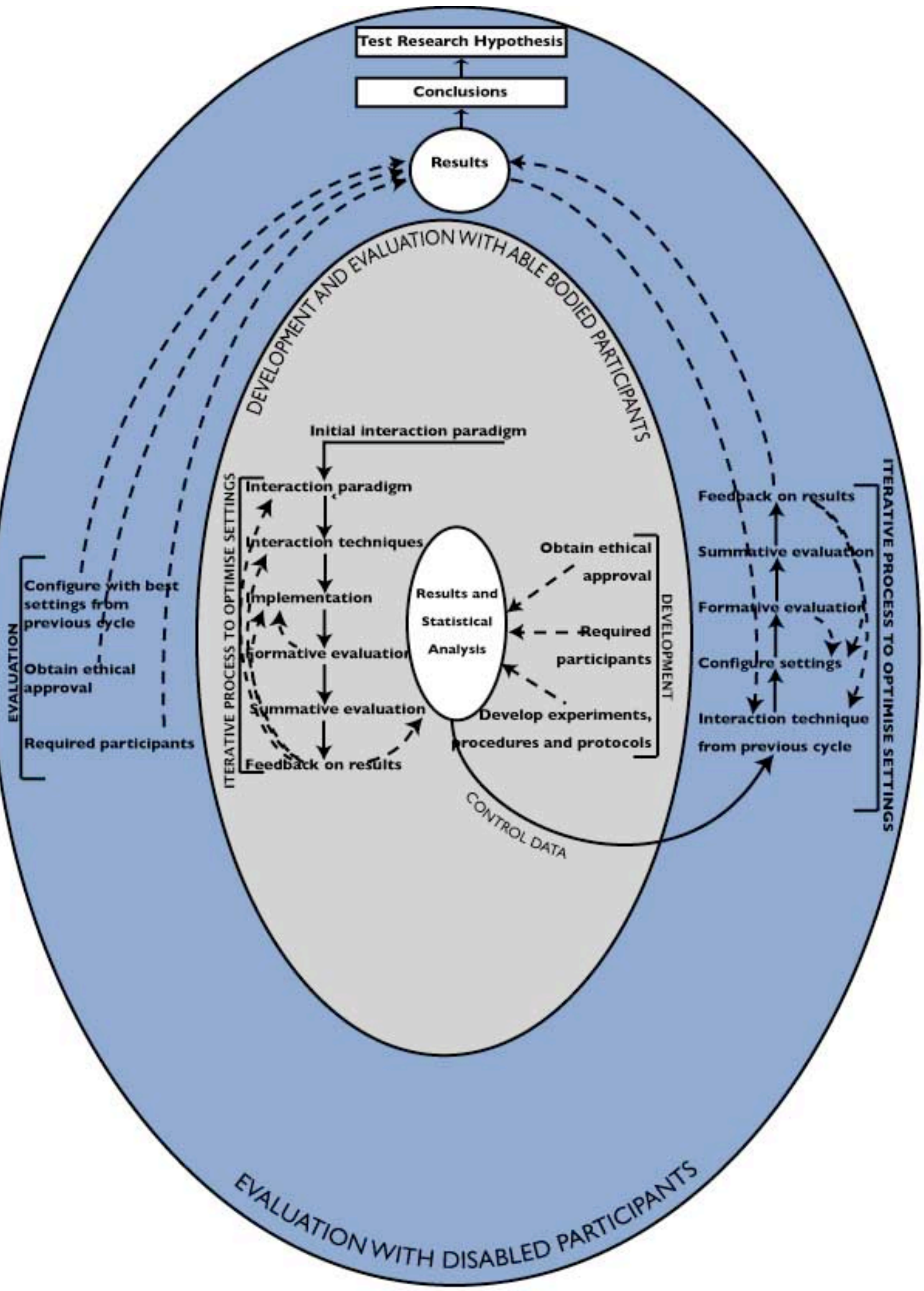


Figure 3.1 – Research Methods

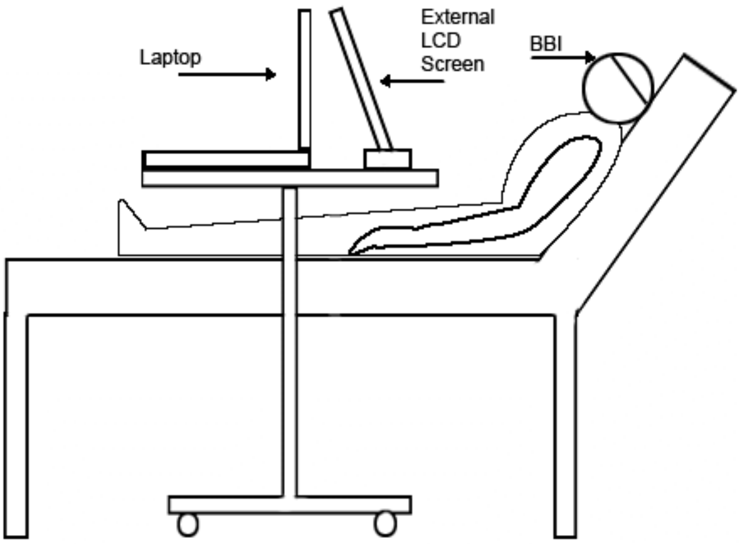


Figure 3.2 – Apparatus

3.3. The Research Settings

The above setup (Figure 3.2) was used when collecting data from brain-injured participants. The interface program was configured by the researcher or carer. An external, 19 inch LCD screen was placed in front of the participant, running an interface program written in MS Visual Basic or C++. This whole set-up was placed on a table that can be taken close to the participant. The three electrodes of BBI were placed on the forehead of the participant. Bio-potentials from the BBI were fed into a laptop computer which faced away from the participant, in order for the carer to launch and configure (if needed) the interface.

Figure 3.3 – Cyberlink™

The BBI (Cyberlink™) signals are detected by three silver chloride plated, carbon filled, plastic sensors in a headband and sent to the interface unit (Figure 3.3). The interface unit consists of a bio-amplifier, analogue to digital converter and micro-controller. The bio-amplifier's function is to amplify electroencephalalographic signals from 0.5 - 50 μV range and electromyographic signals from the mV range to a higher threshold. The signals are filtered and the signal to noise ratio is also improved. An analogue to digital converter changes the analogue signals to six channel digitised signals. The digitised signals are sent to the serial port of the computer where they are translated by a patented decoding algorithm into multiple command signals.

3.4. Structure of this investigation

Investigation is to be carried out in at least three phases. The first phase will be an exploratory one to investigate the possibility of creating a universal or group interface, rather a personalised one. Results from the first phase will feed into the second phase, where a new interface may be developed. This interface will then be evaluated with able-bodied participants to obtain optimised interface settings and evaluated with disabled participants in phase three of this research. Further phases will depend on results at this point and available time. One possibility, given a high degree of success, is to attempt independent use over several weeks without the researcher present.

The structure for each phase is to have the following steps:

- Gain access, recruit and select participants;
- Field studies with existing technology or prototypes;
- Redesign, to refine existing or introduce new design concepts;
- Able-bodied testing to optimise interface;
- Testing with brain-injured participants;
- Repeat the above processes until a positive outcome is achieved (or run out of iterations).

3.5. Summary and Conclusions

This chapter highlighted the challenges involved in this investigation, and the approach chosen to possibly deal with the challenges. Various methodologies were considered before a final selection was made. The chosen methodology is a design research paradigm, guided by principles from HCI research and practice, including engineering design approaches based on psychology research methods (called Human Factors Engineering in North America). A two level research framework uses able-bodied, then brain-injured participants. An initial three-phase structure was envisaged to carry out this research methodology to answer the research question: 'Can the performance of the BBI be improved by the use of novel interaction paradigms'. Design, implementation and evaluation of the novel interaction paradigms will be carried out in phase one and phase two. The methodology addresses known challenges to develop an appropriate interface needed for severely brain-injured individuals to communicate during their daily routines. The chosen methodology combines elements of engineering design and design science to create novel interaction paradigm and to evaluate their effectiveness.

Chapter 4 – A Novel Interaction Paradigm for Impairment Groups

This chapter describes phase one of this research. Two interfaces were developed to address the research question, and some of the challenges described in Chapter 3. Experiments were conducted. This was in an exploratory study (Allanson *et al.*, 1999, Amant & Cohen, 1997) to investigate whether:

1. A universal access interface can be developed;
2. Disabled participants can be grouped together, when developing interfaces, e.g. one for cerebro vascular accident (stroke), another one for locked in syndrome etc;
3. Using a novel enhancement for cursor control of the BBI (discrete acceleration) can improve the time to reach a target through more effective control and with less frustration;
4. Users can use the interface effectively with minimum learning.

The challenges above were taken from the list of challenges described in Sections 3.1 and 3.2.

Phase one was a short study lasting two months, and it needed as many participants as possible. The researcher and a medical practitioner carried out a study with eleven able-bodied participants from Milton Keynes and nineteen disabled participants from Mother Teresa's Missionaries of Charities New Delhi and Vimhans Hospital New Delhi. These institutes cared for people of various disabilities, but this study only involved individuals with brain injury. The experiments in Delhi lasted one month and produced very valuable data. This was a rather intensive study with regular visits to institutes. Each able and disabled participant was visited only once since this was an exploratory study.

A demonstration of the interface was made and the participants were asked to use the interface to give answers 'Yes' or 'No' to the questions being asked. The interface was a maze similar to Doherty's with predefined paths and controls. Two versions of this interface were developed and evaluated, one without discrete acceleration (Figure 4.1) and one in a novel interaction paradigm, discrete acceleration (Figure 4.2). Initial preparatory studies in Milton Keynes had confirmed suspected usage problems with Doherty's tunnel interface. A new interface paradigm was thus developed to attempt to overcome these problems. The effectiveness of the two interfaces could thus be compared in the Indian studies. An unmodified interface could not have provided any further worthwhile insights.

The discrete acceleration paradigm pushes the cursor in the direction of travel. When a cursor enters a particular area of the interface (areas 1 to 6, Figure 4.2) an algorithm jumps the cursor towards the intended target.

The user interface automated the research task of collecting x, y coordinates of navigation and the time to reach targets to investigate any similarities between participant profiles (Rubin, 1994). A statistical analysis (t-test) of usage/data would investigate whether adding discrete acceleration could reduce the time taken to reach the targets. Results could determine the suitability of discrete acceleration for group interfaces. The hope was that the acceleration algorithm could be parameterised to suit impairment groups. Should this be not possible, personalised interfaces using discrete acceleration and/or further new interaction paradigms would be developed.

4.1. Design and Development

The starting point for this study was results obtained using Cyberlink™ as a BBI (Doherty *et al.*, 2000, 2001, 2002), combined with insights from initial independent research of the Cyberlink with able-bodied participants in Milton Keynes (mostly doctors). This initial research checked the abilities of able-bodied participants to reach Yes and No targets in Doherty's tunnel interface (Figure 4.1).

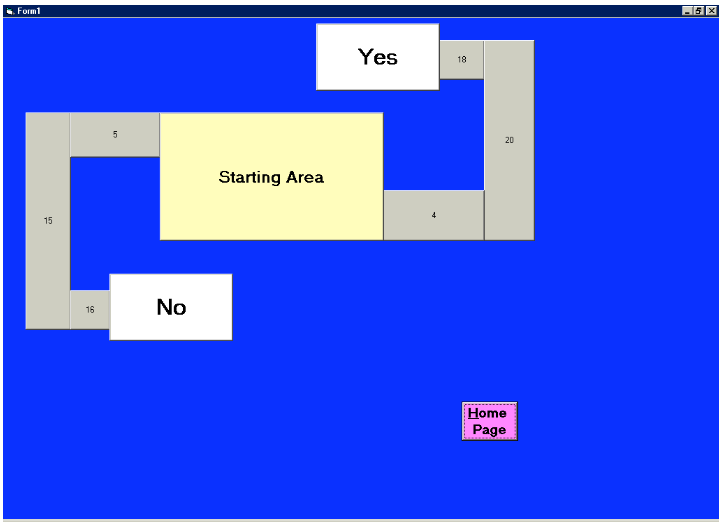


Figure 4.1 – Basic Tunnel Interface

Doctors liked the maze because a brain-injured person could be asked to navigate pre-specified paths to demonstrated control and intelligence, thus replicating the use of Cyberlink interfaces as a diagnostic tool (Doherty *et al.*, 2000). Two three-turn tunnels to targets constrained the cursor's movement.

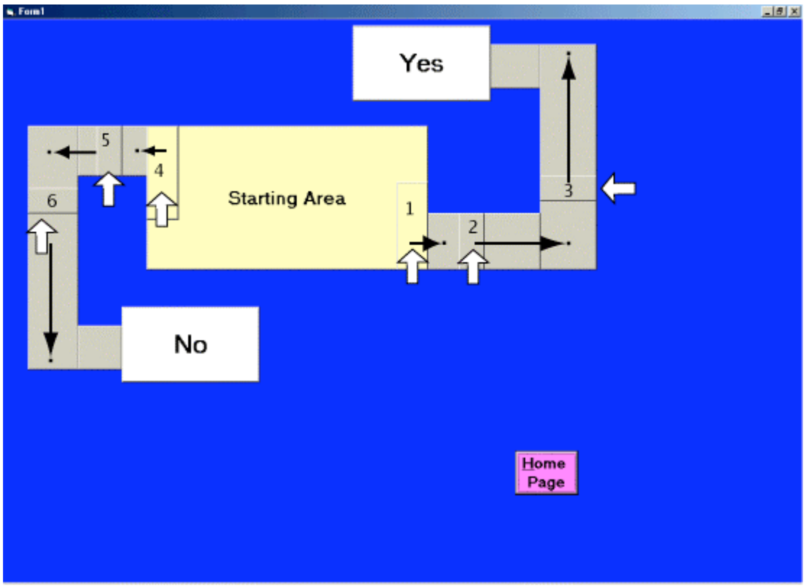


Figure 4.2 – Interface with discrete acceleration

There were two main difficulties when using Doherty's tunnel interface. Firstly the cursor became stuck in corners, frustrating users. This problem was addressed using discrete acceleration. Secondly the cursor starts to leave the 'Starting Area' (due to unwanted bio-potentials) before an individual could decide the target route. To address the second problem, when the interface program starts, the cursor could start in the middle of the screen in an area called ‘Starting Area’, and stay there for a period of time, specified at the configuration stage before using the interface. This would stop the cursor going all over the screen in an uncontrolled manner, making the user lose control and confidence. This will also give the disabled user a rest between reaching a target and going for the next one. The time allocated for staying in the ‘Starting Area’ can be set for each user to cater for individual preferences and disability. The starting point being in the middle will also give the user an option to have targets in any part of the screen according to the user preference and not solely by predefined design choices.

An alternative interface was thus developed to test this conjecture that discrete acceleration coupled with a pre-specified delay in the ‘Starting Area’ could address known usage problems (Figure 4.2). A new interface with discrete acceleration could address problems which were confirmed in this phase. It operates as follows:

1. After a configurable delay, the user can move the cursor away from the ‘Starting Area’, in order to answer Yes or No;
2. Entering pre-defined areas in the maze makes the cursor jump to the far side of the zone in the direction of travel, thus accelerating the cursor by a discrete step (based on the size of the area).

Discrete acceleration coupled with a delay at the ‘Starting Area’, could deal with the problem of the cursor getting stuck in corners. It also gave the user a controlled and faster technique for navigating the cursor towards the target. One way tunnels, with no option to go back to ‘Starting Area’ while jumping towards the target, were used in this interface. This was to prevent the uncontrolled navigation encountered in Doherty’s tunnel interface, with cursor moving forward and backwards out of control at times.

To support replication of this research, a Flowchart (Figure 4.3), Storyboard (Figure 4.4), State Transition Diagram (Figure 4.5) and Pseudo Code for Doherty's Tunnels Interface are now presented.

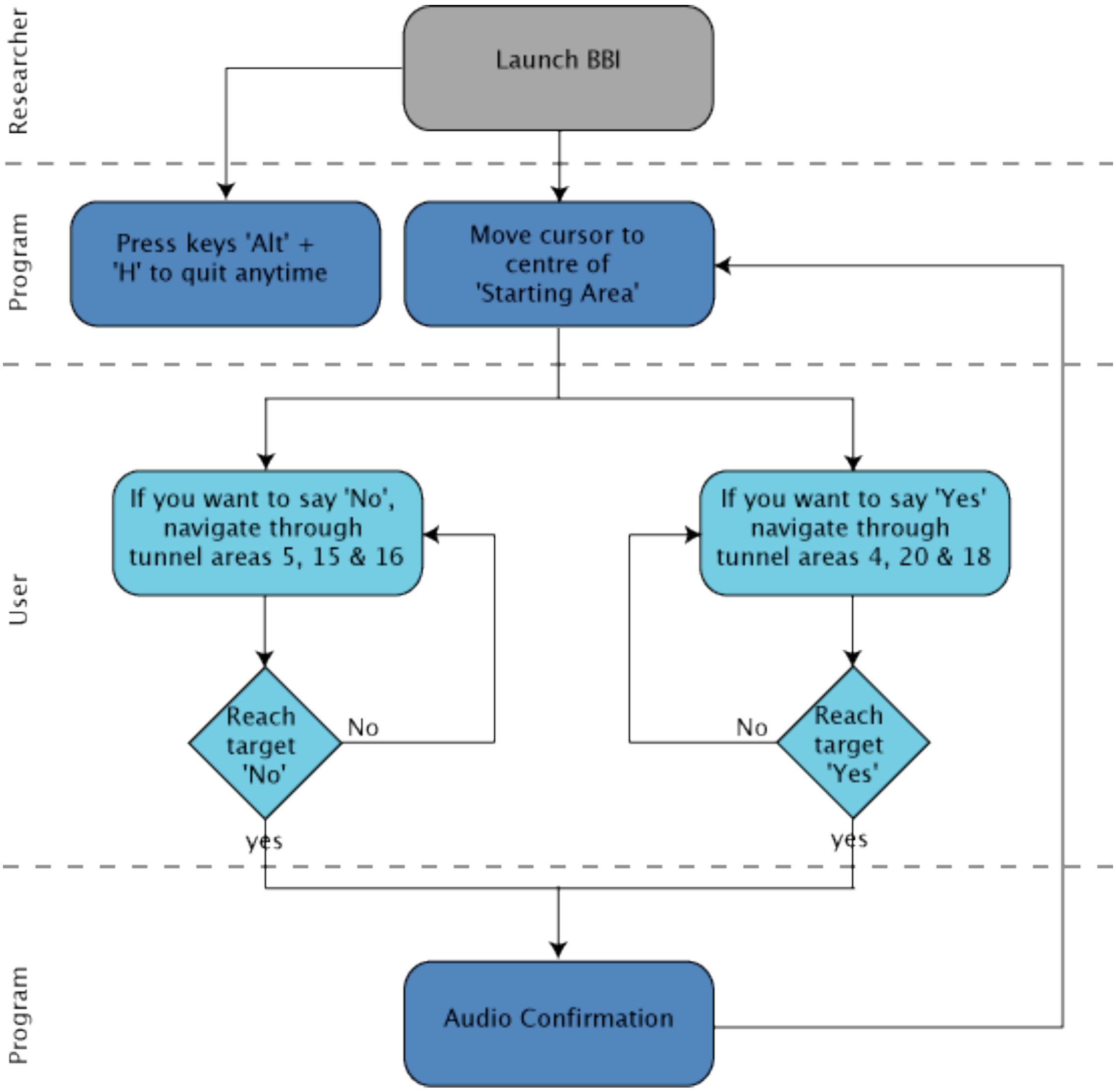
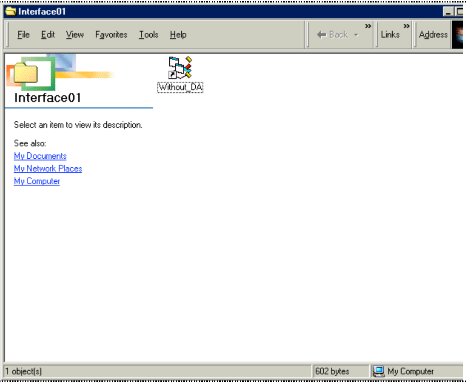
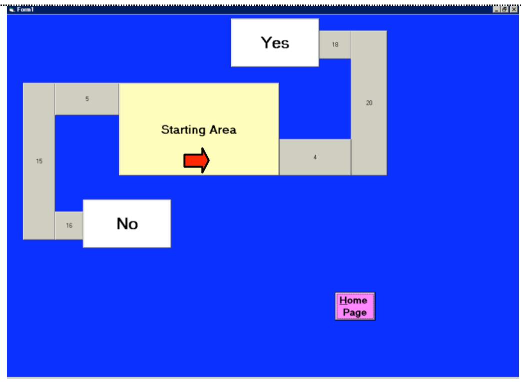


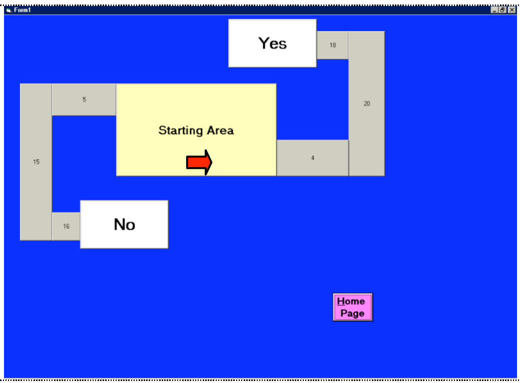
Figure 4.3 – Flow Chart: Doherty's Tunnels Interface



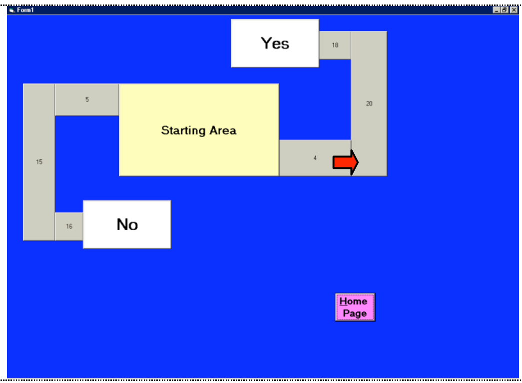
Launch Doherty's tunnel interface, named 'Without_DA'



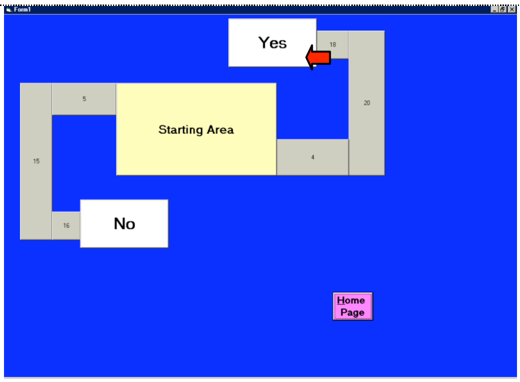
Cursor appears in centre of the 'Starting Area'.



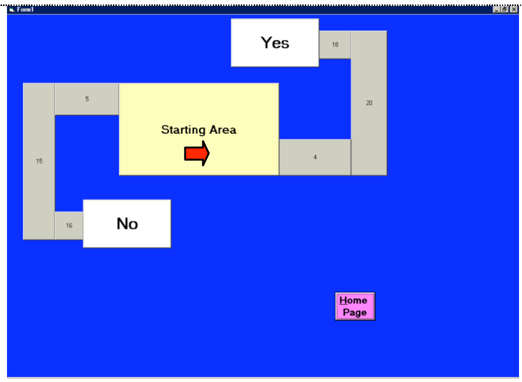
A question will be asked by the carer to which the user would want to respond with a 'yes' or 'no' answer.



Depending on the answer the user will navigate the cursor towards the target, through tunnels.



When the cursor reaches the destination, there is an audio confirmation.



Cursor returns to the centre of the 'Starting Area' to wait for the next question.

Press 'Alt + H' at any time during the process to quit application.

Figure 4.4 – Storyboard: Doherty's Tunnels Interface

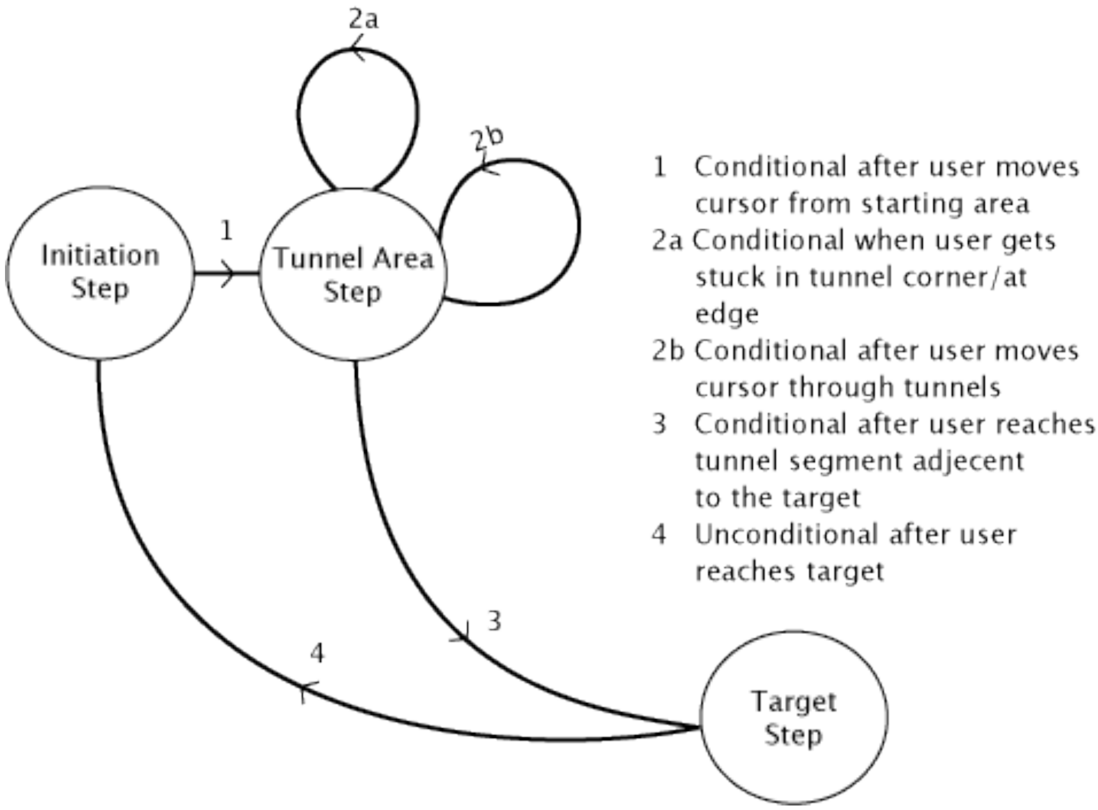


Figure 4.5 – State Transition Diagram: Doherty's Tunnels Interface

Figure 4.5 expresses the abstract task that defines Doherty's tunnel paradigm as a path through the state transition diagram. The path is:
Initial Step.1. (Tunnel Area Step. [2a ¦ 2b])$^{+}$. 3. Target Step.4.

Numbers refer to arcs in Figure 4.5. Arc transitions may involve user actions, system actions, or both. Phrases in the path refer to nodes in Figure 4.5. Node entry generally results in a system action. The $^{+}$ suffix indicates one or more repetitions, in this case of a node entry and arc transition. [x ¦ y] means x or y.

The following Pseudo Code assumes a program that:

- Has a 'Starting Area', tunnels and targets 'Yes' and 'No' as shown in Figure 4.1;
- Keeps cursor within the boundaries of starting, target and tunnel areas;
- Has a file created using current time and date for storing time and x, y coordinates;

- Uses combination keys (Alt + H) for quitting program.

The Pseudo Code for the specific implementation of this interaction paradigm is:

```
Move cursor to starting area
Record time and x, y coordinates of cursor in file
REPEAT
     On mouse move
     Move cursor
     Record time and x, y coordinates of cursor in file
     IF target reached
          Give audio confirmation
          Go to starting area
     ENDIF
UNTIL quit is pressed
```

A Flowchart (Figure 4.6), Storyboard (Figure 4.7), State Transition Diagram (Figure 4.8) and Pseudo Code for the Discrete Acceleration Interface are now presented.

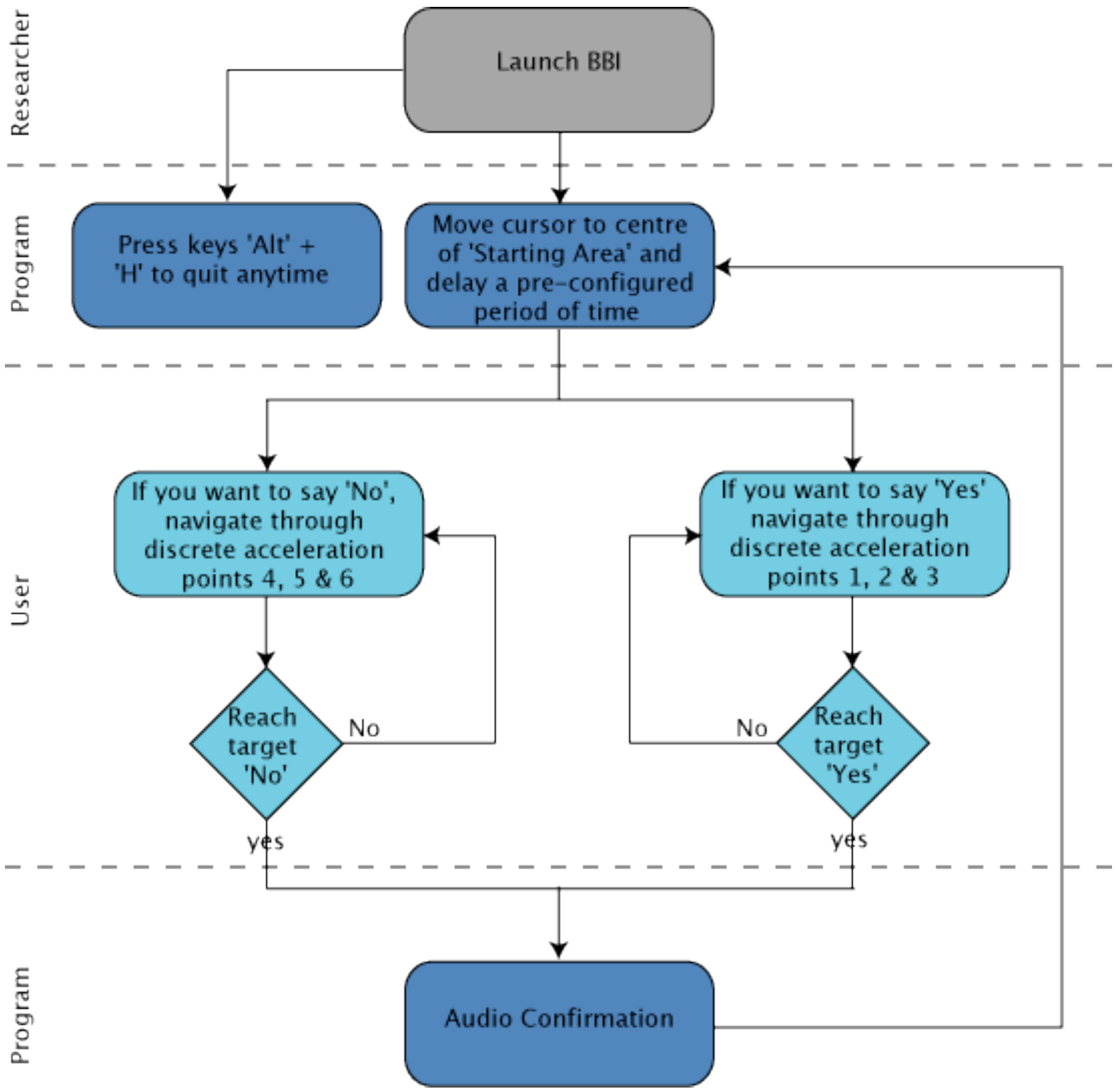
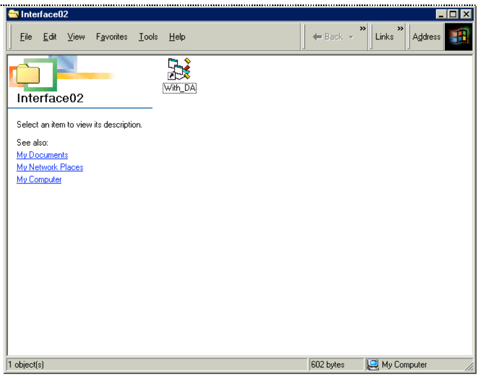
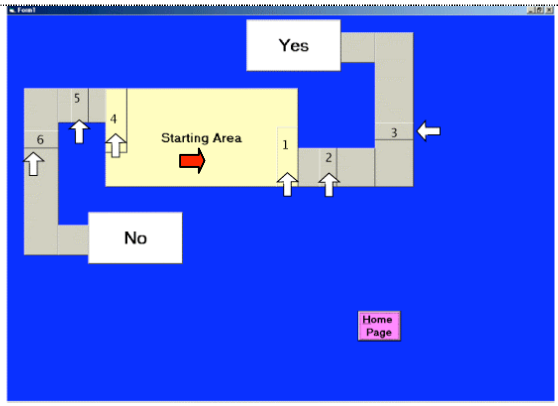


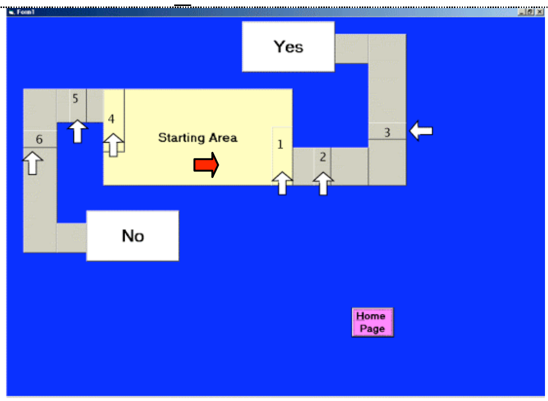
Figure 4.6 – Data Flow Chart: Discrete Acceleration Interface



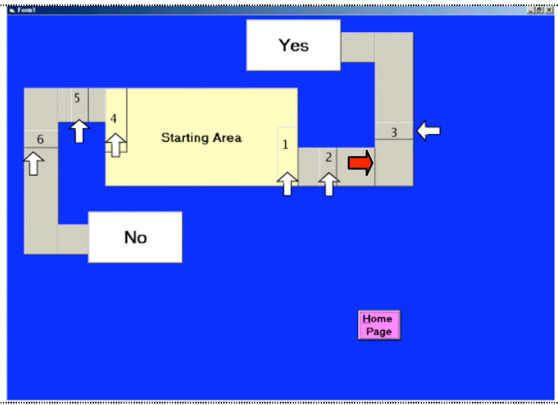
Launch discrete acceleration interface, named 'With_DA'



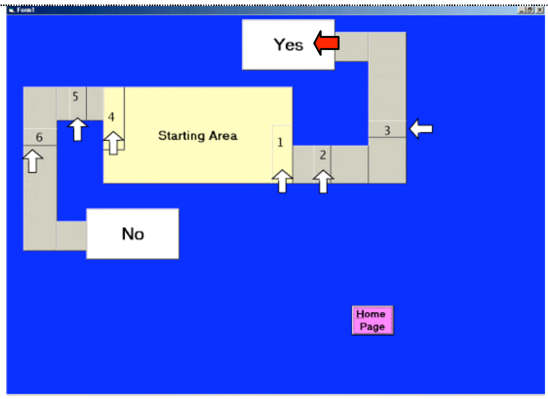
Cursor appears in centre of the 'Starting Area'.



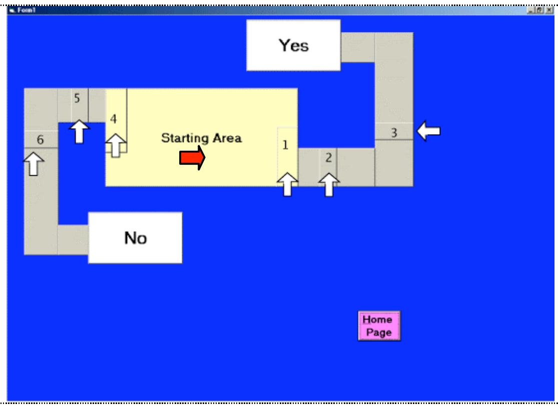
There will be a time delay introduced in the 'Starting Area' to settle user before cursor control is possible. A question will be asked by the carer to which the user would want to respond with a 'yes' or 'no' answer.



Depending on the answer the user will navigate cursor, towards a target, using discrete acceleration zones make the cursor jump towards the target, through the tunnels.



When the cursor reaches the target, there will be an audio confirmation



Cursor will return to the centre of 'Starting Area' to wait for the next question.

Press 'Alt + H' at any time during the process to quit application.

Figure 4.7 – Storyboard: Discrete Acceleration Interface

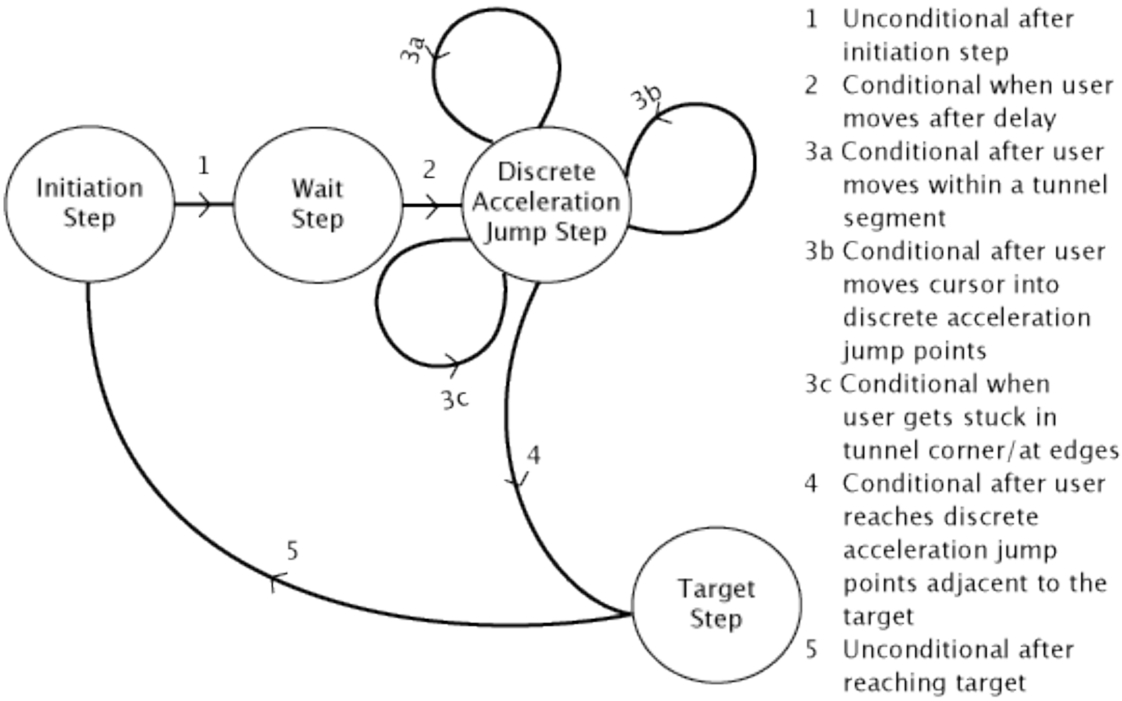


Figure 4.8 – State Transition Diagram: Discrete Acceleration Interface

The abstract task defining this interaction paradigm is expressed via Figure 4.8 as the path:
Initiation Step. 1. Wait Step. 2. (Discrete Acceleration Jump Step. [3a ¦ 3b ¦ 3c])$^+$. 4. Target Step. 5.

The following Pseudo Code assumes a program that:

- Has a 'Starting Area', tunnels and targets 'Yes' and 'No' as shown in Figure 4.2;
- Keeps cursor within the boundaries of starting, target and tunnel areas;
- Create Discrete Acceleration areas;
- Has a file created using current time and date;
- Uses combination keys (Alt + H) for quitting program.

The Pseudo Code for the specific implementation of this interaction paradigm is:

```
Move cursor to starting area
Record time and x, y coordinates of cursor in file
Wait a pre-configured time delay
```

```
Record time and x, y coordinates of cursor in file
REPEAT
     On mouse move
     Move cursor
     Record time and x, y coordinates of cursor in file
     IF cursor comes into discrete accelerations area jump
     to the far side of the zone in the direction of
     travel
     ENDIF
     Record time and x, y coordinates of cursor in file
     IF target reached
          Record time and x, y coordinates of cursor in
          file
          Give audio confirmation
          Go to starting area
          Wait a pre-configured time delay
     ENDIF
UNTIL quit is pressed
```

The two specific interfaces for each interaction paradigm could be evaluated to determine whether:

1. A universal access interface can be developed;
2. Disabled participants can be grouped together and could use common parameters optimised for their medical conditions, when developing BBIs;
3. Using a novel interaction paradigm (Paradigm 1 - discrete acceleration), for cursor control of BBI will improve efficiency and effectiveness;
4. Brain-injured individuals can use BBIs with minimal learning.

4.2. Study Locations and Participants

Tables 4.1 and 4.2 show the details of participants of this phase of research from Vimhans, New Delhi (Institute 1), Mother Teresa's Missionaries of Charities, New Delhi (Institute 2), De Montfort University, Milton Keynes (Institute 3) and Milton

Keynes Volunteers (Institute 4). It should be noted that all permissions and informed consents from the institutions, participants and/or their guardians were obtained before research began (Friedman & Kahn 2003, p.1189). A local medical practitioner assessed each disabled participant for suitability for this research. The ethics boards at each institution approved this research.

Phase one of the research used eleven able-bodied participants from Milton Keynes (Table 4.2) who volunteered for experiments in response to advertisements on the notice board of De Montfort University and local GP practices. There were problems in finding disabled participants for this research. Many submissions were made, demonstrations were carried out and ethical committee meetings were attended, but government hospitals were unable to provide participants. The National Health Service in Milton Keynes provided a letter, to say that the research was safe and valuable, but they could not offer any participants or use of their premises. This resulted in looking abroad for this phase of the research. A city was sought that had hospitals that would provide a large number of participants. Delhi was one possible target. It was also the place where the local medical practitioner had practised in the past. The local medical practitioner was a friend of the researcher and carried out all the medical assessments for this study both local and abroad. Applications were made to the Indian embassy and the relevant hospitals in Delhi, requesting permissions from ethical committees of the hospitals. The institutes carried out the initial selection of participants, but the final selection was carried out by the local medical practitioner who travelled to Delhi for this study with the researcher. The criteria for exclusion were visual impairment, a comatose state or adverse effects of daily medicine intake.

Table 4.1 – Details of disabled participants

Part. No	Institute	Gender Age	Clinical Diagnosis	Medication	Additional Information
1	Institute 1	M70	CVA (Quadriplegic)	Anti-hypertension Aspirin	Nonverbal, understands, obeys commands
2	Institute 1	M17	Paraplegia	None	Nonverbal, Normal
3	Institute 1	M65	Spastic Paraplegia	None	Nonverbal, obeys commands
4	Institute 1	F63	CVA/Quadriplegic with MI	Hospitalised	Nonverbal, obeys commands, clouding thoughts
5	Institute 1	F72	Severe Parkinsonism	Antipsychotic drugs	Unclear, paranoid, delayed response
6	Institute 2	F9	CP with MR, Bilateral squint	None	Poor, slurred, behavioural problems
7	Institute 2	F11	CP with mild MR	None	Poor, IQ 80, highest COG level
8	Institute 2	M10	CP, one eyed, profound hearing	None	Nonverbal, understands commands, highest COG level
9	Institute 2	F10	CP with MR	None	Verbal, obeys commands
10	Institute 2	F11	CP Spastic Hemiplegics with MR	Anti-epileptic, Luminol, Tegretol	Poor, obeys commands
11	Institute 2	M12	CP with MR, Convergent SQ	None	Speech poor, mild ADHD
12	Institute 2	M13	Down's Syndrome, MR, LT CON Squint	None	Poor, few words, understands command
13	Institute 2	F11	CP with MR	None	Nonverbal, highest COG Level, understands command
14	Institute 2	M8	CP with MR	None	Nonverbal, obeys command
15	Institute 2	M13	CP with MR	None	Verbal, IQ 80
16	Institute 2	M14	CP with MR	None	Poor few words, highest cognitive level
17	Institute 2	F9	CP with MR	None	Nonverbal, obeys commands
18	Institute 2	M8	CP with MR	None	Nonverbal, obeys command
19	Institute 2	M10	CP with MR	None	Nonverbal, mild ADHD

Table 4.2 – Details of able-bodied participants

Part. No	Institute	Gender Age	Clinical Diagnosis	Medication	Additional Information
20	Institute 3	M23	Able-bodied	None	Verbal, normal IQ
21	Institute 4	F11	Able-bodied	None	Verbal, normal IQ
22	Institute 3	M40	Able-bodied	None	Verbal, normal IQ
23	Institute 3	M26	Able-bodied	Anti-Peptic Ulcer	Verbal, normal IQ
24	Institute 3	M33	Able-bodied	None	Verbal, normal IQ
25	Institute 4	F50	Able-bodied	None	Verbal, normal IQ
26	Institute 4	F45	Able-bodied	None	Verbal, normal IQ
27	Institute 4	M15	Bilateral divergent squint	None	Verbal, normal IQ
28	Institute 4	F40	Able-bodied	None	Verbal, normal IQ
29	Institute 4	M50	Able-bodied	None	Verbal, normal IQ
30	Institute 4	F36	Able-bodied	None	Verbal, normal IQ

4.3. Study Method

Two interfaces using Microsoft Visual Basic (Figures 4.1 and 4.2) were developed and evaluated iteratively following the research methodology described in Chapter 3, with eleven able-bodied participants before use with nineteen brain injured participants. Apparatus was setup as shown in Figure 3.2 in Chapter 3. At the start of the experiment the participants trained on how to navigate a cursor using the Cyberlink™ on a blank screen. They were instructed to move a cursor on a computer screen horizontally by navigating the cursor with their eyes, using the electrooculargraphic signal (EOG). They followed the researcher's index finger from left to right before attempting to navigate the cursor side to side on the computer screen. To move the cursor vertically, they were asked to tighten their forehead muscles by frowning and hold the cursor in place or push it up and relax the forehead muscles to allow the cursor to come down (EMG). These participants were then encouraged to add navigation in any direction of their choice by imagining an event such as walking along a beach, climbing a hill or carrying out a mental calculation thus invoking the brain waves (EEG). Each participant was encouraged to generate brain waves EEG using imaginations of their choice and notice how the cursor movements respond to their different emotions. They were then encouraged to navigate the cursor on all four directions on a blank using any combination bio-potentials EOG, EMG or EEG. This training did not last more than thirty minutes. The able-bodied participants could do this, but brain-injured individuals were only able to navigate the cursor according to their individual abilities and available bio-potentials. Both able and disabled participants generated different amount of EOG, EMG and EEG. An individual has his/her own profile for generating bio-potentials. Cyberlink™ used all available bio-potentials from a participant. Only one training session was given to participants: simple demonstrations sufficed.

Participants were asked to answer ‘Yes’ or ‘No’ by the researcher using the interfaces. Specific questions were also asked by parents or carers. Medical professionals, attending personnel and relatives, provided questions that were relevant to the participants, which had definite Yes or No answers. The times to reach the targets, the path used to reach the target and the success rate were recorded and analysed. T-tests (Kazdin, 2003) were used to compare the performances of the two interfaces. The user interfaces also automated the tasks of collecting the x, y coordinates of navigation to the targets and also the time to reach targets (Table 4.3). The initial interfaces were developed in English and used by able-bodied participants. The text in the targets was translated into Hindi and Urdu to cater for the brain-injured participants in Delhi.

When the interface program begins, the cursor starts in the ‘Starting Area’. The user had to navigate the cursor to the intended target ‘Yes’ or ‘No’ in a given time interval of five minutes. When the target is reached, an audible confirmation is given and the cursor goes back to the ‘Starting Area’. This process was repeated as many times as required by the participant to communicate. Navigation routes to reach a target (e.g. No) were used to find whether any similarities existed between participant profiles. Appendix 2 shows the record of routes taken by group of Cerebral Palsy participants from Mother Teresa’s Missionaries of Charities, New Delhi.

4.4. Results and Statistical Analysis

There was only limited success with both interfaces due to the various unwanted potentials picked up from the forehead by the Cyberlink™. Some users communicated using this simple interface to answer questions for the very first time since their brain injury. However some able-bodied participants could not move the cursor to one part of the screen using the first interface. Even participants who could use the first interface (Figure 4.1) had to make strenuous efforts, causing frustration and fatigue. Some impaired participants found it almost impossible to control the erratic movements of the cursor or move the cursor in a particular direction using Doherty's tunnel interface. A participant who was paralysed on one side could not steer the cursor to the left. This further confirmed that the need for alternative ways to improve control of the cursor and to ease movement within the maze.

Table 4.3 shows performance data with the two interfaces. T-tests were performed to compare the interfaces with and without discrete acceleration to find out whether adding discrete acceleration made any significant improvement to average times taken to reach targets. T-tests showed that discrete acceleration improved the time to reach the target. Results illustrated that the two sets of data were normally distributed and significantly different at $p << 0.05$. Single tailed and two sampled with unequal variance were used as parameters for the t-test. These results also showed that every participant was an individual with different times to reach targets who cannot be grouped by impairment (details in Appendix 2). Records of individuals' routes indicated that, within the tunnels' constraints, no participant used regular routes to reach a particular target, which may be due to the extensive noise on signals and varying bio-potentials of the Cerebral Palsy group users. This further showed problems with inconsistent control of the cursor and the need for controlling the cursor.

Table 4.3 – Average time taken to reach target with and without using discrete acceleration

Part No (Details of able participants shaded)	Time without discrete Acceleration (minutes)	Time with discrete Acceleration (minutes)
5	0.44	0.25
20	0.45	0.23
13	0.45	0.25
26	0.50	0.37
23	0.56	0.34
16	0.63	0.45
19	0.68	0.59
7	0.75	0.51
4	0.77	0.43
3	0.78	0.5
28	0.78	0.51
1	0.79	0.43
8	0.79	0.5
25	0.79	0.47
15	0.86	0.64
6	0.87	0.51
24	0.89	0.43
29	0.89	0.69
12	0.90	0.5
30	0.93	0.79
18	0.98	0.55
2	0.99	0.89
11	0.99	0.79
27	0.99	0.93
9, 10, 14, 17	Unable to do Anything	Unable to do Anything
21, 22	Unable to do Anything	Unable to do Anything

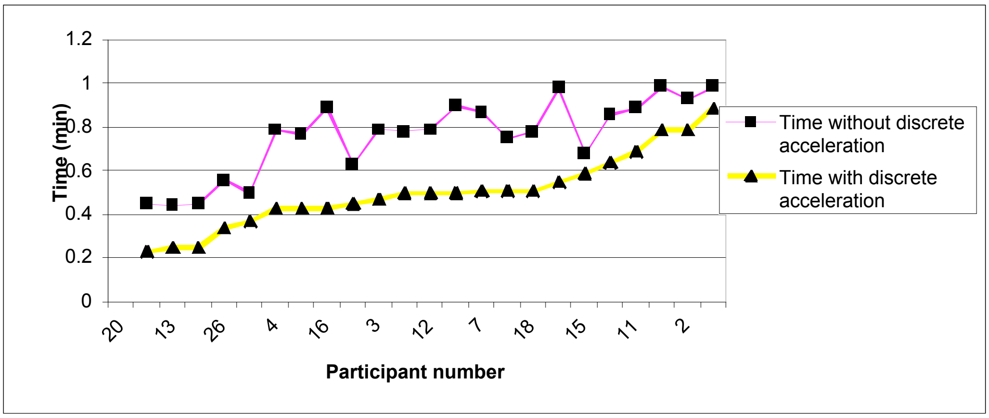


Figure 4.9 – Data for t-test

The results (Table 4.3 and Figure 4.9) show clearly that adding discrete acceleration improves the times taken by individual users to reach the targets. Times taken by the participants were always faster with discrete acceleration, which indicates that improvement has been made on Doherty's interface design.

Uncontrollable bio-potentials (physiological signals) cause the cursor to get stuck in various areas of the tunnel. When impaired users became frustrated, carers had to take over and move the cursor using the traditional mouse. In tunnel and maze interfaces, users who could not move through the predefined route could not communicate at all. An interface to cater for individual needs had to be investigated. All eleven able-bodied participants also confirmed that the interface with discrete acceleration was the preferred choice in comparison to the interface without, when using the two interfaces, thus completing the summative evaluation.

Some participants also created unwanted signals (e.g. from a twitch) which meant there was a need for getting rid of this noise by ignoring certain components of the bio-potentials from such users to implement inclusive design. Worse still, six participants could not use the interface at all (two were able-bodied). It was also found that able and disabled participants found certain areas of the computer screen easy to navigate, while finding other areas much harder to reach when being asked to move the cursor around a computer screen in a controlled manner. This meant an individual interface would be needed for each user with targets at the appropriate places. A target test could be used to find out preferred individual areas of a computer screen for each user.

4.5. Conclusions

A more inclusive interface was still needed. Inclusive design implies (for this research), inclusion of any brain-injured (or able-bodied) user who could respond, the exception to this being those in a comatose state, visually impaired or with adverse medication. Assistive technologies, despite their design purpose, can penalise users whose capabilities do not match the demands of the interface. One fifth of participants, both able and disabled were unable to use either interface (Table 4.3). The results showed that all participants were individuals who cannot be grouped by medical condition. There were also not enough common results to create universal access. In tunnel interfaces, users who could not move through the predefined route could not communicate, which excluded them on the basis of their capabilities. As a result an inclusive interface to cater for individual needs had to be investigated.

Personalisation is required to make the most of each individual's capabilities. A person with no electroocular graphic signal from eye movement may be unable to move the cursor horizontally, but might be able to move the cursor up and down using electromyographic signals. Tunnels do meet the aim of controlling the cursor to a degree, but performance is still adversely impacted by signal noise. The cursor will move around the display with little effort, picking up 'irrelevant' electroocular graphic, electromyographic and electroencephalalographic signals and frustrating users. 'Relevant' signals are very small voltages, which can be lost in the noise. Records of individual routes indicated that, within the tunnels' constraints, no one used regular routes to reach a particular target, indicating that each participant was an individual with different capabilities producing dissimilar bio-potentials (details in Appendix 2). Even with discrete acceleration, similar problems existed. Adding discrete acceleration improved performance, but did not overcome the problems of inconsistency that arise with BBIs. When the cursor got stuck in an area of the tunnel it remained there until the user made an effort and moved it towards a target. There was no time allocated for the user to reach a target. One possible solution to this problem could be to set a predefined time limit to reach a target, failing that to come back to the 'Starting Area' again. This solution could be considered for the next stage of this study.
As for the research hypothesis:
That the performance of the brain body interface can be improved by the use of novel interaction paradigms.
Discrete acceleration did improve the performance as stated in the hypothesis, but the need for a personalised interface remained despite this improvement.

Thus we can summarise. A universal access interface cannot be developed. Disabled participants cannot be grouped together. Adding discrete acceleration for cursor control of BBI improves efficiency and effectiveness. Brain-injured individuals can use BBIs with minimal learning for these two tunnel interfaces.

From this exploratory phase of the study, the next phase of the research took on board the need for a personalised interface and further improvement in performance beyond what was achieved by discrete acceleration.

One possible approach would be to exploit Fitt's Law, but Doherty had already concluded from his investigation that Cyberlink™ did not obey the Fitt's Law. Hence changing the dimensions of the interface based on Fitt's Law may not improve the performance of the BBI. When considering the use of tunnels in an interface, to navigate cursors, Accot and Zhai's (1999, 2001) Steering Law could be considered. The Steering Law can be expressed as

$$T = a + b \int_C \frac{ds}{W(s)}$$

where T is the average time to navigate through the tunnel, C is the path parameterised by *s*, W(s) is the width of the path at *s*, and *a* and *b* are experimentally fitted constants.

Very long sections or very narrow tunnels are very difficult to steer according to this law. Cyberlink™, which was chosen for this research, did not steer well when using tunnels as indicated in Table 4.3, where twenty percent of the participants were unable to steer through the tunnels. Since the Steering Law and the feedback from the participants indicate inherent drawbacks in tunnel-based interaction paradigms, we need to come up with a different approach and discard the tunnel approach for the next stage of this study.

A further approach cannot thus be based on existing major theories for pointing device usage. A new interaction paradigm based on different interactive behaviours is thus required.

Chapter 5 – A Novel Interaction Paradigm for Personalised BBIs

This chapter deals with the second phase of this investigation, the design of a further novel interaction paradigm. The study lasted eight months. The first four months of the study was spent on designing and evaluating a new paradigm with only the development group. The final interface was evaluated with ten able-bodied participants, which excluded members of the development group. An iterative approach was used to develop a prototype using able-bodied participants. The design went through various stages of testing with a development group, with the final test being carried out with ten able-bodied participants.

5.1. Design Challenges and a Possible Solution

This phase of the research investigated the following questions:

1. As group interfaces are not possible, whether personalised interfaces can be designed?
2. Can the final interface be an inclusive interface that can be used by any brain-injured user (except comatose, severely visual impaired or an individual with adverse effects of daily medicine intake)?
3. Can interfaces be developed to facilitate independent usage at user's care homes?
4. How do all BBIs perform in controlled studies?

The challenges above are a subset from the list of challenges described in Sections 3.1 and 3.2.

In addition to the above challenges, this phase of the study addressed problems from Phase one. Twenty percent of the participants, both able and disabled were unable to use the interfaces. The results showed that in tunnel interfaces, users who could not move through the predefined route could not communicate. An inclusive interface to cater for individual needs had to be investigated. A further problem encountered was the inconsistent control of the cursor, which was caused by the 'irrelevant' electrooculargraphic, electromyographic and electroencephalalographic signals being picked by the BBI. Adding discrete acceleration improved performance, but did not overcome the problems of inconsistency that arose with using BBIs in phase one.

Phase one indicated that the users had problems navigating certain parts of the screen or when travelling in certain directions. Two existing recommendations were considered for target practice and personalised individual interfaces in this phase of the study. Sibert and Jacob (2000) recommend a target practice with random target with no target being repeated. Jacko and team (1999) state allowing individual time to reach a target will cater for any individual with minor visual impairment. One possible approach to accommodate varying individual capabilities would be to have a target practice to show individual preference of a screen location through time to reach the target.

Target practice could have a screen with, for example, twenty four targets (Figure 5.1). There would be eight targets at one distance from the starting point, and another eight further away, then another eight further still. Then the participant would be asked to hit each target at random, as each appeared one at a time, within a prescribed time interval. The time taken to reach each target would be recorded and a program could automatically decide which areas are fastest for each participant. The participants could move to any one of the 24 targets, thus choosing the most easy to use individual areas of the screen, for his/her individual interface. Once the user finishes target practice, the program can come up with a tailor-made profile for that particular individual user. Then a second program could create a personalised interface according to the results of the target practice. Different numbers of targets could be set for a particular individual interface, for example 2 to 6 depending on application needed. Targets could also be programmed to do various tasks such as read text, launch applications or switch devices.

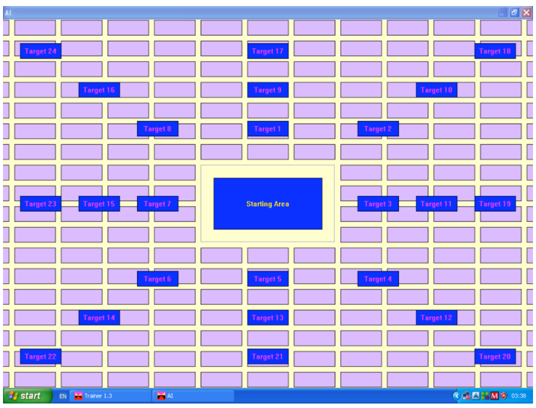


Figure 5.1 – Targets

Automated target practice for a personalised interface based on this results could improve on the previous interfaces described in Chapter 4, but will this automated process work with severely brain injured individuals? Do we need a manual configuration facility to give the carer even better control of the parameters to fine-tune the interface or even over-write the results of the automated process? There could be a manual configuration i.e. to choose an area of the screen and number of targets, if a carer wants to override the automated settings for a particular individual. A program could give the carer options to choose target size, target distance from starting point, tile dimensions, the gap between tiles, number of targets and all time allocations associated with the interface. Default settings could be obtained by using able-bodied participants to optimise parameters. This could be used as a starting profile.

Schlungbaum (1997) states that the individual user interface can be an adapted user interface (adapted to the end user at design time as in phase one), an adaptable user interface (end user themselves may change) or an adaptive user interface (interface that changes its characteristics dynamically at run time which is used in this phase). Schneider-Hufschmidt and his team (1993) state that adaptability increases usability. Phase two aimed to add *adaptable* features to the interface to produce a better match between device demands and user capabilities. This had to be achieved with minimal training time, and allow reconfiguration of the interface at any time. We could see no advantage in remaining with Doherty's tunnel paradigm, which we abandoned in search of a more flexible interface. An interface would combine discrete acceleration within a new paradigm that could also be personalised for individual capabilities. This would reduce the impact of noise and consequent erratic involuntary movement of the cursor by presenting users with targets that best matched their capabilities.

Masliah and Milgram (2000) recommend a goal (target) directed process as a means of communication, which this study took on board when using a 'Starting Area' and target as the end points of navigation. The interface could be a window with targets, tiles, gaps between tiles and a 'Starting Area' for the cursor to start from (Figure 5.6). A interface was developed so that it can be configured to suit each individual according to his or her ability.

5.2. Algorithm

In order to retain the advantages of discrete acceleration, a computer screen can be divided into tiles, which support discrete jumps from one tile to the next predicted one on the user's route, until the target is reached. Lack of regularity in user's cursor paths in study one ruled out a predictive adaptive algorithm, that could immediately jump to a target. Instead an incremental approach was devised as follows:

1. The cursor starts in the middle of the 'Starting Area' and moves across the gaps between tiles, aiming for the target, using the tiles as stepping-stones. The cursor can be moved in any direction after a configurable enforced wait;

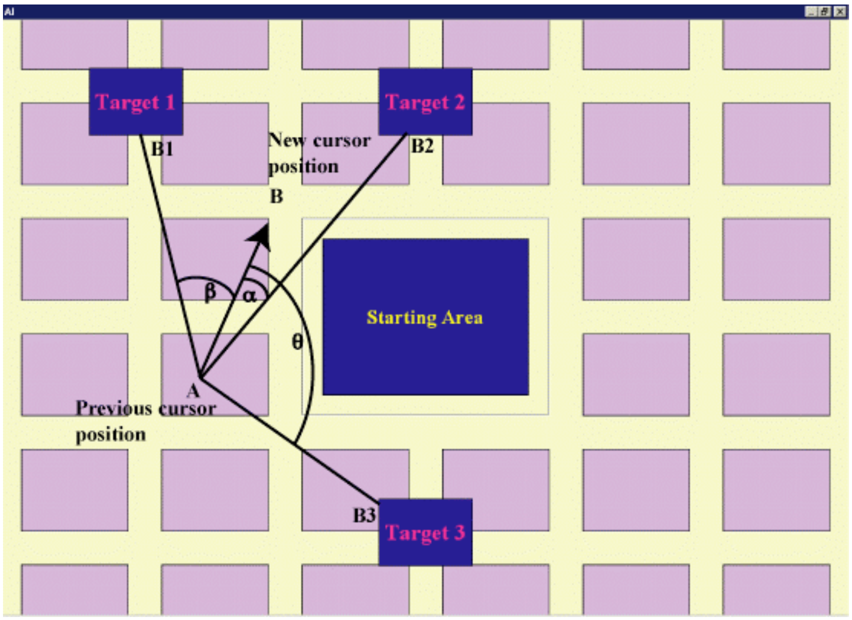


Figure 5.2 – Feedback to the user

2. From the starting point A, once the cursor enters a new tile, the program calculates the angle of travel (Figure 5.2) and takes the cursor to the edge of the tile point B, nearest to any target in that direction and makes that target flash, thus giving feedback to the user (Pope & Bogart, 1996, Pfurtscheller *et al.*, 2004);
3. There is also a provision for the target flash to be switched off or slowed down if it distracts the user or causes any discomfort. An arrow is displayed to give feedback to the user on the direction of travel used by the cursor;
4. The calculation for the next tile is as follows (Figure 5.2). Calculate the angles between each possible target and the AB line. This set is closed by a maximum

angle (initially 30°) either side of AB. If this set is empty, the program waits for another cursor move. Target lines AB1, AB2 and AB3 give angles β, α and θ. Then the program finds the smallest angle and considers the corresponding target (in above example, Target 2, since α is the smallest) as the one that the user wants to reach. The selected target blinks. If there are two targets below 30 degrees in the direction of travel, the algorithm will wait for another cursor move from the user before deciding on the target;

5. Once the cursor has moved to the edge of a tile, the user has to steer the cursor over the gap into an adjacent tile, at which point step 2 (above) or 6 (below) is taken;
6. In addition to the tiles, a small surrounding area was designated around each target (a neighbourhood), so that when the cursor, reaches that area, it gets pulled into the target (Figure 5.3);

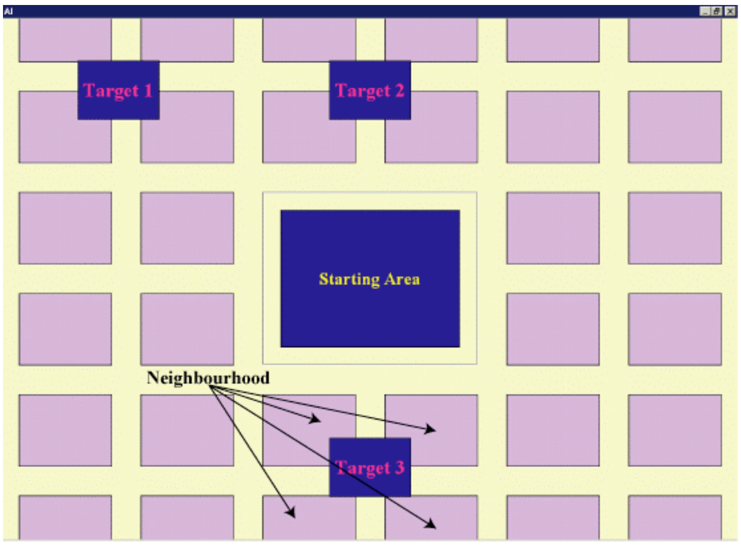
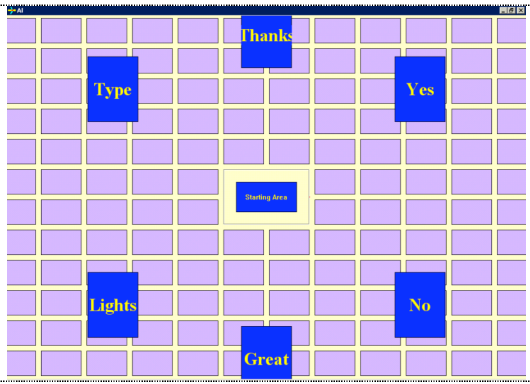
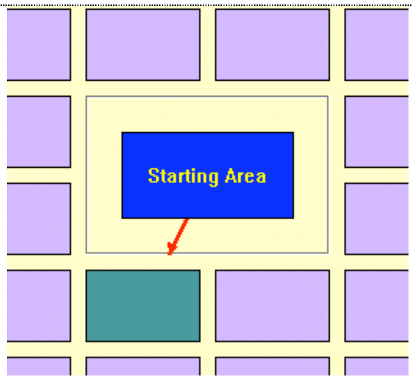


Figure 5.3 – Neighbourhood

7. As soon as the user reaches the target, it stops blinking, but this might not be the intended target. The algorithm allows the user to move the cursor to go to another target as long as the 'Target Time' set at the configuration stage, does not lapse. If a target is reached and the cursor is kept at the target for the duration of 'Target Time', the target will be chosen by the algorithm and the cursor will go back to the 'Starting Area' for the next question or target;



When the personalised BBI is launched the cursor moves to the 'Starting Area' and waits for a pre-configured time. Then the user moves the cursor jumping tile to tile *en route* to a target.



The red arrow indicates the last movement of the cursor. The green coloured tile indicates the position of the cursor *en route*. The target blinks, as the cursor moves towards a target, as per the algorithm described in Section 5.2.

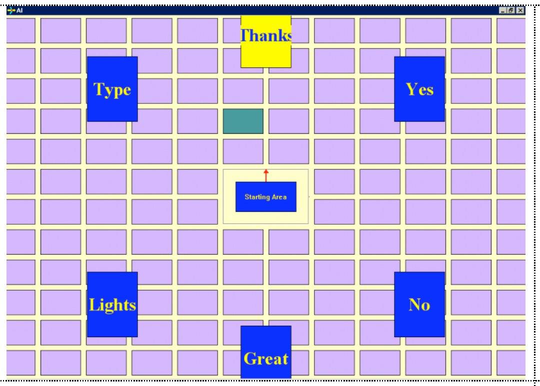
If the cursor moves towards a target on the left, the red arrow indicates the last movement of the cursor (left). The 'Lights' target blinks as per algorithm described in Section 5.2.

If it further moves towards another target the red arrow indicates the last movement of the cursor (diagonal). The target 'Yes' blinks as per algorithm described in Section 5.2.

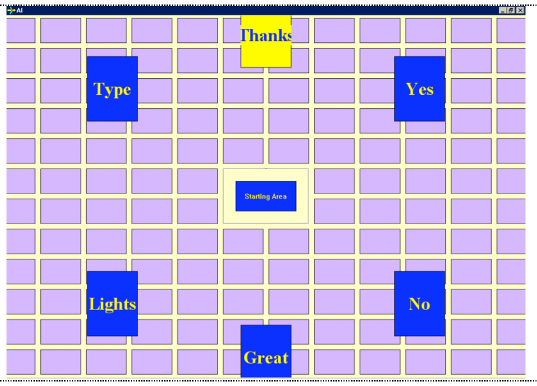
Figure 5.4 – Storyboard: Moving Cursor to Targets (Part 1)

8. There are thus two conditions to be satisfied for the algorithm to consider a target as the user's intended target:
   8.1. The cursor must be within the target area. If it is the target will stop blinking (if it is blinking the algorithm indicates to the user that the cursor needs further moving);
   8.2. With the above two conditions satisfied, the cursor should wait for a pre-specified time interval on the target.

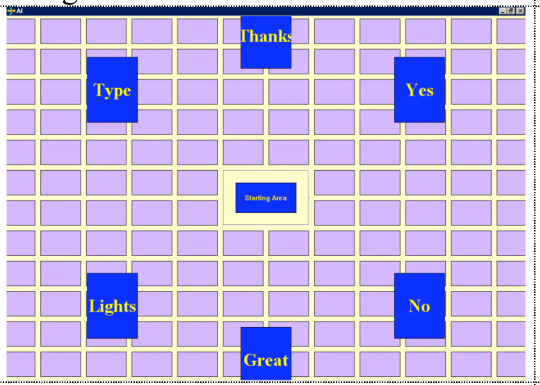
The storyboards in Figures 5.4 and 5.5 show how the algorithm functions when the cursor moves around the personalised discrete acceleration interface when moving towards a target. The application that configures this hybrid interaction paradigm is called 'Trainer' (Section 5.6).



If the cursor moves towards a target above, the red arrow indicates the last (up) movement of the cursor. The 'Thanks' target blinks as per algorithm described in Section 5.2. This sequence is repeated as the user navigates the screen



When neighbourhood of the intended target 'Thanks' has been reached, the cursor is kept in the target until target time has elapsed. 'Thanks' stops blinking. The word 'Thanks' is output (text to sound conversion) by the program while the target is lit.



The cursor moves to the 'Starting Area' and waits for a pre-configured time and awaits the next question to be answered by the user.

Press 'Esc' at any time during the process to quit application.

Figure 5.5 – Storyboard: Moving Cursor to Targets (Part 2)

5.3. Initial Interface

An algorithm for the personalised tiling with discrete acceleration interface improved the previous interface, but there were other issues such as 'look and feel', maximum flexibility on configuration, feedback to users, and minimum user frustration that had to be addressed in this second phase of the research.

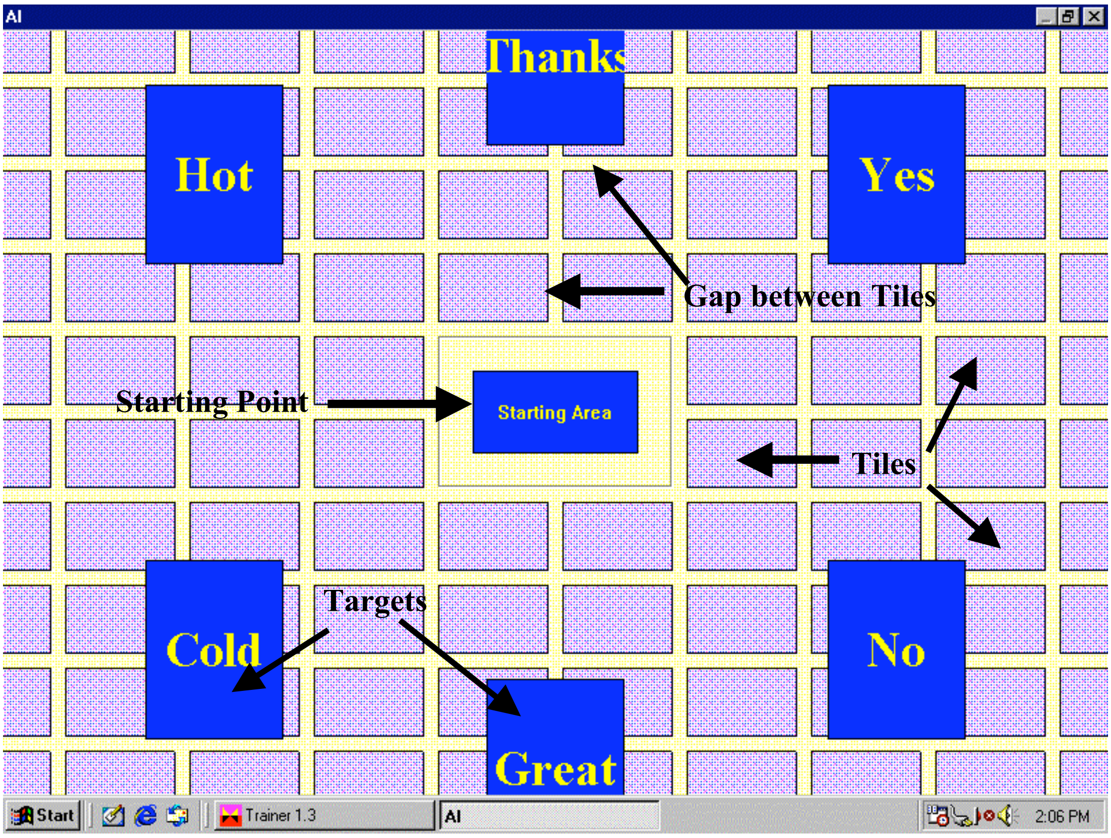


Figure 5.6 – Targets, tiles and gaps between tiles

Look and feel issues were addresses through Gestalt Laws of visual perception (Ware 2000):

- Law of Similarity – Our mind groups similar elements to an entity. The similarity depends on relationships constructed about form, colour, size and brightness of the elements;
- Law of Proximity – Spatial or chronological closeness of elements are grouped by our mind and seen as belonging together;
- Law of Symmetry – Symmetrical images are seen as belonging together regardless of their distance.

A screen conforming to Gestalt Laws was designed (Figure 5.6), where objects with similarity, proximity and symmetry were grouped together. Pickford (1972) reports on an experiment carried out by Fechner in 1876, where, out of nine shapes, the rectangle was chosen by a group of five hundred men and women (33%) as their best liked. Schiff (1980) states that even infants can perceive rectangular shapes, which further backs the argument for rectangles as a building block for an interface. Hence the rectangle was chosen as the shape for the ‘Starting Area’, tile and the targets.

Previous investigations show that users have emotional reactions to colours and fonts, this interface gave the option for making changes to suit any user (Laarni, 2003). Laarni’s study also showed that white or yellow text on blue background was more readable, which was taken as the default setting for the interface.

A target test was devised to choose the best parts of the computer screen to suit an individual user. Target enlargement to reduce pointing time was also considered at this stage (Zhai *et al.*, 2003, Ren & Moriya, 1997) but since Cyberlink™ was not a Fitt’s Law device, it was not adapted. Hence the target sizes were fixed as a default, but there was also a provision for carers to change any of these parameters manually as described in Section 5.1. There was also audio feedback (Brewster, 2003, Gnanayutham *et al.*, 2003). The configuration settings took care of all time intervals. There were individual maximum times allocated for every target, which meant the interface automatically recovered to the original position (i.e. starting point in the middle), taking care of error recovery.

Prototypes were developed for phase two that dropped tunnels in favour of placing target buttons in areas suited to individual users. Figure 5.6 shows an example of this interface. If a disabled user moves a cursor in one particular direction consistently, an individual interface could be created to communicate effectively. The severity of the disability of the participants made only electroencephalalographic signals available for communicating. The target test used a protocol whereby the participant followed a fixed repetitive scheme (Millan, 2003).

5.4. Design Iterations

A four member development group (Table 5.1) evaluated interface versions formatively throughout the development process. Then ten able-bodied participants tested the final version. There were two components to this interface program, the trainer and the profiler. The trainer ran the target test and created the ‘ini’ (e.g. ‘Trainer_John’) file for the profiler (Figure 5.14). The profiler then created an executable personalised interface file, which was launched by a carer every time the user wanted to communicate. Table 5.1 shows the details of participants who evaluated all the versions of the interface before the final version was evaluated by ten able-bodied participants. This development group consisted of participants from De Montfort University.

Table 5.1 – Details of the participants used in the development group

Part. No	Gender/Age	Clinical Diagnosis	Medicines	Additional Information
31	F40	Able-bodied	None	Regular computer user
32	M45	Able-bodied	None	Regular computer user
33	M50	Able-bodied	None	Regular computer user
34	M42	Able-bodied	None	Regular computer user

The first iteration gave a beep every time a target was reached in a pre-allocated time. Hearing a beep did not sound encouraging for the users. The beep was changed into applause for well done, but the development group felt that the feedback was not encouraging and requested a text reader be developed for the next iteration. The use of audio feedback was of paramount importance for this application as a communications tool. In addition to this, some disabled participants could also have some visual impairment and benefit from audio feedback.

Target tests can produce a user profile with more than one target in the same direction, e.g. three targets in the vertical direction one behind the other (Targets 1, 9 and 17 in target test, Figure 5.1). This meant the user going through a target into the next one. This problem was addressed by introducing a field in the configuration window called 'Target Time' which was the minimum period the user had to keep the cursor in the target to indicate selection of that particular target. When the user kept the cursor on the target for the 'Target Time', the target was chosen. This also gave the user an opportunity to change his or her mind and select another target.

A facility to change dimensions (targets, tiles and gap between tiles) was introduced in this iteration. This facility was to enable manual configuration i.e. to choose an area of the screen and number of targets, if a carer wants to override the automated settings for a particular individual. A facility for a report on the completion of target tests was also created to make available a printable version of the details of the interface for reference. This modified version was accepted by the development group. However three further modifications still needed to be added for the next iteration:

- Programmable targets for launching application and switching devices;
- Facility to start the C++ interface program and the BBI with one mouse click. If the C++ interface program and the Cyberlink™ device are started independently, BBIs can move a cursor to some part of the screen without any user control. One way to address this problem is to control the cursor at the start of navigation itself by placing the cursor in the starting area and introducing a preconfigured delay;
- The targets appeared at random in the target practice instead of in a predictable manner.

The final iteration was tested and accepted by the development group and then tested by ten able-bodied participants, in order to optimise settings of the interface. Targets were chosen according to the time taken to reach them in the target practice. Data from this target practice automatically created the final executable profile for each individual user. There was also a report created with all the data after the target practice, showing times and dimensions used in the interface. This version enabled the user to configure the target to launch applications or send a signal to the parallel port of the computer to switch on/off a device.

5.5. Final Interfaces

The Trainer described in Section 5.4 is still a universal design that only takes account of user differences at run-time. Irregularities in user input rule out jumping directly to the nearest predicted target. Instead, a step-by-step approach is taken that leaves the user in control at each point. There is not only an automated process to personalise interfaces, but also provides manual choices to change any parameter of the interface to better match the needs of a brain-injured individual.

The run-time profile interface thus has further features that allow the cursor's path to be controlled by settings for a specific user (Figures 5.10 - 5.15). These settings include:

- Time spent on the 'Starting Area' to relax the user before navigating towards a target;
- Time spent on each tile to control the bio-potential to allow navigation to take place;
- Size of tile to suit each user, smaller tiles will control the cursor better, but will take longer to reach the target;
- Gap between tiles to suit each user, the bigger the gap, the more work for the user and time to reach a target, depending on the ability of the user.

5.6. The Trainer Interface

The flowchart (Figures 5.7, 5.9, 5.16 and 5.19), storyboards (Figure 5.8, Figure 5.10 to Figure 5.14, Figures 5.17, 5.18 and 5.20) and state transition diagram for Trainer are now presented, to support future replication and extension of this work.

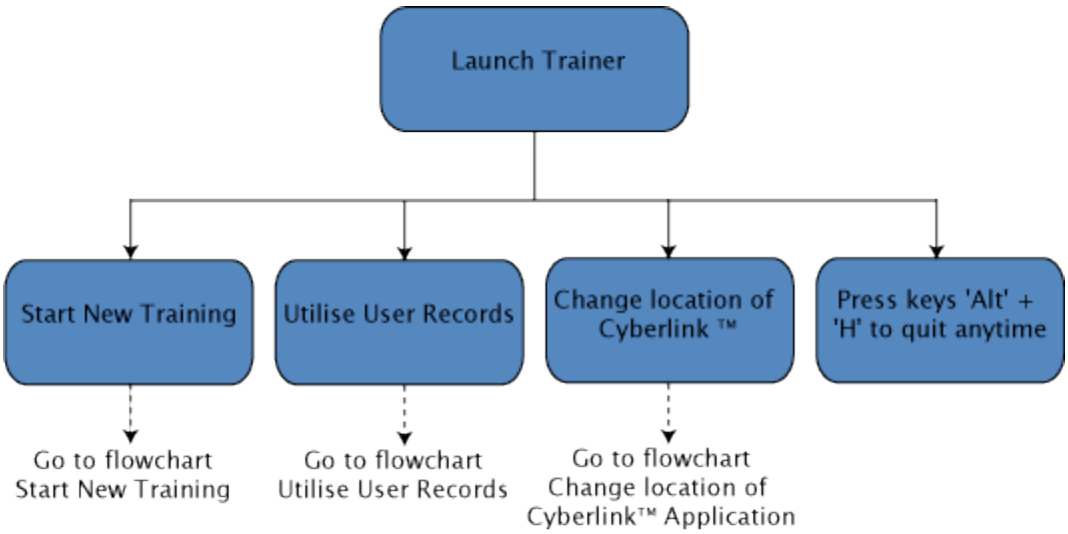


Figure 5.7 – First level: Flow Chart for Trainer

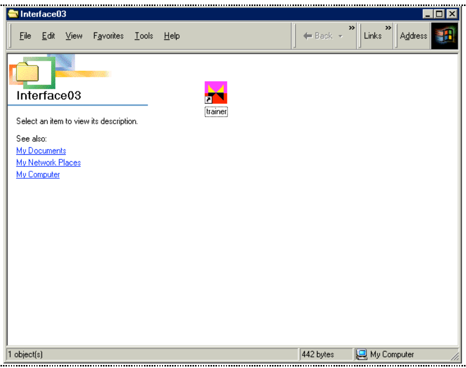
<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Launch trainer, by double clicking on the icon named ‘Trainer’</td>
<td>The trainer opens up giving four options. Choose ‘New Training’</td>
</tr>
</table>

Figure 5.8 – First level Storyboard: Trainer

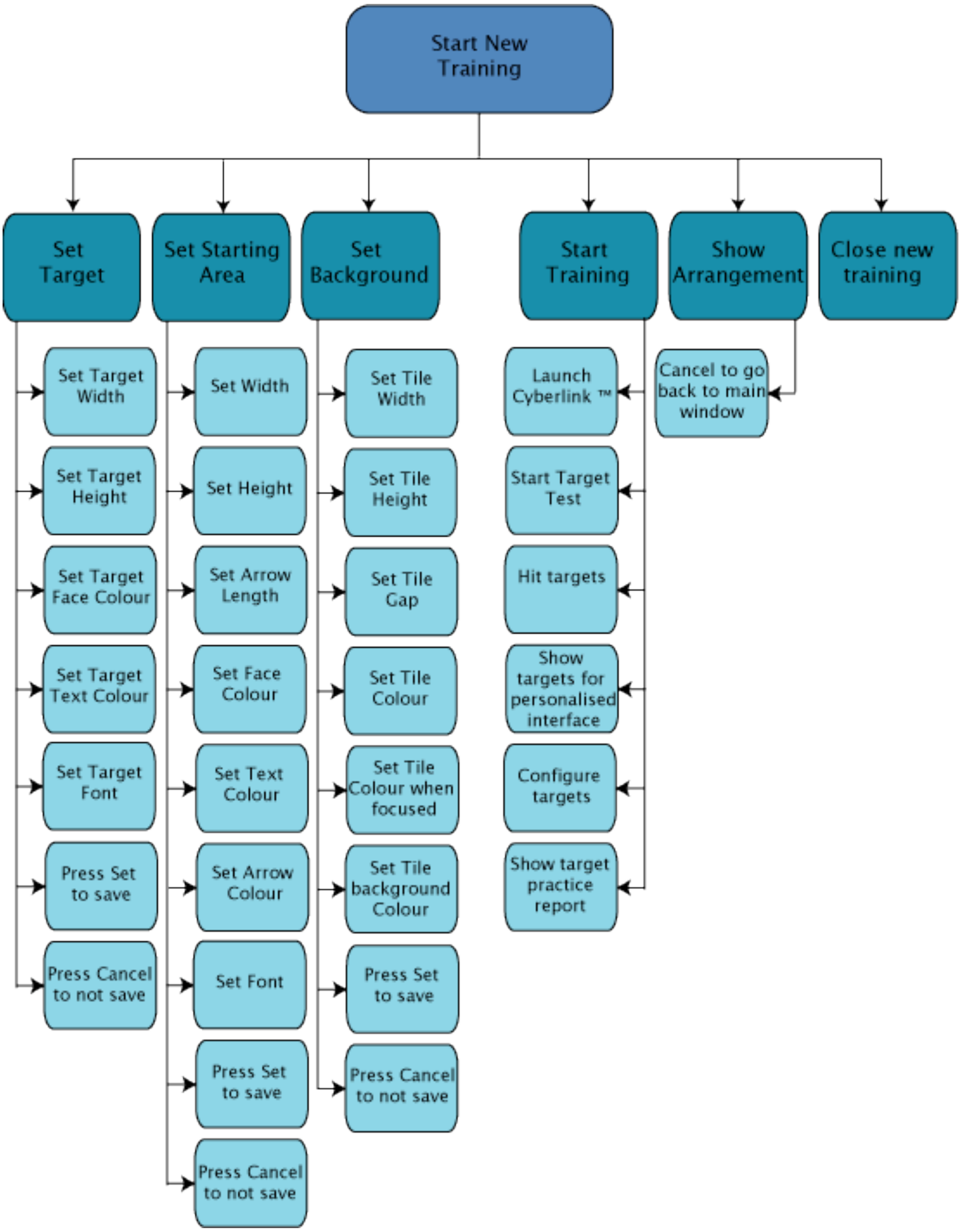
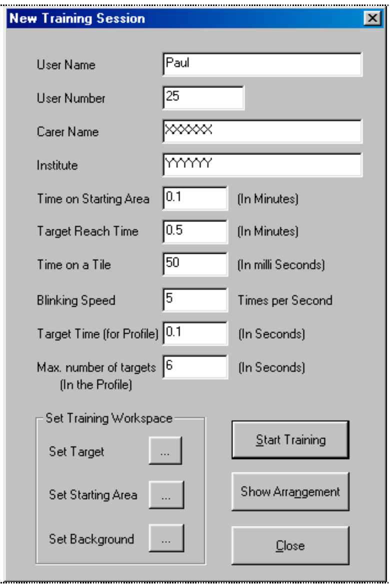
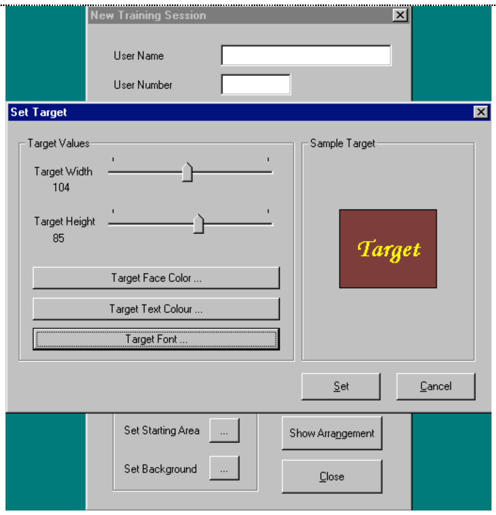


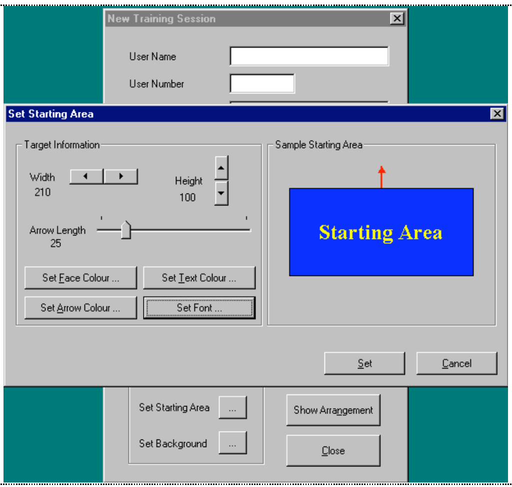
Figure 5.9 – Second level: Flow Chart for Start New Training



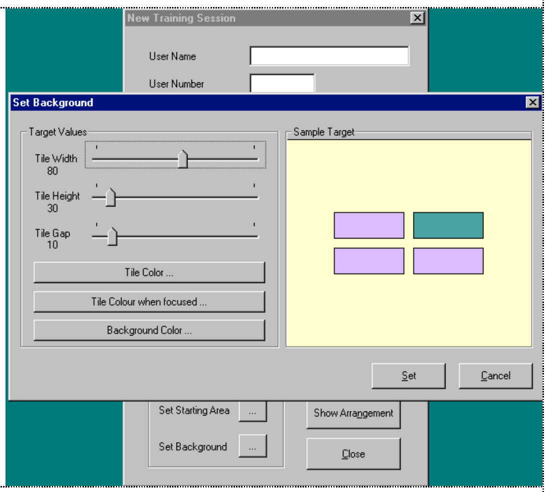
'Start New Training' window has input boxes for: 'User name; User Number; Carer Name; Institute, Time on Target Area; Target Reach Time; Time on Tile; Blinking Speed; Target Time and Maximum Number of Targets'. Enter details and click on 'Set Target'



Change the target width and height as necessary. Choose 'Target Face Colour'

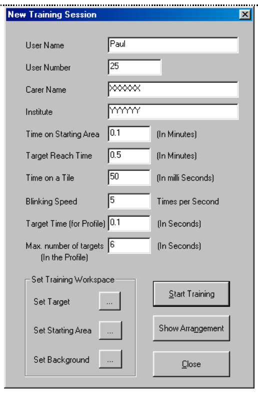


Set 'Width', 'Height' and 'Arrow Length' using sliders. Choose 'Set Face Colour'. Repeat steps shown in Figure 5.10. Repeat the same process for 'Set Text Colour', 'Set Arrow Colour' and 'Set Font'.

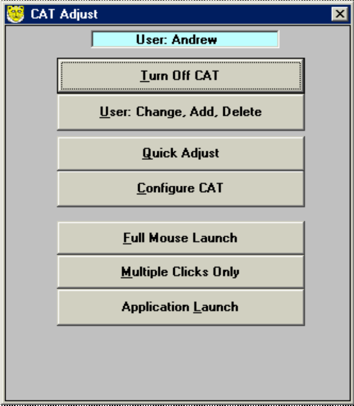


Set 'Tile Width', 'Tile Height' and 'Tile Gap' using sliders. Repeat steps shown in Figure 5.10 for 'Tile Colour', 'The Colour when focused' and 'Background Color'.

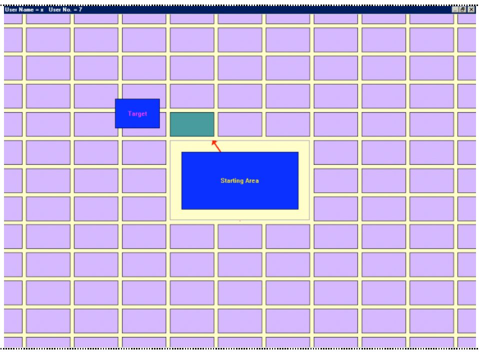
Figure 5.10 – Storyboard: Start New Training A



Choose ‘Start Training’. Both Cyberlink™ interface program and the BBI will start together.

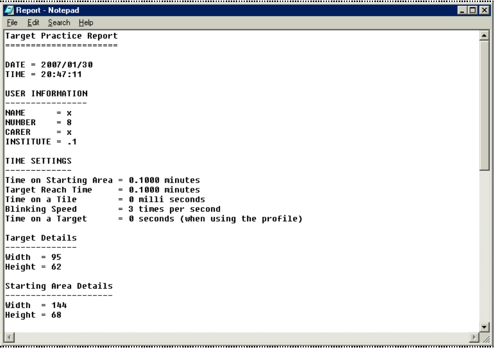


Choose ‘Full Mouse Launch’ for Cyberlink™ operation (Other options are not used in this program). This window will disappear and the target test screen will appear.

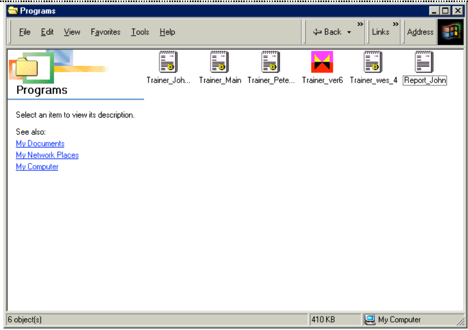


Twenty four random targets appear and the user tries to hit the targets within a pre-configured time. The tile under the cursor is highlighted to show the route taken. The red arrow indicates the direction of travel. The participants could move to any one of the 24 targets and choose their preferred individual areas of the screen. On presentation of all targets, the target test screen closes and a smaller window opens indicating ‘End of Target Practice Session’.

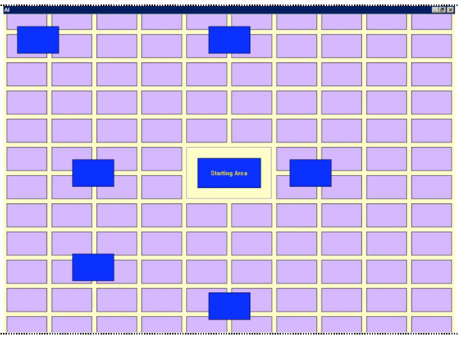
Figure 5.11 – Storyboard: Start New Training B



Target practice report is displayed. Close window using exit button in top right corner.

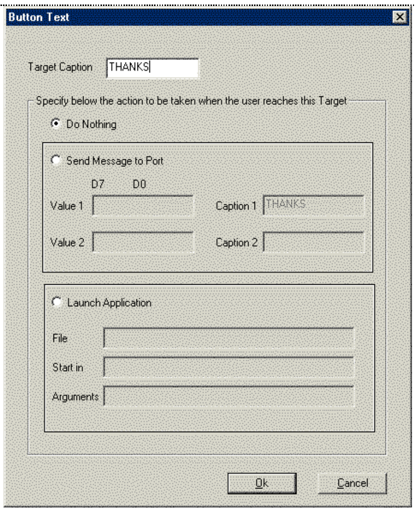


Note: Text files with configuration parameters and the target practice report are saved in the same folder as the Trainer application for retrieval later on if needed, as shown above.

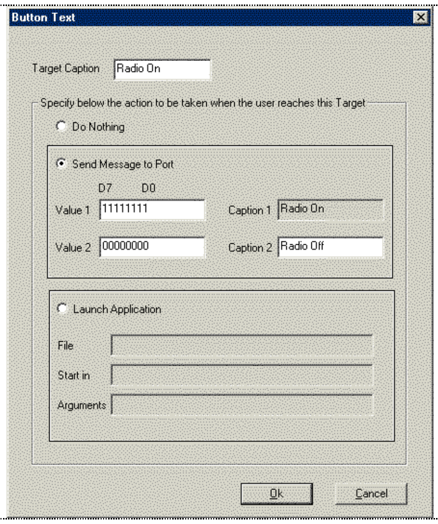


After saving the configuration parameters file, each target can be customised by double clicking on the targets.

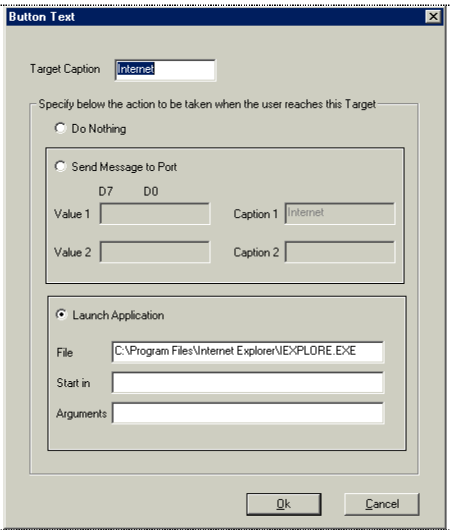
Figure 5.12 – Storyboard: Start New Training C



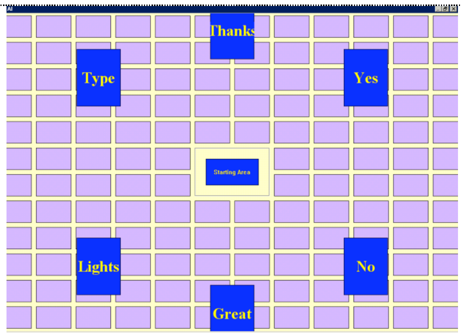
Select relevant option using radio buttons, Type in Target Caption to have text with sound.



Optionally, type binary digits to send to parallel port to control devices.

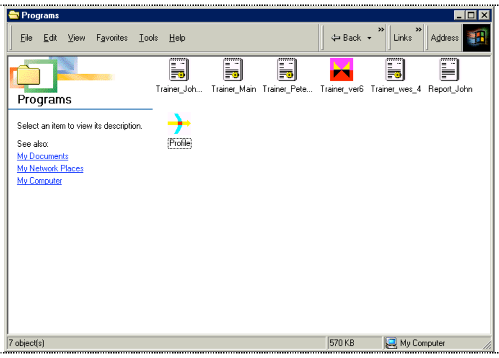


Alternatively, launch applications by filling in file name and location.



All carer set up is now complete. Section 5.1 and Figure 5.3 give full details of the algorithm that run the interface shown above.

Figure 5.13 – Storyboard: Start New Training D



Personalised profiles will appear in the same folder as the Trainer application for retrieval by the Carer. To launch the personalised interface the carer has to double click the profile icon shown above. There is no need to run the target test again unless the condition of the user has changed and another profile is needed.

Figure 5.14 – Storyboard: Start New Training E

This completes the second level specifications for Start New Training. The second level specifications for Utilise User Records associated with the created profile are now presented.

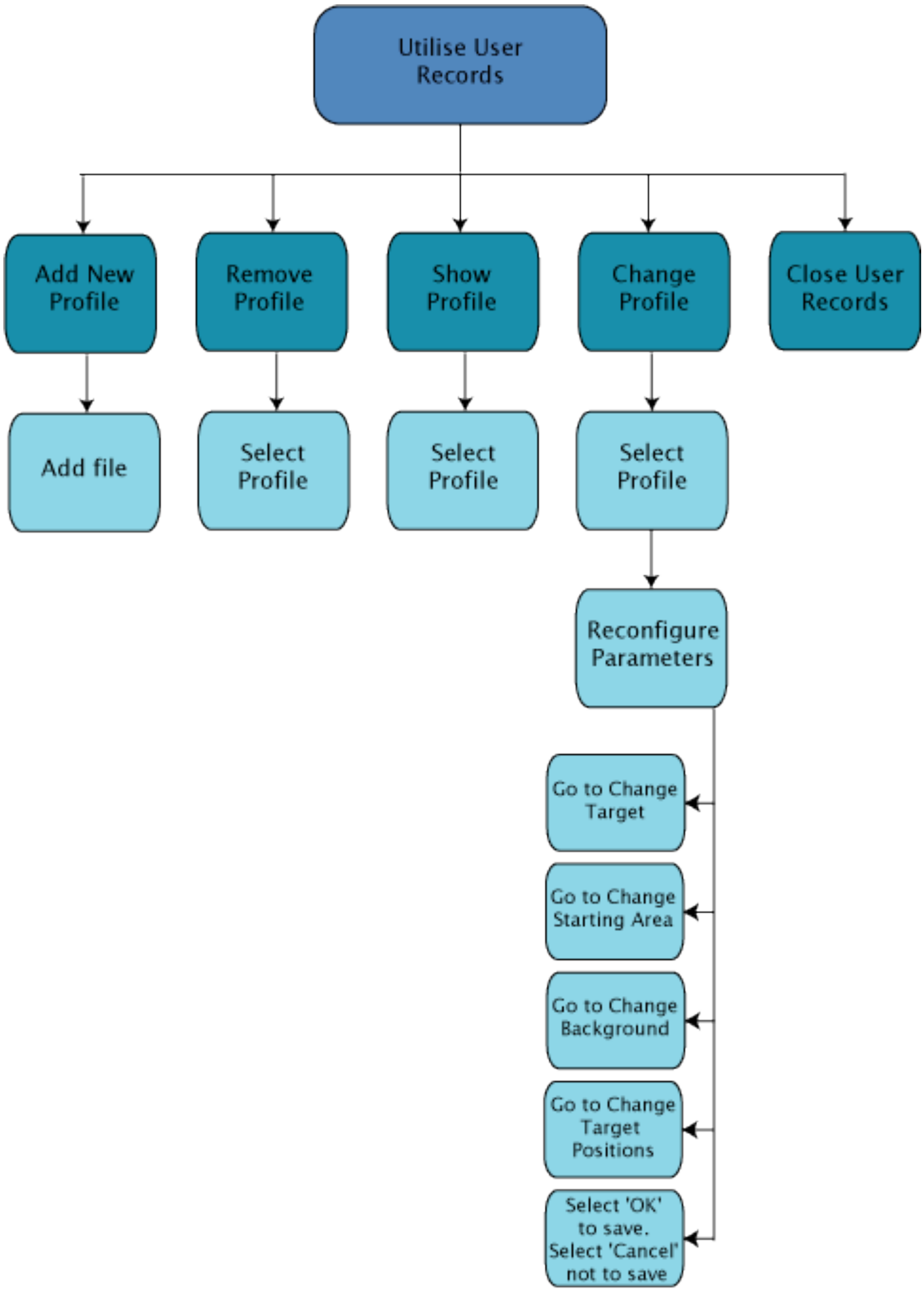
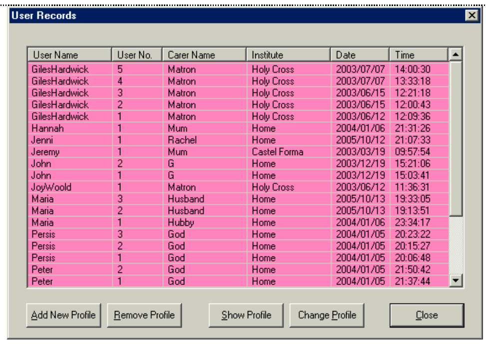
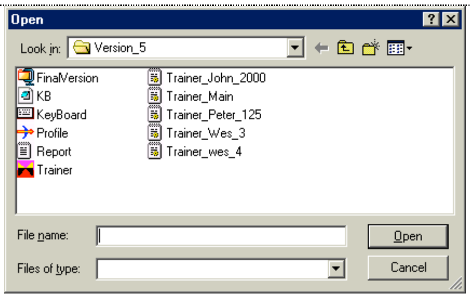


Figure 5.15 – Second level: Flow Chart for Utilise User Records

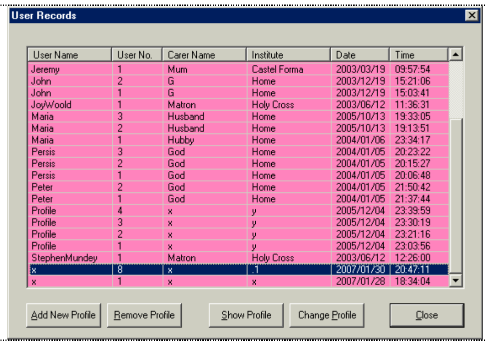
Select 'User Records'



To add a new or existing user, Select 'Add New Profile'



Choose name of New Profile from the folder where the trainer files are saved (refer to end of target practice test). If open is selected, profile will be added to 'User Records'. If not, select 'Cancel'.



To remove existing user or profile, select file and choose 'Remove Profile'.

Figure 5.16 – Storyboard: Utilise User Records A

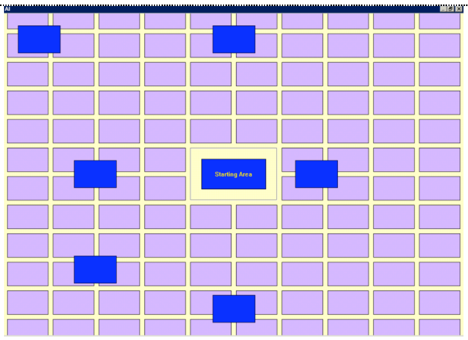
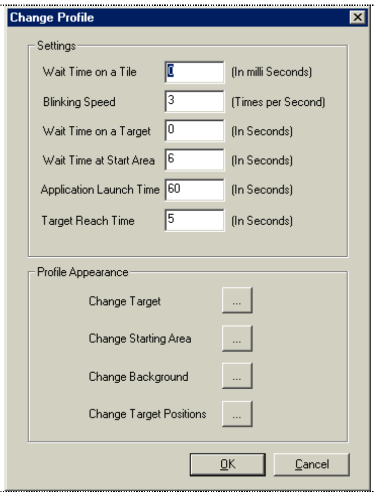
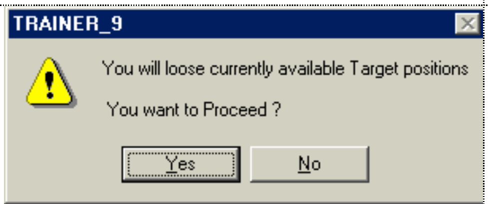
<table>
<tr>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>Interface with configured targets will appear. Close window using exit button in top right corner. Target can be reconfigured by double clicking and following procedure shown in Figure 5.13. To make any changes to existing profile Select ‘Change Profile’ from ‘User Records’ window.</td>
<td>Make necessary changes to setting and profile appearance manually. Select ‘Change Target Positions’ to customise and repeat target customisation as per ‘New Training Session’.</td>
</tr>
<tr>
<td>
</td>
<td></td>
</tr>
<tr>
<td>Choose ‘Yes’ or ‘No’ to confirm. If ‘Yes’ all 24 possible targets will appear. Carer can manually choose locations and configure each target as required for user. This step is used if the user cannot do the target test or if the carer wants to over-write the results of the automated individual profile creation. Select OK or Cancel in the ‘Change Profile’ window. Select ‘Close’ in the ‘User Records’ window, to quit user records.</td>
<td></td>
</tr>
</table>

Figure 5.17 – Storyboard: Utilise User Records B

The next, second level specification is for a simple utility to manage the Cyberlink™ driver.

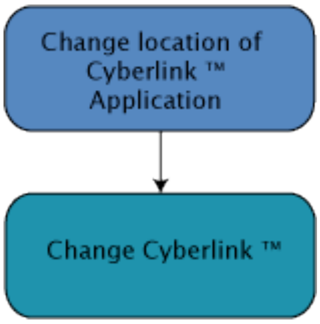
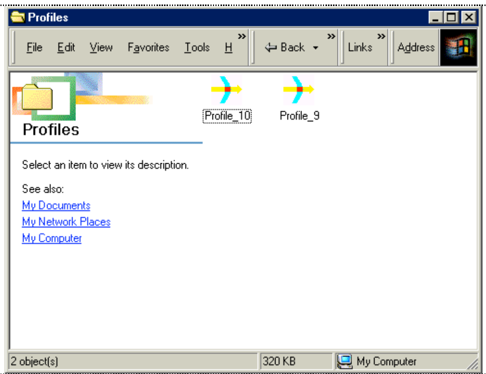


Figure 5.18 – Level two: Flow Chart Change location of Cyberlink™ application

<table>
<tr>
<td>


</td>
<td>


</td>
</tr>
<tr>
<td>To confirm or change the location of Cyberlink, select ‘Change Cyberlink’. This facility is in case the Cyberlink™ driver gets corrupted and needs to be reinstalled or the location of the Cyberlink™ applications is changed. The BBI program automatically launches the Cyberlink™ when it launches the interface, so it needs to know the exact location of the drive software. Make changes and ‘Set’ or ‘Cancel’ as necessary.</td>
<td>Open the main folder where the Trainer application is located. Select the folder where the personalised profile is saved and double click to launch and use from that point onwards.</td>
</tr>
</table>

Figure 5.19 – Storyboard Change location of Cyberlink™ application

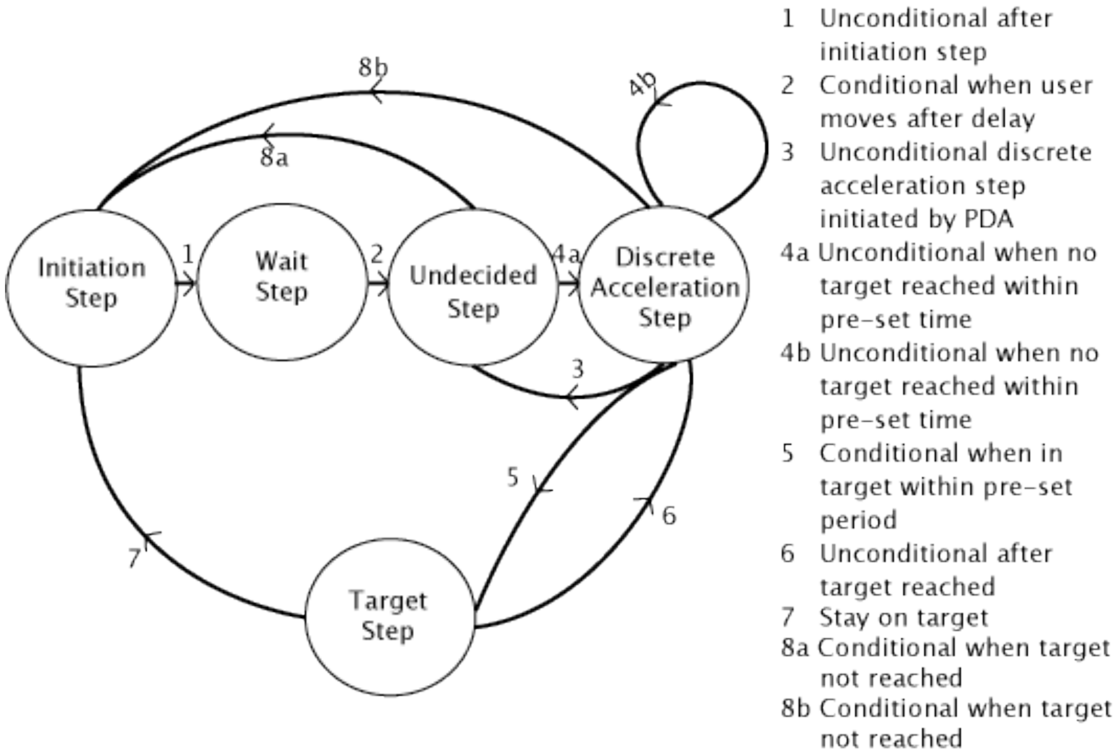


Figure 5.20 – Interface with personalised discrete acceleration

The abstract task defining this interaction paradigm is expressed via figure 5.20 as the success path:

Initiation Step.1. Wait Step. 2. (Undecided Step. 4a. Discrete Acceleration Step. [4b¦3])$^{+}$. 5. Target Step. 7

Figure 5.20 shows the algorithm described in Section 5.2 in a State Transition Diagram. The PDA algorithm commences with the 'Initiation Step' and a pre-configured delay using the 'Wait Step' and 'Arc 1'. Then the cursor is released for the user to navigate the screen towards the intended target using 'Arc 2'. The user moves the cursor through the gap between the tiles using discrete acceleration. An 'Undecided Step' with a pre-configured delay is introduced at each tile to control any noise and give the user time to contemplate the next cursor movement. The 'Discrete Acceleration' and 'Undecided' Steps are repeated using 'Arcs 3, 4a, 4b, 5 and 6' until the intended target is reached. The cursor goes back to 'Initiation Step' after a target is chosen using 'Arc 7' or if the time to reach the target has elapsed using 'Arcs 8a and 8b'.

The following Pseudo Code assumes a program:

- That opens the BBI with a window named 'Trainer' (Figures 5.8) which has four buttons named:
  i. 'New Training – open 'New Training Session' window when pressed (Figure 5.10);
  ii. 'User Records' – open 'User Records' window when pressed (Figure 5.17);
  iii. 'Change Cyberlink' – opens 'Set Cyberlink' window when pressed, where the location of the Cyberlink™ application is entered (Figure 5.20);
  iv. 'Close' – quit the program.

- Has a 'Start New Training' window which has input boxes for: User name; User Number; Carer Name; Institute, Time on 'Starting Area' (delay set by the carer, before the user can, leave the starting area to the intended target); Target Reach Time (time interval given to reach a target, if this time is exceeded the cursor will come back to the starting area); Time on Tile (a delay set up carer to control the erratic movement of the BBI); Blinking Speed (the speed the target blinks when the user travels in the direction of a target, it gives feedback to the user); Target Time (the time the user needs to stay on target to indicate that it was the chosen target) and Maximum Number of Targets (depends on the abilities of the user). The carer/researcher enters the values for these inputs (Figure 5.10);

- Has a 'Start New Training' window which has six buttons named (Figure 5.10):
  i. 'Set Target' – open 'Set Target' window when pressed. The carer/researcher uses the buttons to configure the BBI;
  ii. 'Set Starting Area' – open 'Set Starting Area' window when pressed;
  iii. 'Set Background' – open 'Set Background' window when pressed;
  iv. 'Start Training' – launches the target test sub-routine when pressed;
  v. 'Show Arrangement' – display locations of all twenty four targets used in the target practice;
  vi. 'Close' – close 'Start New Training' window when pressed.

- Has a ‘User Record’ window displaying all the personalised user profiles of the BBI. The carer/researcher uses the buttons to configure the BBI;

- Has a ‘User Record’ window which has five buttons named (Figure 5.17):
    i. ‘Add New Profile’ – open a window to browse hard disk and add user profiles;
    ii. ‘Remove Profile’ – give the option to choose and delete user profiles;
    iii. ‘Show Profile’ – give the option to display an individual profile;
    iv. ‘Change Profile’ – give the option to alter the parameters of a profile;
    v. ‘Close’ – close the ‘User Records’ window.

- That each target can be programmed to convert text to audio, switch on/off devices or launch applications (Figure 5.14);

- Has a window ‘Change Profile’ which has input boxes and buttons to reconfigure over-writing all previous settings for any user profiles manually (Figure 5.18);

- Has an arrow in the ‘Starting Area’ to show the direction of travel (Figure 5.11);

- Has a facility to create a personalised profile at the end of a target test (Figure 5.13);

- That quits when the esc key is pressed any time.

The Pseudo code for the trainer for personalised discrete acceleration follows:

1) Setup

```
OBTAIN personal details (user name, user number, carer’s
name, name of institute)
```

```
OBTAIN target parameters (Time_on_Starting_Area,
Target_Reach_Time, Time_on_a_Tile, Blinking_Speed,
Target_Time, Maximum_Number_of_Targets)

SET interface parameters (Target_Width, Target_Height,
Target_Face_Colour, Target_Text_Colour, Target_Font,
Starting_Area_Width, Starting_Area_Height, Arrow_Length,
Set_Face_Colour, Set_Text_Colour, Set_Arrow_Colour,
Set_Font, Tile_Width, Tile_Height, Tile_Gap,
Tile_Colour, Tile_Colour_when_focused,
Background_Colour)
```

2) Target test

```
FOR twenty four targets
  Move cursor to starting area
  Wait a pre-configured time delay
  Target appears on screen
  Start clock for Target_Reach_Time
  target_test_running = true
  WHILE target_test_running
       IF less than Target_Reach_Time THEN
            On mouse move
            Highlight location of cursor
            Move arrow to indicate direction of travel
            Display cursor to nearest edge of tile in
            the direction of target
                 IF target is reached
                 Make audio confirmation
                 Change text on target to 'well done'
                 Move cursor to starting area for next
                 target
                 target_test_running = false
                 ENDIF
```

```
        ELSE
              On mouse move
              Highlight location of cursor
              Move arrow to indicate direction of travel
              Move cursor to nearest edge of tile in the
              direction of target
        ENDIF
        ELSE
              Make audio confirmation
              Change text on target to 'sorry'
              target_test_running = false
        ENDIF
  ENDWHILE
ENDFOR
```

3) Feedback and data storage

```
Display target practice report on screen
Save report in the folder where 'trainer' program is
located
Display the personalised target on screen
```

4) Set-Up targets

```
For each target
Double click on each target
SET target to convert text to sound or switch devices
on/off or launch an application
```

5) Using the PDA interface

```
Double click on a personalised profile
Display personalised interface of user
FOR any target
  Move cursor to starting area
  Start clock for target reach time
```

```
Wait a pre-configured time delay
IF less than target reach time THEN
     On mouse move
     Calculate angles between each target and the
     last direction of travel
     IF the calculation gives two targets below 30
     degrees in the direction of travel wait for one
     more mouse move THEN
          On mouse move
          Re-calculate angles between each target and
          the last direction of travel and make the
          intended target to blink at the blinking
          speed
          Highlight the tile where the cursor is
          located
          Move the arrow to indicate the last
          direction of travel
          Move cursor to nearest edge of tile in the
          direction of the intended target
     ENDIF
     IF the calculation gives two targets as the
     intended targets wait for one more mouse move
     THEN
          On mouse move
          Re-calculate angles between each target and
          the last direction of travel and make the
          intended target to blink at the blinking
          speed
          Highlight the tile where the cursor is
          located
          Move the arrow to indicate the last
          direction of travel
```

```
            Move cursor to nearest edge of tile in the
            direction of the intended target
        ENDIF
        IF the calculation does not gives two targets
        below 30 AND two targets as the intended targets
        THEN
            On mouse move
            Make the intended target to blink at the
            blinking speed
            Highlight the tile where the cursor is
            located
            Move the arrow to indicate the last
            direction of travel
            Move cursor to nearest edge of tile in the
            direction of the intended target
        ENDIF
        IF target is reached THEN
        Carryout the pre-programmed function of the
        target
        ENDIF
    ELSE
        Move cursor to starting area
    ENDIF
END FOR
```

5.7. Summative Study

The interface with the above specifications was evaluated in a study to investigate whether:

1. Using Personalised Discrete Acceleration will reduce the impact of noise and consequent erratic involuntary movement of the cursor by presenting users with targets that best matched their capabilities;

2. PDA will achieve an improved performance with able users in comparison to the previous results obtained in this area of research using Cyberlink™ as a BBI.

Personalised Discrete Acceleration will be abbreviated to PDA for the rest of this thesis, PDA is a term coined by the researcher, not from any other literature and that it has nothing to do with Personal Digital Assistants. Table 5.2 below shows the details of participants used for evaluating the final PDA Interface. The participants were volunteers from the local area of Surrey and they received no prior training. The participants for this phase of the research were given the training described in Section 4.3. In addition to this, the researcher demonstrated how to navigate the cursor to a target on a computer screen using the PDA interface (Sections 5.1, 5.3 and 5.5, Figures 5.4, 5.5 and 5.11). The participants had to complete the target test, obtain their individual PDA interface and then evaluate the PDA interface.

Table 5.2 – Details of the participants used in evaluating the final interface

Part. No	Gender/Age	Clinical Diagnosis	Medicines	Additional Information
35	F 11	Able-bodied	None	Occasional computer user
36	F35	Able-bodied	None	Rare computer user
37	F40	Able-bodied	None	Occasional computer user
38	M52	Able-bodied	None	Rare computer user
39	M14	Able-bodied	None	Occasional computer user
40	F25	Able-bodied	None	Regular computer user
41	M33	Able-bodied	None	Rare computer user
42	F16	Able-bodied	None	Regular computer user
43	M48	Able-bodied	None	Regular computer user
44	M16	Able-bodied	None	Regular computer user

The target test program automatically created individual profiles at the completion of each target test. The interface for each individual participant consisted of a computer screen with his/her six fastest targets. Each participant was asked to use the interface to give answers to questions. The following data was recorded:

- Percentage of correct answers;
- Any reconfiguration of interface.

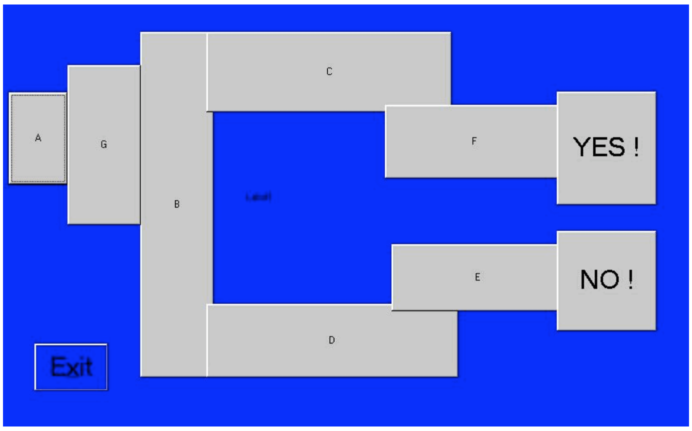


Figure 5.21 – Doherty's Interface

These ten able-bodied participants also tried the interface designed by Doherty (Figure 5.21). The time taken to reach the targets using Doherty's interface was compared with the PDA interface. This test was carried out to measure the progress made using the PDA interface.

Table 5.3 – Summative Evaluation for PDA Interfaces

Participant	Used text to audio	Launched applications	Switched devices
35, 36, 37, 38, 39, 40, 41, 42, 43, 44 (i.e. all)	Yes	Yes	Yes

Every participant was able to communicate using text, launch applications and switch devices at the success rate of 80 - 90%, using a default personalised interface (Profile 2, Table 5.3), when a time restriction of 30 seconds to reach a target was imposed. When this was increased to 60 seconds the success rate reached 100% (Table 5.3). This indicated that PDA interface was an inclusive interface in comparison to Doherty's tunnel interface.

Table 5.4 – Summative Evaluation for Doherty's Interface

Part. No	PDA interface (profile 2)	Doherty's interface
35	4 seconds	Unable
36	3 seconds	5 Minutes
37	4 seconds	Unable
38	3 seconds	6 Minutes
39	6 seconds	Unable
40	7 seconds	Unable
41	8 seconds	4 minutes
42	9 seconds	Unable
43	5 seconds	3 minutes
44	3 seconds	1 minute

The maximum time allocated to reach either Yes or No in Doherty's interface was ten minutes (Table 5.4). Five out of ten able-bodied participants were unable to reach the targets in the allocated time. The minimum time taken to reach the targets using the PDA interface was at least twenty times faster than Doherty's interface (Gnanayutham *et al.*, 2005).

5.8. Optimisation Study

Having compared PDA with Doherty's interface we could conclude that the first three concerns raised in Section 5.1 were positively addressed. Positive outcomes from the comparison study lead to next investigation whether optimised settings for PDA can be obtained with able bodied participants. This could be used as a starting point when evaluating the interface with disabled users.

The algorithm described in Section 5.2 was utilised here to navigate the cursor. Kelton (1997, 1999) states that if a search is made for a configuration of inputs that maximises some key output performance, you need to decide very carefully which configurations you will run (and which ones you will not) and also choose your scenario carefully. As a preliminary response to this recommendation, four target practices with different dimensions for tiles and gap between tiles were presented to the participants (Table 5.5). These were based on the researcher's experience of observing usage and his best judgement. The dimensions for targets and 'Starting Area' were fixed for the experiment since they played no part in navigation of a cursor from 'Starting Area' to the target. This was an experiment with no prior training for the users. The result from this phase was to be used as a starting point for the interface settings to be used in phase three with disabled participants.

Table 5.5 – Profiles used for optimising PDA interfaces

	Tile (pixels)		
Profile	**Width**	**Height**	**Gap**
1. All low	80	30	10
2. Medium, small gap	90	50	10
3. Medium, large gap	90	50	20
4. All high	130	70	20

Ten able bodied participants were used to conduct summative experiments with the four profiles shown in Table 5.5. The four profiles were chosen to give different tile dimensions and different gaps. There was a time limit of one month to conduct optimisation with the ten able-bodied participants, which limited the number of profiles to four and the number of participants to ten. Feedback from the development group had indicated that small and large tiles were difficult to navigate in comparison to medium tiles, hence the choice of four profiles shown in Table 5.5. The development group also indicated that large gap between tiles did not allow the user to control navigation between tiles, hence two small and two medium size gaps between tiles were used for the experiment. The study started with summative evaluations to obtain individual preferences for the four profiles. Then the users completed further summative evaluation using the four profiles to hit targets within a given time interval (24 x 4 trails per participant) and the success rate was recorded (Appendix 3). The data were used to obtain the best profile as the default for the experiments to be carried out with the severely brain-injured participants in the next phase of this research. Results obtained were analysed, and conclusions drawn for the next phase of the research.

The target test (trainer program) automatically collected the data shown below:

- Number of targets reached;
- Time taken to reach the targets;
- Dimensions of targets, tiles and gap between targets;
- Fonts and chosen colours.

The target test consisted of twenty four targets appearing on the screen at random. The interface was configured with the following settings for collecting data for this summative evaluation.

- Time on 'Starting Area' = 0.1 minutes;
- Maximum time to reach target = 1.0 minute;
- Maximum time on each tile = 150 ms;
- Blanking speed = 5 per second;
- Maximum number of targets = 6;
- Screen resolution 800 x 600.

Usage data was recorded for four profiles. The variables being considered in each profile were the dimensions of tiles and gap between tiles. The dimensions of the 'Starting Area' were fixed at 120 pixels in width and 60 pixels in height and the dimensions of the targets were fixed at 100 pixels width and 60 pixels height.

Table 5.5 shows the initial profiles chosen for the study. These were based on observations in previous studies. They were investigated first, before any systematic exploration of the PDA design space. If one the profiles resulted in improved able-bodied performance, it would be chosen as the default for the trainer program. If not, then a more systematic exploration of the design space would be required.

Table 5.6 – Summative Evaluation for PDA Interface: Ranked preferences for profiles

Part. No	Profile 1	Profile 2	Profile 3	Profile 4
35	2	1	3	4
36	2	1	3	4
37	1	2	3	4
38	2	1	3	4
39	1	2	3	4
40	2	1	3	4
41	3	1	2	4
42	1	2	3	4
43	2	1	3	4
44	2	1	3	4

The results of the summative evaluation (of ranked profile preferences by individuals) are given in Table 5.6, with Profile 2 being the most common first choice and Profile 4 being the universally disliked. Eighty percent of the participants preferred Profile 2 with medium tiles and small gap between tiles.

Table 5.7 – Summative Evaluation for PDA: Success Rates

	Successes	Trials	% Success
1. All low	70	240	29.2%
2. Medium, small gap	110	240	45.8%
3. Medium, large gap	45	240	18.8%
4. All high	44	240	18.3%

The dimensions and times recorded during summative evaluation showed (Table 5.7, Appendix 3) that the interface with medium tiles and small gap between tiles (Profile 2) gave a better performance than interfaces with small/large tiles and medium/large gap between tiles, as shown in Table 5.7, when the success rates are compared. Hence Profile 2 was chosen as a good default setting for evaluation with disabled participants. Although Profile 2 is to be the starting point for the next phase of this study, the provision to overwrite any automated process and configure PDA interfaces manually gives the opportunity for carers to personalise using Evidence-Based Personalisation

(Nutley *et al.*, 2003) and to create interfaces to include all brain-injured individuals (except the users with visual impairment, comatose or affected by adverse medication). No further exploration of the PDA design space was required, nor was there time for exhaustive systematic optimisation. The approach was an engineering, rather that scientific method.

5.9. Conclusion

Development with able-bodied participants answered all the questions posed at the beginning of this phase of research. PDA interfaces reduced the impact of noise and consequent erratic involuntary movement of the cursor by presenting users with targets that best matched their individual capabilities with tiles that controlled the movement of the cursor when using bio-potentials to navigate. The interface developed also had the provision for reconfiguration anytime, provided a carer ran the target tests again or used the manual method to alter the interface. This supports the position that individuals are each very different in the way they respond. It also shows how individuals who respond in different ways to the interface can be accommodated in a PDA interface that strives to be inclusive regardless of the capabilities of the user. This phase of the study started with a design for a PDA interface addressing known difficulties brought from phase 1 of this research. The design improved by selecting Profile 2 (medium tiles, small gap). The design can be further improved by carer support for evidence based personalisation, and perhaps by a more exhaustive search of the tile size and gap parameter space.

The participants who evaluated the PDA interface received no prior training, but were asked to hit random target using the four pre-configured profiles being evaluated. The success rate shows that there is no need for prior training to be able to use a PDA interface.

Results from random target tests showed that Profile 2 obtained a success rate of 45.8% in comparison to, 29.2% (Profile 1), 18.8% (Profile 3) and 18.3 % (Profile 4) success rates (Table 5.7). This finding illustrated that the interface with medium tiles and small gap between tiles gave a better performance than interfaces with small/large tiles, small/large targets and medium/large gap between tiles. The targets that were least hit were in the diagonal direction of screen or very near the ‘Starting Area’. Moving a cursor diagonally using Cyberlink™ is much harder than horizontal or vertical movements, hence the difficulty in hitting the diagonal targets. Users seem to leave the ‘Starting Area’ rapidly, instead of a steady start, which makes them over-shoot the targets next to the ‘Starting Area’ and miss them altogether. However this problem does not occur when the PDA interface is utilised to communicate in real time, since targets are fixed, do not appear at random, and the user knows what to expect.

As for the research hypothesis, the performance of the BBI can be improved by the use of novel interaction paradigms. The results show how the PDA interfaces achieved better performance than previous work in this area and also created an optimised inclusive interface that aims to accommodate all users, except the users with visual impairment who cannot read a screen, comatose users, or users affected by adverse intake of medication. This interface also facilitated independent usage at user care homes, as reported in the next Chapter.

Chapter 6 – Impaired Independent Usage

The third phase was a detailed investigation carried out at Holy Cross Hospital Surrey and Castel Froma Leamington Spa nursing home. Both these institutes are rehabilitation centres for brain-injured individuals. This investigation lasted nine months. Consent was granted by the institutes to work with ten nonverbal brain-injured participants. A medical practitioner at each institute cleared each participant medically. After the first two visits, five out of the ten participants were chosen for further investigation. The other five had severe visual impairment, which prevented them from using the BBI, hence they were not used in the research.

The research question addressed in this phase was, can a disabled participant give consistent answers using the PDA interface developed and evaluated by able-bodied participants in phase two of this research? This phase of the study also investigated usage of the PDA interface without the researcher being present for daily meaningful routine communications by severely brain-injured individuals. There was some evidence of independent researcher supported usage of Cyberlink™ as a BBI (Doherty *et al.*, 1999, Junker, 2005), but no independent carer supported usage has been reported with individuals with severe traumatic brain injury such as the participants in this phase of the study (Doherty, 2007, Junker, 2005).

Data from each disabled participant was collected once or twice a week (Wednesday and/or Fridays), depending on the availability and health of the participants. Data collection sessions lasted twenty minutes to one hour, with one or more breaks as needed for each participant. Every visit was recorded and progress noted. The percentage of correct answers given was recorded for analysis. The BBI was also left by the researcher at the Holy Cross Hospital for three weeks in a month, and for one week every month at Castel Froma for independent usage by the carers and medical staff (Vallender, 2007).

The search for participants for phase three of this research began through articles being written requesting participants in disability magazines and web sites connected with brain injury to recruit disabled participants. Partners and parents of brain-injured persons made contact indicating their interest in trying the interface developed by this research. Demonstrations were carried out in all institutes and hospitals to both staff and members of the family of brain-injured persons. Holy Cross Hospital Surrey and Castel Froma Leamington Spa nursing home granted permission for research to be carried out in the premises after obtaining individual consent from parents/guardians of each brain-injured participant. Ten participants were granted consent by the institutes and parents/guardians. Five participants were not included in this study due to their visual impairment. A medical practitioner also accompanied the researcher in the first two visits and any other time when a medical opinion was needed. The medical practitioner checked the medical status of each participant and the regular dosage of medication to assess the suitability of a participant. The medical practitioner also became involved whenever the need arose due to possible changes to medication or well being. There were also carers present when experiments were carried out to help the investigation. At each visit, the condition of the participants were reassessed for continuation in the research, any new development including any change of medication was taken into consideration. The results from phase one (Chapter 4), combined with requesting volunteers at demonstrations (e.g. relatives/guardians of participants and staff from the institutes) to test the interface for safety and any side effects, enabled the ethics committee to grant permission for using their patients.

6.1. Experimental Setup

The experiment to be carried out here is to answer the question, can a disabled participant give consistent answers using personalised tiling and discrete acceleration? Table 6.1 shows details of participants of this phase of research.

Table 6.1 – Details of the participants used in phase three

Part. No	Institution	Gender/Age	Clinical Diagnosis	Medicines	Additional Information
45	Holy Cross	M38	Locked-in syndrome	Phenytoin, Clonazepam	Non-verbal
46	Holy Cross	F61	Severe cerebral haemorrhage, brain stem injury	Bisacodyl supplement, Corsodyl, Ranitidine, Hypromellose	Non-verbal
47	Holy Cross	M45	RTA, Diffuse axonal brain damage	Suppositories	Non-verbal. Can use a foot switch but it takes a lot of effort from the participant
48	Holy Cross	M60	Brain stem injury	Anti-anxiety, cardiac Anti-Depressant Psychotropic,	Non-verbal
49	Castel Froma	M32	Traumatic Brain Injury	Sodium Valproate, Hyoscine	Non-verbal, can respond by thumb occasionally

6.2. Experimental Method

The best settings investigated in phase two (Profile 2) were used as the starting point for this phase. Manual re-configurations had to be made for some individuals, over-writing the automated process due to the severity of the brain injury (participants 46 and 49) and usage of evidence based personalisation (Nutley *et al.*, 2003).

The research question raised in phase three was, can a disabled participant give consistent answers using the PDA interface. The number of targets was from two to six depending on the severity of the disability. The data recorded were: percentage of targets reached to indicate correct answers, behaviour of participant, any reconfiguration of interface, changes in medication, duration of visit, and other input devices used. There was also one participant who had been able to use a foot switch. This gave an opportunity to double check the answers given by the user interface.

6.3. Evaluation of Results

The first step for evaluation was giving each medically cleared participant two tasks to determine their suitability for this research. These tasks were as follows:

- Respond to requests;
- Use Cyberlink and their bio potential to move the cursor around in any direction on the screen.

The head of Participant 46 had to be held by a brace, which prevented any electromyographic signals being used for communications, Participant 49 had a twitch, which resulted in unreliable electromyographic signals being picked up the BBI. This meant these two participants had to rely exclusively on electroencephalalographic signals to move the cursor along the screen, effectively limiting them to two targets. The automated profiles for Participant 46 had to be manually re-configured to bring the targets close to the 'Starting Area' and the height of the target also had to be increased, since she produced only a small amount of electroencephalalographic signals. The targets had to be moved further back manually for Participant 49, since his twitch produced unwanted electromyographic signals which had to be ignored while using only his electroencephalalographic signals for communications. Participants 45, 47 and 48, were able to use some electrooculargraphic signals in addition to electroencephalalographic signals, hence they were able to use four to six targets in their individual profiles.

Encouraging feedback was received from the locked-in syndrome participant, who used his thumb to indicate approval. All five suitable Participants (45, 46, 47, 48 and 49) were able to communicate using the Cyberlink™ (Table 6.4). They could use the Cyberlink according to their own ability, using their personalised interface to communicate. Thus communication with a slightly larger group than Doherty was achieved. Doherty only had partial success with two out of three severely impaired participants. Although the participant numbers are still very small (five in comparison to three by Doherty), it can be confidently generalised, that this inclusive PDA interface enabled all five participants to communicate consistently, for a longer period (nine months in comparison to six weeks by Doherty) and a relatively large increase in successful usage was achieved (75% instead of 60% by Doherty) as shown in Tables 6.2 and 6.3. The communication took the form of asking participants various questions connected with their day to day tasks, e.g., Do you want the CD player on? Do you want the curtains closed? Would you like a bath? Are you tired? How many targets do you see in the screen? (then give choice of answers) etc. Individual profiles of participants (Figures 6.1, 6.3, 6.5, 6.7 and 6.9) and profile settings of participants (Figures 6.2, 6.4, 6.6, 6.8 and 6.10) are now presented. These profiles demonstrate how each participant had his or her individual interface with personalised times to suit their abilities, which made the PDA interface inclusive of the five remaining participants who were different abilities.

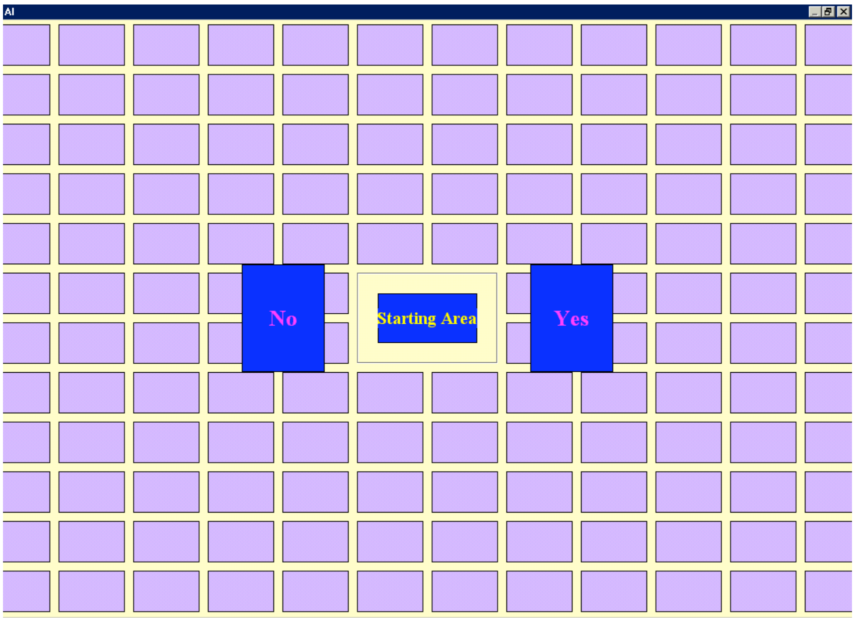


Figure 6.1 – Profile of Participant 46

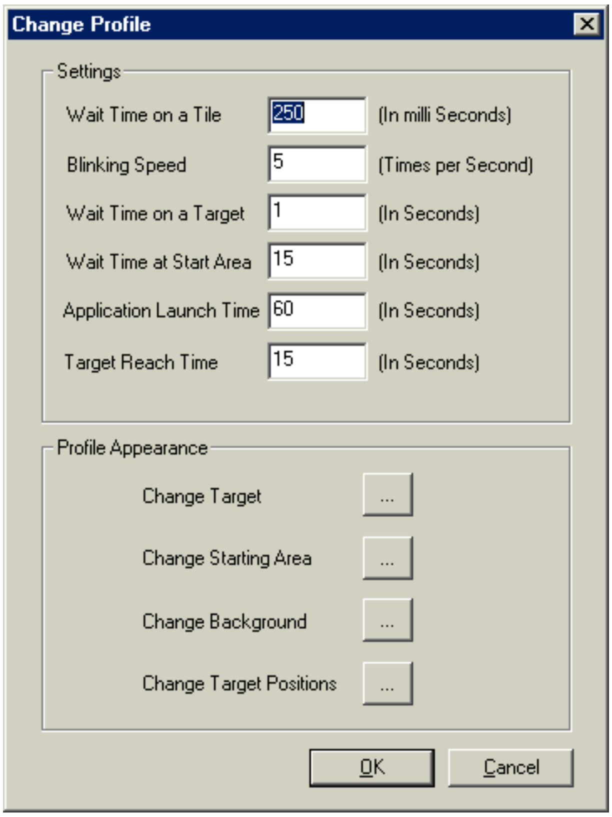


Figure 6.2 – Profile settings of Participant 46

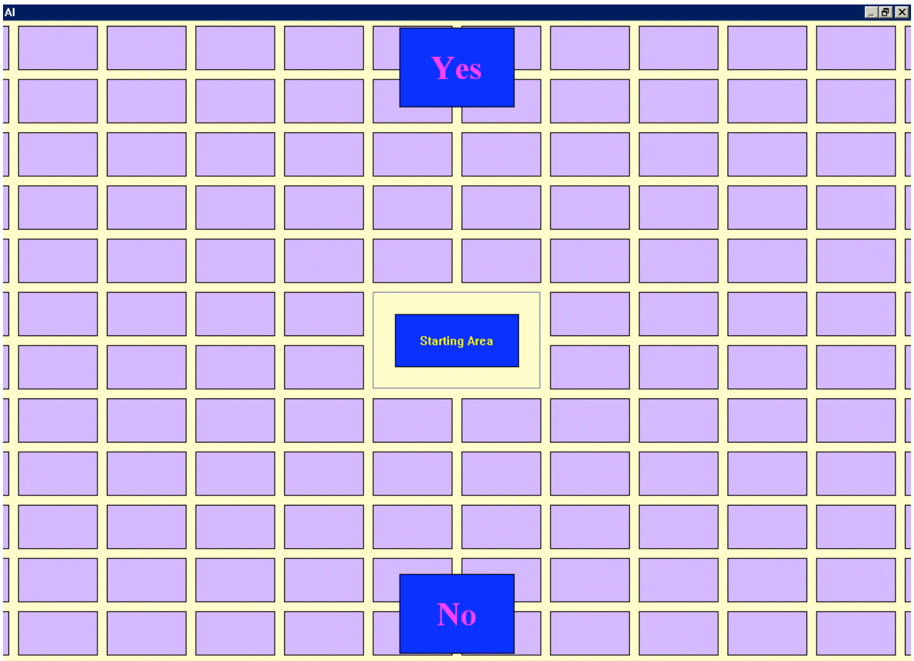


Figure 6.3 – Profile of Participant 49

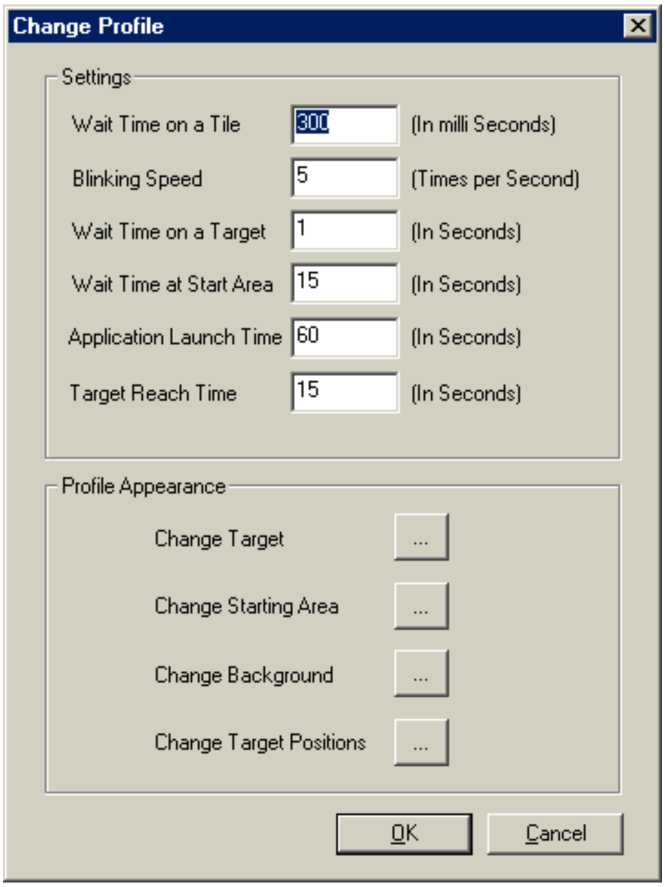


Figure 6.4 – Profile settings of Participant 49

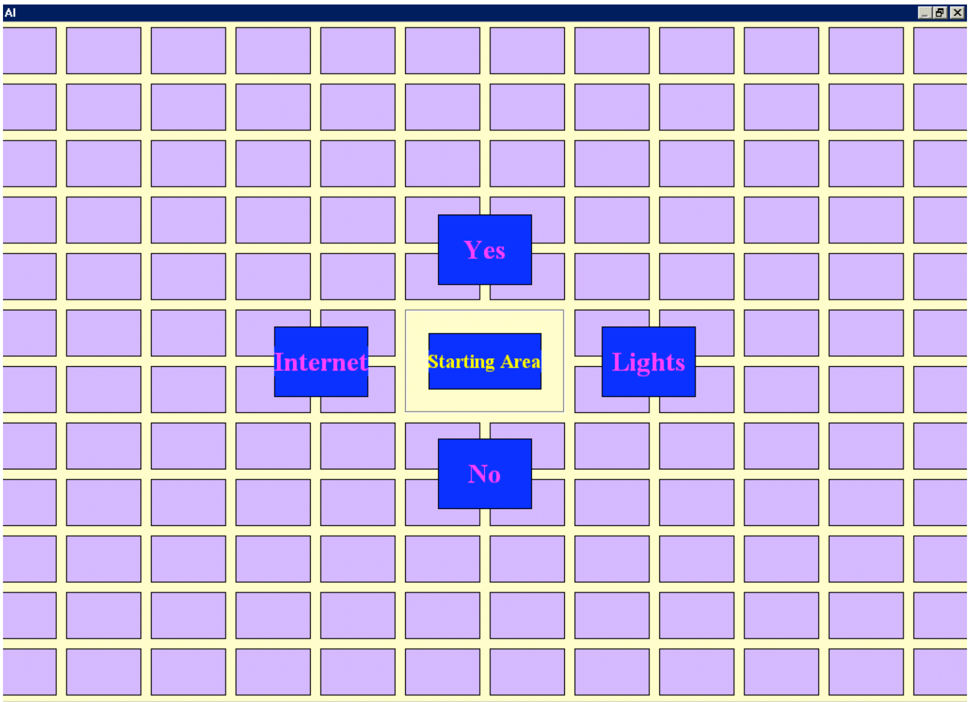


Figure 6.5 – Profile of Participant 47

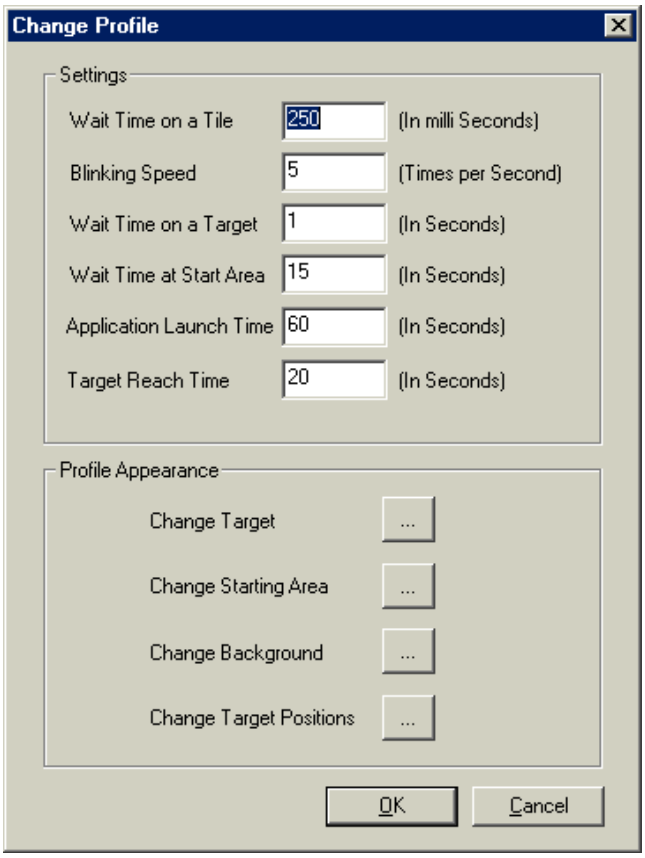


Figure 6.6 – Profile settings of Participant 47

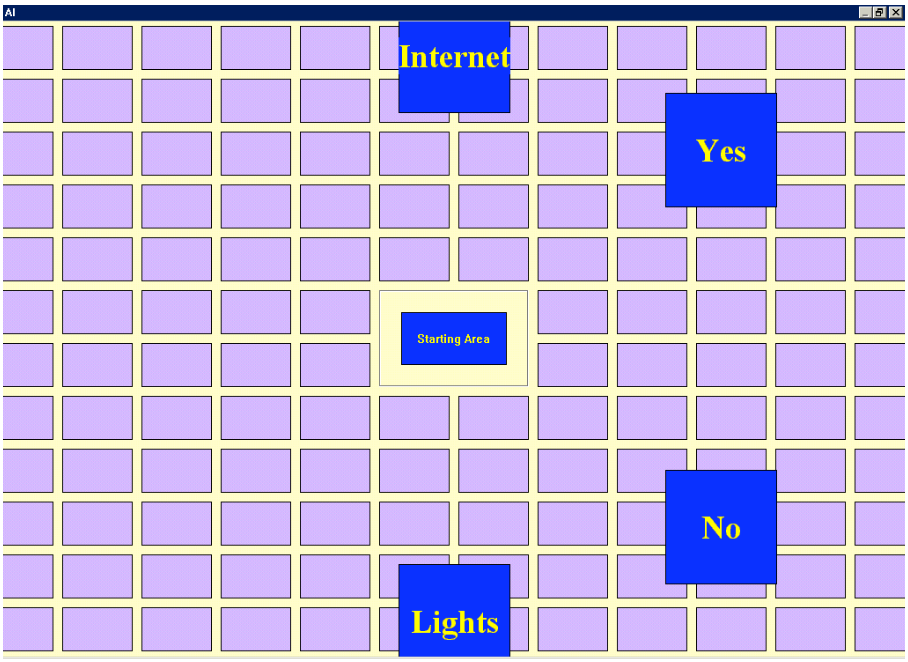


Figure 6.7 – Profile of Participant 48

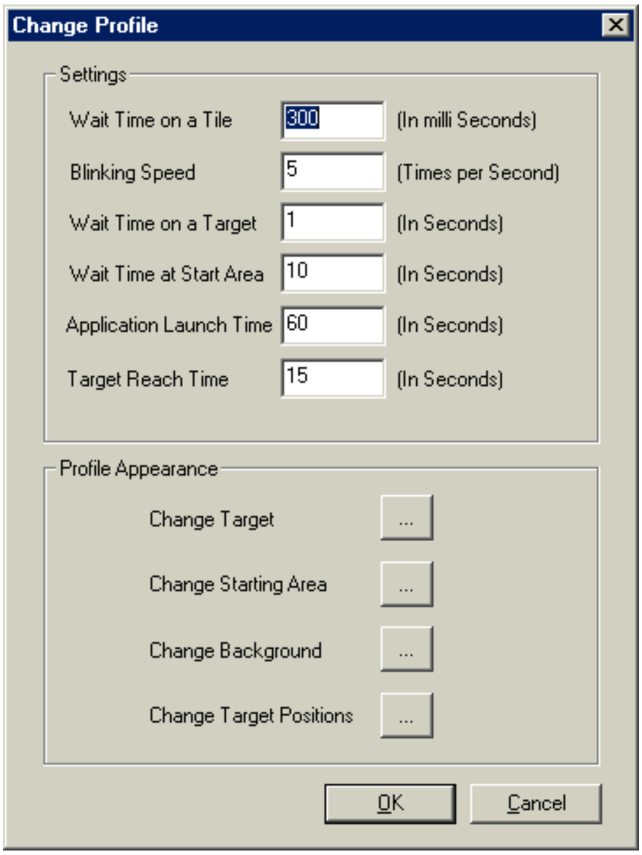


Figure 6.8 – Profile settings of Participant 48

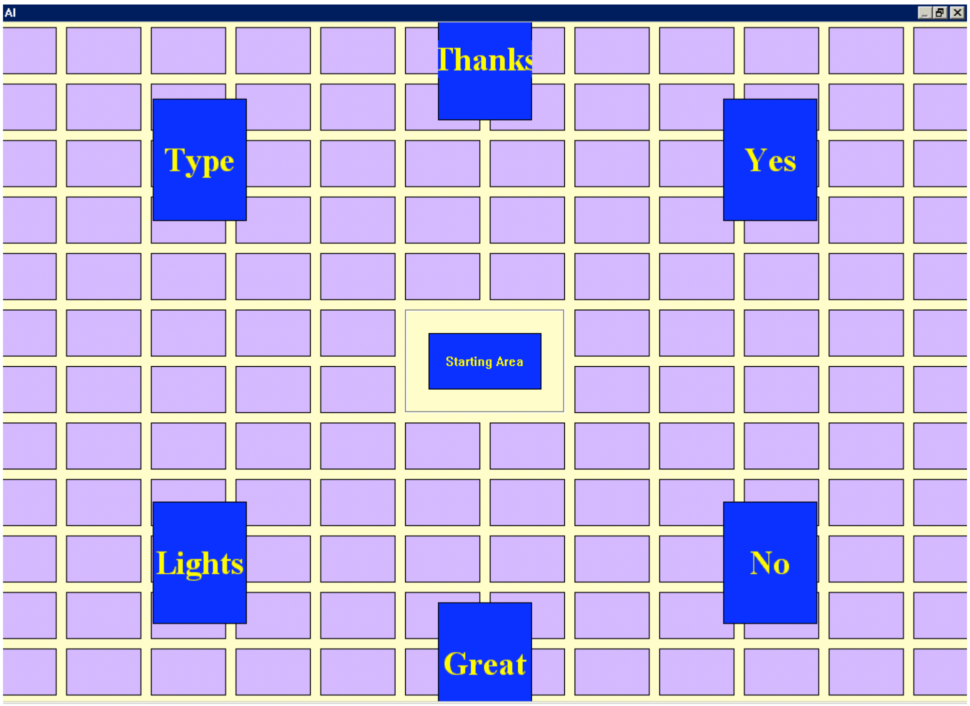


Figure 6.9 – Profile of Participant 45

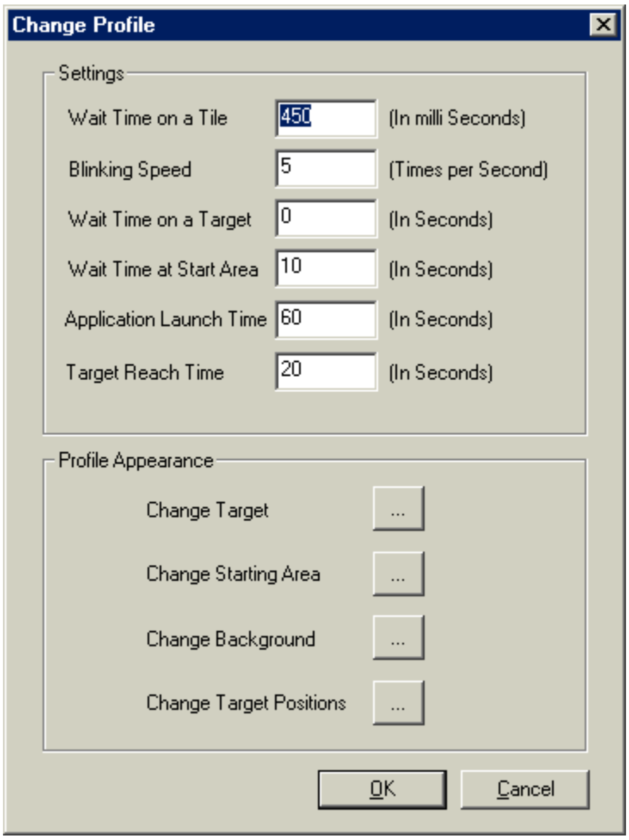


Figure 6.10 – Profile settings of Participant 45

Table 6.2 – Evaluation Results A

		Participant 46			Participant 49			Participant 47	
Date	success	trials	Success Rate (%)	success	trials	Success Rate (%)	success	trials	Success Rate (%)
7/5/03	3	8	37.50	0	8	0.00	4	9	44.44
10/5/03	4	8	50.00	0	8	0.00	5	9	55.56
14/5/03	5	8	62.50	2	8	25.00	5	9	55.56
16/5/03	5	8	62.50	4	8	50.00	9	9	100.00
23/5/03	8	8	100.00	4	8	50.00	7	9	77.78
30/5/03	5	8	62.50	8	8	100.00	7	9	77.78
4/6/03	5	8	62.50	8	8	100.00	8	9	88.89
6/6/03	0	8	0.00	6	8	75.00	8	9	88.89
13/6/03	5	8	62.50	5	8	62.50	6	9	66.67
18/6/03	5	8	62.50	5	8	62.50	6	9	66.67
20/6/03	8	8	100.00	3	8	37.50	7	9	77.78
9/7/03	5	8	62.50	5	8	62.50	7	9	77.78
11/7/03	5	8	62.50	6	8	75.00	7	9	77.78
23/7/03	5	8	62.50	8	8	100.00	8	9	88.89
25/7/03	5	8	62.50	6	8	75.00	7	9	77.78
30/7/03	5	8	62.50	7	8	87.50	7	9	77.78
1/8/03	5	8	62.50	5	8	62.50	5	9	55.56
6/8/03	8	8	100.00	5	8	62.50	6	9	66.67
8/8/03	5	8	62.50	4	8	50.00	6	9	66.67
13/8/03	5	8	62.50	7	8	87.50	7	9	77.78
15/8/03	5	8	62.50	7	8	87.50	7	9	77.78
20/8/03	5	8	62.50	5	8	62.50	6	9	66.67
3/9/03	5	8	62.50	6	8	75.00	6	9	66.67
5/9/03	5	8	62.50	6	8	75.00	7	9	77.78
10/9/03	5	8	62.50	5	8	62.50	7	9	77.78
12/9/03	5	8	62.50	5	8	62.50	8	9	88.89
17/9/03	5	8	62.50	6	8	75.00	7	9	77.78
19/9/03	0	8	0.00	7	8	87.50	8	9	88.89
24/9/03	5	8	62.50	6	8	75.00	6	9	66.67
26/9/03	5	8	62.50	6	8	75.00	7	9	77.78
1/10/03	5	8	62.50	7	8	87.50	5	9	55.56
3/10/03	5	8	62.50	7	8	87.50	7	9	77.78
8/10/03	5	8	62.50	5	8	62.50	7	9	77.78
10/10/03	5	8	62.50	4	8	50.00	9	9	100.00
15/10/03	5	8	62.50	4	8	50.00	7	9	77.78
17/10/03	5	8	62.50	6	8	75.00	8	9	88.89
22/10/03	5	8	62.50	5	8	62.50	8	9	88.89
24/10/03	5	8	62.50	5	8	62.50	6	9	66.67
29/10/03	0	8	0.00	6	8	75.00	6	9	66.67
31/10/03	5	8	62.50	7	8	87.50	7	9	77.78
5/11/03	5	8	62.50	5	8	62.50	8	9	88.89
12/11/03	5	8	62.50	6	8	75.00	7	9	77.78
14/11/03	5	8	62.50	6	8	75.00	8	9	88.89
19/11/03	5	8	62.50	7	8	87.50	7	9	77.78
21/11/03	8	8	100.00	7	8	87.50	6	9	66.67
26/11/03	5	8	62.50	5	8	62.50	6	9	66.67
3/12/03	5	8	62.50	5	8	62.50	6	9	66.67
5/12/03	5	8	62.50	6	8	75.00	7	9	77.78
10/12/03	6	8	75.00	5	8	62.50	8	9	88.89
12/12/03	5	8	62.50	5	8	62.50	7	9	77.78
19/12/03	6	8	75.00	5	8	62.50	7	9	77.78
7/1/04	5	8	62.50	5	8	62.50	8	9	88.89
9/1/04	8	8	100.00	7	8	87.50	8	9	88.89
16/1/04	7	8	87.50	6	8	75.00	7	9	77.78
	Average Success Rate		62.73	Average Success Rate		67.82	Average Success Rate		76.34

Table 6.3 – Evaluation Results B

	Participant 48			Participant 45		
Date	success	trials	Success Rate (%)	success	trials	Success Rate (%)
7/5/03	3	9	33.33	7	15	46.67
10/5/03	6	9	66.67	9	15	60.00
14/5/03	6	9	66.67	8	15	53.33
16/5/03	6	9	66.67	12	15	80.00
23/5/03	5	9	55.56	100	15	666.67
30/5/03	7	9	77.78	13	15	86.67
4/6/03	7	9	77.78	13	15	86.67
6/6/03	9	9	100.00	13	15	86.67
13/6/03	8	9	88.89	13	15	86.67
18/6/03	7	9	77.78	13	15	86.67
20/6/03	7	9	77.78	0	15	0.00
9/7/03	7	9	77.78	13	15	86.67
11/7/03	8	9	88.89	4	15	26.67
23/7/03	9	9	100.00	13	15	86.67
25/7/03	7	9	77.78	13	15	86.67
30/7/03	7	9	77.78	13	15	86.67
1/8/03	6	9	66.67	13	15	86.67
6/8/03	5	9	55.56	13	15	86.67
8/8/03	5	9	55.56	13	15	86.67
13/8/03	7	9	77.78	13	15	86.67
15/8/03	8	9	88.89	0	15	0.00
20/8/03	8	9	88.89	11	15	73.33
3/9/03	7	9	77.78	12	15	80.00
5/9/03	6	9	66.67	12	15	80.00
10/9/03	7	9	77.78	13	15	86.67
12/9/03	8	9	88.89	14	15	93.33
17/9/03	7	9	77.78	13	15	86.67
19/9/03	7	9	77.78	14	15	93.33
24/9/03	8	9	88.89	12	15	80.00
26/9/03	7	9	77.78	13	15	86.67
1/10/03	8	9	88.89	11	15	73.33
3/10/03	6	9	66.67	13	15	86.67
8/10/03	6	9	66.67	0	15	0.00
10/10/03	8	9	88.89	13	15	86.67
15/10/03	7	9	77.78	13	15	86.67
17/10/03	8	9	88.89	12	15	80.00
22/10/03	6	9	66.67	13	15	86.67
24/10/03	7	9	77.78	15	15	100.00
29/10/03	7	9	77.78	13	15	86.67
31/10/03	7	9	77.78	14	15	93.33
5/11/03	8	9	88.89	14	15	93.33
12/11/03	9	9	100.00	13	15	86.67
14/11/03	9	9	100.00	13	15	86.67
19/11/03	7	9	77.78	4	15	26.67
21/11/03	7	9	77.78	13	15	86.67
26/11/03	6	9	66.67	13	15	86.67
3/12/03	8	9	88.89	15	15	100.00
5/12/03	7	9	77.78	12	15	80.00
10/12/03	8	9	88.89	12	15	80.00
12/12/03	7	9	77.78	13	15	86.67
19/12/03	8	9	88.89	13	15	86.67
7/1/04	7	9	77.78	15	15	100.00
9/1/04	6	9	66.67	11	15	73.33
16/1/04	8	9	88.89	13	15	86.67
	Average Success Rate		78.19	Average Success Rate		88.15
Overall Success Rate		74.65				

Table 6.4 – Evaluation Results

Participant	Used text to audio	Launched applications	Switched devices
46, 49	Yes	No	No
45, 47, 48	Yes	Yes	Yes

Participants had to wait in the ‘starting area’ for a user dependent pre-configured delay and then reach the appropriate target within a user dependent pre-configured time, to achieve success. The success rate was measured only with disabled participants. Participant 47 was able to use a foot switch. This was valuable at times for double-checking answers given. The success rate averaged around 75% for all these participants (Table 6.4). As Table 6.4 shows, three participants (45, 47 and 48) could launch applications such and switch devices. We have thus achieved a wider range of functionality than Doherty with similar participants. Participants 45, 47 and 48 had television and music systems in their room and showed interest in doing more with the interface than other participants. These three participants used the PDA to control these devices and also launch applications such as the Internet browser. Participant 47 had days where he wanted to be left alone, which reduced his success rate. However, on a good day he used the interface to communicate, switch devices and launch applications. The ability of these three participants to do more than communicate demonstrated the superiority of a personalised interface that can expand or shrink the number of targets to match an individual’s capability. Doherty’s tunnel interface was restricted to two targets. Several participants had problems with their eyesight and were greatly encouraged by audio feedback that enhanced their experience. The text to sound facility incorporated in the target of the interface also lets users, hear any phrase they wanted to use, not just YES or NO.

The provision of personalisation greatly improved the PDA interface by giving a facility to configure the interface to suit each participant as shown in Figures 6.1 to 6.10. This interface also gives the user the possibility of another target test and reconfiguration at any time, which reduces error frequency. Further flexibility in the interface is provided by adaptable dimensions (manual configurations), fonts and colours, which can cater for colour blindness and other visual impairments. The speech therapists (three from Holy Cross Hospital and one from Castel Froma) and the Matrons in both institutes were able to carry out independent usage of the BBI for daily routine communications. Communications with participants were carried out at least three times a week in Holy Cross Hospital by support staff in addition to the visits by the researcher. Apparatus was left for independent usage three weeks a month at Holy

Cross hospital. Independent usage was carried out at Castel Froma three times a month minimum, but the Apparatus was left there only one week per month.

6.4. Conclusions

All five participants chosen for this phase of the research were able to use the interface to varying degrees to communicate and control applications. This demonstrated the inclusivity of interface, leaving out only participants who had serious visual impairment, were in comatose or adverse effect of daily medicine intake. The rate of success averaged around 75% for all participants. Participants 46 and 49 were able to use the interface to communicate using a two target Yes or No interface, due to the severity of their brain injury. Participants 45, 47 and 48 had television and music systems in their rooms and showed interest in doing more with the interface than the other participants. They were able to switch devices on and off and also launch the Internet using their interface. The success rate for Participants 45 and 48 averaged around 75%, but Participant 47 had days where he wanted to be left alone, which reduced his success rate. The ability of these three participants to do more than communicate demonstrates the superiority of a personalised interface that can expand or shrink the number of targets to match an individual's capability.

The research question addressed in phase three, can a disabled participant give consistent answers using the PDA interface? was answered here with a 75% success rate. Previous research in phases one and two fed valuable data into this phase, resulting in the answer to the research question. This phase shows that the combined discrete acceleration and personalised tiling allows faster and more extensive interaction. Discrete acceleration has been shown to improve performance. A flexible interface can be configured to suit each person, with targets positioned by either using the target test program or manually placing them where participants wish. As a result, we have been able to extend effective interaction for some users to tasks beyond simple communication.

The apparatus was left at the premises of Holy Cross Hospital and Castel Froma nursing home for independent usage without the researcher. The carers were able to use it as part of their communication with the disabled individuals. A portable BBI which can be used in the field outside the laboratory environment to carry out independent usage for daily routine communications was one of the main achievements of this research.

Chapter 7 – Conclusions and Future Work

This research improved on the existing work of Doherty by developing new interaction paradigms. It created two interaction paradigms, discrete acceleration and personalised tiling with discrete acceleration. This research extended the scope of BBIs, in terms of both the population who can use them and in terms of what (some) users can do with them. This research was completed with patients in their own homes or nursing home environments and it was not a laboratory exercise with laboratory subjects. There was no need for extensive training or any off-line processing.

Doherty's success was limited and inconsistent. It was clear that improved control over the cursor would extend the population of brain-injured who could use BBIs, as well as the functionality that could be accessed through it. The research hypothesis of this study *that the performance of the Brain-Body Interface can be improved by the use of novel interaction paradigms* was achieved in this research. The application of novel interaction paradigms to this area of BBIs is an original contribution to knowledge. Previous work in this area had some limited success, but the user interaction paradigms produced in this research improved on the previous one by developing an individually configurable interaction paradigm, thus creating a more inclusive interface. The patients who were non-verbal, paraplegic and tube fed now had the ability to communicate, which was not possible previously. This also gave them a say in controlling their own environment without decisions being made by others on their behalf.

Forty nine participants were used in this research at various stages to conduct formative and summative evaluations, while Doherty used forty four participants. Doherty used forty four participants (twenty eight disabled and sixteen able-bodied) for the exploratory stages of his investigation. The same total number (albeit twenty one disabled and twenty three able-bodied) was used for the exploratory stages of this investigation. Doherty used three brain-injured participants to evaluate the final interface of his research, while this research used five brain-injured participants to evaluate the final interface. The final evaluation (phase 3) was carried out over a longer period of time in comparison to Doherty's evaluation to discover whether the participants could use the interface with any consistency as part of their routine communication. This part of the study also indicated that the developed PDA interfaces could be used independently for daily routine communications by the care homes, without the researcher being present. Hence this research facilitated daily routine communication between the carers and the patients in their own environment at the convenience of the patient. The setup of the apparatus was simple and didn't need any special expertise or medical knowledge.

There were other challenges encountered in this investigation apart from the ones highlighted in Section 3.1, such as the lack of any up to date information on participants, the participants not having eyesight tests or other tests further to their head injury, no score for GCS scales or Ranchos Los Amigos Scale of Cognitive Functioning. Due to this challenge, a medical practitioner conducted preliminary medical checks and also checked the medical records and daily medication intake before clearing the participants for the study.

A methodology had to be chosen to address the many challenges of this investigation. The chosen methodology was a design research paradigm, guided by principles from HCI research and practice, including engineering design approaches based on psychology research methods. A two level research paradigm using able-bodied then brain-injured participants was used for developing and evaluating novel interaction paradigms. A three-phase minimum structure was employed to carry out this research methodology, which was sufficient to answer the research question. The methodology addressed known challenges to develop an appropriate interface for severely brain-injured individuals to communicate during their daily routines. The main task was to develop algorithms that can let the user navigate a screen in a controlled manner, enhancing cursor control of the BBI to improve the time to reach a target. The chosen methodology combined elements of design, engineering and science to create novel interaction paradigms and to evaluate their effectiveness. The chosen methodology drew on Gould and Lewis's three principles of design for usability, using iterative methods to refine the interface design. This was not a classic engineering design approach, but an iterative HCI approach with attempts at optimisation. It combined field usage of prototypes with field evaluation. For each phase of the study, there were various issues to be addressed such as, refining methods and approaches, ethical approval, recruitment of both able and disabled participants and conducting experiments.

7.1. Phase one studies

The results of this exploratory study showed that every participant was an individual, who could not be grouped in any way. In tunnel and maze interfaces, users who could not move through the predefined route could not communicate, thus excluding them due to their personal abilities. An inclusive interface to cater for individual needs had to be investigated. In this exploratory study, both able and disabled participants found certain areas of the computer screen easy to navigate, but others were much harder to reach. This meant that targets should be placed in their preferred areas rather than any predefined location of the screen. Personalisation was required to make the most of each individual's capabilities. There were even able-bodied participants who were unable use this interface. There were further problems with inconsistent control of the cursor.

Tunnels do meet the aim of controlling the cursor, but performance is still adversely impacted by signal noise. The cursor will move around the display with little effort, picking up bio-potentials, thus frustrating users. Records of individual routes indicated that, within the tunnels' constraints, no one used regular routes to reach a particular target, indicating each participant produced dissimilar bio-potentials.

Participants also confirmed that discrete acceleration was the preferred choice in comparison to Doherty's interface. Adding discrete acceleration improved performance, but did not overcome the problems of inconsistency that arose with BBIs. The t-test shows that with/without discrete acceleration, sets of data were significantly different at $p \ll 0.05$ level. However, six participants (some able-bodied) could still not answer questions at all using a Cyberlink. For the able-bodied users, there was no question of them being disabled in any way, but may have been very adversely affected by a pervasive problem with cursor control, thus calling for a personalised interface. Alternative designs for speeding up tunnel navigation were considered, but discarded. This would have resulted in a smaller display area, as per Steering Law, which may not have worked well with the common combination of visual impairment and shared use of the display from a distance. There was also no need to give extensive training to the participants before these two interfaces could be used.

As for the research hypothesis, the performance of the BBI was improved by a novel interaction paradigm, but the need for a personalised interface was more important than the benefits of discrete acceleration.

7.2. Phase two studies

Phase two introduced a further novel interaction paradigm, personalised tiling which was combined with discrete acceleration (from phase one). This reduced the impact of noise and consequent erratic involuntary movement of the cursor. This interface presented users with targets that best matched their individual capabilities and tiles that controlled the movement of the cursor when using bio-potentials to navigate the interface. The data obtained shows that individual differences were significant, but participants were able to reach the targets. This supported the position that individuals are each very different in the way that they respond. It also showed how these individuals who respond in different ways to the interface can be accommodated in the PDA interaction paradigm, which strives to achieve an inclusive interface design regardless of the capabilities of the user. The participants for evaluating the PDA interface received no prior training, but successfully achieved the objective, which proved that this interface needed minimum training. Doherty used game playing to establish the correct settings before testing his 'Yes/No' interface, whereas PDA is self-contained and supports all necessary configurations.

Improved default settings for PDA were obtained with able-bodied participants, to be used as a starting point when evaluating the interface with disabled users in phase three of the research. Results from random target summative tests showed that Profile 2 was the best. This finding illustrated that the interface with medium tiles and small gap between tiles gave a significantly better performance than the other three profiles. This statistically shows that there is a difference between each profile and that the best one that could be chosen. The summative evaluation (of ranked profile preferences) also indicated that 80% of users preferred Profile 2 to the other three profiles. The alternative for the parameters used in the four profiles for optimising the PDA interface were based on experience with by the development group utilised in this phase of the study. The improved individual interface obtained shows the users can successfully navigate their individual PDA interface achieving 100% success. The minimum time taken to reach the targets using PDA was at least twenty times faster than Doherty's interface.

7.3. Phase three studies

This was the final phase with the PDA interaction being evaluated by the disabled participants. All five participants chosen for this phase of the research were able to use the interface with varying degree of application to communicate. This indicated an inclusive interface, which only left out participants who had serious visual impairment, were comatose, or had adverse effect by their daily medicine intake. The rate of success averaged around 75% for all the participants. The ability of three participants to do more than communicate demonstrates the superiority of a personalised interface that can expand or shrink the number of targets to match an individual's capability. Doherty's tunnel interface is restricted to a fixed number of targets (typically two). Several participants had problems with their eyesight and were greatly encouraged by audio feedback that enhanced their experience. The inclusion of personalised tiling with acceleration greatly improved the interface. Further flexibility in the interface is provided by adaptable dimensions, fonts and colours, which can cater for colour blindness and other visual impairments.

The research question raised in phase three, can a disabled participant give consistent answers using the PDA interface was answered here with a 75% success rate. This phase of the study also showed that PDA interface can be used without the researcher being present independently for daily meaningful routine communications by severely brain-injured individual. This phase showed that the combination of discrete acceleration and personalised tiling allowed faster more extensive interaction. Discrete acceleration has been shown to improve performance. A flexible interface can be configured to suit each person, with targets positioned by either using the target test program or manually placing them where participants wish. As a result, it has been possible to extend effective interaction for some users to tasks beyond simple communication. This also gave this group of people a say in controlling their own environment without decisions being made by others on their behalf. Thus this research facilitated daily real-time communication between the carers and the patients in their own environment without the need for the researcher being present. Phase three also indicated the research hypothesis, *that the performance of the BBI can be improved by the use of novel interaction paradigms* has been achieved in this phase of the research.

7.4. Conclusions of work

This research extended the scope of BBIs, in terms of both the population who could use them and in terms of what users could do with them. It developed, evaluated and refined two new complementary approaches to providing means to communicate, recreate and carry out some simple tasks for people who would otherwise remain unable to perform any such activities and were classified as vegetative. Doherty's Tunnel interface was the baseline of this investigation (Field & Hole, 2004). The results from this research show that these two novel interaction paradigms significantly improved the performance of BBIs.

This research built on Doherty's work in three ways. This study worked with a much larger group of severely impaired participants, especially in phase one (Chapter 4), and thus replicated Doherty's results with a larger population in India and the UK. Secondly, it has combined discrete acceleration and personalised tiling to allow inclusive, faster and more extensive interaction. Discrete acceleration has been shown to improve performance. In addition, a flexible interface can be configured to suit each person, with targets positioned by either using the target test program or manually placing them as the participants wanted. As a result, this research has extended effective interaction for some users to tasks beyond simple communication. This was achieved with a reduced need for adjusting the Cyberlink™ settings before use. BBIs for rehabilitation are still in their infancy, but we believe that our work could be the basis for their more widespread use in extensively extending the activities of severely impaired individuals. This is seen as the main current viable application of BBIs, since anyone who can use a more reliable and efficient alternative input device should do so. Thus it can be concluded that the performance of the BBI can be improved by the use of novel interaction paradigms.

There were various challenges associated with the characteristics of these participants, such as individual disabilities and abilities, effect of medication on individual participants, attention span of an individual and emotions and frustrations when research is being carried out. The PDA interface gave the flexibility to address these issues. The PDA interface provided as essential facility to configure profiles with personalised timings and dimensions which catered for the needs of each participant. The doctors addressed the need for further medical assessment and the suitability of each participant. Hence the developed PDA interface was an inclusive interface that could be used by any brain-injured user, except comatose, severely visual impaired or individuals with adverse effect of daily medicine intake. The flexibility of the interface for personalised configuration to suit each individual gave the opportunity for grounded evidence based personalisation by the carers, parents/guardian and any support staff to improve the performance of the interface. The people around the brain-injured individuals had more knowledge of them than the researcher, and this knowledge was well utilised when configuring interfaces manually or using the automated processes.

Another challenge faced was the type of novel interaction paradigms to be developed. Should it be a universal access, group or personalised interface? Can the developed interface offer a facility to re-configure the interface at any time, if the medical or physical condition of the user changes? The results from phase one and two of this research indicated that every brain-injured was an individual with no common attributes that could be grouped in any way, hence the PDA interface was chosen as the ultimate interface for this group of brain-injured individuals.

There were various challenges faced when controlling the cursor driven by bio-potentials on a computer screen. The cursor had to be controlled in such a way it did not get stuck somewhere in the interface thus frustrating the user. This problem was addressed by the PDA interface which used tiles and a ‘Starting Area’ which delayed the user to a pre-configured time and also if the user did not reach the target in a specified time the cursor was moved back to the 'Starting Area'. Thus any possible frustration was dealt with using these techniques. Moving the cursor across a computer screen using low voltage bio-potentials (0 to 10 μV) is a slow process. A simple enhancement called discrete acceleration was introduced to push the cursor along the direction of travel thus improving the time to reach a target. Phase two of this investigation conducted studies to improve settings for the PDA interface so that a default interface could be produced that could be used as the initial interface for the brain-injured participants thus minimising training. The designed interface was robust and portable to the field, and not just used in laboratory experiments, to enable realistic daily usage for communication. The developed interface also enabled independent carer-supported usage, enabling routine communications to take place in the brain-injured individual's environment without the researcher being present.

7.5. Contribution to Assistive Technology

The application of novel interaction paradigms to this area of BBIs is an original contribution to knowledge. The results obtained showed that the performance of the BBI was improved by the use of novel interaction paradigms. This research extended the scope of BBIs, in terms of both the population who could use them and in terms of what some users could do with them. Thus this research developed, evaluated and refined two new complementary approaches to provide means to communicate, recreate and carry out some simple tasks for people who would otherwise remain unable to perform any such activities and were classified as vegetative. These two paradigms could also be used with other BBIs to achieve similar results. The interfaces are by no means tied to Cyberlink™ only. These interfaces might also be used as diagnostic tools to distinguish between fully comatose and locked-in syndrome.

There were three other contributions that were by-products of this research:

- An interface for a brain-injured person to operate a robotic arm was developed and demonstrated at ICCIT' 2001 conference in New York (Gnanayutham *et al.*, 2001). The interface could carry out some basic functions such as moving a cup to the mouth of a quadriplegic individual;

- A Soft-Keyboard for the disabled was developed and demonstrated at ICCHP 2004 conference in Paris (Gnanayutham *et al.*, 2004). This was an on-screen keyboard that can be used to type or convert text into sound using a BBI;
- A Personalised Tiling Paradigm for Motor Impaired Users was developed and demonstrated at HCI International conference 2005 in Las Vegas (Gnanayutham, 2005). The developed interface enabled motor impaired users to navigate any computer screen in a controlled manner using the tiling paradigm.

7.6. Possible Future work with PDA interfaces

Vision impaired, comatose or individuals with adverse effects of daily medicine intake participants were the three groups of non-verbal quadriplegic brain-injured people who could not be included in this study. Comatose or individuals with adverse effects of daily medicine intake could not respond to any stimulus, but future work could include the vision impaired. This group of people might not be able to use their electrooculargraphic signals, but should be able to use their electroencephalalographic and electromyographic signals. Previous research with vision impairment shows that one way of including visually impaired non-verbal quadriplegic users will be to use musical guidance to direct them to the targets (Rigas & Alty, 1997).

Use of interface agents to closely monitor user trends and change configuration parameters of the PDA could be considered as an enhancement in future. In the case of the PDA interaction paradigm, an adaptive interface could alter dimensions of target tiles and gap between tiles. It can also relocate the targets, change time on tiles, time in starting area and time to reach targets. The interface agent, after having monitored the user for a period of time, could make these changes. There can always be a manual over-writing facility to over write any automatic changes made by the interface agent. Why should people have to adapt to a system, and should not the system adapt to people instead?

The interface used in this research was developed only for the Cyberlink™. If it could be standardised in future to a standard like BCI2000 (a General-Purpose Brain-Computer Interface Application), then the PDA interface could be used with any

BBI. This influence of other BBIs using a PDA paradigm, could possibly further improve the performance of their interface.

At present the text on the targets is fixed. Hence we have a vocabulary of two to six words per individual interface. In the future if we could have a provision for dynamic vocabulary selection, such as a target that opens into a list of words for the user to choose, we could increase the vocabulary of the communication tool by much more than six. Another area is the use of pictures instead of text. This might be the best communication media for some adults after brain injury or children who have brain injuries and cannot communicate using text.

This research improved on the existing work of Doherty by developing a new interaction paradigm which could be fine-tuned using evidence based personalisation. It extended the scope of Brain-Body Interfaces, in terms of both the population who can use them and in terms of what users can do with them. The developed interaction paradigm was used for everyday communication by brain-injured individuals by means of independent usage. It improved control over the cursor extending the population of brain-injured who could use Brain-Body Interfaces, as well as the functionality that could be accessed through it. This study created an inclusive interface which strives to accommodate all users, except the users with visual impairment, users in comatose or users with adverse effects caused by intake of medication.

Thus research hypothesis:

> *That the performance of the Brain-Body Interface can be improved by the use of novel interaction paradigms.*

was achieved in this research. The PDA interface was twenty times faster, reliable, inclusive and flexible than Doherty's tunnel interface. The application of discrete acceleration and personalised tiling to Brain-Body Interfaces, was the original contribution to knowledge. This study took the BBI to the field and was not just a laboratory exercise. It also facilitated independent carer-supported usage of the BBI setup. Further research is being planned to develop an easy to use, portable BBI that could be left at hospitals, care homes and private homes where daily routine communications could be carried out. This study also contributed to Human Computer

Interaction with the methodology used in this research and also to Assistive Technology by the three by-products created *en route* towards proving the hypothesis.

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Appendix 1 – International 10-20 System

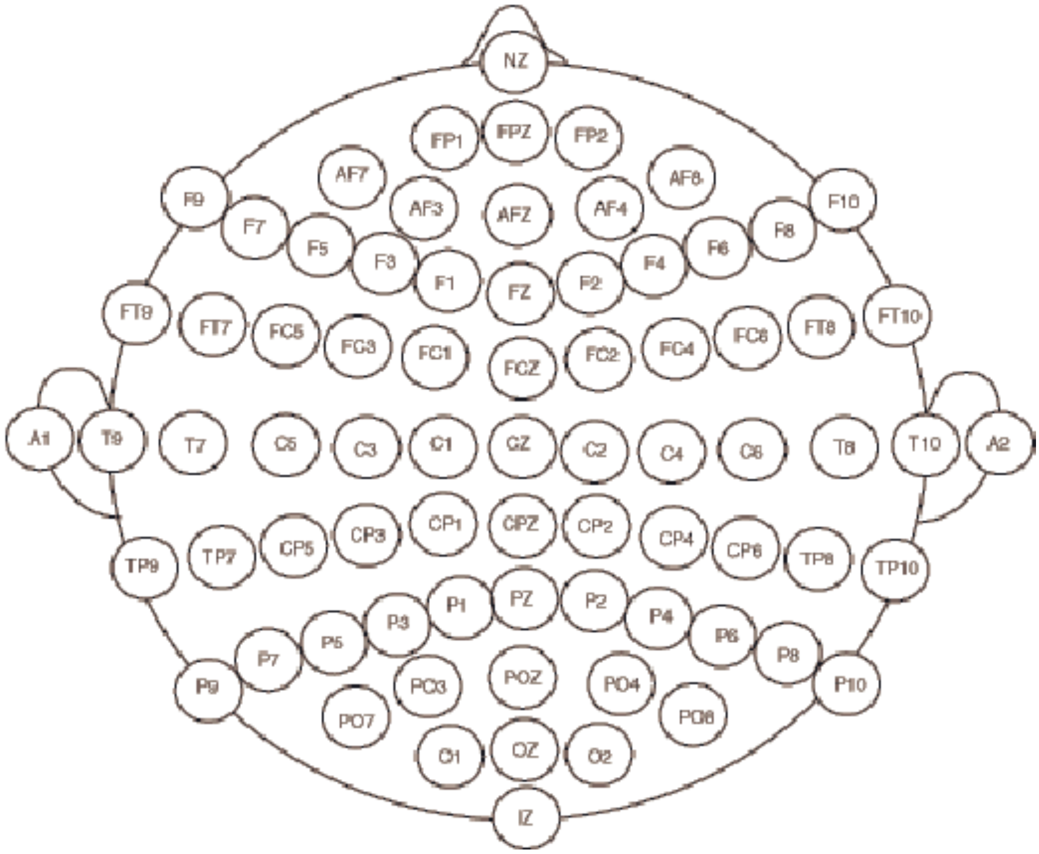

Figure A1 1 – The International 10-20 System

Figure A1 1 shows the location of electrodes on a head for the International 10-20 System. The System has the following characteristics:

- Even numbers- electrodes located on the right side of the head;
- Odd numbers - electrodes on the left side;
- The letter before the number indicates the general area of the cortex the electrode is located above: A stands for auricular, C for central, Fp for prefrontal, F for frontal, P for parietal, O for occipital and T for temporal;
- In addition, electrodes for recording vertical and horizontal (electrooculargraphic signals). Vertical electrooculargraphic electrodes are placed above and below an eye and horizontal electrooculargraphy electrodes are placed on the side of both eyes away from the nose.

Appendix 2 – Coordinates of the Cerebral Palsy Group

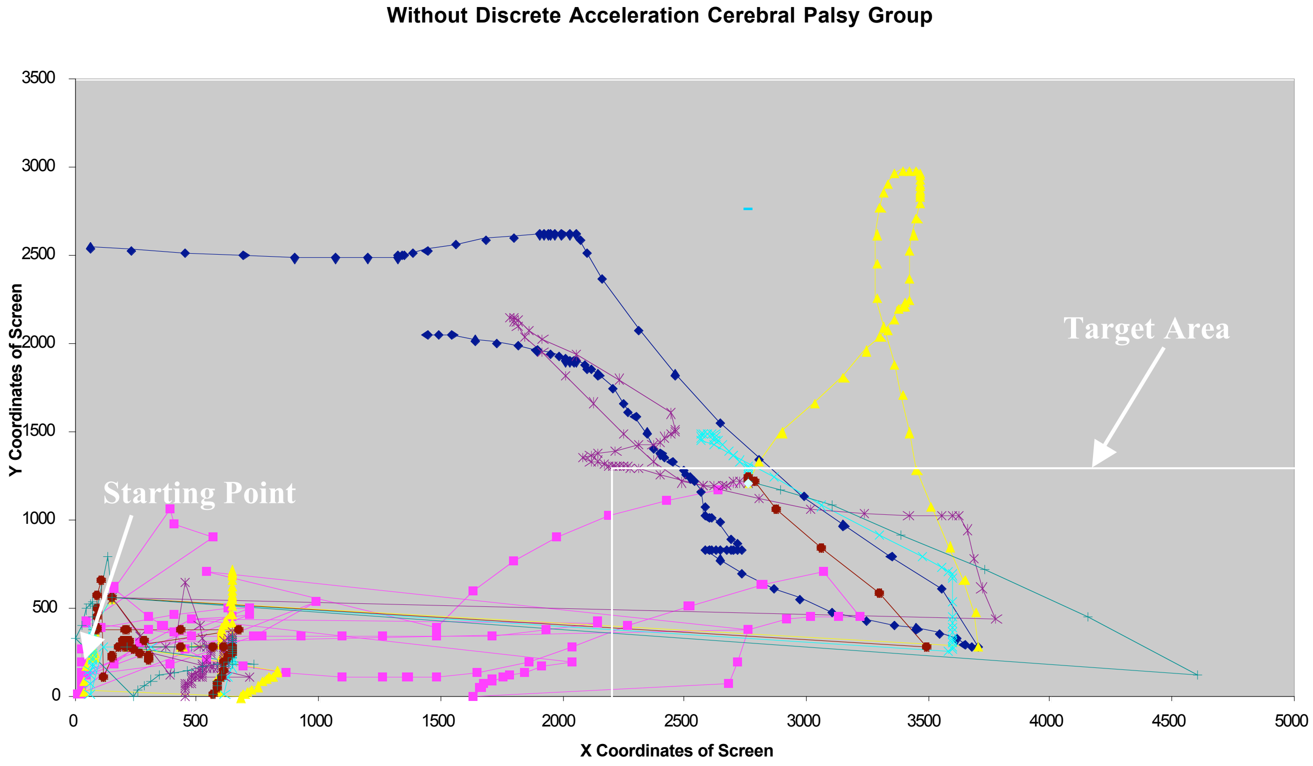

Figure A2 1 – Route taken to reach the target without Discrete Acceleration

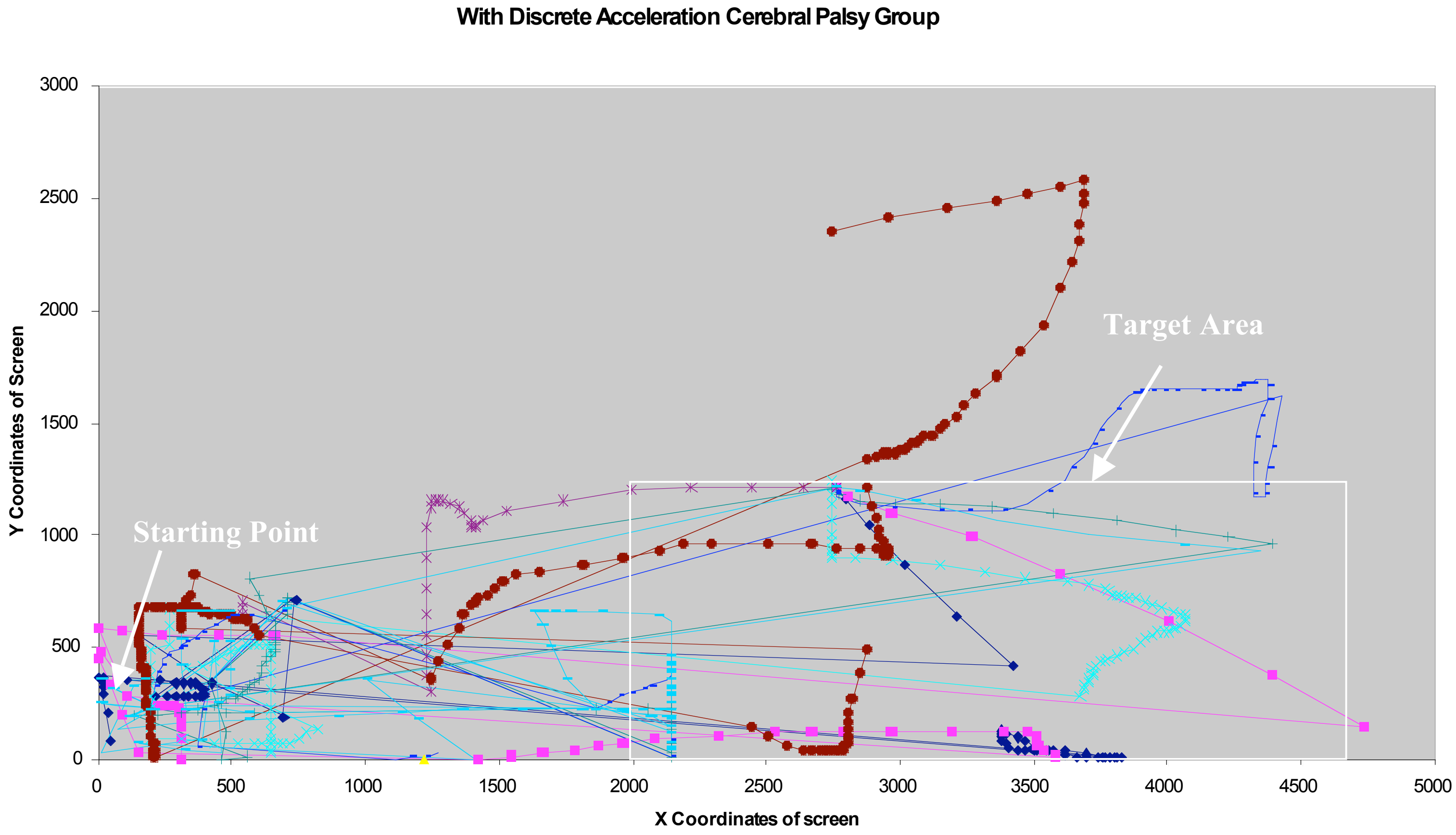

Figure A2 2 – Route taken to reach the target with Discrete Acceleration

Table A2 1 – With Discreet Acceleration Part A

With Discreet Acceleration

Participant 13		Participant 16		Participant 19		Participant 19	
X	Y	X	Y	X	Y	X	Y
2760	1215	14235	3510	2760	1215	3105	105
2640	1215	14490	3555	2775	1215		
2445	1215	14505	3555	2790	1215		
2220	1215	14520	3555	2805	1230		
1995	1200	14535	3555	2820	1290		
1740	1155	14535	3570	2820	1350		
1530	1110	14520	3570	2835	1425		
1440	1065	14490	3585	2850	1515		
1410	1050	14370	3615	2850	1575		
1410	1035	12345	3990	2865	1605		
1395	1035	12345	4005	2865	1635		
1395	1050	12330	4005	2880	1650		
1395	1065	12315	4005	2895	1665		
1365	1095	12300	4005	2895	1680		
1350	1125	12285	4005	2895	1695		
1320	1140	12285	4020	2910	1695		
1290	1155	12285	4035	2910	1710		
1275	1155	12270	4035	2910	1725		
1260	1155	12270	4050	2925	1740		
1245	1155	12255	4050	2925	1755		
1245	1125	12240	4050	2925	1770		
1230	1035	12225	4050	2925	1785		
1230	900	12210	4050	2925	1800		
1230	765	12195	4050	2925	1755		
1230	645	12180	4050	2925	1710		
1230	555	12165	4050	2940	1635		
1230	465	12150	4050	2955	1515		
1230	375	12150	4065	2955	1335		
1245	300	12150	4080	2970	1125		
540	705	12135	4080	2985	930		
540	675	12135	4095	3000	750		
540	645	12135	4110	3015	570		
540	630	12120	4110	3030	435		
		12105	4110	3030	390		
				3045	375		
				3045	360		
				3060	360		
				3075	270		

Participant 7		Participant 7		Participant 8		Participant 8	
X	Y	X	Y	X	Y	X	Y
2760	1215	3525	60	2760	1215	3375	90
2805	1170	3540	45	2790	1170	3375	105
2970	1095	3585	15	2880	1050	3375	120
3270	990	105	285	3015	870	3375	135
3600	825	225	240	3210	645	3390	120
4005	615	255	240	3420	420	3435	105
4395	375	285	240	150	555	3465	90
4740	150	300	225	420	345	3495	60
660	555	300	210	690	195	3555	45
450	555	315	210	735	720	3615	30
240	555	315	195	210	285	3660	15
90	570	315	180	255	285	3690	15
0	585	315	165	285	285	3735	15
75	375	315	150	315	285	3750	15
15	480	315	90	330	285	3765	15
0	450	315	0	360	285	3780	15
45	330			375	285	3795	15
90	195			390	285	3810	15
150	30			390	300	3825	15
1425	0			390	315	0	375
1545	15			375	330	15	375
1665	30			360	345	15	360
1785	45			345	345	15	345
1875	60			315	345	15	330
1965	75			285	345	15	300
2085	90			225	360	30	210
2325	105			105	360	45	90
2535	120			3780	15		
2670	120			3690	30		
2790	120			3615	45		
2970	120			3570	45		
3195	120			3540	45		
3390	120			3510	45		
3480	120			3495	45		
3510	105			3465	45		
3510	90			3435	45		
3510	75			3405	60		
3510	60			3390	75		

Table A2 2 – With Discreet Acceleration Part B

With Discreet Acceleration

Participant 15		Participant 15			Participant 6		Participant 6		Participant 6			Participant 12		Participant 12		Participant 12		Participant 12	
X	Y	X	Y		X	Y	X	Y	X	Y		X	Y	X	Y	X	Y	X	Y
2760	1215	225	195		2745	1245	3960	570	615	75		2760	1215	4320	1680	480	630	2145	75
2745	1215	315	210		2745	1185	3945	555	645	75		2760	1200	4335	1695	495	645	2145	60
2745	1200	375	225		2745	1140	3915	540	675	75		2760	1185	4350	1695	510	645	2145	45
2775	1185	435	240		2745	1065	3900	525	690	75		2760	1170	4365	1695	570	645	2145	30
2850	1155	465	255		2745	1005	3870	495	720	75		2850	1140	4380	1695	1860	225	2145	15
2985	1140	480	270		2745	975	3840	480	750	90		2970	1125	4380	1665	1905	255	705	720
3150	1140	510	270		2745	945	3810	465	780	120		3150	1110	4380	1605	1950	285	690	660
3345	1125	525	285		2745	930	3780	450	825	135		3255	1110	4350	1530	1995	300	420	345
3570	1095	540	300		2745	915	3765	435	330	405		3390	1110	4335	1440	2040	315	390	225
3810	1065	555	315		2745	900	3750	435	390	420		3480	1140	4320	1320	2070	330	375	60
4035	1020	570	330		2835	900	3735	420	435	435		3555	1200	4320	1245	2100	345	1110	0
4230	990	585	345		2970	885	3720	405	465	465		3615	1245	4320	1185	2130	360	1170	15
4395	960	600	360		3150	870	3720	390	495	480		3645	1305	4320	1170	2145	375	1230	15
195	225	615	390		3315	840	3720	375	525	495		3690	1350	4335	1170	2145	390	1275	30
315	210	615	420		3465	810	3705	360	555	510		3720	1410	4350	1170	2145	405		
390	210	630	435		3630	795	3705	345	585	510		3750	1470	4365	1170	2145	420		
480	210	630	465		3705	780	3690	330	600	510		3780	1515	4365	1185	2145	435		
585	210	645	465		3765	765	3690	315	630	510		3810	1560	4365	1230	2145	450		
1860	225	660	480		3780	750	3675	285	645	510		3825	1590	4380	1305	2145	465		
2055	225	660	495		3795	735	270	675	645	495		3855	1620	4395	1395	2145	480		
2145	225	660	510		3810	735	270	600	645	480		3870	1635	4410	1515	2145	465		
2145	195	660	525		3825	735	270	510	645	450		3885	1635	4425	1620	2145	435		
2145	165	660	540		3840	720	195	495	645	390		3900	1635	195	225	2145	405		
2145	135	660	570		3855	720	195	420	645	315		3900	1650	210	330	2145	390		
2145	75	660	615		3885	720	195	375	645	225		3915	1650	225	390	2145	375		
2145	30	630	660		3915	705	195	330	645	165		3945	1650	240	420	2145	360		
705	720	600	735		3945	690	195	285	645	120		3990	1650	240	450	2145	345		
705	705	570	810		3975	675	195	255	645	90		4035	1650	255	465	2145	330		
705	720	2760	1215		4020	660	195	225	645	75		4125	1650	270	480	2145	315		
2145	15				4050	645	195	195	645	45		4185	1650	300	495	2145	285		
705	720				4065	645	195	165	645	30		4215	1650	315	510	2145	255		
705	690				4065	630	195	150				4245	1650	330	525	2145	225		
705	645				4065	615	195	120				4260	1650	360	540	2145	195		
420	345				4050	600	195	90				4260	1665	375	555	2145	165		
480	120				4035	585	315	90				4275	1665	390	570	2145	135		
465	0				4020	585	435	75				4275	1680	405	585	2145	120		
555	15				4005	570	525	75				4290	1680	435	600	2145	105		
135	195				3990	570	585	75				4305	1680	465	615	2145	90		

Table A2 3 – Without Discreet Acceleration Part C

With Discreet Acceleration

Participant 18		Participant 18		Participant 18		Participant 18		Participant 18	
X	Y	X	Y	X	Y	X	Y	X	Y
2880	1215	330	705	465	645	180	315	3690	2580
2895	1125	330	675	450	645	180	300	3600	2550
2910	1080	315	645	420	645	180	255	3480	2520
2925	1020	315	630	405	660	180	240	3360	2490
2925	990	315	615	390	660	195	210	3180	2460
2940	975	315	600	375	675	195	180	2955	2415
2940	945	315	585	360	675	195	150	2745	2355
2940	930	2880	495	345	675	195	105		
2940	915	2850	390	315	675	210	75		
2955	915	2820	270	285	675	210	45		
2955	930	2805	210	270	675	210	15		
2955	945	2805	165	240	675	2880	1335		
2940	945	2805	135	225	675	2910	1350		
2910	945	2805	105	210	675	2940	1365		
2850	945	2805	90	180	675	2955	1365		
2760	945	2805	75	165	675	2985	1365		
2670	960	2790	60	150	675	3000	1380		
2505	960	2790	45	150	645	3015	1380		
2295	960	2775	45	150	630	3030	1395		
2190	960	2760	45	150	615	3045	1410		
2100	930	2745	45	150	600	3060	1410		
1965	900	2730	45	150	570	3075	1425		
1815	870	2715	45	150	555	3090	1440		
1650	840	2700	45	150	540	3120	1440		
1560	825	2670	45	150	525	3150	1470		
1515	795	2640	45	150	510	3165	1500		
1485	765	2580	60	165	495	3210	1530		
1455	735	2505	105	165	480	3240	1575		
1425	720	2445	150	165	465	3285	1635		
1410	705	600	555	165	450	3360	1710		
1395	690	585	585	165	420	3450	1815		
1365	645	555	615	165	405	3540	1935		
1350	585	555	630	180	405	3600	2100		
1305	510	540	630	180	390	3645	2220		
1275	435	525	630	180	375	3675	2310		
1245	360	510	630	180	360	3675	2385		
360	825	495	645	180	345	3690	2475		
345	735	480	645	180	330	3690	2520		

Participant 11		Participant 11		Participant 11		Participant 11		Participant 11	
X	Y	X	Y	X	Y	X	Y	X	Y
2760	1215	330	240	2145	180	900	195	210	225
2850	1200	420	240	2145	105	570	180	210	225
3060	1155	570	240	2145	60	330	165	210	225
3360	1065	1860	225	2145	45	75	135	15	345
3705	1005	1980	210	2145	60	210	225	210	225
4065	960	2130	195	2145	75	210	225	180	240
4350	930	2145	180	2145	105	210	225	195	240
195	225	2145	165	2145	120	210	225	315	240
360	225	2145	180	2145	150	210	225	390	240
450	255	2145	195	2145	165	210	225	570	210
495	285	2145	150	2145	180	210	225	1860	225
495	315	690	705	2145	225	210	225	2070	195
495	345	420	345	2145	270	210	225	2145	150
495	405	390	90	2145	315	210	225	2145	120
495	525	15	30	2145	360	75	240	705	720
495	660	135	330	2145	390	15	255	420	345
480	660	420	345	2145	420	210	225	135	195
465	660	435	525	2145	435	195	225	705	675
450	660	465	30	2145	420	120	195	2760	1215
435	660	330	45	2145	405	210	225		
420	660	150	75	2145	390	210	225		
405	660	1410	0	2145	375	210	225		
390	660	1200	180	2145	360	210	225		
375	660	1005	360	2145	330	210	225		
360	660	1860	225	2145	300	210	225		
345	660	1755	360	2145	285	210	225		
330	660	1695	510	2145	270	210	225		
315	660	1665	600	2145	255	210	225		
315	615	1635	660	2145	240	60	315		
315	540	1665	660	2145	225	15	345		
315	420	1710	660	2130	225	15	360		
330	225	1770	660	2100	225	180	360		
210	225	1890	660	2040	225	210	225		
195	240	2100	645	1965	225	210	225		
180	240	2145	615	1815	225	210	225		
210	240	2145	555	1590	225	210	225		
240	240	2145	465	1365	225	210	225		
270	240	2145	300	1140	210	210	225		

Table A2 4 – Without Discreet Acceleration Part A

Without Discreet Acceleration

Particpant 13			Participant 16		Participant 16			Participant 19		Participant 19			Participant 7		Participant 7		Participant 7	
X	Y		X	Y	X	Y		X	Y	X	Y		X	Y	X	Y	X	Y
2760	1215		2760	1215	645	240		2760	1215	645	255		2760	1215	3600	300	630	105
2820	1185		2760	1230	630	225		2895	1170	645	240		2760	1230	3600	285	615	15
2940	1110		2760	1245	615	195		3105	1080	645	225		2760	1245	3600	270		
3135	945		2790	1215	615	150		3390	915	630	195		2760	1260	3585	255		
3315	765		2880	1065	600	105		3735	720	615	165		2760	1275	150	555		
3495	525		3060	840	585	75		4155	450	600	120		2760	1290	75	375		
3690	285		3300	585	585	45		4605	120	585	90		2760	1305	75	360		
150	555		3495	285	570	15		150	555	585	60		2730	1335	75	345		
345	330		150	555				135	795	570	15		2700	1365	75	330		
570	60		285	315				75	375				2685	1395	75	315		
645	570		300	225				75	450				2655	1425	75	300		
660	435		300	210				75	510				2640	1455	75	270		
675	405		300	225				75	525				2625	1455	75	255		
690	405		270	240				75	540				2625	1470	75	240		
720	405		240	270				60	525				2625	1485	75	225		
750	405		225	300				45	495				2610	1485	75	210		
780	405		225	315				30	405				2595	1485	75	180		
210	285		210	315				0	330				2580	1485	75	165		
360	300		195	315				240	0				2565	1485	60	150		
540	315		180	285				255	30				2565	1470	60	120		
645	330		150	225				285	60				2565	1455	60	75		
645	315		120	105				315	90				2625	1425	60	15		
645	300		105	660				345	120				2700	1365	120	285		
645	270		90	570				405	135				2865	1245	315	285		
645	240		90	495				465	150				3060	1080	540	285		
645	210		90	450				525	165				3300	915	645	285		
645	195		90	390				585	180				3480	795	645	270		
645	165		90	375				645	180				3555	735	645	255		
645	150		210	375				735	180				3585	705	645	240		
645	135		435	375				210	285				3600	690	645	225		
645	120		675	375				480	285				3600	675	645	210		
645	105		210	285				645	300				3600	540	645	195		
645	90		435	285				645	315				3600	450	645	165		
645	75		570	285				645	330				3600	420				
645	45		615	285				645	345				3600	390				
630	15		645	285				645	315				3600	360				
			645	270				645	285				3600	330				
			645	255				645	270				3600	315				

Table A2 5 – Without Discreet Acceleration Part B

Without Discreet Acceleration

Participant 8		Participant 8		Participant 8	
X	Y	X	Y	X	Y
2760	1215	2040	285	405	465
2640	1170	1860	195	105	390
2430	1110	1650	135	30	270
2190	1020	1485	105	30	195
1980	900	1365	105	30	105
1800	765	1260	105	30	75
1635	600	1095	105	30	45
1485	390	870	135	30	30
540	705	690	165	30	15
2760	375	540	210		
2715	195	450	270		
2685	75	405	360		
1635	0	360	405		
1665	45	300	450		
1680	75	165	615		
1710	90	390	1065		
1755	105	405	975		
1785	120	570	900		
1845	135	45	420		
1920	165	300	375		
2040	195	480	345		
480	435	600	345		
45	120	765	345		
390	180	930	345		
735	345	1095	345		
990	540	1260	345		
15	15	1485	345		
165	180	1710	345		
270	300	1935	375		
2760	375	2145	420		
2925	435	480	435		
3015	450	645	450		
3135	450	720	465		
3225	450	30	105		
3075	705	30	120		
2820	630	30	135		
2520	510	720	495		
2265	405	630	495		

Participant 15		Participant 15		Participant 15	
X	Y	X	Y	X	Y
2760	1215	600	660	30	270
2745	1215	2760	375	30	255
2730	1215	2745	615	30	240
2685	1185	210	15	30	225
2625	1155	195	225	30	195
2535	1095	2760	375	30	180
2460	1050	2745	570	30	150
2385	1020	225	15	45	105
2265	960	225	150	75	60
2085	885	225	315	120	15
1905	795	2760	375		
1755	660	2775	450		
1605	540	2805	540		
1440	405	2835	630		
1290	270	2850	705		
540	705	360	15		
525	660	420	90		
510	615	480	180		
495	585	525	270		
480	570	2760	375		
465	555	2775	405		
465	570	2790	435		
510	765	2805	435		
540	705	2820	450		
540	705	2835	465		
540	705	2835	480		
540	705	2775	435		
540	705	2685	375		
540	705	2535	315		
540	705	480	435		
570	750	285	405		
585	780	105	375		
585	795	30	360		
525	810	30	345		
480	810	30	330		
465	780	30	315		
465	750	30	300		
495	720	30	285		

Participant 6		Participant 6		Participant 6	
X	Y	X	Y	X	Y
2760	1215	3630	1365	510	285
2775	1260	3675	1275	540	285
2790	1290	3735	1185	570	285
2805	1320	3765	1140	585	285
2820	1335	3780	1110	600	285
2850	1350	3795	1095	615	285
2895	1365	3795	1065	630	285
2955	1365	3795	1050	645	285
3015	1380	3795	1005	645	270
3060	1395	3795	930	645	255
3120	1395	3795	840	645	240
3150	1410	3795	720	645	225
3165	1425	3810	540	645	195
3195	1440	3810	405	630	165
3210	1440	3810	315	600	90
3240	1440	3810	270	585	15
3270	1440	150	555		
3285	1440	75	375		
3315	1440	75	345		
3345	1440	90	330		
3375	1440	105	315		
3405	1425	165	315		
3435	1425	330	300		
3450	1425	525	285		
3480	1425	705	270		
3495	1425	825	270		
3510	1425	210	285		
3525	1425	240	285		
3540	1425	270	285		
3555	1425	285	285		
3555	1440	300	285		
3555	1470	330	285		
3555	1485	345	285		
3555	1515	375	285		
3555	1530	405	285		
3555	1545	435	285		
3555	1515	450	285		
3585	1455	495	285		

Table A2 6 – Without Discreet Acceleration Part C

Without Discreet Acceleration

Participant 12		Participant 12		Participant 12	
X	Y	X	Y	X	Y
1440	2055	2715	870	1965	2625
1485	2055	2715	840	1950	2625
1545	2055	2730	840	1935	2625
1635	2025	2700	840	1920	2625
1725	2010	2685	840	1905	2625
1815	1995	2670	840	1800	2610
1890	1965	2640	840	1680	2595
1950	1950	2625	840	1560	2565
1980	1935	2610	840	1440	2535
2010	1920	2595	840	1380	2520
2010	1905	2580	840	1350	2505
2025	1905	2640	780	1335	2505
2040	1905	2730	705	1320	2505
2055	1905	2865	615	1320	2490
2085	1890	2970	555	1200	2490
2100	1860	3105	480	1065	2490
2115	1860	3240	435	900	2490
2145	1830	3360	405	690	2505
2205	1755	3450	390	450	2520
2250	1665	3540	360	225	2535
2265	1620	3615	330	60	2550
2295	1590	3645	300		
2340	1500	3675	285		
2370	1410	3705	285		
2400	1380	3555	615		
2415	1365	3345	795		
2445	1335	3150	975		
2490	1290	2985	1140		
2505	1260	2805	1350		
2520	1245	2640	1560		
2535	1230	2460	1830		
2565	1170	2310	2085		
2580	1080	2160	2370		
2580	1035	2100	2520		
2595	1020	2070	2595		
2610	1020	2055	2625		
2640	990	2025	2625		
2685	900	1995	2625		

Participant 18		Participant 18		Participant 18	
X	Y	X	Y	X	Y
2760	1215	3315	2100	645	585
2805	1335	3360	1890	645	600
2895	1500	3390	1710	645	630
3030	1665	3420	1500	645	660
3150	1815	3450	1290	645	690
3240	1965	3510	1080	645	705
3300	2040	3585	855	645	720
3330	2085	3645	660	645	705
3360	2145	3690	480	645	630
3375	2205	3705	285	630	540
3390	2220	150	555	630	465
3405	2220	75	375	615	435
3405	2235	75	255	615	405
3420	2250	75	225	600	390
3420	2370	60	225	600	375
3420	2535	45	180	600	360
3435	2625	30	90	600	345
3450	2715	30	30	600	330
3465	2805	675	0	600	300
3465	2835	690	15	600	240
3465	2850	705	30	585	120
3465	2865	720	45	585	30
3465	2880	750	60		
3465	2895	765	90		
3465	2910	780	105		
3465	2940	795	120		
3465	2955	810	120		
3465	2970	825	135		
3450	2985	825	150		
3420	2985	210	285		
3390	2985	435	285		
3360	2970	645	300		
3330	2910	645	360		
3315	2865	645	420		
3300	2775	645	465		
3285	2625	645	525		
3285	2460	645	555		
3285	2265	645	570		

Participant 11		Participant 11		Participant 11		Participant 11	
X	Y	X	Y	X	Y	X	Y
2760	1215	2190	1305	615	105	465	75
2730	1215	2205	1305	720	105	450	75
2700	1215	2220	1305	210	285	450	60
2670	1200	2235	1305	375	285	450	45
2655	1200	2250	1305	510	285	450	30
2625	1200	2265	1305	570	285	450	0
2580	1200	2280	1290	630	285		
2490	1215	2310	1290	645	300		
2370	1335	2400	1260	645	315		
2250	1485	2580	1200	645	330		
2130	1665	2805	1125	645	345		
2010	1815	3015	1065	645	360		
1920	1950	3240	1035	645	345		
1845	2040	3420	1020	630	330		
1815	2100	3555	1020	615	315		
1800	2130	3600	1020	615	285		
1800	2145	3630	1020	615	270		
1785	2145	3660	945	615	255		
1815	2130	3690	780	615	240		
1860	2070	3720	615	615	225		
1920	2025	3780	435	615	210		
2055	1935	150	555	615	195		
2235	1800	270	345	615	180		
2445	1605	390	120	615	165		
2460	1515	450	645	600	165		
2460	1500	510	405	585	165		
2445	1485	525	330	570	165		
2415	1470	540	285	555	165		
2400	1440	555	270	540	165		
2370	1425	555	255	525	165		
2310	1425	555	240	525	150		
2220	1395	540	210	525	135		
2145	1380	525	180	525	120		
2115	1365	510	150	510	105		
2085	1350	495	135	495	105		
2115	1335	480	120	480	105		
2145	1335	480	105	480	90		
2175	1320	525	105	480	75		

Appendix 3 – Data for optimising interface settings for phase three of the research

Please note the following when interpreting the results from the profiles tables:

- Ten able-bodied participants;
- Four profiles with 24 targets in each profile;
- Time on ‘Starting Area’ = 0.1 minutes;
- Maximum time to reach target = 1.0 minute;
- Maximum time on each tile = 150 ms;
- Blanking speed = 5 per second;
- Maximum number of targets = 6;
- No data in a cell indicated that the user did not reach the target;
- Screen resolution 800 x 600.

Table A3 1 – Profile 1

Profile 1 - Data for Analysis (time in sec)										
Participant	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Target 1	10.861			4.810		17.076				17.357
Target 2	23.409									
Target 3	6.102						14.388			
Target 4	16.710			4.349		16.324			0.580	
Target 5	3.045			1.415		2.529	4.795		1.276	0.211
Target 6	6.224	4.665		0.740		8.765	1.820			9.175
Target 7	4.614	15.111								
Target 8	25.540									
Target 9	5.615									
Target 10	5.415									8.892
Target 11										0.759
Target 12	15.148									14.245
Target 13	4.965	1.817		5.690				1.930	3.530	0.455
Target 14	3.024		2.107	1.505		5.745	3.575	3.411		7.662
Target 15	5.930					5.685				
Target 16	8.437					14.393				
Target 17	28.740									
Target 18	10.685									
Target 19	15.840					13.466				
Target 20	50.013	1.135				5.895				10.031
Target 21	5.063			10.869		2.545			5.179	0.667
Target 22	5.555	4.459		3.711		3.479	6.620	1.227		
Target 23										
Target 24	21.673						13.955			

Table A3 2 – Profile 2

Profile 2 - Data for Analysis (time in sec)										
Participant	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Target 1	0.480	12.187		0.605		3.075	10.280			25.611
Target 2	2.525	3.524				0.770	2.189			17.417
Target 3	9.970						32.945			8.754
Target 4	3.000						0.150			10.154
Target 5					1.659	9.708	0.558	3.517		0.230
Target 6	2.760				1.567	5.450	12.645			2.371
Target 7	6.315						18.970			1.369
Target 8	4.550				29.045		11.695			13.375
Target 9	2.687					0.734	4.270		2.782	5.986
Target 10	10.816			0.677		9.604	12.610			28.571
Target 11	44.662			0.737		2.662	3.636			20.015
Target 12	27.149	5.530				15.971	0.471			10.993
Target 13	7.920				1.349	6.435	0.649			0.809
Target 14	29.215					11.406	16.302			0.805
Target 15	13.271			1.216			4.219			9.734
Target 16	8.106			2.875		1.677	2.455			8.324
Target 17	26.421	0.900		1.805		1.387	17.165		2.824	5.244
Target 18	5.209	1.740				3.120	11.623		5.975	5.979
Target 19	40.348	3.822				7.556	11.776			33.775
Target 20	10.866			3.231		13.886	0.859			18.466
Target 21	4.289				4.346		1.045			1.542
Target 22	2.533			1.464		7.573	4.006			1.673
Target 23	3.657				1.010		16.881			14.188
Target 24						1.918				15.097

Table A3 3 – Profile 3

Profile 3 - Data for Analysis (time in sec)										
Participant	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Target 1		4.882					3.625			
Target 2	3.730						8.538			
Target 3	5.202	6.349								
Target 4	4.130									
Target 5	5.475	3.260					0.185			
Target 6							1.838			
Target 7	5.080						3.477			
Target 8							1.331			
Target 9	4.756						11.825	0.667		
Target 10	2.481									
Target 11							13.040	2.104		
Target 12		5.452								
Target 13	5.510	3.586					0.496	4.227		
Target 14							2.368	0.877		
Target 15	3.284						1.258			
Target 16							14.326			
Target 17	3.993						4.003			
Target 18		3.205					14.893			
Target 19	1.501									
Target 20	3.162						0.965			
Target 21	2.028	3.471					2.129			
Target 22	1.178	5.595					0.945			
Target 23							2.166			
Target 24							11.372			

Table A3 4 – Profile 4

Profile 4 - Data for Analysis (time in sec)										
Participant	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
Target 1	0.448						39.804			
Target 2	2.943						15.975			
Target 3	1.176						3.702			
Target 4	3.260						2.915			
Target 5	4.494						0.135			
Target 6							0.448			
Target 7	2.478						22.637			
Target 8	1.876						10.383			
Target 9	0.809						29.262			
Target 10	0.619						6.415			
Target 11							2.542			
Target 12							4.141			
Target 13	2.587						1.193			
Target 14	5.355						0.545			
Target 15	3.037						1.059			
Target 16							49.369			
Target 17	0.615						4.298			
Target 18	4.825						3.675			
Target 19	3.586						10.060			
Target 20	3.224						24.180			
Target 21	3.017						5.478			
Target 22	2.805						0.829			
Target 23	5.585						23.086			
Target 24	4.121						9.24			

Appendix 4 – Brain Injury Assessments and Diagnostic Tests

Patients with brain injury require frequent assessments and diagnostic tests (Sears and Young 2003). These include:

- **Neurological Exam:** A series of questions and simple commands to see if the patient can open their eyes, move, speak, and understand what is going on around them, e.g. a standard way to describe patient responses may be used (Roy, 2004). Most hospitals use the Glasgow Coma Scale (very useful for predicting early outcome from a head injury, e.g. whether the person will survive) or Rancho Levels of Cognitive Functioning (have proven more valuable for predicting later outcomes of head injuries*)*;
- **CT (Computed Tomography) Scan:** An X-ray that takes pictures of the brain or other parts of the body from different angles (Beers, 2003);
- **MRI (Magnetic Resonance Imaging) Scan:** Magnetism is used, instead of X-rays, to take pictures of the body's tissues (Owen *et al.*, 2005, Coleman, 2005, Kitamura *et al.*, 2003);
- **MRA (Magnetic Resonance Angiogram):** A test to look at the blood vessels in the brain and neck. (Beers, 2003);
- **ICP Monitor:** A small tube placed into or just on top of the brain through a small hole in the skull. This will measure the pressure inside the brain called intracranial pressure (Brettler, 2004);
- **EEG (Electroencephalograph):** A test to measure electrical activity in the brain (Chatrian *et al.*, 1996, Kostov & Polak, 1997b, Kotchoubey *et al.*, 1997);
- **Spinal Cord Disruption:** A head injury can be caused by damage to the spinal cord. Different injuries and degrees of spinal cord damage can be categorised by ASIA Impairment Scale (Dawodu, 2001);
- **PET (Positron Emission Tomography):** A test of brain functions using radioactive molecules (Beers, 2003, Owen *et al.*, 2005, Coleman, 2005);
- **Magnetoencephalography (MEG)** is the study of visual evoked brain activity in the human fetuses (Eswaran, 2002a, 2002b);
- **Near-infrared brain imaging** is the newest of a series of non-invasive methods for studying human brain function. It offers the possibility of combining neuronal and hemodynamic measures of brain changes in response to cognitive demands (Fabiani & Gratton, 2005).

Appendix 5 – Recommendations and Standard for Monitoring Brain Injury

There are various recommendations and standards for monitoring comatose and other unresponsive states (Chatrian *et al.*, 1996) such as:

- Detecting electroencephalographic signal (EEG), for a short period of thirty minutes or continuous monitoring of the electroencephalalographic signals. EEG is measured with electrodes on the scalp. The pattern of changes in the signals reflects some brain activity; for example the occurrence of certain kinds of oscillation patterns is known to be correlated with certain vigilance states of the subject. (Niedermeyer, 1987);
- Detecting signals when a person concentrates on an object termed evoked potential (EP) also called event-related brain potential (ERP). P300 signal (Kalat, 1995) is also a form of evoked potential (Donchin *et al.*, 2000). A signal termed N400 (negative potential) can also be elicited by faces and knowledge inhibition (activation of a visual or auditory word representation would induce the activation of knowledge). ERPs were recorded with a longitudinal and a transverse branch of w x electrodes placed according to the 10–20 system (Debruille *et al.*, 1996);
- Obtaining signals when users can indicate their interest in specific stimuli by choosing to attend or ignore it. Steady-State Visual Evoked Potential or SSVEP (Cheng *et al.*, 2002);
- Monitoring respiration, limb and body movements using stimuli applied to cardiac pace maker electrodes, termed electrocardiogram or ECG (Strum, 2002);
- Detecting limb and body movements (Fridlund, 1994, Berkow *et al.*, 1997) termed Electromyography (EMG);
- Detecting eye movements (Knapp *et al.*, 1995) termed electrooculargraphy (EOG);
- Detecting mental natural activity such as motor imagery (Pfurtscheller & Neuper, 2001);
- Detecting activity recorded from the cortical surface, termed electrocochleography (ECoG), which has a higher spatial resolution than electroencephalalographic signals (Lal *et al.*, 2005).

Appendix 6 – Glossary

Assistive technology Device - Any assistive, adaptive or rehabilitative device that enables independence for the disabled

Bio-potential - an electrical potential that is measured between points in living cells, tissues and organisms.

Brain-Body Interface (BBI) - is a real-time communication system designed to allow a user to voluntarily send messages without sending them through the brain's normal but only using bio-signals from the brain

Comatose - condition after a traumatic brain injury, which makes people completely paralysed, unable to speak or respond to anything

Cyberlink™ - a BBI Brain-Body Interface (manufactured by Brain Actuated Technologies) that detects bio-potentials using three silver chloride plated, carbon filled, plastic sensors in a headband and sends it to the interface unit

Discrete Acceleration - a paradigm that pushes the cursor in the direction of travel

Electroencephalalography (EEG) - Electroencephalalography measures electrical brain activity that results from thoughts or imagined movements

Electromyography (EMG) - Electromyography measures an electrical signal resulting from a contracted muscle

Electrooculargraphy (EOG) - Electrooculargraphic signals are low frequency signals derived from the resting potential (Corneal-Retinal Potential) by ocular or eyeball movements

Evoked Potential (EP) - a signal detected in the electroencephalalographic range is the evoked potential, also known as an event related brain potential (ERP), e.g. P300 and N400

Interaction paradigm - a pattern underlying an open family of interaction techniques that exploit common knowledge of effective user interface features

Invasive Brain-Body Interface - signals obtained by surgically inserting probes inside the brain

Local Field Potential (LFP) - signals in a human frontal cortex using implanted microwires in the sensorimotor regions of the neocortex.

Locked-in syndrome - condition after a traumatic brain injury, which makes people completely paralysed, unable to speak or respond to anything, but are cognitively intact.

Low Frequency Asynchronous Switch Design (LF-ASD) - a low-frequency asynchronous switch design is based on electroencephalalographic signals in the 1 - 4 Hz frequency range

Non-invasive Brain-Body Interface - electrodes placed externally on part of the body

PDA - a personalised interfaces using discrete acceleration

Slow Cortical Potentials (SCP) - Slow cortical potentials are signals of the cerebral cortex, which can be collected from the scalp surface

Steady-State Visual Evoked Potential (SSVEP)/ Steady State Visual Evoked Responses (SSVER) - responses obtained when users can indicate their interest in specific stimuli by choosing to attend or ignore it

Appendix 7 – Publications

Gnanayutham, P., Bloor, C., Cockton, G., (2001), Robotics for the brain injured: An interface for the brain injured person to operate a robotic arm, Antoniou. G., Deremer. D., (Eds.), October 2001, ICCIT'2001, New York, 93-98.

Gnanayutham, P., Bloor, C., Cockton, G., (2002), Researching Applications for Brain Computer Interface, Ability Magazine, Issue 42, March 2002, 20 – 21.

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Doherty, E., Stephenson G., Gnanayutham P., Fernandes, J., (2003), Robotics in Health Care – Designing Robot Controls to Accommodate Disabilities, Careers in Mathematics Symposium, October 2003, New York.

Doherty, E., Wong, Y., Fernandes, J., Gnanayutham, P., Stephenson G., (2003), The OWI-007 Robotic Arm, Cyberlink Interface, and Visual C++ Interface are a Great Help to the Handicapped and a Good Platform for Teaching Technology, Njedge.net Conference, October 2003, New York.

Gnanayutham, P., Bloor, C., Cockton, G., (2004), Soft-Keyboard for the disabled, Miesenberger, K., Klaus, J., Zagler, W., Burger, D., (Eds.), ICCHP2004, July 2004, Springer-Verlag Publishers, Paris, 999 – 1002.

Gnanayutham, P., (2004), Assistive Technologies for Traumatic Brain injury, September 2004, ACM SIGACCESS Newsletter, issue no. 80, 18 – 21.

Gnanayutham, P., Bloor, C., Cockton, G., (2005), Discrete Acceleration and Personalised Tiling as Brain-Body Interface Paradigms for Neurorehabilitation, CHI 2005, April 2005, ACM Press, Portland, Oregon, 261 - 270.

ROBOTICS FOR THE BRAIN INJURED: AN INTERFACE FOR THE BRAIN INJURED PERSON TO OPERATE A ROBOTIC ARM

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This paper discusses a pioneering area of research that is being carried out by Sunderland University that allows brain injured persons to do simple tasks using robotic arms. Although robotics have been used for helping disabled persons in various areas of disability, very little research has been done with the brain injured persons and robotics. This paper discusses the implementation of a simple model, which consists of brain body interface, a computer, an interface program, an electronic circuit to interface the computer to the robotic arm and a robotic arm. We hope to improve the lives of brain injured people once the pilot studies are completed

1 Introduction

This an extract from the statement presented to the 56th Session of the UN Commission on Human Rights in Geneva, in early April 2000, by Bengt Lindqvist. "Throughout the centuries we have designed and constructed our societies, as if persons with disabilities did not exist, as if all human beings can see, hear, walk about, understand and react quickly and adequately to signals from the world around them. This illusion, this misconception about human nature, this inability to take the needs of all citizens into account in the development of society, is the main reason for the isolation and exclusion of persons with disabilities, which we can observe in different forms and to different degrees all over the world. It will take a long time to change this pattern of behaviour, which is deeply rooted in prejudice, fear, shame and lack of understanding of what it really means to live with a disability".

"World estimates show that there are more than 500 million people who are disabled as a consequence of mental, physical or sensory impairment. This makes people with disabilities one of the world's largest minorities" [1].

The statement by the Commissioner on Human Rights shows that it is a right for all human beings to live without any prejudice and the second statement by Dr. Agarwal shows that the disable community is one of the world's largest minorities, which certainly need to be addressed. Many researchers and careers keep contributing to the area of disability to lessen the prejudice as we reach the twenty first century. Computer technology, Artificial Intelligence and the Human Computer Interaction also contribute to the goal set by the United Nations to make user interfaces that can be used by any user including users with special needs.

University of Sunderland has been carrying out extensive research in brain body interfaces for brain injured and has created human machine systems, which gives hands free access to the computers. This facilitates simple communications between the brain injured and the outside word, which was not possible until few years ago.

In this paper, we take the brain body interface communications a step further where the brain injured persons will not only communicate but will also be able to do simple tasks such as lifting a small item and having a closer look. Remember this is the only the beginning of research in the area of robotics for the brain injured.

2 Robotics for the brain injured

In this section we look at the communications devices used by the brain damaged users and the new device for carrying out simple tasks using a Robotic arm.

2.1 Brain Body Interfaces

Not all users with special needs can use a mouse, trackball, and keyboard or have the ability to speak to a speech recognition system. So we need a device that provides communication capabilities for those who cannot use any of the regular input devices.

There are many brain body interfaces; e.g.

- HeadMouse™ - (using wireless optical sensor that transforms head movement into cursor movement on the screen [10].
- Tonguepoint™ - a system mounted on mouth piece [9].
- Cyberlink™ - a brain body actuated control technology that combines eye-movement, facial muscle and brain wave bio-potentials detected at the users forehead [8].

All the devices above have their advantages and disadvantages. A user with cerebral palsy will not have good motor abilities to operate the 'Tonguepoint™'. A user with spinal vertebrate fusion may not be able to turn his or head and the HeadMouse™ will be of no use to this user. At present only the cyberlink™ seems to be applicable to the brain injured because it uses a combination of signals.

2.11 Cyberlink™

'Cyberlink™' can be used as a control technology that combines eye movement, eye blink, facial muscle and brain wave bio-potentials detected at the user's forehead to generate a mouse input that can be used for communicating. Cyberlink™ uses the forehead as noninvasive site, for convenience and also because it has a rich variety of bio-potentials. The signals for communications are obtained by attaching probes on the forehead of the patients. Basically it is 3 silver/silver chloride contact electrodes (i.e. non-invasive), which are placed on a headband that picks up EEG (brain wave), EMG (muscle movement wave) and EOG (Eye ball movement) signals when applied on the forehead. These are then fed into an amplifier box and then to the mouse port, so the computer just sees the device as a mouse, which, is used to control the cursor. The main signals used are due to muscle movement, only about 10% is due to thought processes (Brain wave). We used the cyberlink to communicate with the brain injured persons to get basic yes/no answers this time we want to go a step further and make the brain injured user perform simple tasks using a robotic arm.

University of Sunderland carried out extensive research in the area of brain body interface devices for communication instead of the regular devices for the brain injured persons. For many years brain injured patients were written off as vegetative patients but now there are some groups of brain injured who are able to communicate using the brain body interface devices [5,6,7]. There is still research being done in this area.

2.2 *Model for operating the robotic arm using the brain body interface*
The Model consists of following components:

1. A cyberlink™ brain body actuated control technology system that connects to the computer via the serial port
2. A computer with a parallel port and serial port free. An Interface program written in Visual Basic™ to operate the functions of the robotic arm
3. An Electronic circuit to read the parallel port of the computer and operate the motors that manipulate the robotic arm [2]
4. A robotic arm (Super Armatron™) that is operated using a series of motors [2]

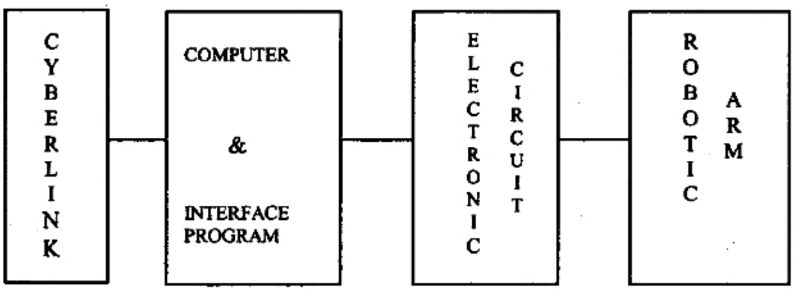

Fig. 1

The diagram in figure 1 shows the model for operating the robotic arm using the brain body interface. The computer needed one serial port for the cyberlink™ and a parallel port for the electronic circuit that interfaced the computer with the robotic arm. The cyberlink probes were attached to the forehead of the user and the other end of the cyberlink was connected to the serial port of the computer.

The computer had a program written in Microsoft Visual Basic 6.0™, which had six paths for controlling the robotic arm. The paths ended up in one of these functions, arm go up, arm down, arm left, arm right, open claw and close claw. When one of these six functions were triggered, the program sent a binary code to the parallel port, which drove one of the motors to carry out what was requested by the user. The Electronic circuit used in the above setup is shown below.

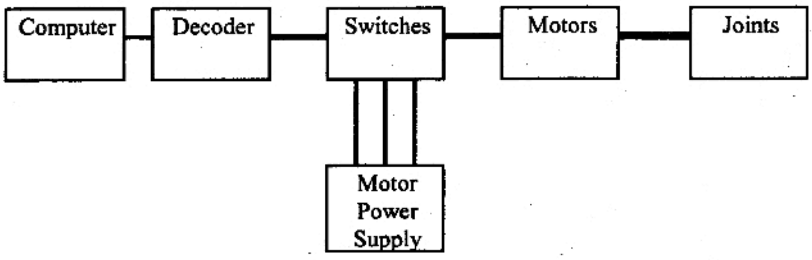

Fig.2

In the above diagram we see the block diagram of the electronic circuit that was used. The output from the parallel port was decoded and used for switching transistors. The transistors switched the motors on and off in either direction [2]. The mechanical side of the circuit included aligning shafts and making sure there were no vibrations.

3 Discussion

The meaning of the word "Robot" is slave worker (from the 1923 play Rossum's Universal Robots). The early uses of robots were mechanical devices using gears and levers. The advent of computers and the fast and furious new technology has given the robots the capability to perform sophisticated tasks others than mundane routine jobs. Robots are in action in the Military, Health sector, Manufacturing, Space exploration, Mining etc.

This paper tackled the area of giving this sophisticated and powerful robot as a tool for the brain injured who perhaps need it more than any other category of people. The research carried out at the University of Sunderland gave the brain injured people the opportunity to communicate using brain body interface devices [5,6,7], this new area of robotics for the disable mainly the brain injured is going to open a vast area of research which will end up in very useful applications for all the people regardless they have special needs or not.

Robots are being used in places such as Japan for caring for the physically handicapped people. These robots do the daily routine chaos thus taking the burden away from the careers and also saving a lot of money. The operators control these mobile robots through the Internet and mobile phones [12]. The new trend in robotics is to control robots remote using the Internet or mobile phone.

Robots have been in science fiction for many years and but now there is some exciting new research going on at the moment which is going to change many a brain injured person's life. Blinking or moving forehead muscles are quite tedious process for a brain damaged person. One new approach taps into electrical noise generated by the brain. A probe on the scalp is used to measure tiny amounts of current as the nerve cells fire. These biofeedback signals (EEG) can be used to communicate. The users can control these biofeedback signals and create regular patterns in order to use it as a cursor in a computer or operate other devices [3].

In another approach, probes are planted directly into person's brain to detect neurons in the area that once carried out a physical function for example controlled an arm. The area of research is very useful to locked-in patients. The electrodes planted contains proteins which encourage nerve cells to grow near the electrode [11]

The future of this research area covered in this article will only be successful if the government, commercial organisation, research personnel and care-givers work together to create robotic hands and feet for this group of handicapped people. There is whole world of applications to be created for the brain injured people.

4 Acknowledgements

We thank Professor Doherty for all the work he is doing in the area of brain injured people and all his encouragement in this new area of research "Robotics for the brain injured".

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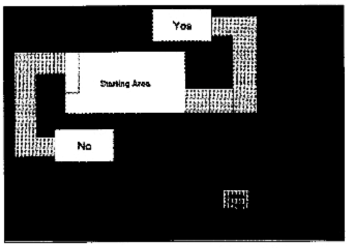
Interface to the brain

For the past eighteen months Paul Gnanayutham (De Montfort University), Chris Bloor (University of Sunderland) and Eamon Doherty (Fairleigh Dickinson University) have been working on new applications for brain computer interface devices. This study has necessitated researching various applications for users with special needs. The applications researched are still in their embryonic stage and therefore need more testing before they can be widely available.

Not all users with special needs can use a mouse, trackball, and keyboard or have the ability to speak to a speech recognition system. So we need a device that provides communication capabilities for those who cannot use any of the regular input devices.

There are many interfaces available. For instance there is HeadMouse, which uses a wireless optical sensor to transform head movement into cursor movements on the screen; Tonguepoint, a system mounted on a mouthpiece, and Cyberlink, which is a brain/body actuated control technology that combines eye-movement, facial muscle and brain wave bio-potentials detected at the user's forehead.



Simple Interface to say YES/NO

All interface devices have their advantages and disadvantages. A user with cerebral palsy will not have good enough motor abilities to operate Tonguepoint, and a user with spinal vertebrate fusion may not be able to turn his or her head, so the HeadMouse will be of no use. At present only Cyberlink (www.brainfingers.com) seems to be most suited to brain-injured people because it uses a combination of signals rather than relying on only one particular signal.

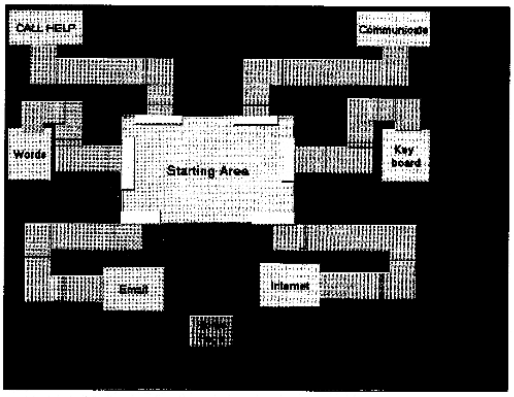
Gaining control

Cyberlink can be used as a control technology that combines eye movement, eye blink, facial muscle and brain wave bio-potentials detected at the user's forehead to generate a mouse input that can be used for communicating. Cyberlink uses the forehead as a non-invasive site for convenience and also because it has a rich variety of bio-potentials. The signals for communicating are obtained by attaching probes on the forehead of the patients. Three silver/silver chloride contact electrodes (ie non-invasive) are placed on a headband to pick up EEG (brain wave), EMG (muscle movement wave) and EOG (eyeball movement) signals when applied on the forehead. These are then fed into an amplifier box and then to the mouse port, so the computer just sees the device as a mouse, which is used to control the cursor.

Cyberlink comes with various games for recreation and training which are used to introduce Cyberlink to new users. However, there is one particular program of interest in the study, and that is the CAT (part of the Cyberlink program). This application allows a user to access a computer desktop via the Cyberlink, using EOG, EMG and EEG to move around the desktop and open files and applications by blinking or other signals from the cyberlink. CAT can be configured according to the needs of individual users. The team in all the applications described in this article used CAT.

Doherty and Bloor used the Cyberlink to communicate with brain-injured, non-verbal persons in the United States. Previously any communication would have been impossible with this group. The special users were also able to write simple words when prompted using the soft keyboard and Cyberlink.

In the UK the University of Sunderland has been carrying out extensive research in the area of brain-body interface devices as a means of communication for brain-injured persons, who for many years were written off as vegetative patients. Now, some groups of brain-injured people are able to communicate using the brain body interface devices, although there is still more research to be done in this area.



A complicated Interface for doing various tasks

A taste of things to come

In the last two years Gnanayutham, Doherty and Bloor have been working on further research into diverse areas. This article deals with some of this new research, although many of the ideas still need extensive testing on users with special needs.

Robots have been part of science fiction for many years, although some users with special needs already use robots for simple household chores. However, the brain-injured group has not harnessed this technology. The team has therefore been working to help a brain-injured user perform simple tasks using a robotic arm.

A paper, presented at ICCIT New Jersey last year, explained how a robotic arm can be interfaced with a Cyberlink to perform simple tasks for brain-injured people, using a computer with one serial port for the Cyberlink and a parallel port for the interface to the robotic arm.

Robotics aid movement

A Visual Basic program displayed six paths for controlling the robotic arm. The paths ended up in one of the functions of: arm up, arm down, arm left, arm right, open claw and close claw. When one of these six functions was triggered, the program drove a motor to perform the operation requested by the user, and the robotic arm was able to move left, right up, down and use claws to pick up a small object. This showed that in future brain-injured people could use robotics to do some basic tasks such as picking up a small object and moving it closer to the Cyberlink user.

Gnanayutham took this technology to India, where the brain computer technology was tried using simple Visual Basic interfaces which allowed the users to communicate by using simple phrases and access applications such as the internet. The interfaces were translated to the local language and included simple phrases such as 'Thank you', 'Yes', 'No', 'I am hungry' and so on. The users were able to go to the internet site and access the sites set as default by their carers.

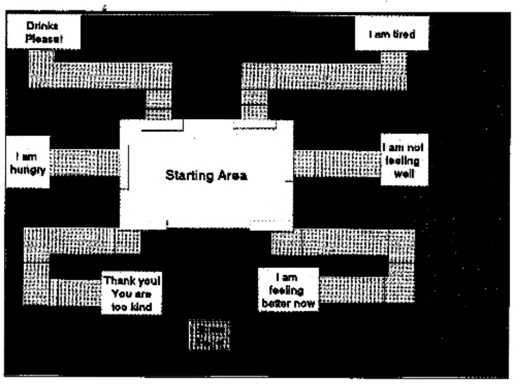
Using the internet worked as long as the browser refreshed periodically without any user intervention. Sites that could be viewed using the interface were news and sports, which gave the users some recreation. The participants in India were a mixed sample aged from eight to 70 years. The older participants had Parkinson's disease, the after-effects of strokes or had become non-verbal after various illnesses. They were able to use a simple Visual Basic Yes/No interface to communicate with their families for the first time in many months.

The brain-body interface was also tested at Mother Theresa's Institute for children with cerebral palsy. Out of 30 children tested, 12 were able to use the brain-body interface via the Visual Basic interfaces to communicate with their carers. The other children couldn't communicate because they were unable to comprehend the text on the Visual Basic interface.

Valuable lessons

The main lesson learnt in India was that it is impossible to create one interface and expect it to be used for every participant with traumatic brain injury. Every person has a slightly different version of disability, therefore any program we create has to cater for individual needs. Cyberlink was the best choice of brain computer interface for this research since it used variety of signals to communicate.

There is still a lot of research being done at the University of Sunderland in this area and the team is grateful to the following Indian Institutes for their help and encouragement - Vimhams, AIMS and Missionaries of Charities.



This interface gives some common phrases that can be used for communications

Artificial Intelligence to Enhance a Brain Computer Interface

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Abstract

This paper discusses an investigation carried out in designing and testing neurorehabiliatory communication interfaces for nonverbal quadriplegic and other clinically brain damaged persons. For many years this group of people could not communicate with the outside world and this was accepted as norm. This important study collected the information from neurologically disabled persons by conducting simple communication tasks and created interfaces for communicating with the outside world for the very first time. The study was conducted in two phases the first phase being an exploratory study and second phase being the new improved version taking into account the results from the first phase. It was proved from the first phase of the study that every disabled person is an individual and cannot be grouped in any way when designing interfaces. It was also discovered that the users found the brain body interface impossible to use without artificial intelligence support to steer the cursor on a computer screen.

1 Introduction

This paper deals with this category of disability and provides means to communicate reliably for the very first time (the best existing work is not reliable [4]). Over the last four decades advances have been made in the design and construction of aids and appliances for disabled people. Having considered various assistive devices this research chose the Cyberlink™ as the best device for the brain injured quadriplegic nonverbal participants. The design process involved using the Cyberlink™ with appropriate programming interfaces. Various interfaces were designed to cater for different brain injured groups. These interfaces were tested with participants. This was the first phase of this project, which proved beyond any doubt, that every disabled person regardless of having a particular type of disability was still an individual with his or her own characteristics. Hence each one needed an individual profile not a group profile based on some generic clinical syndrome or diagnosis. This characteristic was included in the second phase of the design. This necessitated giving the disabled user a target test, where targets appeared at random, at different parts of the screen, and the user has to move the mouse cursor on to the target at a within particular time specified by the program. Areas for placing the targets and the number of targets could thus be chosen to cater for each individual user, giving his/her individual profile.

2 Brain Body Interface

Assistive technology may be helpful in allowing these people some form of control of a personal computer allowing them to communicate or recreate. Assistive technologies fall into various categories. One of the categories is Brain Body Interface, which may be the only technology suitable for brain injury [5]. There are many brain body interfaces; e.g.

- HeadMouse™ - using wireless optical sensor that transforms head movement into cursor movement on the screen [15].
- Tonguepoint™ - a system mounted on mouth piece [13].
- Cyberlink™ - a brain body actuated control technology that combines eye-movement, facial muscle and brain wave bio-potentials detected at the users forehead [8].

All the devices above have their advantages and disadvantages. A user with cerebral palsy will not have good motor abilities to operate the 'Tonguepoint™'. A user with spinal vertebrate fusion may not be able to turn his or head and the HeadMouse™ will be of no use. Only the cyberlink™ seems to be applicable to the brain injured because it uses a combination of signals [6]. The research only concentrated on communications for the brain injured, hence dealt with the electric signals emanating from brain waves, muscle contraction, eye movement or some combination thereof. Having considered various assistive devices this researcher chose the Cyberlink™ as the best device for brain injured nonverbal quadriplegic participants [3, 9, 10, 14].

3 Experimental Methods

This section deals with the methodologies used and the two phases of the investigation. Phase one was carried out in the following institutes Mother Teresa's Missionaries of Charities New Delhi, Vimhans New Delhi, Choithram Hospital And Research Centre Indore. Phase two of this investigation was carried out at the following institutes Holy Cross Hospital Surrey, Castel Froma Lemington Spa and at various private homes.

3.1 Methodology

The ethics boards at each institution approved these inquiries for the investigation of the Cyberlink as an assistive technology. It should be noted that the investigators obtained all permissions and informed consents from the institutions, participants, and/or their guardians before research began. A wide range of research methods is used in Human-Computer Interaction (HCI, [7]). For brain-body interfaces, methods range from experiments with unimpaired individuals on aviation tasks [12] to a blend of experiments and field studies [4]. The study reported here uses naturalistic inquiry [2] within field studies. Very little was known about the participants at the beginning of the research. The information available about the participants varied greatly, inconsistent, and unreliable. The cognitive level of the participants and their ability to perform tasks varied greatly from week to week. Contextual Inquiry and Design is a user-centred technique employed by industry to learn about the role people play in their organisational settings [1].

3.2 Participants

The participants had a diverse background of physical abilities ranging from no disability to severe motor impairment. All have formal assessments from large hospitals that diagnosed mental retardation or brain injury. The objective mental ability of some participants is unknown due to brain injury and can only be obtained from estimates of the attending personnel and from parents. The responsible physicians or their guardians were asked to provide approximate ratings Participants for the phase one of the study fell into these groups:

- Group 1 – Brain injured because of Cerebro vascular accident (Stroke)
- Group 2 – cerebral palsy with mental retardation with/without sensory deprivation
- Group 3 – highly spastic cerebral palsy with mental retardation
- Group 4 – persons with no physical or mental impairments that affect Cyberlink™ use
- Group 5 - (miscellaneous) – A case of severe Parkinson disease was included in the study

It was decided upon examination of resources, that thirty participants would be the maximum amount of participants that could be accommodated in the phase one of this study study. The results obtained from phase one was used as the foundations for the second stage of this investigation. The ten participants for phase one could be assigned to one of three groups:

- Group 1 – Brain injured because of Cerebro vascular accident (Stroke)
- Group 2 – Traumatic brain injury and brain stem fracture
- Group 3 – Miscellaneous

However each participant is an individual with little similarity to the other. Each participant was able to get an individual interface according to the target test results.

3.3 Phase One

The first program in this phase was to see whether the participant could move the cursor in all directions within a tunnel based program similar to that reported in [4]. It was found that most participants were able to do part of this controlled experiment but because there were various potentials being picked in their forehead by the Cyberlink™ the users were finding it almost impossible to control the cursor on a computer screen. This showed that there was a necessity to control the cursor. This finding brought in the second set of interfaces written in Visual basic. The idea here was to control the cursor and keep it in the maze. The participants were able to use this but it took a lot of effort, causing frustrations and fatigue. This suggested a need for Artificial Intelligence in this interface. This enabled the users to communicate using this simple interface and answers their questions for the very first time after the brain injury (Figure 1). The VB program analysed the direction of the cursor and moved the cursor along to help the user. The 'Yes/No Program' allowed motor impairment persons to answer leading questions put forward by the medical professionals, attending personnel or relatives. The interface has three-turn maze to reach the target and the cursor has been kept in a pipeline, which did not allow the cursor to move beyond the pipe. The doctors liked the maze because the brain injured person could be asked to navigate prespecified paths that demonstrated some form of control and intelligence [4]. Times taken to reach the target were recorded. The participant was asked to navigate the cursor to select the yes or no in relevance to the asked leading questions, which were randomly selected. Ten questions were randomly selected and asked randomly to different participants. A more sophisticated was also created for some of the participants to use simple phrases to communicate. This interface is shown in Figure 2.

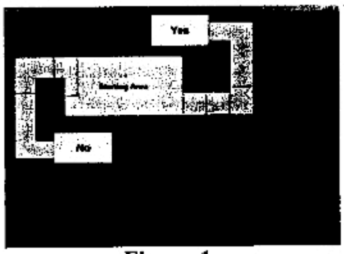

Figure 1

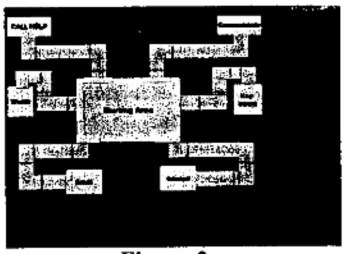

Figure 2

3.4 Phase Two

This phase of the program was to solve problems encountered in the first phase. The programming language used this time was Visual C++. The first problem encountered was the unintentional movements of the cursor when brain body interface is used. The cursor moved around the computer screen without much control from the user, picking up EOG, EMG and EEG signals,

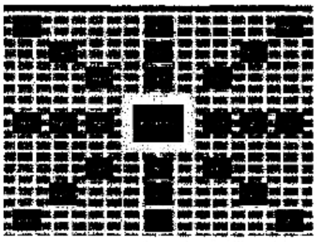

Figure 3

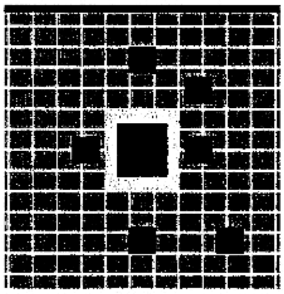

Figure 4

which brought frustration to the user. This necessitated in the need for controlling cursor, so that the user can take full control. This was done by splitting the computer screen into tiles and configuring the time spent on each tile, size of tile, gap between tiles, time to reach a target, etc., to suit each individual user. With this new interface the users were able to take full charge of the brain body interface Cyberlink and the control of the cursor. It takes a lot of effort for a disabled person using Cyberlink™ to move the cursor from a particular area of a computer screen to another using brain wave voltage, which are very small. This meant artificial intelligence had to be added to the Interface design. Single targets appeared randomly in different parts of the screen, the user had to reach each target in a given time interval. A user can have two to six targets at the final desktop depending on the severity of their disability. The targets are shown in (Figure 3). The final individual interface can look like Figure 4. Artificial Intelligence played a big part in the final design. Fuzzy logic sets were used to enhance this interface. And the final the design was tested with volunteer brain injured participants. The results obtained showed that some of the participants were able to communicate for the first time after their injury. The program itself was easier to use after adding artificial intelligence and running the target-testing program to create individual profiles for each user. As explained earlier the screen is split in to tiles with a gap between the tiles. The carer can choose the dimensions of the tiles, targets, time delay on each tile etc. This gives the opportunity to individually configure each interface. The only movement to be done by the users will be to jump from tile to tile. The users of this phase of the investigation were severely disabled, there was hardly any EOG and EMG, the researcher had to depend very much on EEG, which is the thought process. The program calculated the direction each time the user moves the cursor from tile to tile, if there is a target in that direction, the target blinks to indicate to the user the intended target and takes the cursor to the nearest edge of the tile in the direction of the target, this is repeated until the user reaches the target or moves the cursor to a tile touching the target, this minimises the effort needed by the user. If there are no targets in that direction, the fuzzy logic algorithm waits for further cursor movement by the user. The program chooses the target by calculating the minimum angle from the direction of the cursor, in case there is more than one target in the same direction. Figure.4 shows a typical interface, the targets can be programmed to say simple phrases such as YES/NO, launch applications or send signals to the parallel port. So a brain injured user can communicate, launch the Internet or send a signal to the parallel port and switch the light on.

3.0 Conclusions and discussions

This investigation shows how Artificial Intelligence can be used to enhance a Brain Computer Interface. By adding fuzzy logic the interfaces became communication devices for the severally brain injured giving them the first opportunity to communicate. More artificial intelligence can be added by using Knowledge base and also neural nets to discover any patterns than can be utilised to enhance the communications, thus creating neuro-fuzzy systems. The researcher would also like to suggest that the medical community could also investigate the use of the Cyberlink™ with persons of locked in syndrome as a tool to assess their consciousness level. Any study in partnership with computer scientist and medical professionals will open wide avenues of research in rehabilitation medicine.

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Robotics in Health Care – Designing Robot Controls to Accommodate Disabilities

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ABSTRACT: Approximately 6 million Americans suffer from brain injury or spinal chord injury. An unknown subset of this group is severely motor impaired and may not be able to feed themselves independently. We at FDU created a few prototypes of mental / facial controlled robotic arm systems that allow a man to independently eat a snack. However one of the prototypes was much better than the rest because it used good design criteria for the buttons on the interface. The design criteria came from interviews with Bruce Davis and the results from the application of the mathematical equation of Fitts' Law.

INTRODUCTION: Approximately 6 million Americans suffer from brain injury and spinal chord injury. An estimated two percent of the population of the United States suffers from brain injury [1]. To improve the quality of life for such individuals, the group in England and the United States have collaborated on designs for an interface using visual c++ that is used in conjunction with a brain computer interface to control a robotic arm. Several prototypes were created for use in the United States with the Don Johnston Sensor switch but one was better because the designs of the buttons incorporated data from a mathematical equation.

In this paper we will also look at Paul Gnanayutham's design in England that requires the user to use a Cyberlink Mental Interface to direct a cursor to buttons to select robotic functions. Paul uses the Cyberlink because it can use low strength signals that the Don Johnston sensor switch cannot detect and this suggests the Cyberlink is better for severely motor impaired with little to no ability to perform facial muscle activity.

PROF. DOHERTY'S APPARATUS FOR USE WITH LESS SEVERELY MOTOR IMPAIRED PERSONS: We used a Don Johnston sensor switch and transducer for creating a mouse click [2]. The sensor switch was attached to an electrode on the paralyzed man's forehead with tape (See Figure 1). The laptop was an IBM Thinkpad with an 866 MHz processor and Windows XP was used along with a device driver to allow us to send signals to the robotic arm via the parallel port. The robotic arm was an OWI-007 and the interface board was assembled by the students and was an RAI-007. Both the items are available from the Images Corporation [3].

PROF. DOHERTY'S DESIGN PHIILOSOPHY: It is our design philosophy to use one giant button that restrains the cursor and keeps it on the button so as to eliminate distance and be more easy to select according to the Fitts' Law equation. (See Figure 3) The more you reduce distance to the button, the more you reduce the difficulty to select it. It is also mathematically demonstrable that the larger the button, the easier it is to select the button.

PROF. DOHERTY'S METHODOLOGY: The user was instructed to look at the screen and every 2 seconds a new robotic arm function such as "grip open" or "grip close" would appear. The user's cursor was restrained on the button. The user only had to furrow his or her brow slightly to perform a click.

PROF DOHERTY' RESULT: The user was able to eat one snack independently in a ten to fifteen minute session if there was no major equipment failure.

Figure 1. Bruce Using Sensor Switch to Operate a Robotic Arm to Eat Snacks

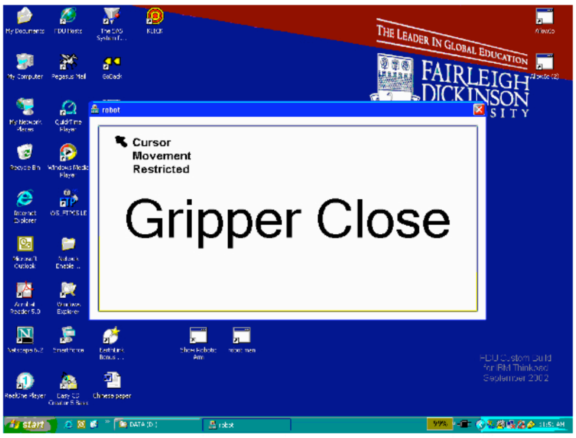

Figure 2. One Large Interface Button that Changes Robotic Function Messages Every 2 Seconds with the Cursor Restricted

PAUL'S METHODOLOGY FOR USE WITH CYBERLINK AND MORE SEVERELY MOTOR IMPAIRED PERSONS: The user was instructed to look at the screen and think as well as make faces to move the cursor to the button. A series of paths were used to guide the cursor toward the target but also allowed the user to make the cursor "back out" if the user changed his or her mind and decided not to select that function (See Figure 3).

PAUL'S APARATUS: Paul used a Pentium 133 MHz computer because he was also working with test subjects in developing nations that did not have access to computers that Prof. Doherty's test subjects had access to. The robotic arm was a discontinued radio shack Armatron that can be obtained on many online auctions for about twenty US dollars. The idea of using arm was that it was approximately 50 dollars cheaper than Prof. Doherty's arm, which makes a difference in some developing nations. The mental interface was a Cyberlink mental interface that can be found at B.A.T. technologies [4].

PAUL'S. DESIGN PHIILOSOPHY: It is our design philosophy to allow the user to move the cursor at anytime to select a button to operate a robotic arm function. There is some difficulty involved but it allows the user more freedom and the user is not wasting time waiting the opportunity to choose a button as in the Doherty design. We try to use big buttons and less distance to the cursor in our design because the Fitts' Law equation show a relationship between cursor size and distance to the button and difficulty. (See Figure 4)

PAUL'S RESULT OF USE WITH CYBERLINK WITH MORE SEVERELY MOTOR IMPAIRED PERSONS: Larger buttons were easier to select then small buttons and large buttons took less time than selecting small buttons. This design allowed the user more freedom to control the robot arm than the prof. Doherty design but the result was that it required more skill [5]. There are tradeoff in any designs.

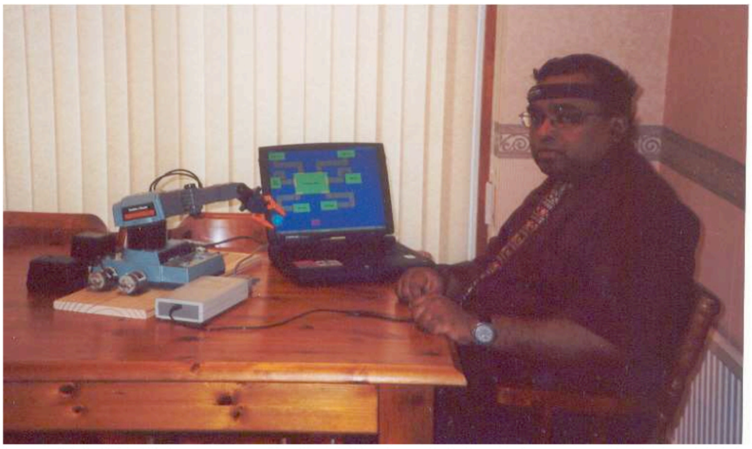

Figure 3. Prof. and Ph.D. student Paul Gnanayutham with the Radio Shack Armatron and Cyberlink Mental Interface

DISCUSSION OF FITT'S LAW:

By substituting numbers in the equation, we see that a small target such as a button at distance X is more difficult to obtain or "click" than the same size small target at distance 2X. We can also substitute numbers and see a large button at distance X is easier to "click" or obtain than a small button at distance X.

ID is a metric derived from the Fitt's Law equation.

$$\mathbf{ID = -log_2 (W_s/2A)\ Bits\ /\ Response}$$

A = distance to target, measured in distance or in pixels on the computer screen,

W_s = Width of Target or Variability of Movement

IP = ID / t, bits per second (bps)
where t = time in seconds to hit target

Figure 4 . Fitt's Law Equation

Distance in Pixels to Button	Width of Button	Index of Difficulty
100	100	1
100	300	.59
200	100	2

DISCUSSION OF BOTH RESULTS: We see that Paul's design allows a more severely motor impaired person the ability to improve his or her life by doing small activities of living with the robotic arm. Paul's design allows a person the ability to move the robotic arm parts in any order they want so there is no specified sequence. However; we see by Fitts' Law that larger buttons are easier to select than smaller buttons. The equation also demonstrates that buttons that are closer to the cursor are easier to select than the same size button far away.

Prof. Doherty's design restricts the cursor to the large button, which makes selection of robotic commands to operate the arm very easy to do. Test trials with disabled persons also demonstrate this. However; the Fitts' law equation does not produce a valid answer when the distance is zero but at values close to zero we see the difficulty is almost non existent. Prof. Doherty's design is simple to use and reliable but the operation of the arm is extremely slow and all commands must be selected in a specified sequence.

CONCLUSION: The designs of Prof. Doherty and Paul Gnanayutham are both good. Paul's use of the Cyberlink allows more severely disabled persons than those in Prof. Doherty's study the ability to move the robotic arm because the Cyberlink uses both EEG from the brain and EMG from muscles where the sensor switch used by Prof. Doherty uses EMG from muscle movements. However; we see by Fitts' Law that Paul's design requires more skill by the user to select buttons to control the robotic arm. Prof. Doherty's design requires much less skill but is more time consuming and the waiting through the sequences of robotic commands could bore the user. In the end it is up to the disabled person, their families, and their medical personnel to which system they should use.

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The OWI-007 Robotic Arm, Cyberlink Interface, and Visual C++ Interface are a Great Help to the Handicapped and a Good Platform for Teaching Technology

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INTRODUCTION

It was my opinion until recently that combining the goals of inspiring students to learn, helping the handicapped, and using inexpensive technology was not possible. Then I found that the OWI-007 robotic arm, (an off the shelf biological interface device, an electronic interface kit connecting RS232 to robotic arm), could be combined with student made visual basic or visual c++ .net programs to make a mental / facial controlled system for quadriplegic people. The robotic arm system just described has allowed Bruce Davis the opportunity to independently feed himself snacks for the first time in sixteen years [1].

Declining Number in Computer Students

It is generally agreed that computer hardware, software, and electronic technologies change at a fast rate. Many adult learners and full time students at my university have expressed anxiety over such changes and have left computer science for fields that change at a slower pace and thus alleviate their anxiety with respect to rapidly changing technology. Some of these same students that left have privately told me that it is their perception that computer science is a very cold technology oriented field that does not allow one to serve humanity by improving people's lives.

Increasing Computer Science Enrollment and Inspiring Students

With these sentiments in mind I created a class called Mind Operated Devices with Robotics that inspired the morale of the class and the department. Many faculty and students at the university sent email, called, or said to me in person that they were also inspired by the work as was featured in the school magazine with a circulation of 100,000 people; the New York Times; and local television. [2,3] There are many factors that influence enrollment, such as a sluggish economy, or lack of employment. It would be arrogant and inaccurate to say that my class was the only factor in the upswing in enrollment and the retention of students. However; nine students have come up to me unsolicited, and told me that they came to my university or changed plans to transfer. This was solely because they wished to work on brain computer interfaces and robots with the handicapped people and I. It's my belief that any community college or university could implement a similar class that generates similar publicity and boosts enrollment. It appears to me that the popularity of the class is because it allows people the opportunity to learn technology while fulfilling the most fundamental human desire to help our most helpless members of society. All the students said they like the class because they can build, test, and document a complete system from start to finish with real users. People in industry have called and told me they like the humanitarian aspects of the project but really have respect for students who can see a project through to term with full documentation.

The Development of the System

Part I. The Hardware

The class started with students studying the fundamentals of signals generated from the brain and muscle movements. Such signals are known as electroencephalography (EEG) and electromyography (EMG). The students were also introduced to two quadriplegic men who wanted to move items on a table or eat snacks. The students then learned to do a *contextual inquiry and design* to obtain the facts about what the men wanted and the environment they wished to use the proposed system in [4]. The students then had paper prototypes of the proposed system

The third step was to have each student purchase an OWI-007 robotic arm trainer kit. The arm was chosen because of its high functionality of five degrees of freedom while maintaining a low cost. Many of the students put the robotic arm kit together and learned principals such as torque, kinesthetics, and about servomotors. This electro-mechanical construction let me lead into the next topic of electronics. The students learned to read a schematic, identify and understand components, and finally how to solder parts in a printed circuit board. This meant that we had the hardware components of the course completed. We also had the paper prototypes and user requirements from the contextual inquiry and design that drove the design of the remaining parts of the system.

Part II. Developing the Software Interface

The fourth step was to create the software interface. One could have used any visual integrated development environment but we chose Microsoft visual c++ .net because of the student pressure on the faculty to use software that is of interest to private industry and thus improve student chances for employment upon graduation. The software consisted of a large button that changed text every two seconds showing a different robotic function (see figure 1). The button took up approximately one fourth of the user's laptop screen so that the text was a minimum of 48 point and thus allowed persons with low vision to see the button. The changing of the text at a rate of two seconds was done after doing some basic target acquisition tests with user. A slower rate allowed some users with more severe trauma an opportunity to select the button more consistently because of their impaired perceptual motor response but the slower time frustrated other users. The two second timer can be easily implemented by a command SetTimer(1,2000,NULL) in the OnInitDialog function. The fundamental idea of this interface is that commands are shown to the user one at a time and the user only needs to do one event, namely click, to operate the arm. This is also generally known in the assistive technology software development field as single switch software control.

It was later discovered that the cursor often moved off the large button due to the shifting of the laptop or involuntary movements of the user. Visual c++ and all the other visual languages allow one to define the button as a rectangular object and then confine the cursor it. Please see figure 2 for defining such a shape and restricting the cursor. The OnTimer function caused text to change every 2 seconds and incremented a counter. If the user saw the desired function on the screen and clicked, another function would check the value of the counter and send a signal corresponding to the desired robotic function to the port to operate the robotic arm (see figure 3). We modified the program so that the arm would stop flashing commands and the arm would continue the desired robotic arm motion until the user clicked again. Once the user clicked again, the arm would stop and the button would cycle through the commands again.

The switch we originally used was a Cyberlink mental interface that cost two thousand dollars. It could take EEG or EMG or any combination and use them to do a single event such as a click. The performance was acceptable but we wished to find a lower cost solution for economically disadvantaged users.

We then used the Don Johnston sensor switch that was approximately five times cheaper than the Cyberlink. However it could not detect and use EEG from brain waves but could be tuned to accept small signals detectable on the frontallis or brow. This signal went to a Don Johnston transducer that could be manually configured at any time to create a double click, single click, space bar, or enter button control. We liked the low price and flexibility of the Don Johnston sensor switch. It is important to remember that the sensor switch does not detect EEG and thus leaves out large populations of users without muscle movements, such as those with advanced ALS.

The quadriplegic people were able to use the two input devices to operate the robotic arm to move objects around a table for entertainment purposes and Bruce Davis could feed himself (figure 4). It is noteworthy that Bruce Davis was the only participant who takes food orally. The students were presented with plaques and filmed with Mr. Davis. This increased the moral of the students and Bruce as well as his long-term care facility. Joel Fernandes has made friends with the impaired test subjects in addition to learning his visual c++ interfacing skills and electronics. Joel is also really happy that he has had his first chance to implement a system from beginning to end, see it used, and write a report. Joel's skills were valued enough that he was given a short-term paid software development position at Helen Hayes Rehabilitation Hospital. He has also felt a personal fulfillment from helping others and implementing theoretical concepts. Many computer science departments only teach concepts and students and employers sometimes complain such students cannot build or implement systems for actual users.

Paul Gnanayutham has a variation of the interface for use with the Radio Shack Armatron. He has worked with hospitals in England and India under the tutelage of Dr. Chris Bloor to further improve the lives of quadriplegic worldwide. Paul has also found that students in England and India have responded with the same enthusiasm to apply technology for the service of others.

New Uses of the Technology as a Teaching Tool

I recently wanted to teach tele-robotics because students indicated a need for government entities to hire people to control work on hazardous materials from a safe location. I then added Microsoft Net-meeting objects to the toolbox in visual c++ and changed the interface. This has allowed the laptops with robotic systems connected to a network to become telerobotic systems. We did have to add a $20 low-resolution webcam. We found the delay of the video and robotic movements acceptable for our recreational purposes.

Future Uses as a Teaching Tool

It is our opinion that the system can be adapted, as a teaching tool as student and industry desires change. Gary Stephenson and his associates for example are working with me on adding another webcam and microphone so that the telerobotic system can have telemedicine applications. Gary does some consulting for the NHS in England and wishes to upgrade the quality of the parts when the concept is proven to work reliably.

We have also already used the same single switch software concepts and programming techniques with the sensor switch to operate an onscreen telephone with a text to speech voice synthesizer. This allowed non-verbal paralyzed users to operate a telephone and communicate again as demonstrated in the New York Times [3]. This also boosted student and department moral and has probably positively increased enrollment as students tell their family and friends on TV and in person about the wonderful systems they developed.

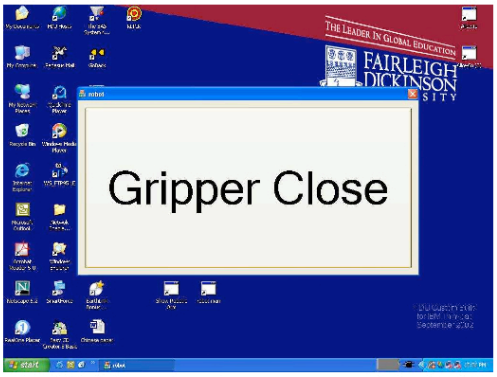

Figure 1 – One Large Button Interface

```
Crect rcBtn;
CWnd* pBtn=GetDlgItem(IDC_BUTTON1);
PBtn->GetWindowRect(rcBtn);
SetCursorPos(rcBtn.left+20, rcBtn.top+20);
```

Figure 2. The Visual C++ Code to Restrict the Code to the Surface of the Button

Figure 3. Bruce Davis Using a Cyberlink, Student Program, and Robotic Arm

```
void CrobotDlg::OnBnClickedButton( )
if ((counter==1)&& (is_moving==false))
    {
          _outp(lpt1,gripper_open);
          is_moving=true;
    }
    else if ((counter==2)&& (is_moving==false))
    {
       //button1.SetWindowText("Gripper Close");
       _outp(lpt1,0x01);
       is_moving=true;
    }
    else if ((counter==3)&& (is_moving==false))
    {
        //button1.SetWindowText("Wrist Left");
        _outp(lpt1,0x06);
        is_moving=true;
    }
```

Figure 4. A Portion of the Visual C++ .NET Code to Operate the Robotic Arm

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Soft Keyboard for the disabled

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Abstract. This paper discusses an investigation carried out in designing and evaluating a neurorehabiliatory communication interfaces for nonverbal Quadriplegic and other clinically brain injured persons. Research was conducted where brain-injured persons communicated using a brain-body interface and a computer program with simple text such as Yes, No, Thanks etc. This research was further developed into a soft keyboard, which gave a brain-injured person an interface to create simple sentences. The users used the soft keyboard with a brain body interface. This paper reports on the soft keyboard developed and the experimental results of this research.

1 Introduction

This study collected the information from neurologically disabled persons by conducting simple non-invasive communication tasks and created interfaces for communicating with the outside world for the very first time, after a brain injury. Soft keyboards have been designed and implemented for disabled users in the past but this study covers the new area of soft keyboards for the brain-injured. This group of non-verbal, quadriplegic users will manipulate the keys using a brain body interface. As medical technology not only extends our natural life span but also leads to increased survival from illness and accidents, the number of people with disabilities is constantly increasing. World estimates show that there are more than 500 million people who are disabled as a consequence of mental, physical or sensory impairment. This makes people with disabilities one of the world's largest minorities [1]. Approximately 5.3 million people, currently live with disabilities resulting from brain injury [12]. It is estimated that there are 2.2 annual hospital admissions for traumatic brain injury for every 1000 people of the population in the Western World [12]. A certain percentage of these brain-injured people cannot communicate, recreate, or control their environment due to severe motor impairment. At the 52nd meeting of the Third Committee, on 29 November 2001, the representative of Mexico introduced a draft resolution on an international convention on the rights of persons with disabilities and was adopted on 19 Dec. 2001.

2 Assistive Technology

Assistive technologies fall into various categories [11]. The research reported here only concentrated on communications for the brain injured, hence dealt with the electric signals emanating from brain waves, muscle contraction, eye movement or some combination thereof [9]. Having considered various assistive devices, we chose the Cyberlink™ as the ideal device for the brain injured non-verbal participants [2][3][4][5][7]. Cyberlink™ consists of three electrodes (non invasive) in a headband wired to an instrument that magnifies brain waves 500,000 times. Through biofeedback techniques and slight facial movements, patients can use the Cyberlink™ to communicate via a computer interface. The signals for communications are obtained by attaching a probe on the forehead of the patients. Basically it is 3 silver/silver chloride contact electrodes (non-invasive), which are placed on a headband and pick up EEG (brain waves), EMG (Facial Muscles) and EOG (eye movements) signals. These are then fed into an amplifier and then to the mouse port, so the computer just sees the device as a mouse, which controls the cursor [5][9].

3 Past Research

Past research involved using the Cyberlink™ with appropriate communicating interfaces. The design process went through various stages of development. It started with a simple interface written in Visual Basic, which gave the opportunity for this group of disabled people to say yes or no for simple questions [7][8]. This research proved beyond any doubt, that every disabled person regardless of having a particular type of disability was still an individual with his or her own characteristics. Hence each one needed an individual profile not a group profile. The next design problem encountered was the unintentional movements of the cursor when a brain-body interface is used. This identified a need for better control over the cursor. This was done by splitting the computer screen into tiles and configuring the time spent on each tile, size of tile, gap between tiles, time to reach a target etc to suit each individual user. Now this research has been taken a step further by changing the targets into a soft keyboard that uses cursor control and audio feedback to help participants make simple sentences.

4 The Soft Keyboard

A soft keyboard (Fig.1) is made up of alphanumeric keys (shown in blue), control keys (shown in green) and configuration keys (shown in grey). This is an on-screen keyboard that can be configured to suit and individual user. The keyboard can be used in two modes: normal and scan mode. In normal mode, the user moves the cursor to a key and keeps the cursor on a key for a pre-defined time. This will display the alphanumeric character, read the key in an audible voice and jump to the middle of the Starting Area. This will be repeated for each character. This is to cater for brain-injured users who can move the cursor but cannot perform a click. In the scan mode the keys will be scanned row by row and the user need to perform a click and choose the key. This will display the alphanumeric character, read the key in an audible voice and continue scanning. The control keys perform Backspace, Caps Lock, New Line (or enter), Read (reads what the user has written in the display window), Clear (clears everything in the display window) and Exit. There are two grey configuration buttons, "Close" and "Change Workspace". These two buttons are for the exclusive use of the carer. "Close" button is to close the application. When you click on the "Change Workspace" button, it will open into window shown in Fig.2. This window enables the carer to change the following parameters of the keyboard:

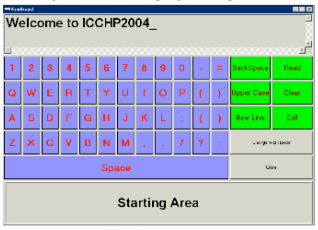

Fig.1

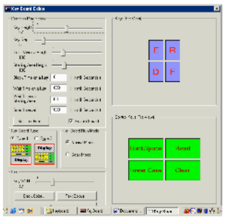

Fig. 2

- Key Height/Key Gap
- Keyboard Layout
- Text Window Height
- Stating Area Window Height
- Wait time on a Key
- Wait time on the starting area
- Font
- Enable/Disable Sound

5 Experimental Results

The ethics boards at each institution approved this research, using Cyberlink™ as an assistive technology. It should be noted that the investigator obtained all permissions and informed consents from the institutions, participants and/or their guardians before research began. When it came to this research, there was no previous methodology so a new methodology was developed. The approach used was one of developing a prototype interface using non-disabled people as test subjects, then evaluating the interface with brain-injured participants. This allowed better feedback at the development stage and faster development. Many versions of the programme were developed to get the appropriate individual interface. The keyboard was tested with ten able participants for refining the prototype. Having designed the prototype, the keyboard was tested with five brain-injured participants. Two of the disabled participants (39yrs, 60yrs male), were able to make simple sentences e.g. "I am hot", "I am tired", "I can understand", "thank you" etc. There were carers who believed these two patients did have the capacity to understand but until this study there was no evidence to prove this. The next two participants (32 yrs, 43yrs, male) gave inconsistent results and one disabled participant (61yrs, female) was unable to use it at all.

6 Conclusions

This keyboard was evaluated with Cyberlink™ but can be used with any mouse or switch; hence the researcher hopes other users with motor sensory deficiencies will consider it [6]. The most powerful feature of this keyboard was the "Change Workspace" which offered configuration facilities for this keyboard to set individual preferences according to the level of disability.

Acknowledgements

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Assistive Technologies for traumatic brain injury

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Abstract

This paper discusses an investigation carried out on choosing the appropriate brain-body interface for a group of non-verbal severely brain injured participants to aid communication and recreation. Although extensive research has been carried out in the last few years with invasive and non-invasive brain-body interfaces for the traumatic brain injured community, not enough has filtered through to be used as an everyday tool for communications.

Introduction

Assistive technologies have done much to improve the quality of life of individuals with impairments. However, one group has received little, if any, benefit to date from assistive technology. This is the traumatic brain injury community. Approximately 5.3 million people worldwide currently live with disabilities resulting from brain injury [11]. It is estimated that there are 2.2 annual hospital admissions for traumatic brain injury for every 1000 of the population in the Western World [15]. In the UK, it is estimated that 5.2 out of every 10,000 people suffer a serious head injury each year. Although many research groups are doing extensive research in the assistive technology area, very little technology has filtered through to the traumatic brain injury sufferers.

Brain-Body Interface

Over the last four decades advances have been made in the design and construction of aids for the brain-injured. These fall into two categories. The first requires the use of some movement, speech, or breath to operate a computer input device. Examples include: HeadMouse™ - using wireless optical sensor that transforms head movement into cursor movements [13,24], Tonguepoint™ - a mouth piece [28], eye-tracking – a camera follows eye movements [14]

A user with cerebral palsy may not have sufficient motor ability to operate the 'Tonguepoint™' or users with spinal vertebrate fusion may not be able to turn their head, so the HeadMouse™ will be of little use to them. Users who are partially paralysed may not be able to move their eyes. Hence there is a need for special assistive devices for this group of people. This is done by using the electrical signals emanating from brain waves, muscle contractions, eye movements or some combination of these (using the bio-potentials) [23]. The last ten years have seen many research groups working on developing Brain-Computer Interfaces, either invasive [19, 28, 22, 20] or non invasive types [2, 1, 25, 29]. The researchers mentioned in these references have set up brain-computer interface labs, carried out extensive work and also implemented many applications such as spelling, operating robots and controlling wheel chairs. Many of these research ideas are slowly entering into the community.

As for my research the Cyberlink™ [12,16], was used as the brain-body interface [8,9], which is an example of the second category of aid. It is a brain-body actuated control technology that combines eye-movement, facial muscle and brain wave bio-potentials detected at the user's forehead. Having considered various assistive devices for our research, Cyberlink was chosen as the best device for brain injured quadriplegic nonverbal participants [22].

Eamon Doherty using the Cyberlink has opened up an entirely new spectrum of assistive technologies [4-7], which are particularly appropriate for people with traumatic brain-injury, especially those who suffer from "locked-in" syndrome, and appear to be comatose, but are actually sentient [3]. The Cyberlink uses a combination of bio-potentials [10] read from three silver/silver chloride contact electrodes (non-invasive) attached to a users forehead. The signals for communications are obtained by attaching a headband, which holds these electrodes in place, over the forehead of the patients. A cable from the headband feeds these signals into an amplifier that amplifies them 500,000 times and then separates out EEG (brain waves) [17,18,21,25], EMG (Facial Muscles) and EOG (eye movements) signals [21]. The Cyberlink connects to the mouse port, so the computer just sees the device as a mouse, which controls the cursor. It is thus possible to operate the cursor using either a combination of physiological signals, or through EEG, EMG or EOG signals alone.

Conclusions and Discussions

As this study shows extensive research has been carried out in the last few years with invasive and non-invasive brain-body interfaces for the traumatic brain injured community, not enough has filtered through to be used as a everyday tool for communications. One of reasons for this lies with the ethical areas of the research. For any research to be tested with real patients, consent has to be obtained from the participants or the institute which looks after them. The laws can be so stringent in this area; obtaining consent to work disabled participant becomes almost impossible. Any study in partnership with computer scientist and medical professionals will also open wide avenues of research in this area.

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Discrete Acceleration and Personalised Tiling as Brain-Body Interface Paradigms for Neurorehabilitation

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ABSTRACT

We present two studies that have advanced the design of brain-body interfaces for use in the rehabilitation of individuals with severe neurological impairment due to traumatic brain injury. We first developed and evaluated an adaptive cursor acceleration algorithm based on screen areas. This improved the initial design, but was too inflexible to let users make the most of their highly varied abilities. Only some individuals were well served by this adaptive interface. We therefore developed and evaluated an approach based on personalized tile layouts. The rationales for both designs are presented, along with details of their implementation. Evaluation studies for each are reported, which show that we have extended the user population who can use our interfaces relative to previous studies. We have also extended the usable functionality for some of our user group. We thus claim that personalized tiling with discrete acceleration has allowed us to extend the usable functionality of brain-body interfaces to a wider population with traumatic brain injury, thus creating new options for neurorehabiliation.

Author Keywords

Neurorehabiliation, ,Input Devices, Brain-Body Interfaces, Cyberlink™, Assistive Technology. Accessibility.

ACM Classification Keywords:

H5.2. User Interfaces, Input Devices and Strategies.

IMPAIRMENT, ASSISTIVE TECHNOLOGY AND BRAIN-BODY INTERFACES

On December 19 2001 the General Assembly of the United Nations adopted Resolution 56/168, entitled "Comprehensive and integral international convention to promote and protect the rights and dignity of persons with disabilities" [23]. The world is committed to reducing the impact of physical and cognitive impairment on an individual's quality of life. However, as medical technology not only extends our natural life span, but also leads to increased survival from illness and accidents, the number of people with disabilities increases. Estimates are that more than 500 million people worldwide are disabled as a consequence of mental, physical or sensory impairment, which makes people with disabilities one of the world's largest minorities [1].

Assistive technologies have done much to improve the quality of life of individuals with impairments. However, one group has received little, if any, benefit to date from assistive technology. Traumatic brain injury can completely remove the ability of individuals to communicate, recreate, or control their environment in any way. Approximately 5.3 million people, currently live with disabilities resulting from brain injury [19]. It is estimated that there are 2.2 annual hospital admissions for traumatic brain injury for every 1000 of the population in the Western World [23]. In the UK, it is estimated that 5.2 out of every 10,000 people suffer a serious head injury each year [36].

Existing assistive technology is of limited, if any, use for many people with traumatic brain injury. However, assistive technologies may be the only means for such people to communicate, control their environment and recreate via a personal computer. Over the last four decades advances have been made in the design and construction of aids for the brain-injured. These fall into two categories. The first requires the use of some movement, speech, or breath to operate a computer input device. Examples include:

1. HeadMouse™ - using wireless optical sensor that transforms head movement into cursor movement on the screen [21,34]
2. Tonguepoint™ - a system mounted on mouth piece [38]
3. Eye-tracking – a system follows eye movements [22]

Many traumatic brain-injured are so impaired that they cannot use any devices in this category. A user with cerebral palsy may not have sufficient motor ability to operate the 'Tonguepoint™'. Users with spinal vertebrate fusion may not be able to turn their head, so the HeadMouse™ will be of no use. Users who are partially paralysed may not be able to move their eyes. The needs of such severely impaired individuals are being addressed by a second category of aid that requires no movement, speech, or breath to operate them. Instead, they use electric signals emanating from brain waves, muscle contractions, eye movements or some combination of these [33]. The last ten years have seen many research groups working with this second category of aid, developing Brain Computer Interfaces, either invasive [28,7,39,32,30] or non-invasive types [29,5,4,2,35,6,42].

The Cyberlink™ [20,25], used in our research, is an example of the second category of aid. It is a brain-body actuated control technology that combines eye-movement, facial muscle and brain wave bio-potentials detected at the user's forehead. Having considered various assistive devices for our research, we chose the Cyberlink as the best device for brain-injured quadriplegic nonverbal participants [14]. It may be the only usable aid for brain-injured nonverbal quadriplegic participants [20]. Previous research by the last two authors and Eamon Doherty using the Cyberlink has opened up an entirely new spectrum of assistive technologies [11-16], which are particularly appropriate for people with traumatic brain-injury, especially those who suffer from "locked-in" syndrome, and appear to be comatose but are actually sentient [9]. One such individual has become a very valuable contributor to research, yet his capabilities went unrecognised for many years [3,15,24]. Brain-body interfaces are particularly relevant to this group, since their apparent comatose state rules out all other interaction devices.

The Cyberlink uses a combination of signals [17] read from three silver/silver chloride contact electrodes (non invasive). The signals for communications are obtained by attaching a headband, which holds these electrodes in place, over the forehead of the patients. A cable from the headband feeds these signals into an instrument that magnifies them 500,000 times and then separates out signals from EEG (brain waves) [26,27,31,36], EMG (Facial Muscles) and EOG (eye movements) [31]. The Cyberlink connects to the mouse port, so the computer just sees the device as a mouse, which controls the cursor. It is thus possible to operate the cursor using either a combination of physiological signals, or through EEG, EMG or EOG alone. Moving the cursor is a form of biofeedback, and thus people can learn to use slight facial movements and/or changes of mental state (e.g., relaxing or tensing) to control the cursor.

In this paper, we report how we have built on previous work in collaboration with Eamon Doherty to develop two new complementary interaction paradigms for brain-body interfaces. Doherty found that successful participation in research does contribute to the cognitive and neural rehabilitation for traumatic brain injury [11-16]. We therefore saw much value in seeking to extend the scope of brain-body interfaces, in terms of both the population who could use them and in terms of what (some) users could do with them. Thus in two studies we have developed, evaluated and refined two new complementary approaches to providing means to communicate, recreate and carry out some simple tasks for people who would otherwise remain unable to perform any such activities.

TRAUMATIC BRAIN INJURY AND BRAIN-BODY INTERFACES

Doherty conducted various initial experiments using games to investigate the response of able and disabled participants [14]. Then he went on to develop a simple Yes/No communication interface [11-13]. Doherty's participants used the Cyberlink in their normal care settings and some were able to communicate with medical staff, their carers and family for the first time in years. Doherty thus established the possibility of brain-body interaction for the brain-injured, resulting in a profound impact on two of his participants and their families [11,13].

Doherty's success was limited and inconsistent, although two participants could use no other computer input device. While for them, anything was better than nothing, it was clear that improved control over the cursor would extend the population of brain-injured who could use the Cyberlink, as well as the functionality that could be accessed through it.

The Cyberlink can pick up various unwanted bio-potentials, and thus move the cursor to an unintended area of the display. Such uncontrollable, erratic movements cause users frustration and fatigue. Bringing the cursor back under control takes considerable effort, and may be impossible. Doherty reduced the impact of input noise by restricting the path of the cursor, first within a series of different maze structures, and finally using tunnels leading to buttons [11-14].

The research reported here was carried out in two studies. The first aimed to replicate Doherty's work with his tunnel interface. Once replicated, a small change, adding discrete acceleration to cursor movement, was made to the interface that greatly improved performance overall. However, this change was not enough to make the most of the wide variations in capability in the user population. A second study incorporated discrete acceleration into a more flexible and personalised interface. This proved to be usable by a larger (albeit still tiny) population than in Doherty's studies, and over a wider range of functionality.

The next section covers general issues concerning iterative prototyping with traumatic brain-injured users. Subsequent sections cover each study in detail, ending with conclusions from our studies.

HCI RESEARCH WITH BRAIN-BODY INTERFACES FOR THE TRAUMATIC BRAIN-INJURED

Four general issues need to be considered before presenting details of the two studies. Firstly, working with brain-injured participants presents considerable challenges that make it extremely difficult to control confounding variables, and even to measure them. Secondly, ethical approval may require demonstration of existing prototypes to reassure institutions and guardians. Also, medical approval is required for each session, as a participant may be considered too unwell on a specific day. Lastly, design approaches require the use of formal experiments to inform design and evaluation. Simpler iterative development is not enough.

Brain-Injured Participants

Some of the participants in our studies may or may not have locked in syndrome. We have no accurate statistics on how many locked-in state people exist in the world. Although medical technology has advanced immensely in the last forty years, assessing the brain-injured is still very challenging. Their cognitive abilities are often not assessed because of their physical inability to respond to anything [18]. Medical personnel find it hard to establish the appropriate medical classification with this group of disabled patients (e.g. so as not to give a patient a diagnosis of coma when they actually have locked-in syndrome — [9]). This further complicates matters in performing research with such participants, since it is not known if some of these people are aware but unable to respond, or are really comatose.

One participant in Doherty studies has his medical revised from comatose to persistent vegetative state (a.k.a. locked in syndrome) [14]. Our prototypes are thus diagnostic tools that have been used to distinguish between the fully comatose and the locked in. This makes it very difficult to know whether usability problems are due to our prototypes, or due to the fact that a participant may be comatose and unable to interact with anything at all.

Our studies have also triggered medical staff to reassess participants' capabilities. These have often not been fully assessed due to the challenges associated with brain trauma. We have encountered participants who were partially blind, but no medical tests had been carried on their sight, since such tests cannot establish whether the brain is processing information from the eyes.

Thus research with traumatic brain injured inevitably starts with a lack of crucial information about participants from medical personnel, caregivers and the relatives. As a result, a researcher can come to know more about a participant's capabilities than anyone else. Even so, the severity of brain injury made it very difficult to know what information was being processed, e.g. the eyes maybe working but the brain might not process any information from the eyes. However, as noted, the service of medical practitioners was very valuable during initial visits, since they could advise on the condition of the participant and authorize an experimental session, and also initiate tests to investigate capabilities.

Further problems arise from the difficulty of tracking participants over long periods. Some participants become more capable as a result of the Neurorehabilitation associated with Cyberlink use and move onto other devices (as in Doherty's more recent studies). Sadly, participants may also die during the course of the research. Several died during Doherty's studies and one of our most capable participants has died since the submission of this paper. This makes it impossible to compare alternative interfaces over a long period with the same participants.

Difficulties in access to, and understanding of, severely impaired users means that it is best to develop a prototype interface using able-bodied participants, then evaluate the interface with brain-injured participants. This allows rapid feedback at the development stage, given the relative ease of access to able-bodied participants. Also, if able-bodied users have difficulties, it is highly likely that brain-injured users would be even more challenged. It is thus best to iterate with able-bodied users until a prototype is suitable for use with severely impaired users.

Ethical and Medical Approval

Several institutions in India and the UK supported this research. The ethics boards at each institution approved this research, using the Cyberlink as an assistive technology. Permissions and informed consents were obtained from institutions and all participants and/or their guardians before research began. A medical practitioner assessed the physical suitability and any medication that ruled out participation in a specific session.

The researcher conducted demonstrations for the staff of participating institutes and for participants' family members. The audience in these demonstrations could use the Cyberlink to assure themselves on safety aspects, and also address any doubts they had about the technology.

Design Research Methods

Human Computer Interaction investigates how people interact with computers with the aim of improving the design of interactive software [9,10,33,37,40]. Many research methods can be applied to the study of computer tools and how humans interact with these tools [18]. However, HCI is also a design discipline, which requires a particularly broad combination of methods when developing and evaluating.

Doherty's research combined formal experiments with wider field studies [11]. The research reported here has been more experimental in nature, using a method known as naturalistic inquiry [8]. Each version of the new brain-body interfaces was used with a group of participants to collect data from the performance of tasks with the tool. Trends in the data gave rise to questions that were used to form hypotheses that can be tested in further experiments.

This is an extension [11] of the familiar HCI approach of iterative development driven by evaluation, where at each iteration, a version of a design is updated to incorporate the findings of a previous iteration, and is then evaluated. In our approach, formal experiments are needed to both inform design and to explore causal hypotheses that attempt to explain evaluation results. The researchers conducted experiments with able participants before choosing dimensions, for tunnels, starting area, target area etc., before taking the interface to the final experiment. This is vital when using novel interaction technologies. With more established technologies there may be less need for formal experiments [11]. A key point here is that the motivation for both experiments and design options can often only be understood in the context of a long series of prototypes. Designs are not rationally synthesised from first principles, but instead are focused responses to specific challenges arising within naturalistic enquiry [8].

One key issue for this research has been how to handle wide differences in capability, both between individuals and at different times for the same individual, for several impairments. Assistive technologies may be improved by some form of adaptation to individual needs. Doherty however had largely explored universal designs, which were the same for all participants, although a range of Cyberlink settings had to be set manually at the start of an experimental setting [11-14].

Adaptation can take three forms [41]:

Adapted user interface – adapted to end user at design time

Adaptable user interface – the end user can make changes

Adaptive user interface – the dynamic behaviour can change at run time

Previous work by Doherty used *adapted interfaces*, with Cyberlink parameters determined for each session. We began our studies with the view that an *adaptive* user interface would improve performance. This turned out to be true in the first study, and the adaptive discrete acceleration algorithm was retained for the second study. However, further benefits were achieved by adding *adaptable* features in the second study.

STUDY ONE: DISCRETE ACCELERATION FOR BRAIN-BODY INTERFACES

The starting point for this study was the results of Doherty and his collaborators, combined with insights from the first author's initial independent use of the Cyberlink [16]. There were two aims. One was to replicate Doherty's results with his tunnel interface (Figure 1 [12,13]). The other, based on the author's initial independent use of the Cyberlink, was to explore the potential of adaptive cursor algorithms within the tunnel interface, with the hope of overcoming the inconsistencies and limitations reported in Doherty's work.

Study one needed as many participants as possible. The total number of participants was thirty. There were problems in finding suitable participants in the UK. Eleven able-bodied participants were recruited for initial prototypes, but the researcher (first author) had to work with Indian institutions to find disabled participants for this phase. The researcher and a medical practitioner carried out a study with nineteen disabled participants abroad using Mother Teresa's Missionaries of Charities, New Delhi and Vimhans, New Delhi.

Study one was a rather intensive study, lasting two months, with regular visits to institutes. Each participant was visited only once, as this was an exploratory study. This phase of the research checked the abilities of the participants to reach Yes and No targets in a tunnel interface (Figure 1). This let some users communicate using this simple interface to answer questions for the very first time since their brain injury. Questions were provided by medical professionals, attending personnel or relatives, and were randomly selected from this pool. Doctors liked the maze because the brain-injured person could be asked to navigate pre-specified paths that demonstrated control and intelligence, thus replicating Doherty's use of Cyberlink interfaces as a diagnostic tool with doctors [11].

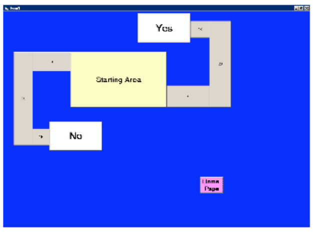

Figure 1 – Basic Tunnel Interface

Doherty's final interface (Figure 1 [13], i.e., two three turn tunnels to targets that constrained cursor movement, was tested with all participants). The route and the time taken to reach the targets were recorded to provide insights for future design refinements and extensions. As expected, there was only limited success due to the various potentials picked up from the forehead by the Cyberlink™. Even some able-bodied participants in initial prototyping could not move the cursor to one part of the screen. Even participants who could use the first interface had to make strenuous efforts, causing frustration and fatigue. Some impaired participants found it almost impossible to control the cursor, or could be unable to move the cursor in some directions. A participant who was paralysed on one side could not steer the cursor to the left. This confirmed that ways had to be explored to improve control of the cursor and to ease movement within the maze. An alternative interface had been prepared to test this conjecture (Figure 2). It used 'discrete acceleration' to address known problems from Doherty's research, which were confirmed in this study, and operates as follows:

1. The user moves the cursor in a particular direction
2. Pre-defined areas in the maze make the cursor jump onward in the direction of travel, thus accelerating the cursor by a discrete step (based on the size of the area). Figure 2 highlights some of these areas.

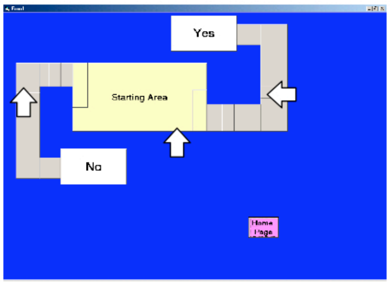

Figure 2 – Example areas for discrete acceleration

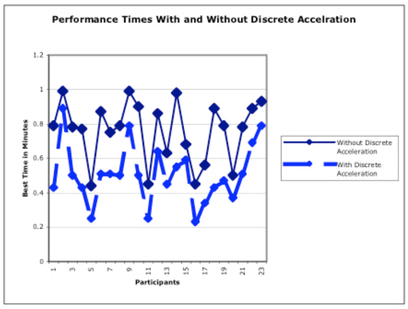

Figure 3 – Mean times with/out discrete acceleration

Evaluation

The results from study one showed clearly that adding Discrete Acceleration improved the times taken by individual users to reach the targets. Figure 3 shows that participants' average times were always faster with discrete acceleration. A t-test shows that the differences are significant at the 1% level.

However, six participants (some able-bodied) could not answer questions at all using the Cyberlink. For the able-bodied users, there was no question of them being comatose rather than locked in. They may have been very adversely affected by a pervasive problem with cursor control. Uncontrollable bio-potentials (physiological signals) cause the cursor to get stuck at various areas of the tunnel. When impaired users became frustrated, carers had to take over. Tunnels do meet Doherty's aim of corralling the cursor, but performance is still adversely impacted by signal noise — the cursor will move around the display with little effort, picking up 'irrelevant' EOG, EMG and EEG signals, frustrating users. 'Relevant' signals are very small voltages, which can be lost in the noise.

Records of individual's routes indicated that, within the tunnels' constraints, no one used regular routes to reach a particular target, which may be due to the extensive noise on signals. This further showed problems with consistent control of the cursor. Extensive cursor tracking data was collected, but there was no discernible regularity, and thus there appears to be no opportunity to extend adaptive cursor movement using AI techniques such as neural nets [15].

In tunnel and maze interfaces, users who could not move through the predefined route could not communicate. Hence an interface to cater for individual needs had to be investigated. In the first authors' exploratory studies, both able and disabled participants found certain areas of the computer screen easy to navigate, but others were much harder to reach.

Summary

This first study allowed us to conclude that:

- Adding discrete acceleration improves performance, but does not overcome the problems of inconsistency that arise with brain-body interfaces. There was no apparent basis for more intelligent adaptive acceleration due to major inconsistencies in user performance and behaviour across sessions.
- A 'universal design', even in the form of an assistive technology, penalises users whose capabilities do not match the demands of the interface — personalisation is required to make the most of each individual's capabilities (a person with no EOG from eye movement may be unable to move the cursor horizontally). There were even able-bodied participants who were unable use this interface.

The need for a personalised interface was more important than the benefits of discrete acceleration. Alternative designs for speeding up tunnel navigation were not tested. In theory, shorter tunnels may have been as effective as discrete acceleration (short distance to targets is an option in Personalised Tiling Interfaces). However, this would have resulted in a smaller display area, which may not have worked well with the common combination of visual impairment and shared use of the display from a distance (participants' bed postures could place them some distance from the display).

STUDY TWO: PERSONALISED TILING FOR BRAIN-BODY INTERFACES

Study two aimed to add adaptable features to the interface to produce a better match between device demands and user capabilities. This had to be achieved with minimal training time, and allowing reconfiguration of the interface at any time. We could see no advantage in remaining with Doherty's tunnel paradigm, which we abandoned in search of a more flexible interface that would combine discrete acceleration within a new paradigm that could be personalized for individual capabilities, and thus hopefully reduce the impact of noise and consequent erratic involuntary movement of the cursor by presenting users with targets that best matched their capabilities.

For the second study, it proved possible to recruit participants within the UK. The first author wrote an article requesting participants in disability magazines and web sites connected with brain-injury to recruit disabled participants, and was contacted by partners/parents of brain-injured people. Demonstrations were made at both Holy Cross Hospital, Surrey and Castel Froma Nursing Home, Leamington Spa to hospital/care staff and partners/parents of brain-injured persons. Both organisations granted permission for research to be carried out at their premises after obtaining individual consent from each participant. Ten participants were granted consent by the two institutes. The study lasted nine months. The first four months of the study was spent on design. The design went through various stages, with tests initially carried out with ten able-bodied participants. The evaluations were both summative and formative. There were five versions of the interface program.

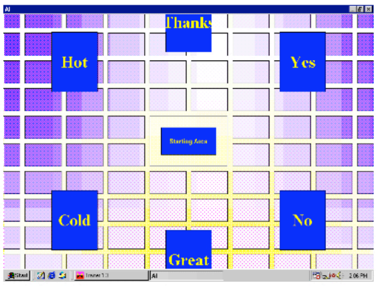

Figure 4: Targets, tiles and gaps between tiles

Prototypes were developed for study two that dropped tunnels in favour of placing target buttons in areas suited to individual users. Figure 4 shows an example of this interface. Then the interface was tested with the disabled participants, using the individual abilities and bio-potentials that could be used. If a disabled user moves a cursor in any direction consistently we were able to create an individual interface and communicate effectively. The initial tests with the disabled participants were to find out how much EEG, EOG or EMG that can be harnessed. The severity of the participants gave only EEG signal for communicating.

In order to support discrete acceleration, the computer screen is divided into tiles, which support discrete jumps from one tile to the next predicted tile on the user's route. However, the lack of regularity in user's cursor paths in study one ruled out a wholly adaptive algorithm, with the following algorithm being implemented instead:

- The user moves the cursor through the gaps between tiles and aims for target using the tiles as stepping-stones. The cursor can be moved to any direction if the users choice.
- When a cursor reaches a tile. The program calculates the angle of travel and takes the cursor to nearest edge to any target in that direction and makes the target flash.
- If there are no targets or two targets in the same direction of travel, the program waits for the user to make another cursor movement and repeats the previous step.
- The configuration took care of all timings, there were individual times allocated for every task, which mean the interface automatically recovered to the original position (i.e. starting point in the middle) this taking care of error recovery.

An earlier attempt to use fuzzy logic to control cursor movement is reported in [15]. The above is still however a universal design that only takes account of user differences at run-time. Irregularities in user input rule out jumping directly to the nearest predicted target. Instead, a step by step approach is taken that leaves the user in control at each point. A wholly automated approach would introduce high error recovery costs given the limited capabilities of the traumatic brain-injured.

The interface thus has further features that allow the cursor's path to be controlled by settings for a specific user (Fig. 5). These settings include Time spent on the starting area to relax the user before navigating to a target, time spent on each tile to control the bio-potential in such a way controlled navigation can take place, size of tile to suit each user, smaller tiles will control the cursor better, but will take longer to reach the target, gap between tiles to suit each user, bigger the gap the more work for the user and time to reach a target, depending on the disability of the user. With these parameters in place, the personalized tiling interface is operated as follows:

- A carer creates an individual profile using the configuration window (Figure 5) to set dimensions (tiles, gaps between tiles, targets, starting area), times (for reaching target, delay on a tile or starting area, on a target) and number of targets.
- The "start training" button (Figure 5) is pressed.
- A target test appears (Figure 6), and where a single target appears at random on the display. Users have to reach each target in a given time interval. If a user doesn't reach a target in the allocated time the cursor returns to the starting area to minimise frustrations from not reaching a target. The time to reach each target is recorded.
- At the end of the target test, the fastest targets are chosen for a user's individual profile. A user can have two to six targets as the final desktop profile, depending on the severity of their disability, and the tasks they need to perform.

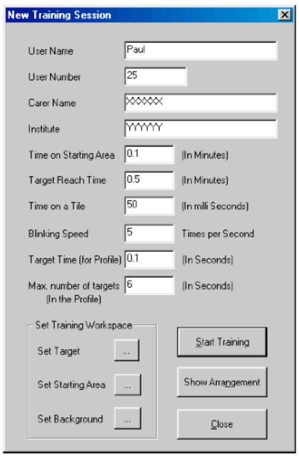

Figure 5: Configuration Window

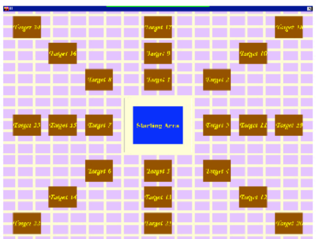

Figure 6: Target test

There is also provision for the font and colour to be changed to suit each user, to cater for sight disabilties. The interface can also be configured to read out the text label of a target when hit. Further configuration windows allow words or phrases such as YES/NO, THANKS etc to be associated with a target (Figure 7). Once this test was done an individual profile was created. When the BCI interface had to used next time, all the carer had to do was to double click a desktop profile icon.

Study two also aimed to extend the usable functionality of brain-body interfaces for severely impaired users. Features were added to launch applications for a pre-configured time limit (Figure 8) and to use switch devices to send signals to the parallel port for a pre-configured period (Figure 9 — use of parallel port to control a robotic arm for a disabled user has already been demonstrated [16]). The interfaces to these extensions currently require considerable technical expertise, including the direct entry of binary strings. They were developed quickly for sole use by the researcher. However, the ability to switch on devices and launch applications can enrich the lives of brain-injured individuals. Interfaces that can be used by carers and family need to be developed to make this more accessible.

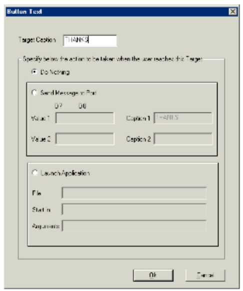

Figure 7: Text to audio and target caption configuration

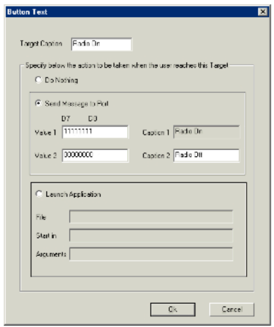

Figure 8: Configuration for switch devices

These extensions allow a brain-injured user to communicate using text to audio, launch a program such as the Internet or send a signal to the parallel port and switch on the light television etc. The application launched was mainly the Internet, though there is potential here for future users of this interface.

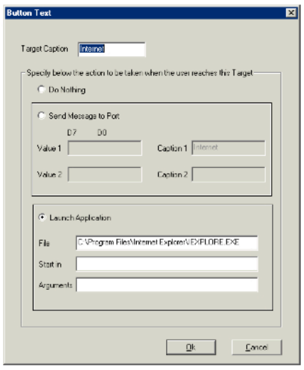

Figure 9: Configuration to launch applications

Evaluation

Ten brain-injured volunteers were recruited to evaluate the fifth and final version. Five were unable to participate in the research. This was due to the visual impairment of these participants. They thus cannot be compared with the three participants in Doherty's later studies, who all had adequate vision. It is better to think of study two as only having five, rather than ten, suitable participants.

The five suitable participants produced hardly any EOG and EMG, making cursor control very dependent on EEG, i.e., on the brain rather than the body. They are thus comparable to the three participants in Doherty's later studies, and like them, there was no evidence that they could use alternative input devices. The head of Participant 5 had to be held by a brace, which prevented the EMG being used for communications. Participant 10 had a twitch, which also resulted in unreliable EMG signals. This meant these two participants had to rely on EEG to move the cursor along the screen, effectively limiting them to a two-target Yes/No interface for communicating with an average success rate of 70%.

The evaluation was started by giving each participant two tasks to determine their suitability for the research. These tasks were as follows:

- Respond to requests from the researcher
- Use Cyberlink and their bio potential to move the cursor around in any direction on the screen

We received encouraging feedback from a locked-in syndrome participant, who used his thumb to indicate approval. All five suitable participants (4, 5, 8, 9, 10) were able to communicate using the Cyberlink. They could use the Cyberlink according to their own ability, using a personalised interface to communicate. We have thus achieved communication with a larger group than Doherty, who only had partial success with two out of three severely impaired participants. The numbers are still very small, but we are confident that we can generalize from the relatively large increase in successful usage.

Participant	Used text to audio	Launched Applications	Switched Devices
1,2,3, 6, 7	No (due to visual impairment)		
5, 10	Yes	No	No
4, 8, 9	Yes	Yes	Yes

Table 2: Study two results

Participants 4 and 8 were also able to use a switch (assistive device). This was valuable at times for double-checking the answers given. The success rate averaged around 70% for these participants. As Table 2 shows, three participants (4, 8, 9) could launch applications and switch devices, a task which some of Doherty's more able participants had also managed to achieve [14] (but not by his locked in participants [13]). We have thus achieved a wider range of functionality with similar participants.

Participants 4, 8 and 9 had television and music systems in their room and showed interest in doing more with the interface than the other participants. The success rate for participants 4 and 9 averaged around 70%, but participant 8 had days where he wanted to be left alone, which reduced his success rate. However, the ability of these three participants to do more than communicate demonstrates the superiority of a personalized interface that can expand or shrink the number of targets to match an individual's capability. Doherty's tunnel interface is restricted to a fixed number of targets (typically two).

Several participants had problems with their eyesight; and were greatly encouraged by audio feedback that enhanced their experience. The text to sound facility also let users, hear any phrase they wanted to use, not just YES/NO.

Summary

The inclusion of personalised tiling greatly improved the interface. This interface also gives the user the possibility of another target test and reconfiguration at any time, which reduces error frequency. Further flexibility in the interface is provided by adaptable dimensions, fonts and colour, which can cater for colour blindness and other visual impairments.

CONCLUSIONS

We have built on Doherty's work in four ways. We have worked with a much larger group of severely impaired participants, especially in study one, and thus replicated Doherty's results with a larger population in India and the UK. Secondly, we have combined discrete acceleration and personalised tiling to allow faster and more extensive interaction. Discrete acceleration has been shown to improve performance. A flexible interface can be configured to suit each person, with targets positioned by either using the target test program or manually placing them where participants wish. As a result, we have been able to extend effective interaction for some users to tasks beyond simple communication. We have achieved this with less need for adjusting the Cyberlink's settings before use. Doherty used game playing to establish the correct settings before testing the Yes/No interface [11-13], whereas the application in study two is self-contained and supports all necessary configuration. Brain-body interfaces for rehabilitation are still in their infancy, but we believe that our work could be the basis for their more widespread use in extensively extending the activities of severely impaired individuals. We see this as the main current viable application of brain-body interfaces, since anyone who can use a more reliable and efficient alternative input device should do so.

ACKNOWLEDGEMENTS

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Personalised Tiling Paradigm for Motor Impaired Users

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Abstract

This paper presents an investigation that was carried out to design and develop a paradigm for motor impaired users to navigate a computer screen. And also test whether the improvements obtained using tiling with Cyberlink™ can be transferred to other devices. Many motor impaired users have difficulty with mouse movements and holding the cursor at a precise position on a computer screen to highlight an icon or launch an application. This paper discusses an investigation carried out in designing and testing an accessibility program for users with motor impairment. The researcher drew motivation for this study from the previous research designing interfaces for the brain injured and using the Cyberlink™ as the assistive device. The rationale for the design is presented, along with details of its implementation.

1.0 Introduction

Motor impairment can be defined as "a loss or limitation of function in muscle control or movement or a limitation in mobility. This may include hands that are too large or small for a keyboard, shakiness, arthritis, paralysis, and limb loss, among other difficulties [28]." Motor impairment could cause irrational movements of the cursor when some of this group of users try to use a pointing device. The cursor can move around the computer screen without much control from the user, which brings frustration to the user [29]. This necessitated in the need for controlling cursor, so that the user can use it with full control. The researcher drew enthusiasm for this study from the previous research designing interfaces for the brain injured carried out at the University of Sunderland [9 - 16]. As medical technology not only extends our natural life span but also leads to increased survival from illness and accidents, the number of people with disabilities is constantly increasing. At the 56th Session of the UN Commission on Human Rights in Geneva (April 2000) Bengt Lindqvist stated: "It will take a long time to change this pattern of behaviour, which is deeply rooted in prejudice, fear, shame and lack of understanding of what it really means to live with a disability". At the 52nd meeting of the Third Committee, on 29 November 2001, the representative of Mexico introduced a draft resolution on an international convention on the rights of persons with disabilities, which the Committee recommended for adoption by the General Assembly. General Assembly resolution 56/168, entitled "Comprehensive and integral international convention to promote and protect the rights and dignity of persons with disabilities", was adopted on 19 December 2001 [27]. Assistive technology may be helpful in allowing the motor impaired people some form of control for a personal computer, allowing them to study, work, communicate or recreate but more work needs to be done to seamlessly integrate assistive technology to computer interfaces.

Various research methodologies were considered before the choosing the appropriate one for this investigation [35, 37, 40, 7, 5, 17]. One method of conducting scientific research in a new area of study with a new tool is to use the tool with a group of participants and to collect data from the performance of tasks with the tool [19, 30]. The data then display trends that allow other questions to be formed. These questions can be used to form a hypothesis that may be tested in further experiments. This method is known as naturalistic inquiry [3]. Research was carried out using Naturalistic Inquires, Formative research methods and Empirical Summative research methods. The approach used for this research was one of developing a prototype interface using non-disabled people as test subjects, then evaluating the interface with brain-injured participants. This allowed better feedback for faster interface development.

The experiment involved reaching targets on a screen in a controlled manner using joystick and tracker ball using the developed artefact. Cyberlink™ was used as the controlling device with data obtained from previous research [9 - 16]. Formative and summative evaluation was carried out with able-bodied participants to obtain optimum data for time spent on each tile, dimensions of tile and gap between tiles. Results obtained were recorded and analysed. The results obtained with the able-participants were used as the default settings for the evaluation with disabled participant.

2.0 Assistive Technology for motor impaired

There are various assistive technologies for motor impairment here are some examples:

- Trackball – Upturned mouse, rolling the mouse ball with fingers [22]
- Joystick – A stick looking device that can be moved around in all directions to simulate a mouse [25]
- Eye-tracking – a system that follows the movements of the eyes [26]
- HeadMouse™ - using wireless optical sensor that transforms head movement into cursor movement on the screen [24].
- Tonguepoint™ - a system mounted on mouth piece [39].
- Sip/Puff Switch - a two position switch by a simple sip or puff [24]
- Software such as Sticky Keys that make difficult keystrokes more accessible [28, 20]
- Voice recognition systems [28, 20]
- Text entry systems to help enter messages with fewer keystrokes [28, 20]
- Cyberlink™ - a brain body actuated control technology that combines eye-movement, facial muscle and brain wave bio-potentials detected at the users forehead [21, 31].

Assistive technologies are used as determined by individual needs. Motor impairment assessments can help the choice of assistive devices [23, 44]. All the devices above have their advantages and disadvantages [32, 41]. A user with cerebral palsy will not have good motor abilities to operate the 'Tonguepoint™'. A user with spinal vertebrate fusion may not be able to turn his or head and the HeadMouse™ will be of no use.

3.0 Experimental Methods

The experiment involved reaching targets on a screen in a controlled manner using joystick and tracker ball, as pointing devices. Cyberlink™ was used as the controlling device with data obtained from previous research [14]. Formative and summative evaluation was carried out with able-bodied participants to obtain optimum data for time spent on each tile, size of tile and gap between tiles. Results obtained were recorded and analysed. The results obtained with the able-participants were used as the default settings for the evaluation with disabled participant.

3.1 Methodology

Wide ranges of research methods are used in Human-Computer Interaction [17]. Research was carried using Naturalistic Inquires [3], Formative research methods and Empirical Summative research methods [4]. The main task here was to produce an artefact that delivered improved performance in specific settings, an artefact that can produce individual profiles and use sophisticated input control algorithm [14]. An evolutionary iterative development methodology was used to get the best possible version [1, 8].

3.2 Experiment

There are wide differences in capability, both between individuals and at different times for the same individual, for many groups of impairments [14]. This indicates that some form of adaptation to individual needs may improve accessibility of each individual user [42]. The rationale for the artefact developed here for motor impaired, uses the

"Personalised Tiling Paradigm" used successfully for the brain-injured participants [14] in previous research. The artefact developed for the motor impaired is described in this section.

Adaptation can take three forms [42].

- *Adapted* user interface – adapted to end user at design time [9 – 12]
- *Adaptable* user interface – the end user can make changes (this study)
- *Adaptive* user interface – the dynamic behaviour can change at run time [13, 14]

This investigation was conducted in two phases. Phase one was the development phase. The main task in this phase was to produce an artefact that delivered improved performance in specific settings, an artefact that can produce individual profiles. An evolutionary iterative development methodology was used to get the best possible version. Iteration was driven by Phenomenological formative evaluation [34, 38] then mainstream empirical methods were used for experimental summative evaluation [33, 36, 2, 18]. The iterative approach used was that of developing a prototype [1] interface using non-disabled people as test subjects using qualitative and quantitative evaluation. This allowed better feedback at the development stage and faster development. The interface developed here was to work with any assistive device used by motor impaired computer users. Able-bodied participants were used to test various versions of the interface program to derive the final interface. Phase two of this investigation was the evaluation phase with the disabled participant to complete the final testing process [6].

The programming language used this time was Visual C++. The interface program controlled the movement of the cursor on the computer screen and stopped any irrational uncontrolled steering of the mouse on the computer screen. In order to support 'Personalised Tiling Paradigm', the computer screen was divided into tiles (Fig. 1), which support discrete jumps from one tile to the next predicted tile on the user's route and configuring a time delay on each tile (Figs 2 & 3). The width and height tiles, gap between tiles and time delay on each tile were configured to suit each individual user (Figs 2 & 3). Each user was able to have an individual profile to suit their disability and assistive device. The interface program worked in the background so the user did not see anything different on the computer screen but the movements of the cursor was controlled for any irrational movements using the individual personalised tiling paradigm.

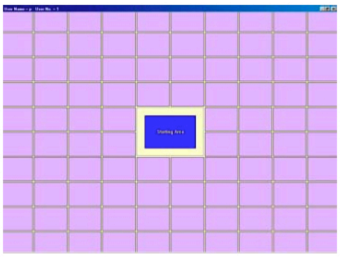


Figure 1: computer screen split into tiles transparently
(This diagram shows the process that takes place transparently to user)

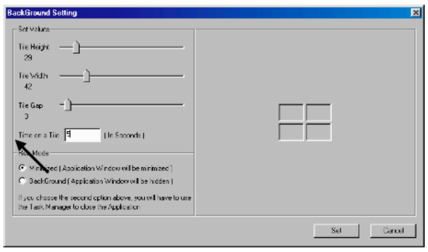


Figure 2: Configuration of time delay on each tile

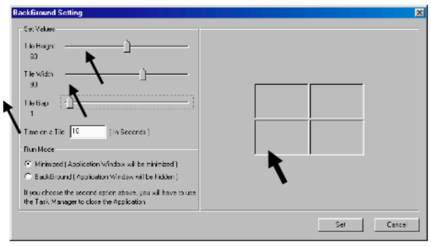


Figure 3: Configuration of Tile Height, Tile width and Tile Gap

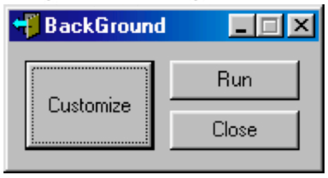


Figure 4: Opening window

The interface program operates using the following algorithm.

- The user launches the program which opens as shown in Fig. 4
- The user chooses 'customize', which open the window as shown in Figs. 2 and 3
- Customize window is utilised to set individual tile dimensions, gap between tiles and delay in each tile as shown in Figs. 2 and 3
- Then a radio button is chosen to either keep the program window in the task bar or completely hide it from the screen as shown in Figs. 2 and 3
- Pressing the 'Run' button will run this program in the background controlling the cursor navigation on computer screen
- Pressing the close button (Fig. 4) will quit the program and return to uncontrolled cursor navigation

3.3 Results

Phase one of the experiments was conducted with ten able bodied participants (four females aged 11 to 40 and six males aged 14 to 52) and phase two was conducted with two motor impaired cerebral palsy participants (male 48 yrs old and female 56 yrs old). The results obtained in phase one was used as optimum settings for evaluation of the interface in phase two.

3.31 Phase One

The aim of this phase was to find the optimum dimensions for the tiles, delay in each tile and gap between tiles. Two pointing devices (Cyberlink™ was used as the controlling reference);

- Tracker Ball
- Joystick

were used with different dimensions for tiles (5 x 5, 15 x 10, 20 x 15, 30 x 20, 35 x 22.5 mm²), delay (1, 3, 5, 10 sec) in each tile and gap between tiles (04, 1.2, 2, 4, 8 mm) [41, 40, 43]. The participants also had to complete a formative evaluation by trying to reach the targets in an allocated time interval using one pointing device at a time and indicate their preferences on the five variations of the interface. The following date was recorded to give summative feedback from each participant.

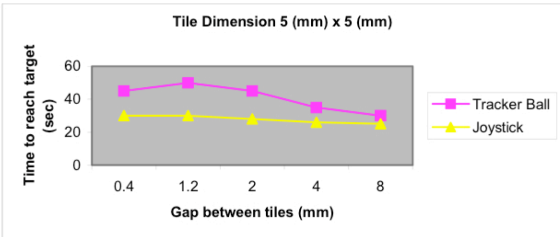
- Time taken to reach the targets
- Dimensions of tiles, delay in each tile and gap between tiles
- Any reconfiguration to the original settings

The results obtained showed that as the delay increased the time to reach the target also increased (table 1). This was consistent with the previous results obtained using Cyberlink™ [14]. Hence the optimum time on each tile was accepted as one second.

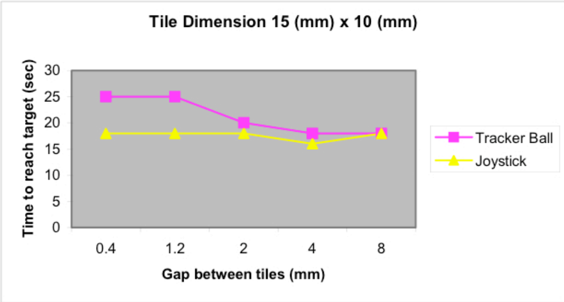
Table 1: time to reach target versus delay (tile 15 x 10 mm², gap between tiles 1mm)

Delay in each tile	Time taken to reach target
1 sec	20 sec
3 sec	35 sec
5 sec	45sec

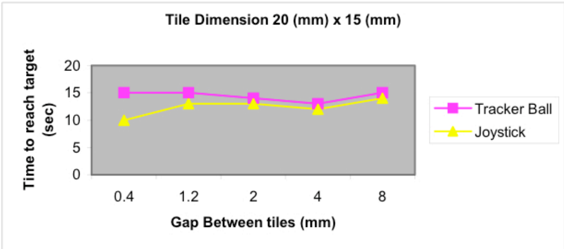
The next part of the experiment was to find the optimum dimensions for the tiles and the optimum gap between the tiles. Tracker ball and the joystick were used with various tiles and various gaps between tiles. Graphs 1 to 5, show the average time to reach target versus gap between tiles for each of the different tile settings.



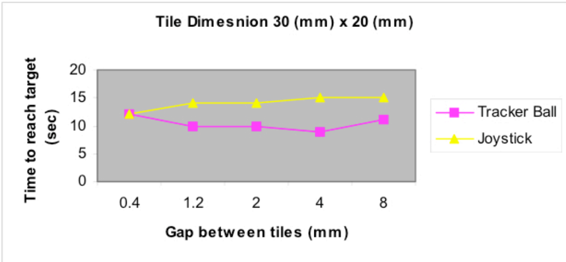
Graph 1: Data for tile 5 x 5 mm²



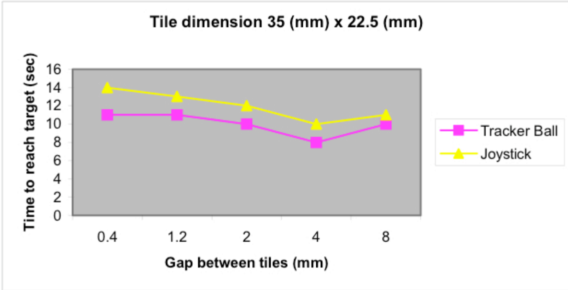
Graph 2: Data for tile 15 x 10 mm²



Graph 3: Data for tile 20 x 15 mm²



Graph 4: Data for tile 30 x 20 mm²



Graph 5: Data for tile 35 x 22.5 mm²

The graphs 1 to 5, show that the optimum tile dimensions is the largest tile (35 x 22.5 mm²) and the optimum gap between tiles is 4 mm. Hence the optimum data for motor impaired user, using summative evaluation was 35 x 22.5 mm² tile, with 4 mm gap between tiles and 1 second delay in each tile. The formative evaluation using the able bodied participants also yield the same results for the easiest interface.

Table 1: optimum results obtained from pervious research for Cyberlink™

Tile width	Tile Height	Gap between tiles	Delay in each tile
36 mm	12.5 mm	4mm	1 sec

The data from previous research for Cyberlink™ is shown above in table 1. The result obtained in this study is consistent with the previous research conducted by the researcher with Cyberlink™ for non-verbal paraplegic participants. The only difference is the smaller tile for the Cyberlink™ interface to control the cursor, to stop picking up noise due to unwanted bio-potentials.

3.32 Phase Two

Phase two of this study was conducted by visiting participants at their homes and letting the motor impaired participants use the navigation program at their environment, using their individual pointing device. It should be noted that the investigator obtained all permissions and informed consents from participants before research began. Two one-hour visits per participant were conducted and data recorded. Data collected from each participant shows the improvement made by the personalised tiling paradigm (Table 2). Optimum setting obtained in phase one was used as the starting configuration for all participants with the provision of changes if and when need. The times taken to reach a target on screen was recorded using with and without the navigation program and the progress was noted.

Table 2: Results obtained in Phase Two

Part. No	Pointing Device used	Average time to reach a target with navigation program (secs)	Average time to reach a target without navigation program (secs)
1	Tracker Ball	35	60
2	Joy Stick	32	45

4.0 Conclusions and discussions

This investigation shows how Personalised Tiling Paradigm can be used to enhance navigation of a computer screen by controlling the movement of pointing devices and help the users navigate with their individual personalised profile according to their disability and their assistive device. The researcher would also like to suggest further investigation should be done to investigate whether using an input algorithm to accelerate the cursor towards a target or addition of artificial intelligence would further increase the performance of this interface program. Another area to explore will be a scanning mechanism for switch users to scan the tiles until a target is reached. Any study in partnership with computer scientist and medical professionals will open wide avenues of research in rehabilitation for motor impaired computer users. The study also shows the consistency of between optimum results of this research and the previous work by the researcher. The experiment shows that the improvement using tiling with Cyberlink™ can be transferred to other devices such as tracker ball and joystick. More evaluation is being carried out for phase two of this investigation to achieve a statistically significant result.

5.0 Acknowledgements

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All the Latest

Feature: The State of Brain Body Interface Devices

Source: UN, 11 October 2006
Submitted by Paul Gnanayutham

Debunking the myth that 'thought control of computers' is new, Paul Gnanayutham takes a look at what is happening in the search for the ultimate assistive technology. Gnanayutham, at the University of Portsmouth, has been working with Gilbert Cockton and Chris Bloor of the University of Sunderland on brain-body interfaces over a number of years.

Research has been carried out on the brain's electrical activities since 1925. Brain-computer interfaces (BCIs), also called brain-body interfaces or brain-machine interfaces provide new augmentative communications channels for those with severe motor impairments. In 1995 there were no more than six active brain computer interface research groups, in 2000 there were more than twenty and now more than thirty laboratories are actively researching in brain computer interfaces. Brain-computer interface is a communication system that does not depend on the brain's normal output pathways such as speech or gestures but by using electrophysiological signals from the brain. There are two types of brain body interfaces namely invasive (signals obtained by surgically inserting probes inside the brain) and non-invasive (electrodes placed externally on part of the body).

Non-Invasive Brain-Body Interface Devices
Brain activity produces electrical signals that can be read by electrodes placed on the skull, forehead or other part of the body (the skull and forehead are predominantly used because of the richness of bio-potentials in these areas). Algorithms then translate these bio-potentials into instructions to direct the computer, so people with brain injury have a channel to communicate without using the normal channels. Various research groups have developed Brain-Computer Interfaces using, Electrocochleography, Electroencephalalography, Magnetic Resonance Imaging and Slow Cortical Potentials.

Invasive Brain-Body Interface devices
Various protective tissues, the skull, blood flow and other brain matter between the scalp and area of the brain generating the signal can distort the bio-potentials drawn from the outside of the scalp. Hence invasive electrodes can give better signal to noise ratio and obtain signals from a single or small number of neurons. The invasive category of Brain-Body Interfaces have been developed using Electroencephalalography, Electromyography, Electrocochleography, magnetic resonance imaging and slow cortical potentials, Neuroprosthetic signals, Low-frequency asynchronous switch,

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Source: UN, 16 May 2007

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Source: BBC, 15 May 2007

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Source: econsultancy, 14 May 2007

The cost of failing to usability test designs before deployment has unfortunately been shown again in Scotland's controversial election results.

What's all the Chatter about Twitter?
Source: UN, 12 May 2007

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Source: UN, 11 May 2007

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Web 2.0, Part 2: Serious Business Tool or Silly Waste of Time?
Source: ecommercetimes, 9 May 2007

Web 2.0: a 'best of both worlds' scenario, where employees or

Due to the cost, lack of evaluation with participants outside research laboratories and the lack of support by the main software manufacturers to integrate them into mainstream operating systems and applications many of the above mentioned Brain-Body Interfaces remain a laboratory exercise. This trend is likely to continue unless computer manufacturers see a need to invest in this area of special needs. The diagnostics and measurements of brain injuries have progressed but the rehabilitation area still needs more training in the use of assistive technologies, rather than just after care.

Brain Body Interfaces are used in labs and encouraging results are obtained, but hospitals and nursing homes (especially govenrment run ones) are very reluctant to try this research due to ethical (need permission from the participant if they are over 18, how many brain injured patients can do that?) reasons, also hospitals are scred of being sued if things go wrong. The hospitals and nursing homes we worked were either private or abroad. What I did was for the hospital staff and the parents/guardians to try out cyberlink, which is three electrodes on your forehead, just like the pads used in hospitals for ECG.

Research is being done in positron emission tomography and functional magnetic resonance imaging in the identification of residual cognitive function in persistent vegetative state patients, in order to investigate the possible use as a brain body interfaces. Research is also being done in wearable wireless brain body interfaces where technology such as bluetooth is proposed for transmitting and receiving signals from the participant.

Paul Gnanayutham
University of Portsmouth

customers have all the useful features in one place, or a lot of people killing time watching inane videos?

When Observing Users is not Enough - 10 Guidelines for getting more out of Users' Verbal Comments
Source: UXMatters, 8 May 2007

Observing a user perform a task can provide more reliable information than simply asking the user how easy it is to perform the task. This article provides ten guidelines to help you get more out of users' verbal comments.

CHI 2007 - Can User Centred Design be Harmful?
Source: UN, 6 May 2007

A meeting at CHI 2007 produced the surprising argument that user-centred design is a bad idea. Instead, a range of alternative approaches were proposed for HCI projects in developing countries.