Developing Brain-Body Interfaces for the Visually Impaired

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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. This group of individuals with severe head injury has received little from assistive technology. A certain percentage of these brain-injured people cannot communicate, recreate, or control their environment due to severe motor impairment. 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. Previous research in this area developed brain-body interfaces so that this group of brain-injured people can communicate, recreate and launch applications communicate using computers despite the severity of their brain injury, except for visually impaired and comatose participants. This paper reports on an exploratory investigation carried out with visually impaired using facial muscles or electromyography (EMG) to communicate using brain-body interfaces. Seven out of eight visually impaired participants were able to communicate the interface developed in this research.

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 individuals with disabilities is constantly increasing. World Health Organization (2005) estimates that there are more than 600 million people 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 some form of

disability, exceeding the population of almost every European state (EC 2002). In comparison to different 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. Brain-injured patients typically exhibit deficiency in memory, attention, concentration, analysing information, perception, language abilities, emotional and behavioural areas (Serra and 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). A certain percentage of these brain-injured people cannot communicate, recreate, or control their environment due to severe motor impairment. This group of severely head injured people is cared for by nursing homes that cater for their wellbeing in every possible way. Their loved ones also play a major role in the wellbeing of this group of people.

1.1 Traumatic Brain Injury

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 amyotrophic lateral sclerosis, brain stem stroke 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 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).

1.2 Brain-Body Interfaces

The brain is the centre of the central nervous system in humans as well as the primary control centre for the peripheral nervous system (Fig.1). The building blocks of the brain are special cells called neurons. The human brain has approximately 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.

The three main components of the brain are the cerebellum, cerebrum and brainstem. 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 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.

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 Pedley 1990). 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 BCI (Vaughan *et al.* 2003). A brain-body 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 as defined by Wolpaw (Wolpaw *et al.* 2000). 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).

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.

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 and number of electrodes or the international 10-20 system (Pregenzer *et al.* 1994). Authorities dispute the number of electrodes needed for collection of usable bio-potentials (Berg *et al.* 1998). There is only one agreed standard for the positions and number of electrodes that is the International 10-20 system of electrodes (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. Invasive electrodes are connected to neurons to collect bio-potentials. 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), 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 (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).

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 Cyberlink™ used in our research, is a brain-body actuated control technology that combines eye-movement (Electrooculargraphy or EOG), facial muscle (Electromyography or EMG) and brain wave (Electroencephalalography or EEG) 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, since it was non-invasive without any medical intervention and easy to set-up. Previous work done in this area by the researcher has been well documented indicating the challenges involved in this research (Gnanayutham 2004, 2005, 2006, Gnanayutham *et al.* 2001, 2003, 2005).

2 Methodology

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). A medical practitioner chose suitable brain-injured participants for the research analysing their responses and medication. Comatose and medication that restricted response were used as the criteria for exclusion from this research.

The approach chosen is shown in diagrammatic form in Fig. 3. 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 (Munhall 1989), 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 Fig. 3. Williams states "naturalistic inquiry is disciplined inquiry conducted in natural settings (in the field not in laboratories), using natural methods (observation, interviewing, thinking, reading, writing)". This investigation was carried out in the environment where the brain-injured lived their daily lives and not a laboratory setting. 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 evaluated using able users as test subjects before being evaluated with disabled users. Iteration allowed better feedback for faster interface development. 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.

First phase of the research aimed to replicate previous work in this area using tunnel interfaces (Gnanayutham 2005). 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. This meant that the users could not be grouped according to their disability classification but every user had to have an individually personalised interface (Gnanayutham 2005). The second phase incorporated discrete acceleration into a more flexible and personalised setting (Fig. 2). It also introduced a controlled navigation system, which controlled the movements of the cursor by dividing the computer screen into configurable tiles and delaying the cursor at each tile. 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.

3   Design and Development

An example of this interface is shown in Fig. 2. This interface was tested with the able participants then 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.

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 meant the interface automatically recovered to the original position (i.e. starting point in the middle) this taking care of error recovery. 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. 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 with, size of tile to suit each user etc.

4   Experiments and Results

The approach chosen was iteration driven by phenomenological formative and summative evaluations, which gives the opportunity for building artefacts that can evolve into refined, tried and tested end products when developing artefacts. Formative approaches are based on the worldview belief that reality based on perceptions is different for each person. Formative research has to be systematic and subjective, indicating the experience of individual users. Formative and summative methods compliment each other since they generate different types of data that can be used when developing interfaces. Results obtained in summative methods should be tested using statistical methods, statistical significance, hypothesis validation, null hypothesis etc. Previous research (Gnanayutham *et al.* 2005) showed how five out of ten were unable to participate due to the visual impairment (Table 1). This study was conducted to cater for participants who could not use this developed interface due to visual impairment. There was a need to conduct experiments to find out whether participants with visual impairment could also use this interface to communicate.

This new research conducted at the Low Vision Unit of the National
Eye Hospital (Colombo) for participants aged between seven and eighty
were able to say 'yes' or 'no' using the brain-body interface with seventy
five percent consistency (Table 2). The numbers of participants were
eight and seven participants were able to use the brain-body interface.
Overall a maximum of twenty minutes was spent with each participant, of
which the first few minutes were used to relax the participants and relieve
or at least reduce muscle tension. Then forehead muscles were used to
move the cursor of a computer to indicate 'yes' and 'no', to the questions
being asked using the interface shown in Fig. 2. Although certain tensed
participants needed guidance and help seven out of eight participants
could control the curser to say yes and no by frowning and relaxing (using
electromyography). However one individual (participant 5) would not
relax enough to use the EMG to navigate the BBI in order to
communicate.

5 Conclusions

In this research a flexible interface was developed to suit each individual,
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
communications using the BBIs. 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. Vision impaired participants and comatose participants were the
two groups of non-verbal quadriplegic brain-injured people who could not
be included in the previous study. But this exploratory study showed how
the vision impaired could now be included in using brain-body interfaces
to communicate for the first time using the developed interface.

At present this group researchers are working in two new areas in
addition to the work described in this paper. Exploratory work is being
been done for blind individuals to navigate computer screen using
musical guidance. Research is also being carried out on rehabilitation
robotics for the brain-injured.

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Table 1 - Previous results with brain injured participants

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 – Results with participants with visual impairment

Participant	Age/Gender	Communicated successfully
1	7 Male	Yes
2	22 Male	Yes
3	27 Female	Yes
4	28 Female	Yes
5	45 female	No
6	50 Male	Yes
7	64 Male	Yes
8	80 Female	Yes

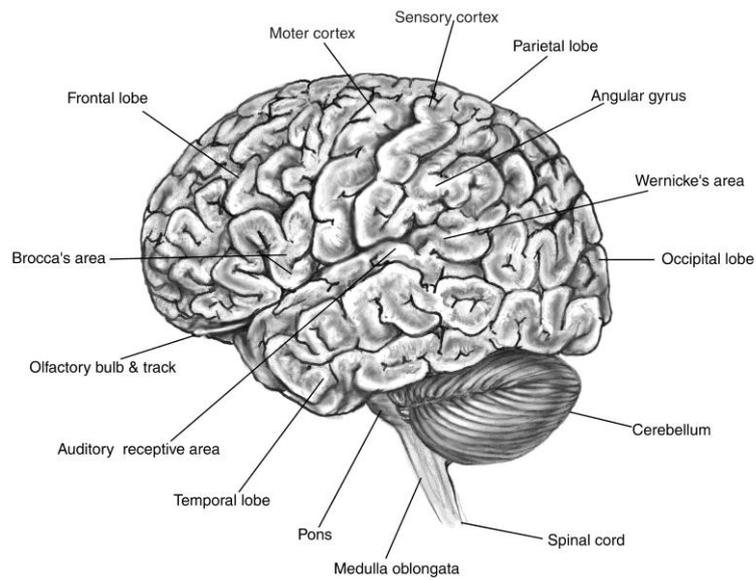**Fig. 1 -** Brain Map (Courtesy of www.headinjury.com)

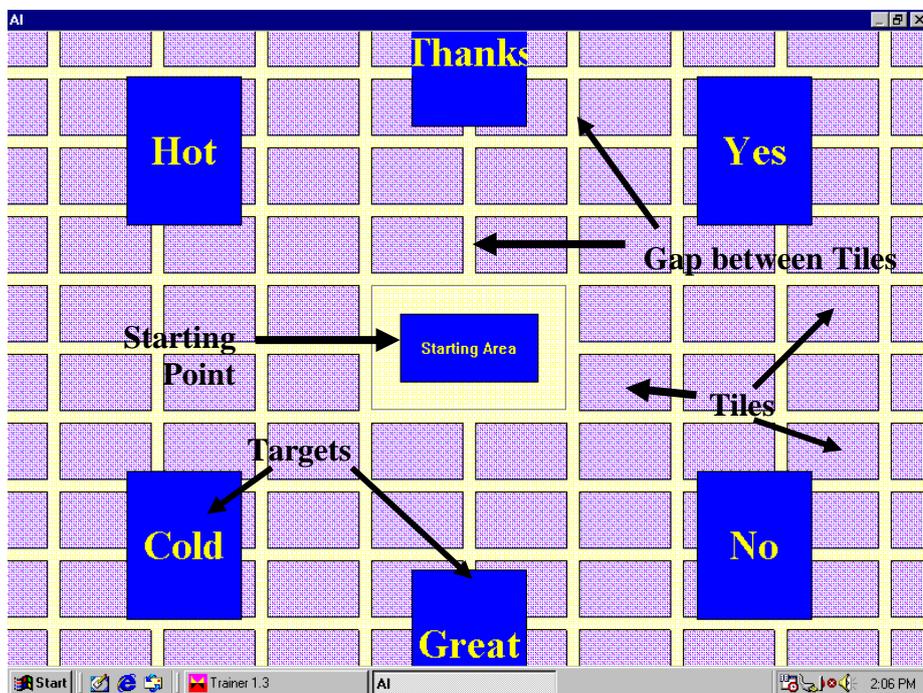**Fig. 2 -** Interface Used for this research

Fig. 3 – Chosen Methodology

Phase One - Exploratory Phase with Able and Disabled Participants

Phase Two - Development Phase with Able participants

Select Topic of Investigation

Design Experimental Study

Design Study

Naturalistic Inquiry

Design Learning Context and Develop

Iterative Interface Design

Obtain Ethical

Implementation

Results and Statistical Analysis

Specify Participants

Formative and Summative Evaluation

Develop Experiments, Procedures and Protocols

Iterative

Feedback on Results

Data for next Phase

Phase Three - Evaluation with Disabled Participants

Select Topic of Investigation

Data from Phase Two

Naturalistic Inquiry

Apply Data

Configure with optimum settings from Phase Two

Apply Interface Design

Obtain Ethical Approval

Configure settings

Results

Formative Evaluation

Specify Participants

Iterative

Feedback on Results

Conclusions and Discussion