“One-Button” Brain-Computer Interfaces

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Abstract — The number of people with brain injuries is increasing, as more people who suffer injuries survive. Some of these patients are “locked in” their own bodies, aware of their surroundings but almost entirely unable to move or communicate. Brain-Computer Interfaces (BCIs) enable this group of people to use computers to communicate. BCIs tend to be hard to navigate in a controlled manner, and so the use of “one button” user interfaces is explored. This kind of interface is the simplest, and is the most universally accessible. It may be a useful “stepping stone” for a disabled person before he or she attempts to use a more sophisticated interface.

I. INTRODUCTION

People who have suffered a brain injury may have difficulties communicating. In the most extreme case, the patient may be non-verbal and quadriplegic. Some patients are cognitively intact but unable to communicate at all, which condition is termed "locked in syndrome". The authors are particularly interested in improving accessibility for this neglected group of people, in areas such as communication, recreation, and controlling the environment.

This paper describes work, currently in its initial stages, which aims to provide access to off-the-shelf software, using a “one button” interface.

“One button games” are games in which the only control is a single button, which may be pressed or not pressed. At first, this seems a very limiting user interface. However, Berbank-Green [1] discusses one-button games and lists many ways in which games can be played using only one button.

A one-button interface, as the name suggests, has only one control: a button which can be pressed or not pressed. This is the most minimal control a user can exercise, and so is the most “universal”, in the sense of being accessible to the maximum number of users [16].

Such an interface clearly has its limits, and will not be suitable for all types of software. In this paper we discuss contexts in which a one-button interface will bring benefits to severely disabled people, by providing an immediately usable interface.

II. BRAIN INJURIES

A. Injuries to the brain

A traumatic brain injury (TBI) is an acquired brain injury caused by trauma such as a blow to the head, an impact with a blunt object, or penetration by a sharp object [23]. Common causes of TBI are motor vehicle accidents; bicycle accidents; assaults; falls and sports injuries [23], [17] (p. 216).

The primary mechanism in many cases of TBI is diffuse axonal injury, i.e. widespread damage to axons (brain cells) caused by shearing or rotational forces [23]. At the microscopic level, the direction of the shear may be visible [17] (p. 218).

Other causes of brain injury which are not classified as TBI are called acquired brain injury (ABI). There are many possible causes for an ABI, including: stroke (cerebrovascular accident, CVA); Amyotrophic Lateral Sclerosis (ALS); brain tumour; haemorrhage; infection; encephalitis; and medical accidents [4].

B. Numbers of people with brain injuries

Powell [24] reports that approximately one million people in Britain attend hospital every year as result of head injury. The incidence of disabled survivors is 100-150 per 100 000 – or more than 120 000 people in the UK suffering from long-term effects of severe head injury.

Improvements in road safety have reduced the number of people who suffer a head injury. For example, Cook and Sheikh [7] report a 12% reduction in bicyclist head injuries in England between 1991 and 1995, ascribed to the increased use of bicycle helmets over the period. Reductions in drink-driving and increased use of seat belts, crash helmets and air bags have reduced the incidence of head injury in many countries [17] (p.216). However, as medical care has improved, the number of people who survive a brain injury has increased [23]. Powell [24] reports that the number of brain injured people has increased since the 1970s, because the mortality rate has dropped since that time.

C. Assessment of brain injury

When a person suffers a moderate or severe brain injury, they will enter a comatose state. During this period, it is possible to assess the severity of the injury by gauging the responsiveness of the patient. The Glasgow Coma Scale, developed by Jennett and Teasdale, is commonly used [23]. Upon regaining consciousness, the patient will experience a period of post-traumatic amnesia (PTA). The period of PTA is judged to have ended when the patient is able to form new memories [23].

The periods of the coma and of the PTA give a reliable indication of the severity of the brain injury. A coma period of more than six hours, or PTA of more than 24 hours is classed as a severe injury, which accounts for 5% of all head injuries [24]. Other methods of evaluation are more suitable for assessing the patient's longer-term prospects of recovery. These include the Rancho Levels of Cognitive Functioning [14].

Some patients remain in the comatose state, or transition to a persistent vegetative state (PVS). PVS patients are unable to move or communicate, and are not aware. Some other patients are cognitively intact and aware of their surroundings, but are unable to move or communicate. This condition is known as *locked-in syndrome*.

Recent cases have been reported of patients who were misdiagnosed as being in PVS, when they were in fact locked in [20]. Monti and team [18] describe patients who are outwardly non-aware and non-communicative, but who can answer questions using MRI scanning. As patients diagnosed as PVS are more routinely scanned for cognitive activity, so the number of diagnosed locked-in patients may increase, and the number of PVS patients decrease correspondingly [18].

D. Consequences of brain injury

The consequences of brain injuries fall into three general categories: cognitive effects; emotional and behavioural effects; and physical effects [4].

Powell [24] lists the effects of brain injury most often noted by relatives of the injured person. These effects include personality changes, slowness, poor memory, irritability, bad temper, tiredness, depression, rapid mood changes, tension and anxiety, and threats of violence.

E. Rehabilitation after a brain injury

As medical technology advances, more people survive brain injury. However, survival is not the same as quality of life. Rehabilitation is the process of regaining lost skills, or developing coping mechanisms to replace them.

Rehabilitation has two stages: the acute stage, where medical professionals stabilise the patient. The second stage is where family and carers take over. Broadly, successful rehabilitation depends on the severity of the brain injury. However, every patient responds differently to treatment, and different skills may be regained at different times (e.g. regaining walking and remembering skills) [4].

Full recovery (to the same state as before the injury) is a reality for mild injuries, but "as a general rule the more severe the injury, the longer recovery may take, and the less complete it may be" [4]. However, on a positive note, some patients continue to improve, even years after the brain injury [4].

III. BRAIN-COMPUTER INTERFACES

A Brain-Computer Interface (BCI) is a system for controlling a computer that does not depend on the brain's normal output pathways such as speech or gestures. Instead, a BCI will use any of the *bio-potentials* which are under the conscious control of the user [11]. For people with extremely limited motor ability, a brain-computer interface is the only way in which they can use a computer.

A. Bio-potentials

Bio-potentials are electrical signals originating in the brain and nervous system. The existence of electrical currents in the brain was first discovered in 1875 by Richard Caton [27]. These can be detected and used to control hardware and software.

Bio-potentials may be detected in two ways: invasive and non-invasive. Invasive methods involve surgery to place electrodes within the body or brain; non-invasive methods take measurements from the surface of the body. Invasive techniques provide higher amplitude signals with improved signal to noise ratio, but carry the risks of surgical procedures. In this study, we consider the use of only non-invasively measured bio-potentials: electroencephalography (EEG), electromyography (EMG), and electrooculography (EOG).

Electroencephalography (EEG) is the measurement of electrical waves produced by the brain. The existence of these regular waves was first published by Hans Berger in 1929 [2].

These waves have amplitudes ranging from approximately 1uV to 100μV at the surface of the scalp. The frequencies measured range from approximately 1Hz – 30Hz, the dominant frequency depending on the person's mental state [6], [27].

Electromyography (EMG) is the measurement of electrical signals originating from muscle movement. These signals have the same frequency range as EEG and an amplitude range of 0.2 to 2000µV [13].

Electrooculography (EOG) is the measurement of electrical activity caused by eyeball movements. The range of frequencies is relatively low, from 1.1 to 6.25 Hz. The amplitude is higher than EEG, around 1 - 4mV [13].

Other non-invasively measured bio-potentials may be used for BCIs, but are not used in this study. These include evoked potentials, (e.g. P300 and N400); steady-state visual evoked potentials; and slow cortical potentials [13].

E. Commercially available Brain-computer interfaces

BCI hardware ranges from devices intended for playing computer games through to medical-grade EEG machines. The following table shows currently available consumer-level BCI hardware. These only measure non-invasive bio-potentials.

Table II: Commercially available BCI hardware. Prices are approximate.

Name	**Manufacturer**	**Approx Cost in £**
Cyberlink™	Brain Actuated Technologies Inc [3]	£1400
Neural Impulse Actuator™	OCZ Technology [22]	£85
Enobio®	Starlab [26]	£3150
EPOC	Emotiv [8]	£200
Mindset	Neurosky [19]	£130

In this study, the Cyberlink™ hardware with Brainfingers software has been used. This follows in the footsteps of successful studies [9] which have enabled locked-in patients to communicate.

Cyberlink/Brainfingers lets the user control the mouse cursor and mouse button clicks using bio-potentials. The software is configurable, so that different users can control the mouse using different EEG frequency bands, and also EOG and EMG, if appropriate.

IV. USABILITY OF BRAIN-COMPUTER INTERFACES

Participants invariably have a lot of difficulty in controlling the mouse cursor with Cyberlink. To move the mouse cursor at will, the user must be able to consciously control four separate 'channels' of bio-potential: one channel to move the cursor up, one to move it down, one for left, and one for right movement. Adding the ability to generate mouse button events further complicates the task facing the user. This difficulty means that in practice BCIs are difficult to use. Typically when using Cyberlink, the mouse cursor moves quickly to a corner of the screen and then stays there. This frustrates users, making it even harder to bring the cursor back under conscious control.

These difficulties have been addressed by developing the novel User Interface paradigms, *Discrete Acceleration* and *Personalised Tiling* [10]. Another approach, discussed here, is to make the interface easier to use by reducing the number of channels which the user must control. The simplest possible configuration is a one-button interface, requiring only one channel of information. To use this kind of interface, the user only needs to be able to consciously control one bit of information over time. The advantage of such an interface is its simplicity. Being the simplest kind of interface, it is as "universally accessible" as possible.

V. EVALUATING A ONE-BUTTON INTERFACE

To investigate the difficulty of using Cyberlink, a focus group was convened (six programming students, all male, age range early twenties to early thirties). The focus group participants were able-bodied.

A. Methodology

Standard methodologies for HCI design, e.g. Usability Engineering [21] or Contextual Design [15], stress the importance of "knowing the user" [21] and so evaluation with the intended users of the system is the norm.

Designing software for people who are severely disabled by brain injury is challenging, for reasons including the person's communication difficulties and medical needs [12]. Because of this. in the case of designing for severely disabled people, a different methodology is called for. Gnanayutham and George [12] provide case studies where initial investigations are carried out with able-bodied participants, before evaluation with disabled participants begins.

In this study, a similar methodology is followed.

- The development process is iterative, as the most useful artefacts must be evolved and refined from earlier prototypes.
- Prototypes are initially tested using able-bodied participants.

- Summative evaluation is used to measure the usefulness of the prototypes.
- Formative evaluation takes account of users' perceptions throughout the development cycle.

The process could be thought of as a spiral, because we seek to iteratively improve a design based on feedback; and the circle of participants expands over time (fig. 1).

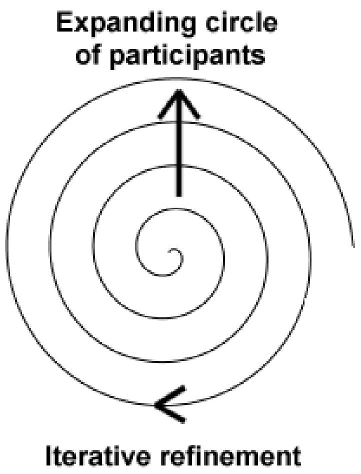

Figure 1. Methodology

B. Design

The focus group participants were asked to solve a “Fifteen Puzzle” [5] using Cyberlink. The fifteen puzzle was chosen for its familiarity and simplicity. The puzzle consists of 15 numbered tiles and a space arranged in a 4x4 grid. A tile horizontally or vertically adjacent to the space can be moved into it. The puzzle was “shuffled” by making 100 moves at random, the goal of the puzzle being to restore it to its initial state. Figure 2 shows the puzzle in its initial state (a) and shuffled (b).

The action required of the user was to generate a mouse-click event at the appropriate time, using Cyberlink. The tiles were “scanned”, i.e. highlighted one at a time, each for a period of one second, in numerical order. When the mouse button was “clicked”, the highlighted tile would move to the space. Figure 3(a) shows one tile highlighted. When the user generates a mouse-click event using Cyberlink, the highlighted tile moves to the space, as shown in fig. 3(b). The “scanning” technique has been used for numerous augmentative and alternative communication schemes [25].

Figure 2(a). Fifteen Puzzle in initial state.

Figure 2(b). Fifteen Puzzle shuffled.

The participants were given time to familiarize themselves with Cyberlink, and did not start the puzzle until they were able to generate a mouse click event at will.

Only moveable tiles were highlighted. It was recognized that the “artificial intelligence” (AI) of a user interface must not be intrusive. However, in the case of the 15 puzzle, most tiles cannot be moved. Scanning all 15 tiles would result in a lot of wasted time and frustration for the user; and so it was decided to only scan the tiles which could be moved into the space.

Variations in the UI elements were tested, to see if some visual cues would improve the one-button interface. One visual cue was to show, underneath the puzzle, the tiles which would be highlighted, in the order in which they would be highlighted. The other was to show a “progress bar” on the highlighted tile, showing how much longer the tile would be in the highlighted state. The variations were numbered as shown in table II.

Figure 3(a). Highlighted tile before mouse-click event.

Figure 3(b). Highlighted tile after mouse-click event.

Table II: User Interface Variations

Variation #	Show highlight-able tiles	Show progress bar
1	No	No
2	Yes	No
3	No	Yes
4	Yes	Yes

The mean time per click and mean number of errors per click were measured, for the four different UI types. An error was recorded if a tile was moved twice in succession. The design of this evaluation was within-subjects, with the order of the UI variations randomized, to counterbalance learning and fatigue effects.

Pilot testing revealed that solving a thoroughly randomized 15 puzzle was difficult for some participants, so the puzzle goal was simplified. The new goal was to make the top row of tiles all the same fruit type. It was felt that this change would not affect the measurement of mean time per move and mean number of errors per move, and would put participants under less pressure to "perform".

C. Results

Mean time per tile movement, for the four UI variations, is shown in table III.

Table III. Mean time per tile movement

Participant #	Mean time to move a tile for UI version			
	#1	#2	#3	#4
1	2.22	2.10	2.06	2.46
2	2.64	2.38	2.00	2.13
3	2.37	3.03	2.13	2.37
4	2.36	2.05	1.93	2.01
5	1.88	2.78	2.38	2.14
6	1.74	2.18	2.08	2.13

Mean number of errors per tile movement, for the four UI variations, is shown in table IV.

Table IV. Mean number of errors per tile movement

Participant #	Mean no. errors per tile movement per UI version			
	#1	#2	#3	#4
1	0.15	0	0	0
2	0	0.08	0	0.06
3	0.02	0	0	0.05
4	0.09	0.05	0.09	0.08
5	0	0.08	0	0
6	0	0.1	0	0.03

Feedback from the focus group members was that the one-button interface was immediately usable, compared with 2-axis mouse cursor control.

Mean time to move a tile was close to 2 seconds, regardless of UI variation. For each puzzle run, 15% or fewer moves were mistakes, counted as a tile being moved and then immediately moved back to its former position. Half of the puzzle runs had no mistakes.

Participants commented that highlighting the tiles in a consistent order, e.g. always clockwise, would be an improvement over numerical order. The participants also suggested other ways to improve the interface by reducing the amount of time spent waiting for the chosen tile to be highlighted. These were to add a "double click" or "hold" action to speed up scanning.

D. Interpretation of results

Adding a progress bar to the highlighted tile received favourable comments from the participants. However, this did not result in any significant improvement in mean time to move a tile, or number of errors. Neither did displaying all tiles which would be highlighted. Indeed, this may have been a distraction.

Scanning time was one second per tile. On average there are three tiles which may be moved into the empty space. The mean time of just over 2 seconds per tile movement suggests that users were able to move a tile the first or second time it was highlighted. It may be that this time would be hard to improve upon, whatever UI improvements were made.

The low error rate and low time per tile movement shows that the one-button interface was easy to use compared with a 2D cursor-control interface. However, the participants' comments and ideas for speeding up scanning suggest that it can become frustrating waiting for the chosen tile to be highlighted.

VI. DISCUSSION

The focus group findings show that one-button interfaces are quickly usable and offer a low error rate. This suggests that it may be fruitful to design a one-button brain-computer interface that would work with off-the-shelf software. One might call this an "accessibility layer".

It is the authors' view that it is better to attempt to make existing, "off-the-shelf" software accessible, rather than to write new software with accessibility features. The reasons are that writing new software is expensive and time consuming; and a small number of researchers cannot hope to provide every type of software required.

The "accessibility layer" would be used in two phases: a configuration phase, and a run-time phase. During the configuration phase, rectangles representing clickable areas would be drawn on the screen, over the software to be used. This phase would probably be carried out by an able-bodied person. During the run-time phase, the rectangles would be scanned, i.e. highlighted in turn, and the mouse cursor moved to that location. This would enable a disabled user to click on a button or other UI element in the application by generating a mouse-click event, using BCI hardware such as Cyberlink.

This kind of interface would only be usable with certain types of software, i.e. those based on clicking buttons in dialog boxes. Many applications also require typing. The interface could be extended to also emulate key presses by scanning a software keyboard when required. The software keyboard could use a scanning algorithm designed to reduce the waiting time for the user as much as possible, e.g. one of the algorithms described in [25].

VII. CONCLUSIONS AND FUTURE WORK

The number of people with brain injuries is increasing, as medical care has improved. Some of these patients are cognitively intact, but cannot communicate, except by using a brain-computer interface (BCI). The number of people diagnosed with this condition may increase if diagnostic tests such as those described in [18] become widespread.

BCIs can be difficult to use, and can require a lengthy training period. A "one-button" interface is simpler, and so easier to use, with less training. This type of interface is limiting due to its simplicity, but could find use as a first "stepping stone". When a user outgrows the one-button interface, he or she is ready to move on to an interface that is more sophisticated. It is the authors' belief that the confidence gained by successfully using the one-button interface would help the user, as learning to use a more sophisticated interface may be difficult and frustrating. A one-button interface would not replace a 2D cursor interface, but rather would complement it.

We have outlined a design for an "accessibility layer" allowing a one-button interface to be applied to off-the-shelf software. The types of software to which this could be applied are currently limited. Future work would concentrate on designing accessibility layers for more varied types of software, and on making common applications and operating systems more accessible.

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