Using Human Computer Interaction Concepts to Design Interfaces for the Brain Injured

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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. A certain percentage 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 little 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. This paper discusses using human computer interaction (HCI) concepts to design interfaces for the brain injured to communicate, recreate and control their environment.

1. Introduction

It is generally accepted that HCI is really an interdisciplinary science combining psychology, sociology, and computer science. This discipline includes ergonomically orientated work with interactive computer systems to make them more usable as defined by the International Standards Organisation 9241. Some computer devices and interfaces can have a biological and psychological impact upon those who use them. An example of such an impact is the lengthening of the attention span of a computer user with attention deficit disorder or mental retardation. Classical HCIscientists such as Jagacinski and Monk 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. 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 must learn more human brain. HCI is also a scientific discipline that investigates how people interact with computers effectively. Many disciplines compliment HCI developers to design user-friendly interfaces; one of them is psychology, which analyses human formative reactions to interfaces, including reaction times and task analysis. Cognitive theory has been recognised as a useful tool for analysing human computer interaction. Cognitive task models can be used to model user interaction to develop efficient interfaces, which includes human information processing mechanisms. Cognitive psychology aims to understand the issues of perception, reasoning, communications, actions etc., and regularise engineering and psychology thus helping human computer interaction. Many experimental psychology and scientific methodologies can be applied to the study of computer tools and how humans interact with tools. HCI attempts to find ways of incorporating usability concerns into existing life cycles rather than developing alternative life cycles.

2. 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. The adult brain weighs three pounds and is suspended in cerebrospinal fluid. This fluid also protects the brain from shock. The brain is protected by a set of bones called the cranium or a skull. The three main components of the brain are the cerebellum, cerebrum and brainstem (Figure 1). The cerebellum is located between the brainstem and the cerebrum. 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 computer 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 groves (Kalat 1995). The cerebrum is the section where thoughts (brain waves) are created and memory is stored. Brain waves could also be used be used in brain body interfaces. Cerebrum is divided into two hemispheres and five lobes. The left hemisphere controls the right side of the body while the right side controls the left side of the body. The five lobes of the cerebrum 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 affects 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 use 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 such basic functions as eating, respiration, and 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. In other words, primary brain injury is caused initially by trauma[1], amyotrophic lateral sclerosis[2], brain stem stroke[3] etc., but includes the complications, which can follow, such as damage caused by lack of oxygen, and 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

[1] an acquired injury to the brain caused by an external physical force
[2] a degenerative disorder affecting upper motor neurons in the brain and lower motor neurons in the brain stem and spinal cord
[3] A stroke affecting the area of the brain controls functions such as breathing, instructing the heart to beat. Brain stem stroke may also cause double vision, nausea, loss of coordination speech etc.

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 and 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).

A small number of 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 (PVS). There are normally 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).

Bio-potentials for brain body interfaces

This section describes the bio-potentials that can be used in brain body interfaces. Each bio-potential has its own unique characteristics, such as amplitude, frequency, method of extraction, time of occurrence etc. Each brain-injured patient (apart from persistive vegetative state patients) can provide one or more of the bio-potentials with differing consistencies. Brain injured patients will be able to operate brain body interfaces depending on the reliability of the bio-potential, which they can muster.

Electroencephalalography (EEG)

Electroencephalalography is electrical brain activity that results from thoughts or imagined movements (Kalcher *et al.* 1994). Electroencephalalography can be collected by electrodes placed on the scalp or forehead to trace and record the brain's electrical activity (Berkow *et. al*. 1997). The amplitude of the electroencephalalography can vary between 10 - 100µV when measured on the scalp or forehead. Electroencephalalography forms 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 electroencephalalography from ninety-three participants and decided to classify them as delta, theta, alpha, beta, and high beta (Robinson 1999). Robinson's classification will be used throughout this paper. Some of the classes of electroencephalalography can be used as bio-potentials for brain body interfaces.

Electromyography (EMG)

Electromyography is produced by 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 18Hz, but which resonates 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. Electromyography has an amplitude range of 0.2 - 2000µV.

Electrooculargraphy (EOG)

Electrooculargraphic signals are those low frequency signals that are 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 - 6.25Hz (Berg 1998). Electrooculargraphy has an amplitude range of 1 - 4mV.

Slow Cortical Potentials (SCP)

Slow cortical potentials (SCPs) are signals of the cerebral cortex, which can be collected from the scalp surface. They are electroencephalalography oscillations in the frequency range 1 - 2Hz (Kotchoubey *et al.* 1997) and can be positive or negative. The signals can be 5 - 8µV 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).

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, though SSVEP (e.g. choosing buttons illuminated at different rates, on a virtual telephone keypad to make a phone call). Steady-state visual evoked potential uses 4 to 35Hz frequency range.

P300

The P300 (also called P3) component of the evoked potential is a positive wave peaking at around 300 ms after task-relevant stimuli. This signal occurs in the delta (0.5 - 4Hz) and theta (4 - 7Hz) frequency range. Kotchoubey and his team investigated bio-potentials in patients with severe brain damage. They used oddball tasks (e.g. sine tones, complex tones or vowels o and I) to elicit P300 waves from twenty five out of thirty three patients (Kotchoubey *et al.* 2001, 2002). The P300 is perhaps the most-studied evoked potentials component in investigations of selective attention and information processing in comparison to the other components of the evoked potentials (Patel and Azzam 2005, Farwell and Donchin 1988, Donchin *et al.* 2000).

N400

The N400 is a component of the evoked potential triggered by unexpected linguistic stimuli. It is a negative wave, peaking around 400 ms post stimulus and occurs around 20Hz. 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 1996).

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 as in electroencephalalography, electromyography, evoked potential etc. Electrocochleography is recorded at 300 – 1000µV amplitude and has a frequency of 40Hz (Tran *et al.* 1997, Lal *et al.* 2005).

Low Frequency Asynchronous Switch Design (LF-ASD)

The low-frequency asynchronous switch design operates as an asynchronous brain switch (ABS) which is activated only when a user intends to 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). The low-frequency asynchronous switch design is based on electroencephalalography signals in the 1 - 4Hz frequency range (Borisoff *et al.* 2004) with an amplitude of 10 – 100µV.

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 -30Hz frequency range and they have an amplitude of 6µV. These signals are also prominent in the cerebellum and brainstem sensorimotor regions. These signals are called local field potential**s**.

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 or brainstem strokes or traumatic brain injuries (TBIs). Research has been carried out on the brain's electrical activities since 1925 (Kozelka and Pedley1990). 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 (Birbaumer *et al.* 2000), and now more than thirty laboratories are actively researching in BCI (Vaughan *et al.* 2003). A BCI 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 as defined by Wolpaw (Wolpaw *et al.* 2000a). 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). Allison (2003) states that a brain computer interface 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 brain body interfaces work faster than conventional interfaces (Gnanayutham *et al.* 2005).

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 many BCI and the following is the survey of the non-invasive category of brain body interfaces (figure 2).

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 noise to signal ratio and obtain signals from a single or small number of neurons. Vidal (1973) first mentioned an invasive or direct brain computer interface. 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 (figure 3).

Mechanism of Brain Computer Interfaces

Non-invasive technology involves the collection of control signals for the brain computer interface without the use of any surgical techniques, with electrodes placed on their face, skull or other parts of their body. The non-invasive devices show that, signals obtained are first amplified, filtered and thereafter converted from analogue to digital signal. Various electrode positions are chosen by the developers, who choose electrode caps, electrode headbands with different positions (figure 4) and number of electrodes or the international 10-20 system (Pregenzer 1994). 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 and 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. High-density caps can yield more information but in practice they are hard to be utilised for real time communications. Each method has its own potential sources of error and provided coherence data for different neural disabilities (Nunez *et al.* 1999). There is only one agreed standard for the positions and number of electrodes that is the International 10-20 system of electrodes as shown in figure 4 (Jasper 1958).

Invasive electrodes can give better noise to signal ratio and obtain signals from a single or small number of neurons. Signals collected from the brain require expensive and dangerous measures such as surgery. Neurons are the brain cells responsible for storing and transmitting information from a brain cell. Any mental experience even if unconscious has a signal associated with it. There are two types of electrodes used for invasive brain body interfaces. If signals needed to be obtained with the least noise and from one or few neurons, neurotrophic electrodes were used (Siuru 1999, Kennedy *et al.* 1999, 2000). The other choice was 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 processing of signals in brain body interfaces (Sanchez *et al.* 2005).

4. Challenges with Brain Body Interfaces

A non-invasive assistive technology device named Cyberlink™ was used for this research. Only limited amount of research has been done using Cyberlink™ as the brain body interface. The first one was a control study conducted by the United States Air Force at Wright Patterson Air Force Base in Dayton, to compare reaction times to visual stimuli using Electromyography button and a manual button (Furness 1986, Haas 1995, Berg *et al.* 1998). The second one was done by Doherty on whether Cyberlink™ can be used as an assistive technology for communications by the disabled (Doherty *et al.* 2001, 2002). Doherty used contextual inquiry and design methodology (Beyer and Holtzblatt 1998) to investigate the context of use and achieved a limited amount of success. This research investigated the use of novel interaction paradigms to improve previous work conducted in the area of brain-body interfaces. Although medical technology has advanced immensely in the last forty years, assessing the brain-injured and choosing the appropriate participants is still very challenging. Their cognitive abilities are often not assessed because of their physical inability to respond to anything (Doherty *et al.* 2001). Medical personnel find it hard to establish the appropriate medical classification with this group of disabled patients (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). The researcher had to begin the research with participants with an open mind on their abilities to respond.

Standard input devices used for menu pointing can be seen as a goal directed process, where a user can change the distance to the target or size of the target in an orderly predictable way, for the input devices to obey rules such as Fitts Law (Accot and Zhai 2003). But Cyberlink™ can behave in an erratic way when a user tries to control a cursor on a computer screen, because bio-potentials are much harder to control in comparison to standard motor inputs. The Cyberlink™ can pick various bio-potentials and then move the cursor to an unwanted part of the screen causing erratic movements that could not be controlled, causing frustrations and fatigue to the users. Bringing the cursor back to control takes a lot of effort. This illustrated that there was a necessity to control the cursor. Doherty had to restrict the path of the cursor by creating a predefined maze, which partially solved this problem but this was only a limited success. Doherty's method also gave only one interface for all users that, if a particular user could not move in the predefined route; no communication was possible (e.g. a partially paralysed person will not be able to move a cursor in a predefined maze) and hence this interface was not inclusive of all disabled users. The literature survey showed that participants needed extensive training in many cases before a brain body interface could be used. The researcher wanted the training for using these novel interaction paradigms to be kept to a minimum (just a target test), in order to avoid wastage of time and frustrations to the participants. This meant optimum setting of the interface needed to be obtained before the interface was used with the brain-injured users. Hence some of the challenges faced here are the control of the cursor, avoidance of frustration, minimum or no training, optimum settings and inclusive design. Inclusive design implies, inclusion of any brain-injured user who could respond, exception to this rule will be comatose or visually impairment. Some participants also created unwanted signals (e.g. a twitch) that meant there was a need for getting rid of unwanted signals (noise) by ignoring certain components of the bio-potentials from some users. Another challenge faced was the need for reconfiguration if the medical condition of the user changed, which resulted in the need for a re-configurable interface. Having come across various categories of brain injury the researcher looked for a technique to develop interfaces to cater for each disability group, in phase one of this research. Can the brain-injured participants be grouped together, when developing interfaces, was the question to be addressed here. Researcher 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, which meant an individual interface had to be developed for each user. Perhaps a target test could be used to find out individual areas of a computer screen for each user. The question raised here was should there be a group of novel interaction paradigms or have one novel interaction paradigm that can be personalised? Moving the cursor across a computer screen using bio-potentials was a slow process hence the researcher sought a way to accelerate the cursor on the direction of travel to minimise the effort needed by the users. Hence developed novel interaction paradigms needed to have the following challenges to contend with:

- Rationale for choosing participants for the research.
- Control the cursor
- Avoid user frustration
- Setting to be optimum before being used by the brain-injured users
- Require minimum or no training
- Include any brain-injured user (except comatose or visually impaired)
- Offer facility to re-configure interface at any time
- Offer grouping facility according the classification of the brain injury
- Accelerate the cursor on the intended direction of travel on the screen to minimise the effort needed by brain injured users

5. Approach Chosen

HCI is really an interdisciplinary science combining psychology, sociology, and computer science (Monk and Gilbert 1995). Some computer devices and interfaces have a biological and psychological impact upon those who use them (Pope and Bogart 1996,Castelli *et al.* 1994). Authors such as Auletta (Auletta 1997) discuss the need for more computer interfaces and recording devices that require a variety of biological and environmental inputs. An improvement in our 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 (Allanson *et al.*1999) said that the computer interface developer will soon have a tool kit available to him or her that will allow the addition of biological inputs as an alternate means of control. 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 must learn more about biology. HCI(HCI) is also a scientific discipline that investigates how people interact with computers effectively. Many disciplines compliment HCI developers to design user-friendly interfaces one of them is psychology (Card *et al* 1983), which analyses human formative reactions to interfaces, including to reaction times and task analysis. Cognitive theory has been recognised as a useful tool for analysing human computer interaction. Cognitive task models can be used to model user interaction to develop efficient interfaces, which includes human information processing mechanisms

(Barnard and May 1999). Cognitive psychology aims to understand the issues of perception, reasoning, communications, actions etc., and regularise engineering and psychology (Long and Dowell 1996, Green *et al.* 1996) thus helping human computer interaction. 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). HCI attempts to find ways of incorporating usability concerns into existing life cycles rather than developing alternative life cycles (Carter 1999).

There are various models and techniques for specifying user interfaces (Abowd *et al.* 1989) below are some of the methodologies considered:

- Human-Centered design (Limbourg *et al.* 2001)
- Contextual Inquiry and Design (Beyer and Holtzblatt 1998).
- Universal Access (Stephanidis 2001).
- The Layered Approach Method (Furtado *et al* 2003).
- Usability (Borchers 2001)
- Shneiderman's "Eight Golden Rules of Interface Design" are a guide to good interaction design. These rules are as follows (Shneiderman 1998):
- Usability Engineering Lifecycle (Mayhew 1998).
- Heuristic Evaluation (Baker et al 2002)
- Naturalistic Inquiry (Williams 1986).
- Formative method or formative evaluation (Burns and Grove 1997)
- Summative method or summative evaluation (Kazdin 2003).
- Iteration (Munhall1989)
- New HCI approaches (Rogers 2004)

Having considered the research methodologies on offer the appropriate one for this investigation was chosen, where the final artefact was evaluated by a small number of severely brain-injured participants (Preece *et al.* 2002). The challenges described in the previous section also had to be dealt with by the chosen methodology. The medical practitioner chose suitable brain-injured participants for the research analysing their responses and medication. Comatose, visual impairment and medication that restricted response were used as the criteria for exclusion from this research. The medical practitioner also accompanied the researcher on the first two visits to each brain-injured participant to ensure medical and ethical considerations were adhered to. The medical practitioner was also used 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.

The approach chosen is shown in diagrammatic form in figure 10. The diagram shows the three phases of the research and the iterative processes that were used to develop the paradigms. The iterative processes that were employed in the design and development of the novel interaction paradigms are shown on the left of the diagram and the other issues that influenced the processes are shown on the right side of the diagram. Iteration driven by phenomenological formative and summative evaluations (Munhall1989, Omery1987), gives the opportunity for building artefacts that can evolve into refined, tried and tested end products when developing artefacts (Abowd *et al.* 1989). The final feedback from each phase is shown in the text boxes in figure 10. 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. The data then display trends that allow other questions to be formed. These questions can be used to form a hypothesis that may be evaluated in further experiments. This method is known as Naturalistic Inquiry (Williams 1986). Williams states “naturalistic inquiry is disciplined inquiry conducted in natural settings (in the field of interest, not in laboratories), using natural methods (observation, interviewing, thinking, reading, writing)". Naturalistic inquires were used in this research for investigating topics of interest. Formative research methods and empirical summative methods were used to evaluate the paradigms being investigated in this research (Nogueira and Garcia 2003). Developed prototypes were tested using able users as test subjects before being evaluated with disabled users. Iteration allowed better feedback for faster interface development. Many versions of the interface program were developed to get the final artefact. Formative method or formative evaluation can be conducted during the planning and delivery of research. This method is based on scientific knowledge based on application of logic and reasoning. It produces information that is used to improve a program while it is in progress.

Formative approaches are based on the worldview belief that realities based on perceptions are different for each person. Formative research has to be systematic and subjective, indicating the experience of individual users (Burns and Grove 1997). Formative and summative methods compliment each other since they generate different types of data that can be used when developing interfaces. The iterative development method is a useful approach when initial data is collected from able participants before being tested with disabled participants. Summative method or summative evaluation is used to assess and summarise the value of a completed activity or program. Research is conducted to describe and examine variables in order to test theory. This method is based on conceptualising the project, planning, implementing and communicating the results. A summative method involves precise measurement, representative samples and controlled experiments (Burns and Grove 1997). Results obtained in summative methods should be tested using statistical methods, statistical significance, hypothesis validation, null hypothesis etc., (Kazdin 2003).

First phase of the research aimed to replicate Doherty's work with his tunnel interface (figure 5). Once replicated, a small change, adding discrete acceleration to cursor movement, was made to the interface that greatly improved performance overall (Figure 5, named Novel Interaction Paradigm 1). However, this change was not enough to make the most of the wide variations in capability in the user population. This meant that the users could not be grouped according to their disability classification but every user had to have an individually personalised interface. The second phase incorporated discrete acceleration into a more flexible and personalised interface (Figure 6, named Novel Interaction Paradigm 2). It also introduced a control system, which controlled the movements of the cursor by dividing the computer screen into configurable tiles and delaying the cursor at each tile (Figure 7). This new paradigm also brought the cursor back to a starting point after an elapsed period of time, avoiding any user frustration. Able-bodied participants evaluated this paradigm to obtain optimum settings that can be used in phase three thus avoiding any unnecessary training. Re-configuration facility was available for users by running the target test again and replacing the previous personalised interface. The third phase evaluated the novel interface paradigm developed in phase two incorporating the optimum settings. This novel interface paradigm was evaluated with the disabled participants. This proved to be usable by a larger percentage of brain-injured population than in previous Doherty's studies, and over a wider range of functionality. This achieved the inclusive design, which was sought by the researcher. The chosen approach achieved all ten challenges mentioned in the previous section.

6. Interface Design

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 Theresa'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 5). 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.

An alternative interface had been prepared to test this conjecture (Figure 6):

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.

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.

Prototypes were developed for study two that dropped tunnels in favour of placing target buttons in areas suited to individual users. Figure 7 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 brain injury 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 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 (Gnanayutham *et el.* 2003)

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. Thus, the interface has further features that allow the cursor's path to be controlled by settings for a specific user (Figure 8). The personalised 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 etc.

7. Conclusions and Future

This paper discussed using HCI concepts to design interfaces for the brain injured to communicate, recreate and control their environment. The researchers have built on past work in four ways, having 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, the researchers have combined discrete acceleration and personalised tiling to allow inclusive 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, it has been possible to extend effective interaction for some users to tasks beyond simple communication. This was achieved with less need for adjusting the Cyberlink™ settings before use. 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. It is possible to 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. Thus it has been proved that that the performance of the brain body interfaces can be improved by the use of novel interaction paradigms. At present the researchers are working in three areas. Exploratory work has been done with blind participants using electromyography (muscle movements) to operate a brain body interface to communicate. Research is also being carried out to create 3D interfaces to demonstrate how the mouth can be moved to improve pronunciation skills. Research is also conducted in robotics to help the severely brain inured to move objects such as moving a cup to their mouth.

8. Acknowledgements

Dr. Chris Bloor, Professor Gilbert Cockton, Dr. Ivan Jordanov, Dr. Eamon Doherty and to the following institutes Vimhans, Mother Theresa's Mission of Charity, Holy Cross Hospital surrey and Castel Froma, Leamington spa.

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Appendix

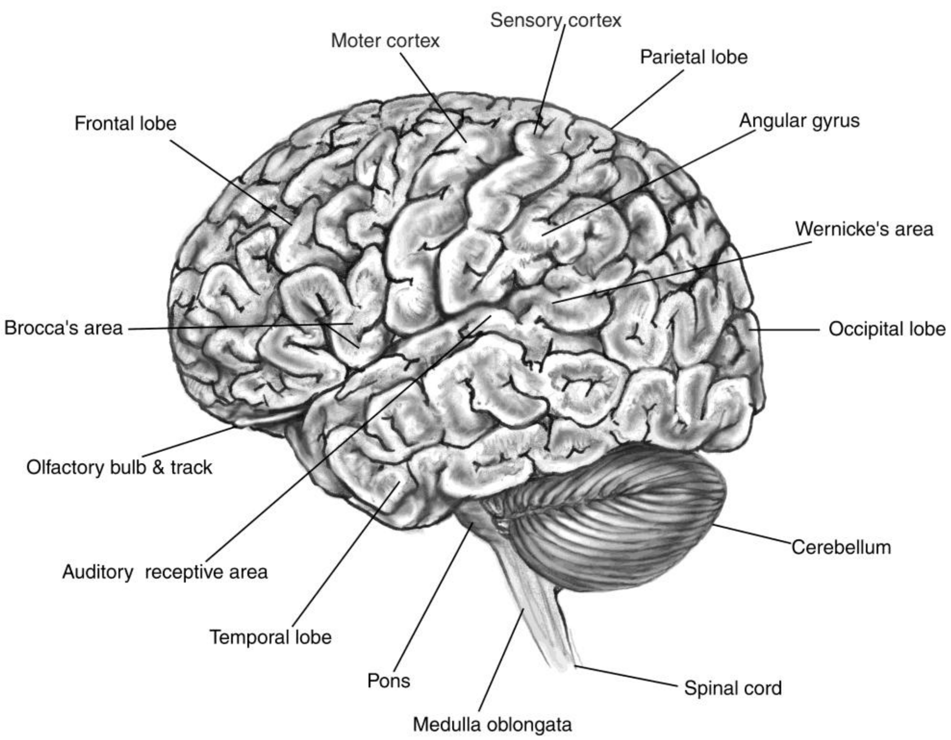

Figure 1 - Brain Map (Courtesy of www.headinjury.com)

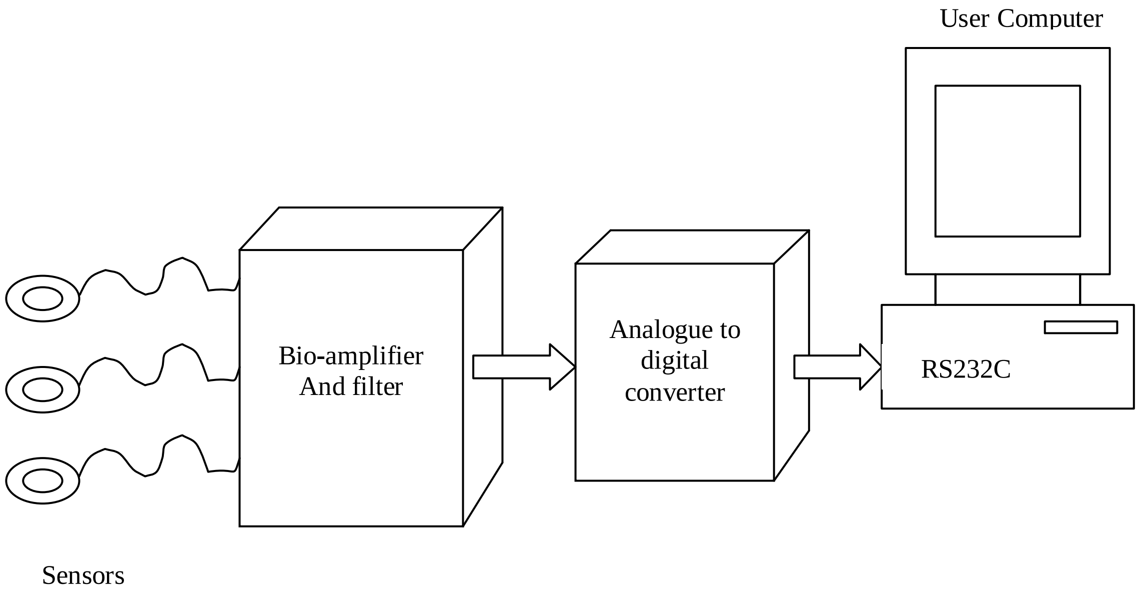

Figure 2 – Non-invasive Brain Computer Interface

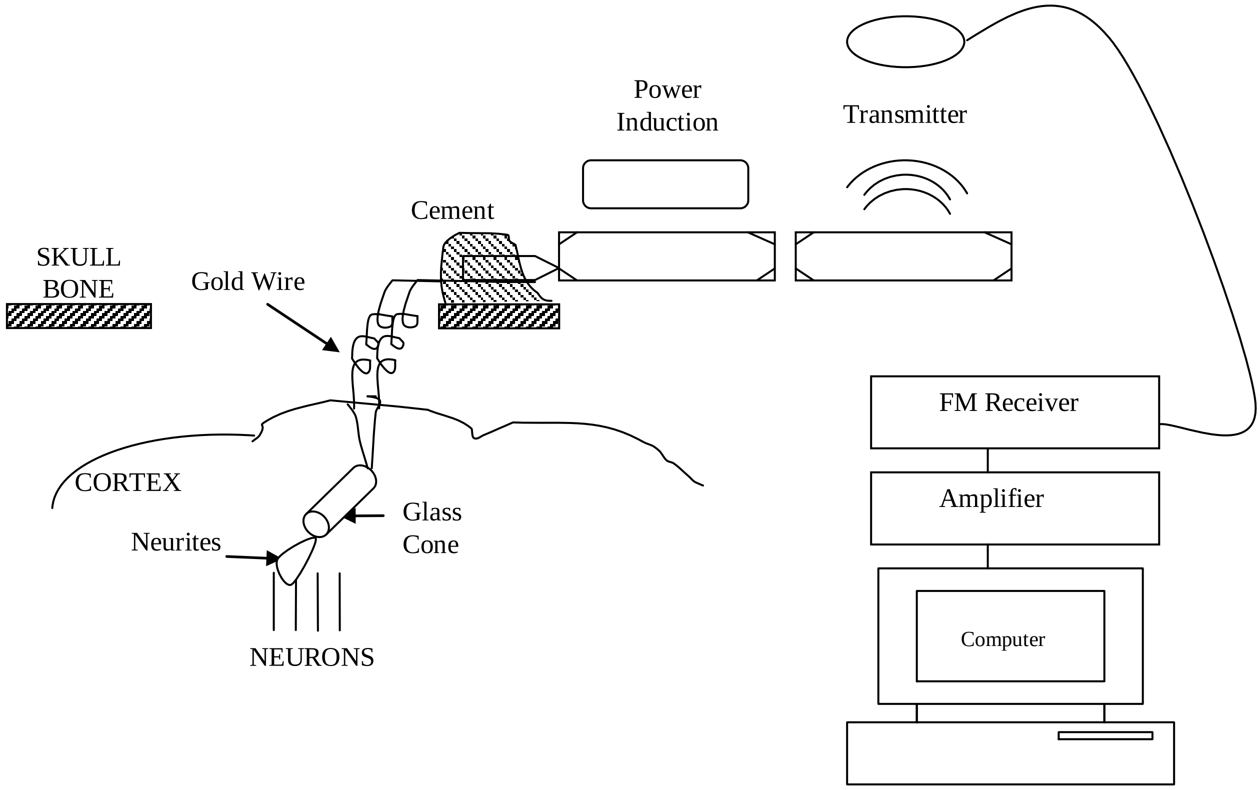

Figure 3 - Invasive Brain Computer Interface

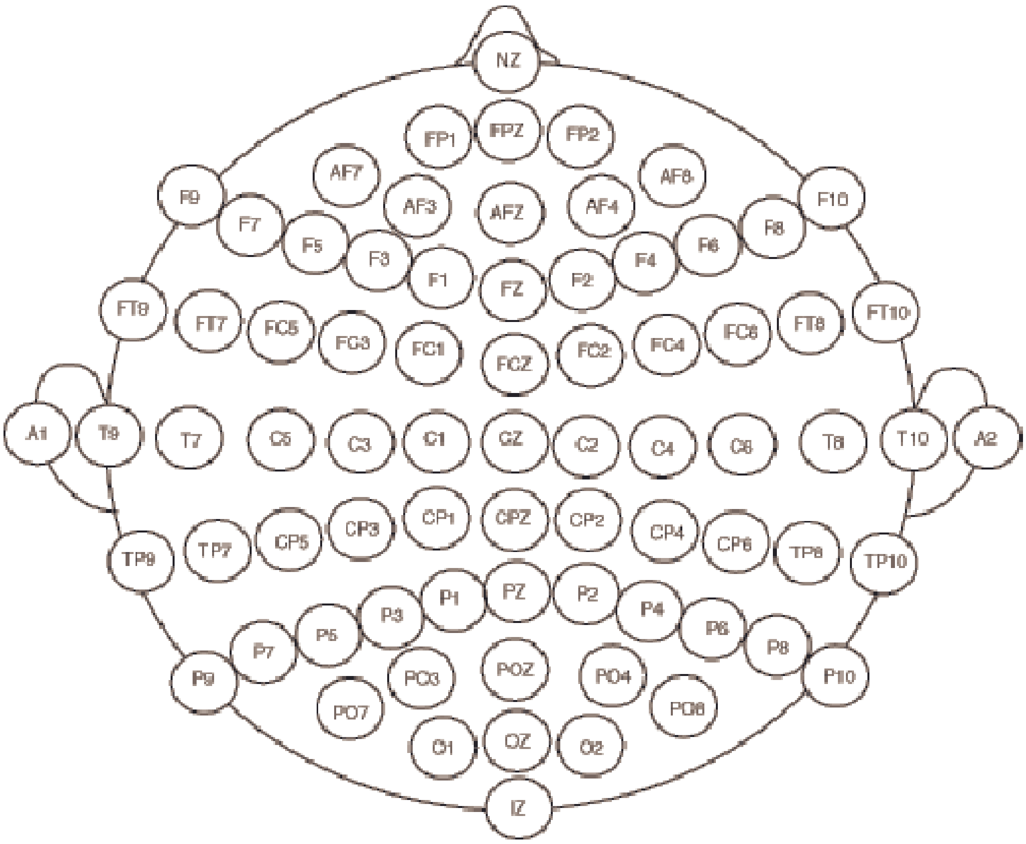

Figure 4 – The extended 10-20 System

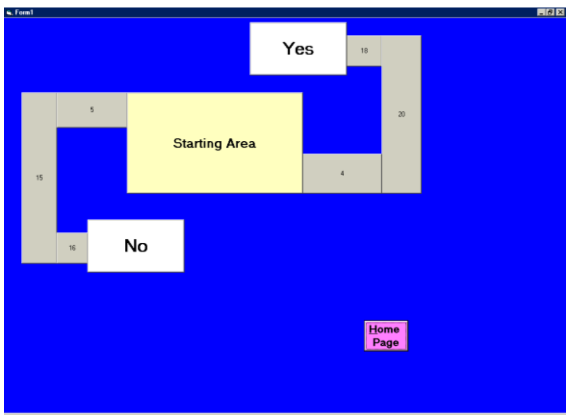

Figure 5 – Basic Tunnel Interface

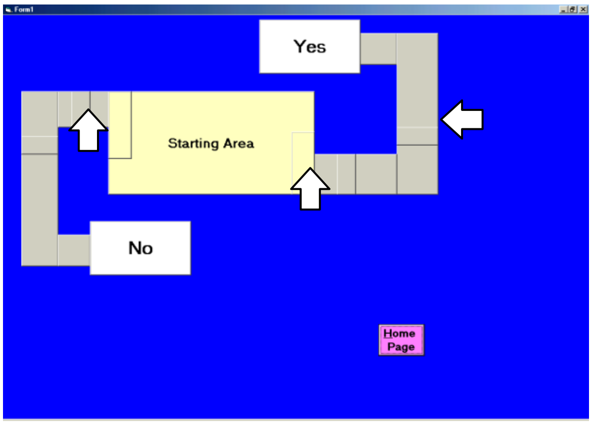

Figure 6 – Example areas for discrete acceleration

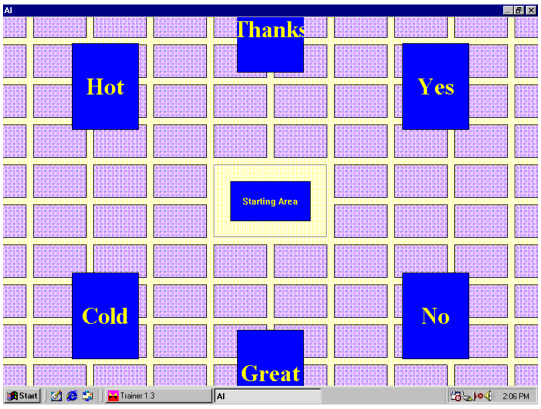

Figure 7 - Targets, tiles and gaps between tiles

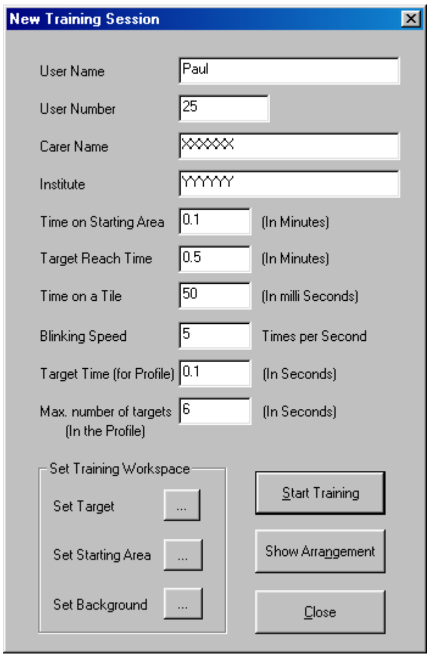

Figure 8 - Configuration Window

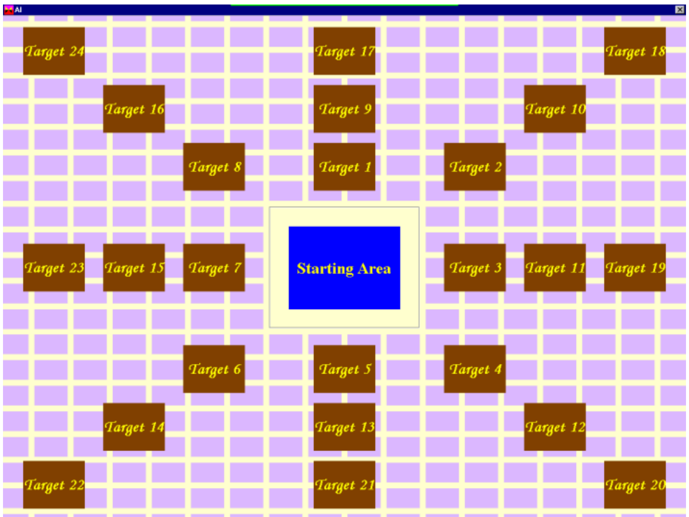

Figure 9 - Target test

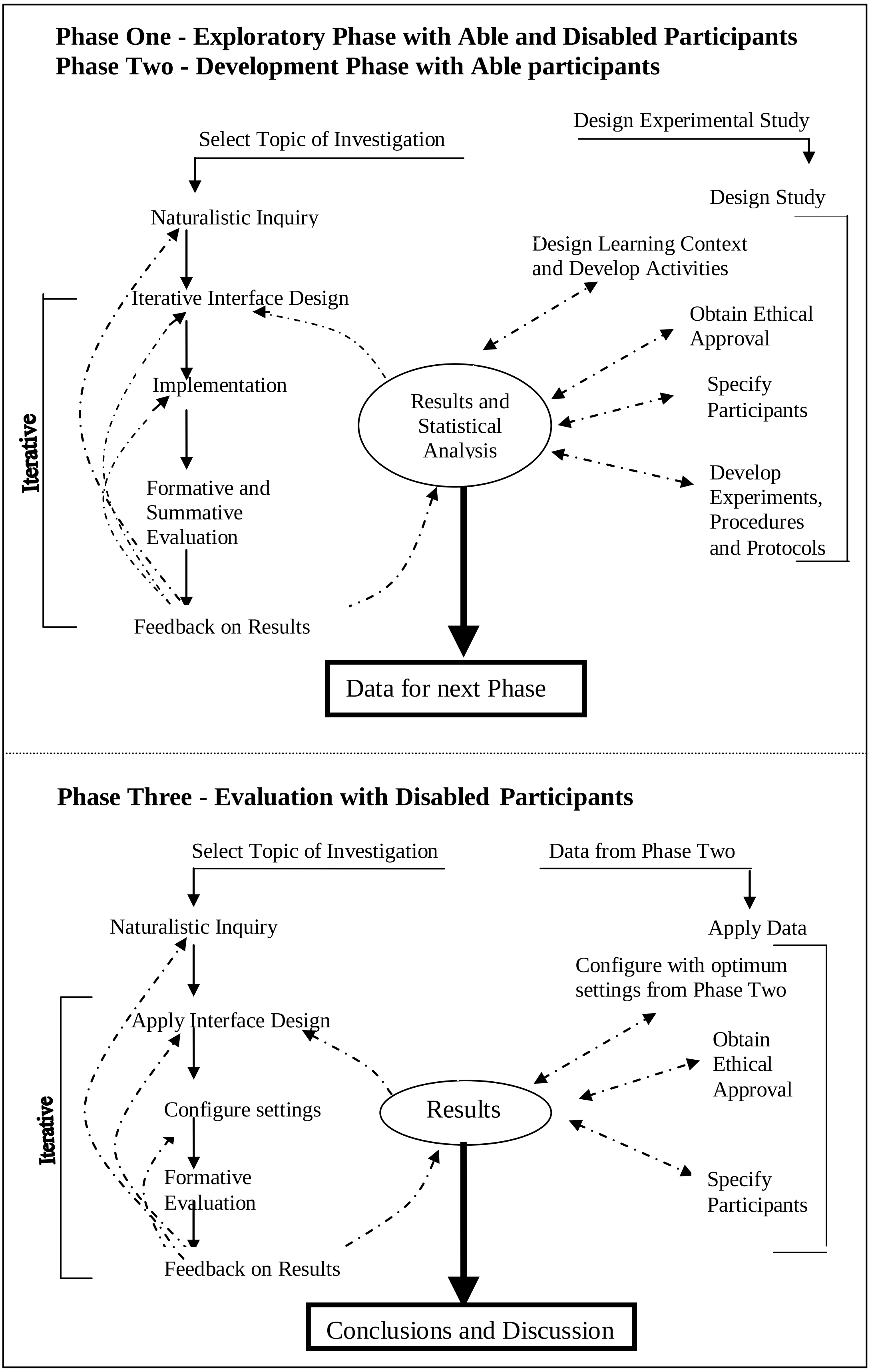

Figure 10.0 – Research Methodology