Adaptive Brain-Body Interfaces

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Abstract. This paper describes an adaptive brain-body interface (BBI) that was designed to cater for traumatic brain injured personnel to use the computer screen as a means for communicating, recreating and controlling their environment. The paper describes how the initial interface was developed and optimised for this group of personnel. It also deals with the challenges involved in designing an adaptive interface and the adaptive features incorporated in to the interface.

1 INTRODUCTION

A brain-computer interface (or 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. There are various brain-body interfaces that have been developed which uses interfaces with fixed configurations but this research looked for an inclusive interface that can be personalised for individual needs of the users. A computer program that would enable a non-verbal, quadriplegia head injured person to communicate, recreate or control their environment. A non-invasive assistive technology device named Cyberlink™ was chosen as the brain-body interface for this research. Cyberlink™ combines eye-movement (EOG), facial muscle (EMG) and brain wave (EEG) bio-potentials detected at the user's forehead to generate input via the mouse port. A major problem encountered while designing this interface was the inconsistent control of the cursor, which was caused by the 'irrelevant' electrooculargraphic (EOG), electromyographic (EMG) and electroencephalalographic (EEG) signals being picked by the brain body interface. This had to be solved by controlling the cursor navigation on a computer screen. The bio-potentials obtained by the brain-body interfaces had a voltage range of micro volts to mini volts, which meant navigating a cursor through a computer screen was a difficult task and needed a method to push the cursor towards the target. The design solution chosen to solve these two issues were to calculate the directions of travel and push the cursor towards the intended target, use tiles to control the cursor navigation and give the users personalised settings to create individual interfaces [1][2] (Figures 1 - 4). There was also need for minimum training since the interface had to cater for the short-term memory of some users.

This study was carried out in three phases. Phase one of this research which was an exploratory one which indicated that the users had problems navigating certain parts of the screen or when travelling in certain directions [1]. Sibert and Jacob [3] recommend a target practice with random target with no target being repeated. Jacko and team [4] 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). 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. Once the user finishes target practice, the program can come up with a tailor-made profile for that particular individual user (Figure 6). Different numbers of targets could be set for a particular individual interface, for example 2 to 6 depending on ability of the user. Targets could also be programmed to do various tasks such as read text, launch applications or switch devices.

Automated target practice for a personalised interface based on this results could improve an interface 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? 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 [5] states that the individual user interface can be an adapted user interface (adapted to the end user at design time), 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 [6] state that adaptability increases usability. Phase two of this research 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. An interface would combine pushing the cursor in the intended direction of travel termed '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 [7] 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 1). Then the user navigates to the intended target via tiles. At each tile an algorithm moves the cursor towards the intended target in a tile. The user only moves between the tiles using the gap. An interface was developed so that it can be configured to suit each individual according to his or her ability.

2 ALGORITHM

A screen conforming to Gestalt Laws was designed (Figure 1), where objects with similarity, proximity and symmetry were grouped together. Pickford [9] 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 [10] 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.

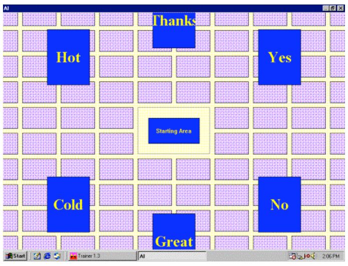


Figure 1 - Targets, tiles and gaps between tiles

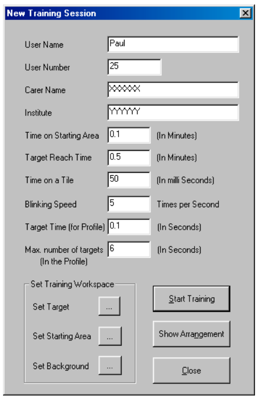
Previous investigations show that users have emotional reactions to colours and fonts, this interface gave the option for making changes to suit any user [11]. Laarni's study also showed that white or yellow text on blue background was more readable, which was taken as the default setting for the interface.

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 [12][13]. Cyberlink™ was not a Fitt's Law device [1], since bio-potentials cannot be used in a controlled manner to navigate a computer screen, 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 to cater for individual needs. There was also audio feedback [14][15]. 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.

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.

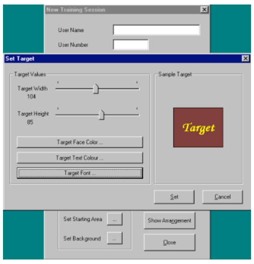
The run-time profile interface thus has further features that allow the cursor's path to be controlled by settings for a specific user (Figures 2 - 4). These settings include:

- 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.



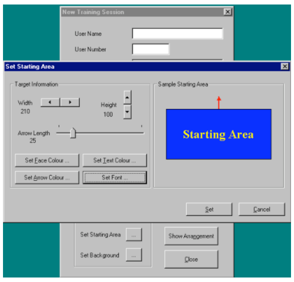
User Name: Paul
User Number: 25
Carer Name: XXXXXX
Institute: YYYYYY
Time on Starting Area: 0.1 (In Minutes)
Target Reach Time: 0.5 (In Minutes)
Time on a Tile: 50 (In milli Seconds)
Blinking Speed: 5 Times per Second
Target Time (for Profile): 0.1 (In Seconds)
Max. number of targets (In the Profile): 6 (In Seconds)

Figure 2 – Personalising the interface



Target Width: 104
Target Height: 85

Figure 3 – Configuring targets



Width: 210
Height: 100
Arrow Length: 25

Figure 4 – Configuring starting area

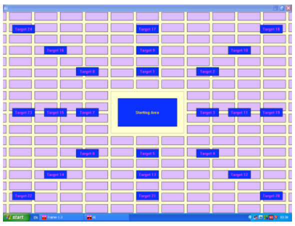


Figure 5 – Targets

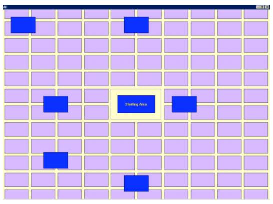
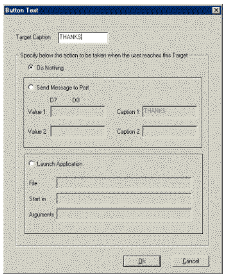


Figure 6 – Personalising the interface



Button Text

Target Caption: THANKS

Specify below the action to be taken when the user reaches this Target

● Do Nothing

○ Send Message to Port

D7 D0

Value 1

Caption 1: THANKS

Value 2

Caption 2

○ Launch Application

File

Start in

Arguments

Figure 7 – Window for configuring individual targets

3 OPTIMISATION

Optimisation was carried out in this phase of the research. Kelton [16][17] 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 1). 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.

	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

Table 1 – Profiles used for optimising interfaces

Ten able bodied participants were used to conduct summative experiments with the four profiles shown in Table 1, in order to optimise the interface. 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 1. 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. 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 results of ranked profile preferences by individuals, eighty percent of the participants preferred Profile 2 with medium tiles and small gap between tiles.

	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%

Table 2 – Summative Evaluation for: Success Rates

The dimensions and times recorded during summative evaluation showed (Table 2) 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 2, 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 interfaces manually gives the opportunity for carers to personalise using Evidence-Based Personalisation [18] 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 design space was required, nor was there time for exhaustive systematic optimisation. The approach was an engineering, rather that scientific method.

4 EXPERIMENT AND RESULTS

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? 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 (Figure 1). Table 3, shows details of participants of this third and final phase of research. 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 [18].

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. 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 [19].

The research question raised in phase three was, can a disabled participant give consistent answers using the personalised interface with discrete acceleration. 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. The configuration information and the personal interface for each participants is shown in Figures 8 – 17.

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 electroocularagraphic 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™. They could use the Cyberlink according to their own ability, using their personalised interface to communicate. 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? These profiles below demonstrate how each participant had his or her individual interface with personalised times to suit their abilities, which made the interface inclusive of the five participants with different abilities.

Part. No	**Institute**	**Gender/ Age**	**Clinical Diagnosis**	**Additional Information**
45	Holy Cross	M38	Locked-in syndrome	Non-verbal
46	Holy Cross	F61	Severe cerebral haemorrhage, brain stem injury	Non-verbal
47	Holy Cross	M45	RTA, Diffuse axonal brain damage	Non-verbal. Can use a foot switch but it takes a lot of effort from the participant
48	Holy Cross	M60	Brain stem injury	Non-verbal
49	Castel Froma	M32	Traumatic Brain Injury	Non-verbal, can respond by thumb occasionally

Table 3 – Details of the participants used in phase three

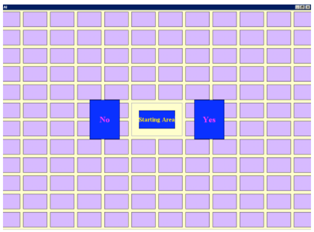
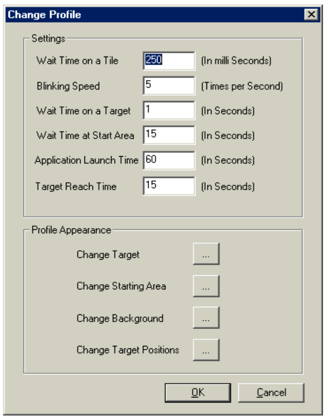


Figure 8 – Profile of Participant 46


Change Profile

Settings

Wait Time on a Tile 250 (In milli Seconds)
Blinking Speed 5 (Times per Second)
Wait Time on a Target 1 (In Seconds)
Wait Time at Start Area 15 (In Seconds)
Application Launch Time 60 (In Seconds)
Target Reach Time 15 (In Seconds)

Figure 9 – Profile settings of Participant 46

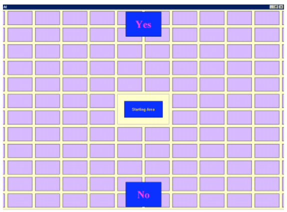
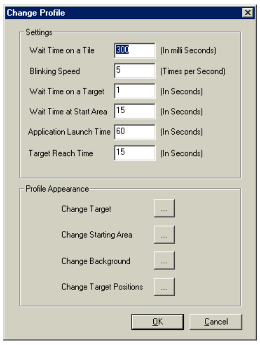


Figure 10 – Profile of Participant 49



Wait Time on a Tile 300 (In milli Seconds)
Blinking Speed 5 (Times per Second)
Wait Time on a Target 1 (In Seconds)
Wait Time at Start Area 15 (In Seconds)
Application Launch Time 60 (In Seconds)
Target Reach Time 15 (In Seconds)

Figure 11 – Profile settings of Participant 49

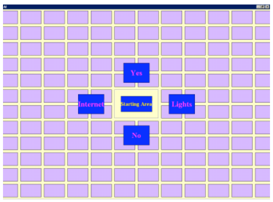
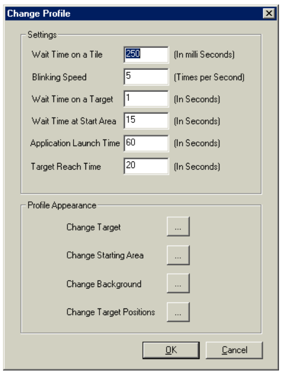


Figure 12 – Profile of Participant 47



Wait Time on a Tile 250 (In milli Seconds)
Blinking Speed 5 (Times per Second)
Wait Time on a Target 1 (In Seconds)
Wait Time at Start Area 15 (In Seconds)
Application Launch Time 60 (In Seconds)
Target Reach Time 20 (In Seconds)

Figure 13 – Profile settings of Participant 47

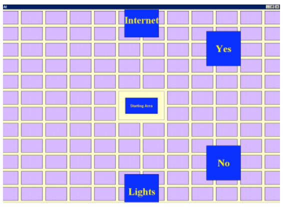
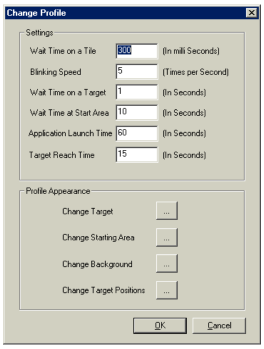


Figure 14 – Profile of Participant 48



Wait Time on a Tile 300 (In milli Seconds)
Blinking Speed 5 (Times per Second)
Wait Time on a Target 1 (In Seconds)
Wait Time at Start Area 10 (In Seconds)
Application Launch Time 60 (In Seconds)
Target Reach Time 15 (In Seconds)

Figure 15 – Profile settings of Participant 48

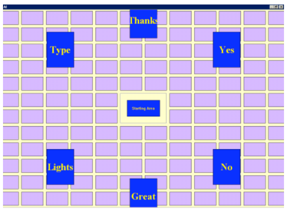
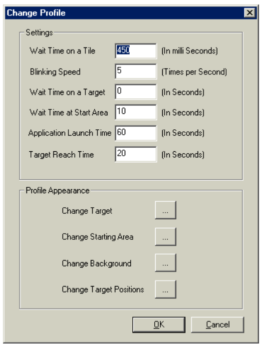


Figure 16 - Profile of Participant 45



Wait Time on a Tile 450 (In milli Seconds)
Blinking Speed 5 (Times per Second)
Wait Time on a Target 0 (In Seconds)
Wait Time at Start Area 10 (In Seconds)
Application Launch Time 60 (In Seconds)
Target Reach Time 20 (In Seconds)

Figure 17 – Profile settings of Participant 45

The success rate was measured only with disabled participants. Participants 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 As Table 4, shows, three participants (45, 47 and 48) could launch applications such and switch devices. We have thus achieved a wider range of 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 interface 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. 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.

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

Table 4 – Evaluation Results

The provision of personalisation greatly improved the interface by giving a facility to configure the interface to suit each participant as shown in Figures 8 to 17. 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

7 CONCLUSIONS & FUTURE WORK

All five brain-inured participants chosen for this 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.

This research 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 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. At present the researchers are working on visually impaired to communicate using the interface developed in this research.

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