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Replacing Indirect Manual Assistive Solutions with Hands-Free, Direct Selection

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Running Head: Hands-free point and click assistive technology

Replacing indirect manual assistive solutions with hands-free, direct selection.

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science

By

JAMES WILLIAM LEONARD JR.
B.S., Louisiana State University, 2006.

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WRIGHT STATE UNIVERSITY

SCHOOL OF GRADUATE STUDIES

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY JAMES LEONARD ENTITLED REPLACING INDIRECT MANUAL ASSISTIVE SOUTIONS WITH HANDS-FREE, DIRECT SELECTION. BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Abstract

Leonard, James. M. S., Department of Human Factors Psychology, Wright State University, 2011. Replacing indirect manual assistive solutions with hands-free, direct selection.

Case study BK is a teenage male who suffers from severe cerebral palsy, making communication very difficult using his current assistive technology. His performance with a manual switch was compared to a hands-free system for computer interaction (Cyberlink Brainfingers/ NIA). BK uses a switch scanning menu, which steps through predetermined options till he chooses the current option being read aloud by pressing a button. A yes/no menu was used for the switch scanning interface for both manual and hands free conditions, as well as the point and click condition. In both hands-free conditions, BK was as fast and accurate as he was with his manual assistive solution that he has been using for almost 10 years now. Results indicate that a hands-free system is a valid assistive technology direction for BK. As in Marler (2004)- perhaps the greatest benefit from a point and click hands-free system could be increased engagement.

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The Problem

BK is a young male with Cerebral Palsy (CP) who has gone through life to this point with severely limited means for communicating with others. His lack of speech ability has been augmented with a switch scanning system. A small computer reads through options, and BK must depress a large button to select the desired option after it is read. His inability to reliably perform timed motor actions foils many of his attempts to use his assistive technology, which relies on temporally arranged options. His physical disability has made the use of keyboard and mouse impossible, in fact even the gross motor control required for switch activation is very effortful for BK. Despite early progress using the switch scanning system to communicate, BK's parents and teachers have reported regression in his ability to communicate. This could be the result of intermittent use of the system, boredom, or simply because the interface is too clumsy and difficult for BK to use.

The goal of this research is to explore alternatives to manual interfaces for BK, in particular an off the shelf BCI device (Brainfingers).

Brainfingers is a computer interaction device capable of measuring bio-potentials from a user's forehead and translating them into computer controls. Brainfingers is capable of emulating both keyboard (discrete) and mouse cursor (proportional) control. His current assistive technology solution (a button activated switch scanning setup) will be compared as a baseline with a hands-free computer interface device (Brainfingers). Both switch scanning (discrete) and point and click (proportional) control conditions will be tested using the Brainfingers system, in hopes of allowing BK direct selection on the computer.

BK

At birth BK suffered hemorrhaging on the brain, resulting in a severe case of dyskinetic (athetoid) cerebral palsy with spasticity and some hypotonia (Taber, 2006). Now 14, he seems cognitively aware, yet has limited means to communicate with other people. After years of practice with a button and switch scanning setup, he still cannot communicate reliably using this system. This is due in part, to learned helplessness and frustration with an interface that is incorrectly matched to his capabilities. The dyskinesia BK suffers from means his body's muscle tone is often at extremes, or mixed in odd ways. He has suffered contortion, even to the point of a dislocated hip. BK also suffers from spasms intermittently. The degree of sensation and perception disturbance he suffers, if any, cannot be confirmed as of this time. For example, early diagnosis suggested extremely limited visual capability. However, it is difficult to assess the extent of BK's vision due to his inability to respond in a consistent way to visual stimuli. We simply don’t know whether BK is able to discriminate colors. On the other hand, BK appears to be sensitive to auditory stimuli, often exhibiting startled responses to unexpected sounds. BK has recently entered high school, if an effective communication and control channel could be opened, it would drastically change his school experience. BK represents someone on the severe end of the Locked-In continuum, with additional complexities due to the uncertainty surrounding his visual system function.

BK's current solution is centered on the Prentke Romich Company Springboard and a large button. The Springboard is an alternative augmented communication device (AAC) with a small monochrome screen that can be programmed to switch scan various sets of options. Thus if his speech therapist asks him about the weather, the appropriate options will be the ones presented. The words will appear on the screen and the options are read aloud one by one through the speaker as they are highlighted (scanned). To make use of this scanning interface, a large "Gumball" type switch (button) is provided to BK. When the button is depressed, the switch is activated and a selection is made. The option last read aloud prior to the button press is the selection.

What BK suffers, dyskinesis, is a mixed muscle tone- often overly rigid, complicated at times by hypotonia (complete lack of tone). It is easy to imagine why reaching out to hit a button in a timed fashion might be difficult, even without the sporadic spasms BK experiences, yet that is exactly what is asked of BK. Since switch scanning interfaces are ultimately tasks of planning, timing, and execution, the process is both very difficult and error prone for BK. BK also exhibits a startle response from touch, loud noises, and sometimes interruption as a result of his condition, which can further frustrate his attempts to use his assistive technology in a noisy classroom. The switch scanning interface is slow and cumbersome; BK must often rely on those around him to guess what he actually means when his answers are not the expected ones. Usually, BK is just asked to repeat the selection process for the question at hand. The repeated attempts frequently leave him visibly tired and/or frustrated. Since he cannot navigate the menus autonomously at this time, his use of the system is limited and largely reactive. That is, someone will most often set up, turn on, and initiate his system to ask him questions, or explicitly for practice. Boredom seems to be a large problem, as things BK can choose to say are always the same when he is using the system. All these factors seem to contribute to a situation of learned helplessness for BK. Indeed, his teachers, parents, and therapists attest to a general backwards progression within the last few years in BK's effort and abilities.

Locked In

BK is one example of a more general problem, namely Locked-In syndrome. In Edgar Allen Poe's story The Cask of Amontillado, a drunken man falls prey to revenge and is sealed into a wall, alive. Every day, many innocent people live in these conditions, entombed in their own bodies, behind walls of flesh. The French use the phrase maladie de l'emmuré vivant, or, “walled in alive disease” to describe this condition. In English, the standard medical term is simply Locked-In syndrome (Taber, 2005, Doherty, 2001, Gnanayutham, 2004). Originally coined by Plum and Posner (1966), Locked-In syndrome describes a condition where a person is cognitively aware, but retains no voluntary control over their muscles, save for their eyes. They referred to those without even eye control as suffering Total Locked-In syndrome. Felzer, & Freisleben (2002) characterize being locked-in as when “…a patient’s mobile mind is locked in an immobile body.” This thesis is applicable to opening a potential channel for interfacing, control, and communication that does not depend on muscle control, as a potential means to ‘unlock’ the door for those who suffer from this condition.

While the standard for Locked-In syndrome remains the same, the problem itself has unfolded. Locked-In syndrome has now become more of a continuum. Instead of limiting the condition's definition to a specific damaged brain area (such as the ventral pons), it is worth noting that various birth defects and diseases and trauma can result in some degree of Locked-In syndrome. This ranges from Total Locked-In syndrome on one end (for instance from trauma or late stage amyotrophic lateral sclerosis or lesion in the brain stem) to the other end with less severe motor impairment (e.g. birth defects, quadriplegia). When speaking about Locked-In syndrome, it is usually assumed the person cannot speak, and needs external help to communicate. The more severe the status, the more complex interface technology will be required to facilitate communication.

Events such as a car crash can cause traumatic brain and/or spinal injury and disrupt motor control pathways. As medical practices advance, more people survive encounters that would have killed them only a few years ago. When a person is in a car accident, the damage has the potential to be vast and varied. For instance the crash might damage or amputate arms or legs, or suffer an internal injury, especially within the brain. The term for complex injuries is called polytrauma. Flexible solutions that can span gaps of motor control loss are needed. Those suffering trauma or disease typically have already completed some developmental milestones and education. Although trauma and disease can affect cognitive abilities, in many of these later onset cases the person developed the cognitive skills needed for communication (e.g., language skills) and these skills are not affected by the trauma or disease. These are the cases that are most likely to benefit from alternative means for communication.

In early onset situations such as BK's, there is some question about the status of basic cognitive skills associated with communication. Can these skills develop under conditions where a child is unable to consistently close-the-loop with the people around him? BK has had eight years of special education classes. However, because of his inability to respond consistently, it is difficult to know the extent of his cognitive abilities. However, observations suggest that BK is very much aware of his social context. For example, he seems to have specific preferences for music. He seems to be motivated by opportunities to interact with other children (particularly girls). He also had a particularly satisfying experience through riding therapy and seemed to form a special relationship with one of the horses. He shows clear recognition at the mention of the horse's name. Thus, we hypothesize that BK has the cognitive capability to communicate – though his skills may be primitive due to the impoverished experience as a result of his lack of muscle control.

Progressive diseases pose equally complex cases that require flexible solutions. Amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig's disease, is a progressive disease that destroys neural pathways over time through demyelization. This means that the person will lose more and more motor control until they are left with only control of their eyes and tongue, which will eventually fade as well. Thus a solution that works for an ALS sufferer will not last without modification. Conditions such as multiple sclerosis, muscular dystrophy, invasive carcinomas, stroke, Huntington's disease, and other conditions which degrade muscle or neural tissue can cause neural complications or motor control attenuation over time (Taber, 2005, Wolpaw, 2002). While other solutions may work for those not yet suffering Total Locked-In syndrome, the most promising are interfaces that directly connect to the brain (BCI – Brain Computer Interfaces). These advanced interfaces do not have to be limited to only the most severe cases, but are useful for providing both discrete and point and click interfaces to a range of needs (Redstone, 2006, Wolpaw, 2002).

In early onset conditions, we hypothesize that early exposure to alternative means for interaction, such as BCI, may be essential to the development of the cognitive skills essential to communication. We believe that people will adapt to any opportunity to close-the-loop and communicate with their social environment.

BCI Activated Solutions

One solution which has been highly praised in the literature as a possible communication solution for people in a locked-in state is brain computer interface technology (BCI) (Doherty, 2000, 2001, 2002, Gnanayutham, 2004, Junker, 1995, 1997, 2000, 2001, Wolpaw, 2002). BCI technology relies on detecting and translating signals from various locations in and on the brain (Vidal, 1973). A few of the signals so far used are alpha, beta, mu, the P300 evoked potential, and sensorimotor rhythms. Though BCI technology is still very young, it has shown the potential for real time control, from switch activation to full prosthetic control. For a more in depth introduction to BCI, consult Wolpaw (2002) and Kubler & Muller (2007).

BCI Switch

In it's first form, electrical communication was a series of key presses. Using the telegraph, one could “speak” by tapping coding messages of long and short beeps in various patterns (Morse Code). The telegraph could be considered among the first electronic assistive technology, allowing people to communicate with others they might never see, hear, or touch. Although manual switch setups are still able to facilitate Morse code, communication through electronic means has improved in leaps and bounds. Other interfaces exist now, consider the photo kiosk, or the atm: a set of options has been predetermined, one must only choose between them. Assistive interfaces can function the same way, allowing a user to choose by navigating menus with a small number of options on each. Switch scanning interfaces navigate these options for a user by presenting them one at a time, the user stops the system when a desired option is presented. This may sound strange to imagine using a computer this way, but how many of us wait impatiently as automated call systems present our options sequentially ("Press 9 to hear this menu again, Press 0 if you would like to speak to a representative..."). Both rely on predetermined possibilities, however direct selection allows the user to indicate intention immediately among options (spatially constrained); switch scanning relies on the patience on the user to wait for the appropriate option to be presented (temporally constrained).

One of the more widely used indirect selection modalities is (switch) scanning. The user is provided with a set of choices from which they must choose. The choices will be cycled (scanned) through at a preset rate, and the user's selection is made by closing a switch. To accomplish navigating large sets of choices quickly, switch scanning scans successively through multiple options, usually row by row, then column by column or vice versa. When the desired option is highlighted, the user selects it using whatever activation system they are using. This could be as simple as a manual switch, or as complex as a brain computer interface (BCI), it only serves to either start, stop, or select items presented by the switch scanning menu. The scanning can also be accomplished by allowing the person to manually step through the selection set, selecting by choosing to dwell on an option for a pre-specified amount of time. BCI technology offers several modalities for discrete activation or “clicking”- for example, the P300 based interfaces are activated by stimulus recognition, and sensorimotor visualization has been used for activation in other interfaces.

P300

The P300 is not really a "brainwave", it is an evoked potential; it is a signal spike 300 ms after a recognized stimulus is presented. This effect has been used to select letters from a grid using a process of elimination not unlike switch scanning, but with only recognition and intent from the user. This method is slow but accurate, taking several passes through rows and columns to determine the desired character, building words within a few minutes. Bayliss and Ballard (2000) demonstrated P300 as a valid command tool in a virtual environment with traffic lights. The users were instructed to stop on red, and responses were reliably demonstrated at the site of a red light. Bayliss (2003) furthered this research to a virtual environment where a highlight would scan over actions and objects, and the user would choose with the recognition response. P300 seems extremely useful for scanning applications as a replacement for a manual switch.

Sensorimotor switches

Brain computer interfaces are most often synchronous, operating during timed windows of control. Synchronous control is presenting a temporal window to the user during which time the user attempts to activate or not activate some control channel. In this way, the user's *control attempt* is *synchronized* with the EEG *recording window*. After the window passes, the control channel is unaffected by the user, they are free to talk and move without fear of accidentally activating the BCI. The goal of course, would be complete asynchronous control,where full control is enabled all the time, with a computer essentially listening in on one's thoughts, monitoring for commands at any time. Synchronous control then usually necessitates switch based control (this or that, 1, 2, or 3, etc.) by modulating a brain signal. Friedman et al. (2010) created a synchronous BCI interface for controlling an avatar in a virtual environment. The user was able to control direction by looking around (gaze) between BCI control windows. When cued, the user chose to move in the direction desired or not, and if within a specified range of another avatar, to "touch" them. This control was accomplished using an EEG to monitor sensorimotor signals. During a BCI enabled control period, the user would visualize moving either their feet (move), their hands (touch), or neither. If a signal was detected for either of the (imagined) movements, the appropriate control activated. The study was notable in that despite a limited set of options, they included a free choice condition, instead of dictating the users actions. Although the NIA is capable of asynchronous control of the cursor, the experiment with BK was done in a synchronous fashion. The interface was paused while the experimenter read the questions, then started immediately after finishing the question.

BCI Point and Click

Scott (1998) asserts that pointing is the most natural method of human communication, whether this be with a finger, hand, eyes, or other body part. Direct selection is the default for an organism, however when manipulating one's body is too difficult, a tool can be employed such as a wand, rfid-scanners, lasers, or lights (Scott, 1998) or increasingly, a virtual cursor. Direct selection by pointing and clicking has become the de facto for human computer interaction (Scott, 1998, Norman, 1986). Initially a revolution over the command line, popularity and mass production have established the mouse as a dominant mode of interaction with computers, facilitating the planar point and click system. A user may sit down and immediately make choices and perform actions in a point and click environment. Though the mouse is ubiquitous, point and click interfaces are not limited to mice; touchscreens, joysticks, joypads, trackballs, and buttons can all be used to control the cursor. As computers become more ubiquitous, mouseless/touchless interfaces are gaining ground. It should be noted that pointing and clicking is often preserved within the interface, despite accomplishing this using a different method of "pointing" (e.g. motion tracking, head tracking, eye tracking, hands free cursor solutions, etc.). Many different BCI control methods have been demonstrated usable for cursor control.

Various brain signals can be used as a continuous control driver. Alpha (8- 13 Hz) waves proliferate during states of meditation and relaxation; beta (18- 28 Hz) waves typically correlate with levels of focus and concentration. These continuous signals can be used to modulate control systems, if one can learn to master them. The mu (8- 12 Hz) rhythm is present in the sensorimotor cortex, and in special neurons that mirror action. When one visualizes or observes someone else perform an action, this frequency lowers in magnitude. These rhythms can be read and used to activate controls by visualizing oneself moving an appropriate body part, and have been implemented for both interface and prosthetic control. Wilson et al. (2009) demonstrated position and velocity control of a mouse cursor by asking participants to visualize making arm and hand movements. These movements caused a decrease in magnitude associated with the mu and beta frequencies which was able to be commanded with sufficient reliability to apply to cursor control. The experiment was conducted using the BCI2000 EEG system, a more affordable EEG setup designed to enable researchers to investigate brain-computer interfaces.

Hybrid/consumer BCI

While the standard in BCI literature is EEG only control, medical grade devices for reading, amplifying, and filtering these signals can easily be as much or more expensive than a car. Medical grade EEG systems also often necessitate an expert to set up and calibrate these systems. A significant time investment is needed to hook up the electrodes properly to the person, and the vast majority of these systems are not portable in any sense. New consumer grade systems are capable of reading several different bio-signals (EMG, EOG, EEG, GSR, etc.) simultaneously with less fidelity and hold great promise as assistive technology (Gnanayutham, 2004). However, some of these (including the NIA) answer a need recognized by Wolpaw (2002) for dry sensors (as opposed to wet gel used with EEG). These systems utilize signals regarded as artifacts in EEG (e.g. EOG, EMG). Such systems (e.g. Emotiv, Neurosky, NIA) are referred to as hands-free interface(s) here.

Brainfingers

Brainfingers is a software suite for the Neural Impulse Actuator (NIA) manufactured by OCZ Technology. The device is a hands-free computer interface that provides channels for control operated by muscles, eye movements, and brain waves (Junker, 1995, 1997, 2000, 2001). The user wears a headband which picks up biopotentials from the forehead, digitizes, amplifies, and then translates the signals into 8 control channels. Brainfingers was born out of Air Force research in cockpit control. Nelson et al. (1997) demonstrated the ability for simulator pilots to use Brainfingers with continuous feedback for single axis control, eventually achieving an average of 80% accuracy with practice. Brainfingers was also explored as a hands-free solution for wearable computers, particularly the muscle channel for clicking while the hands were occupied (Calhoun & McMillan, 1998, McMillan et al., 1999). Simultaneous control of all 8 channels is theoretically possible, however fully realizing this would be an immense challenge. These experiments were done with the muscle channel of Brainfingers, which is certainly the easiest to master. BK has had exposure and practice with the system for the last few years intermittently. BK has demonstrated the ability to select or 'click' with the muscle channel, as well as some proportional control over the muscle channel. The software also includes settings to account for accidental activations, such as BK's propensity to startle. A program is included in the software which was created to work with any third party software one might want to control. It manages the profiles created for controlling Brainfingers, as well as the commands Brainfingers will pass to other programs on the computer. This flexibility, combined with a cheap price, makes the NIA an ideal candidate to evaluate as an activation solution for BK.

Using an earlier version of the NIA (Cyberlink Brainfingers), Marler (2004) demonstrated a clear difference in attention spans and engagement when children with disabilities were given control of the mouse cursor. Video recordings also showed a positive change in facial affect and demeanor in the classroom. She concluded that the change was due to a few related factors: direct control of the mouse cursor, engagement related to the phenomenon, and the advantages gained in a spatial interface over scanning. Redstone (2006) noted a similar positive trend in a case study of two children with cerebral palsy that used Brainfingers compared to their existing assistive technology solutions. Doherty (2000, 2001, 2002) has applied the Cyberlink Brainfingers for use in yes/no and yes/no/maybe point and click tasks, as well as with a prosthetic/robotic arm (Doherty, 2000, 2001, 2002). He also concludes that Brainfingers may captivate the user, increasing attention span and relaxation. However, the most striking conclusion comes from a statement from a head administrator at an institution where some of this research was conducted who stated the participants appeared more relaxed, slightly more self confident, and several saw a distinct decline of involuntary movements/spasms during use of Brainfingers. For the reasons listed above, we posit the following hypothesis: that a point and click interface with hands-free hardware will result in not only more engagement from BK, but shorter response times and higher accuracy. This would represent a step forward in BK's ability to communicate, and serve as a possible model for others suffering a similar degree of locked-in syndrome.

For direct selection to be successful, not only does the interface need to include the desired function, one must be able to accurately identify the icon representing the desired action, manipulate the pointer with precision, and activate the selection. Case BK is additionally complicated by the uncertainty surrounding his visual capability, frustrating common spatial layout assumptions. Direct selection becomes more difficult when the interface itself is obscured. If a person cannot see, how might they navigate a graphical interface? Specialists have reevaluated BK's vision several times over the course of his life (colors, contrasts, motion, tracking ability, etc.), to this point designing a visual interface for BK has been largely trial and error. If BK were to have a reliable communication system, his physicians could better ascertain his visual capabilities. Special steps are taken to provide both visual redundancy and auditory feedback to account for the possibility that BK might not be able to see the point and click interface options.

Figure 1.

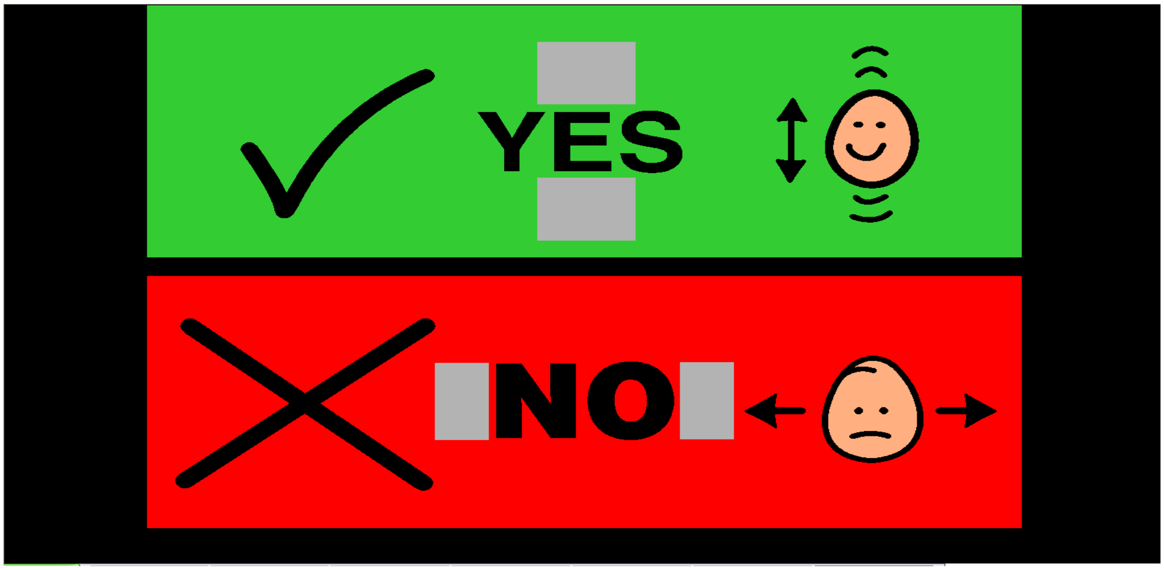

Figure 1. A yes/ no choice menu created in Boardmaker. Used in both scanning and direct selection conditions.

Method

This thesis centers on a nested design which encompasses both hardware and selection method. BK's standard technology includes a manual button, in conjunction with a switch scanning interface. We replicated this in the first condition (Manual Scan). In the second condition, we implemented a hands-free controller with the same switch scanning interface as the first condition (Brainfingers Scan). The third condition uses the hands-free controller, but with a cursor driven, direct selection interface (Brainfingers Direct). Condition 1 (Manual Scan) was compared to conditions 2 and 3 (Brainfingers Scan and Brainfingers Direct) to assess the difference in performance using a manual button vs. a hands-free activation system. Conditions 1 and 2 (Manual Scan and Brainfingers Scan) were compared with condition 3 (Brainfingers Direct) to assess the advantages of point and click selection over scanning. In this way, we obtained and compared data across two different hardware setups and both direct and indirect selection techniques. Dependent measures included both accuracy and response time. In all conditions the menu and sound conditions were the same, except in the Direct Selection condition, where sound was added for cursor position feedback.

Rollosonic, a free mouse based synthesizer package, was used for creating auditory feedback from mouse cursor position on screen. An oscillator's pitch was modulated by y axis (vertical) position of the mouse. The oscillator pitch was tuned so that the extreme bottom was silent (to humans). As the cursor moves upwards, the sound progresses from subsonics, to low bass, upwards through pitch until reaching a sound not unlike a string stretched to its max being plucked when reaching the top of the screen.

A common menu for both switch scanning and direct selection conditions was constructed using Mayer-Johnson's Boardmaker software. The menu, shown in Figure 1, consists of two boxes containing each “Yes” and “No” choices, both in highly saturated colors. When scanned or hovered over, these boxes announced once “yes” or “no”. Selections were made by depressing the switch in the manual condition, or by tensing facial muscles/ jaw in the Brainfingers conditions. If selected, the boxes answer in sentence form in a different voice “The answer is x”, confirming selections.

A list of 30 dichotomous (yes/no) questions was constructed in consultation with BK's parents and teachers. These questions were chosen so that there was an obvious correct response. The same questions were administered nine different times, three times using each of the three different methods for response (Manual Scan (MS), Brainfinger Scan (BS), and Brainfinger Direct (BC). Order was counterbalanced in an attempt to distribute the effects of practice evenly across the three conditions:

MS1, MS2, BS1 BS2, BC1, BC2, BC3, BS3, MS3

Each session was conducted on a separate day. Yes/No responses were recorded and response time was measured manually using a stopwatch. The time elapsed data was analyzed via T-tests (paired 2-tail) and Kruskal Wallis analyses. The results from these analyses and the questions used have been included as an appendix.

Figure 2.

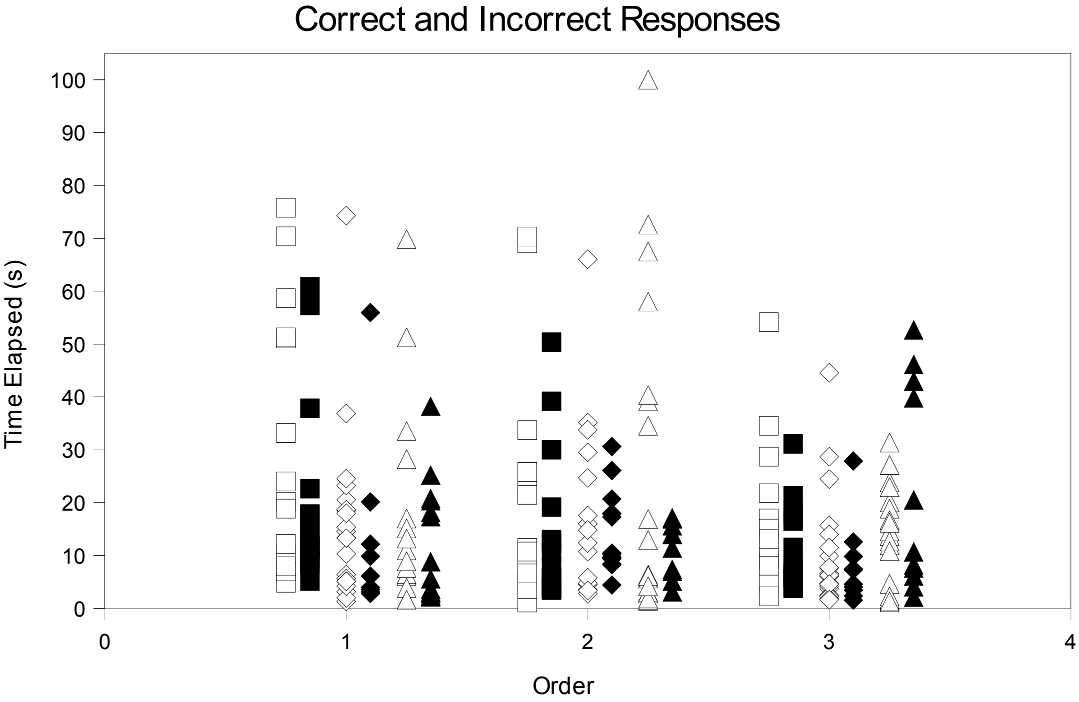

Figure 2. Time Elapsed and Accuracy data grouped by session. MS is shown as squares, BS as Diamonds, and BC as triangles. White (open) markers represent correct answers, the black (filled) represent incorrect. Labels above each pair of correct and incorrect answers indicate the condition, session, and chronological place in the overall session order.

Figure 3.

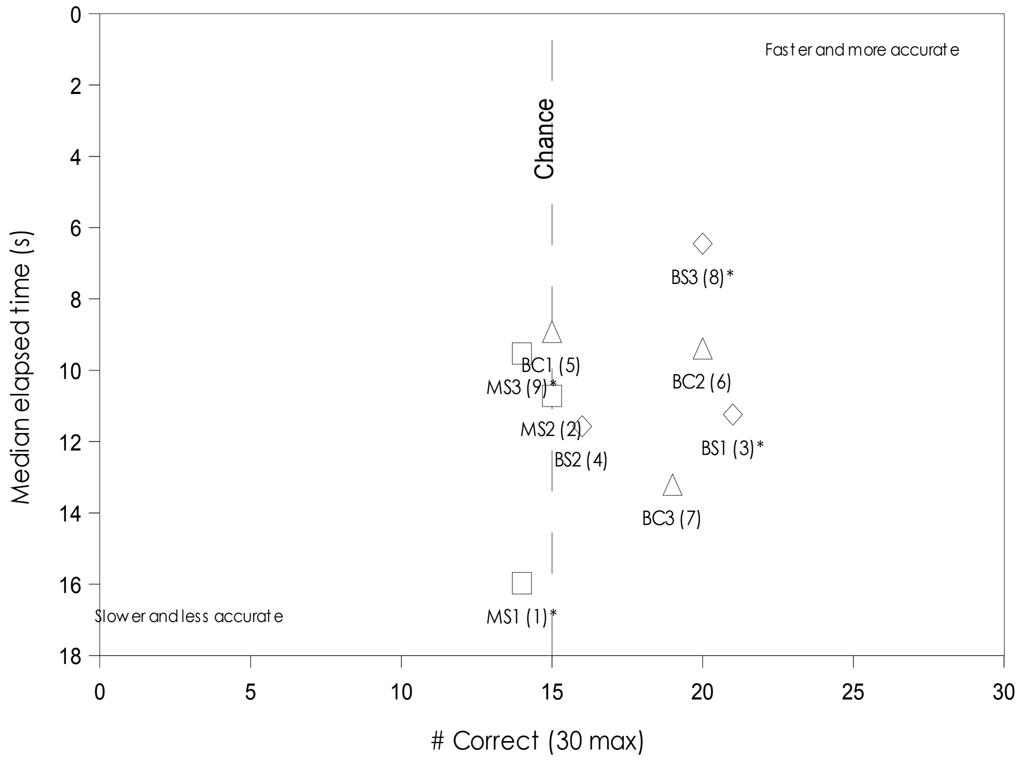

Figure 3. Median Response Time (s) and Number Correct (30 Max) as a function of condition (MS-Manual Switch; BS-Brainfingers Switch; BC-Brainfingers Direct Selection), Attempt with a particular condition (1-3), and Session (1 – 9).

Results

Figure 2 shows the time elapsed and correct/incorrect response data for all sessions. The sessions are not shown in chronological order, but are grouped by order for each condition. Thus, on the X axis, for 1, we find MS1, BS1, BC1, then MS2, BS2, and so on. This is so the difference between conditions can be seen as experience with the condition increased.

Right away one should notice the number of errors in all conditions, and the spread of the scores. Because this is a small data set, these outliers would affect the mean. The distribution does not appear to be normal, suggesting the consideration of nonparametric statistics.

Even in the 3rd try of each condition, we find many errors, even after 6 previous sessions with the same questions. There is a general trend of lower response times, as a function of experience with both the questions and condition order.

Figure 3 shows the number of correct responses and median response times for each of the nine sessions with BK. The labels for each data point indicate the condition (MS, BS, or BC + the order in that condition- 1, 2 or 3), and the session number (1-9). Overall, performance was very poor, especially for a communication system. The highest accuracy was 70% in the third session, which was the first attempt using scanning with the Brainfingers activated scanning (BS1). The shortest median response time was just over 6 seconds in the eighth session, which was the third attempt with switch scanning activated by Brainfingers Switch (BS3). This poor performance to relatively simple yes/no questions testifies to the difficulty that BK has in communicating with the world.

The Manual Scanning (baseline) condition resulted in especially poor performance. None of the three Manual Scanning sessions were above chance accuracy. The 3rd Manual Scanning session, which was also the last session overall, failed to bring median response time below 9 seconds. This baseline represents BK's use of his very similar assistive technology for more than half of his life. This reinforces how inadequate his current manually activated assistive technology really is for his needs.

Brainfingers consistently outperformed the Manual Scanning interface. In contrast to the Manual Scanning condition, which never reached above 50% accuracy, the lowest accuracy Brainfingers session was session 5 at 50%. It should be noted that this low was also BK's first attempt with the Brainfingers Direct condition. The highest accuracy was session 3, BK's first attempt with the Brainfingers Scanning condition. The third attempt of Brainfingers Switch condition (session 8) yielded the fastest overall median response time of just over 6 seconds. The slowest Brainfingers median response time, the third attempt at Brainfingers Direct (session 7) was ~13 seconds , 3 seconds faster than the slowest Manual Switch median response time (and only about 4 seconds slower than the fastest Manual Switch median response time).

The data was analyzed via Kruskal Wallis. All three attempts for each condition were averaged to create representative data set for each condition (MS, BS, and BC). The tests were conducted on the average MS, BS, and BC data for direct comparison between conditions, as well as on the last three sessions, and again with all of these sets but with only correct answers. In addition, an analysis was performed on all time elapsed data, for all sessions. The three conditions were significantly different when data was considered for all sessions and all data ($H = 17.791$, 8 d.f., $P = 0.023$, $p<.05$). More specifically, Kruskal Wallis analysis also confirmed the significant difference between MS and BS conditions ($H = 6.542$, 1 d.f., P =

0.011, p<.05). The 3rd sessions were not significantly different in this average, but it should be noted the P value was just out of range. Full results for the Kruskal Wallis analyses can also be found in Appendix B.

Four T-tests (paired, 2 tail) were also performed, and the results for time elapsed data confirmed a significant difference between the MS and BS conditions. Again the averaged session data sets were used for direct comparison. The 3rd sessions and the correct 3rd sessions were also compared again. MS vs. BS and BS vs. BC both yielded significant differences, but not MS vs. BC (t(29)= 0.02, t(29)= 0.04, and t(29)= 0.15, p<.05 respectively). The average data sets were then further modified by discarding incorrect answers. When only correct answers from the averaged sets were included, the MS vs. BS comparison was significant t(29)= 0.02, p<.05. The other two T-tests were performed using only the last three sessions (no averages), which were the last attempts of each condition. Presumably, these are the sessions with the most practice. Only the MS vs. BS comparison was significant of the three t(29)= 0.02, p< .05. As earlier, the analysis was run again with only correct answers for these sessions, but there was no significant difference for these comparisons. The comparisons results are not directional in nature, so the differences found must be considered in the light of the other factors, like fastest and slowest sessions. The complete results from the T-test can be found in appendix B.

The above comparison of the two different Brainfingers interfaces (BS, BC) with BK's Manual Switch-scanning interface (MS) suggests that a Brainfingers activated interface is comparable, if not superior to the current manually activated interface. The least accurate Brainfingers session (BC1) was at chance accuracy levels, but was as good as the most accurate MS session (MS3). BC1 was also faster than MS3. The fastest performance was a Brainfingers Switch session (BS3), which was the second to last session. The last session was MS3, and although BK had more practice with the questions, the median response time for that session was 3 seconds slower than BS3. BK's performance continued to improve over the 9 sessions, but practice with the questions was not enough to significantly change performance from MS2 (session 2) to MS3 (session 9).

Comparing the two different Brainfingers interfaces (switch (BS) vs. point and click (BC)) suggests that BK's performance is slightly better using Brainfingers activated Switch-scanning (BS). One T-test found significant difference, $t(29)= 0.04$, $p<.05$. The Brainfingers Switch condition included both the highest accuracy (BS1) and fastest median response time (BS3).

However, the differences in performance between these sessions and BC2 and BC3 were small, and this is perhaps most likely due to lack of practice. It should be noted that this was BK's first experience using a direct selection interface.

Though the case seems to be strong for the Brainfingers interfaces, caution should be taken in concluding that any of these interfaces are BK's ultimate solution for his communication needs. The current solution, however, is clearly not working. Brainfingers activate interfaces appear to hold promise for BK as communication solutions and should be further explored. The benefits of direct selection shown in Marler's work are reason enough to pursue a non-manually activated interface for BK, however, using direct selection could prove very challenging for BK.

Discussion

As noted above, the Brainfingers direct selection condition was novel to BK. He has had previous practice using the muscle channel of Brainfingers to control a real time cursor (musical scales, pong, cursor maze), but not this specific context. With practice, BK may exhibit much better performance in the direct selection condition. Performance in this condition was already on par with Brainfingers with a switch scanning interface and better than the manual switch scanning condition. The limited number of sessions was not sufficient for performance to become asymptotic in the Brainfingers conditions, possibly obscuring the true difference in performance between the manual and Brainfingers conditions. BK seemed to enjoy the direct selection experience. His enjoyment could have stemmed from having free control of the selection, or from the additional sound given as feedback from the interface.

A family crisis surfaced just before data collection began. BK's father was diagnosed with oral cancer and required immediate intervention. The decision was ultimately made to conduct the trials for data collection, in order to not continue to postpone them. Additionally, this was the first extended period BK would be with family other than his parents. Stress in the form of fear, separation anxiety, and concern for his father could have all affected his performance. BK's performance in both Brainfingers conditions was still at or above performance using manual switch.

One thing that became apparent was BK's growing boredom with the questions. While we tried to pick productive questions, they were not very pertinent or fun for BK. Future work with BK will be socially based, scaffolding his capability to converse and interact with his classmates, rather just answering yes/no questions about himself. A lesson that can be gleaned from a physical therapist of his is the example that BK does not enjoy his gait trainer time, which helps him build muscle and balance needed for walking. However, if a schoolmate (particularly a girl) is assigned to walk with him as he moves about the school, he quickly forgets his lack of desire and will walk till exhausted. The next interface would do well to make use of this dynamic with his tutors and schoolmates.

There were several possible sources of variance which were uncontrolled, some of which have been noted above. However, the experiment points to BK's quick adaptation to the system, with performance immediately at or above baseline levels in both scanning and point and click conditions. Utilizing an off the shelf BCI such as Brainfingers comes with its own challenges, such as those surrounding training and calibration, but the performance gained by easing the motor requirements on BK outweighs them. Additionally, Brainfingers can be used in both scanning and point and click interfaces, allowing a level of flexibility not previously found in BK's switch driven assistive technology.

Conclusion

Severe cerebral palsy case study BK was no worse with either hands-free condition than with his current button and scanning solution. In fact, several sessions were more accurate and/or faster than his current assistive technology has allowed. The three conditions were also found significantly different by T-tests and Kruskal-Wallis analyses, pointing towards the superiority of the Brainfingers switch-scanning condition (BS). This represents an optimistic prognosis for the hands-free system, given the limited time and practice spent with the switch condition and with no prior exposure to the direct selection condition. More data might have allowed drawing more definitive conclusions on the superiority of a particular interface (or no difference). More sessions may haver also elucidated the difference in performance between Brainfingers Switch and Brainfingers Direct conditions. As discussed above, data collection coincided with a family medical situation. The fear, separation anxiety, and resulting stress could have negatively influenced his performance and thereby hid his true performance levels. More practice with the Brainfingers conditions are needed to ascertain BK's upper limit on performance. This experiment confirms that the hands-free interface (OCZ NIA/ Brainfingers) may be a valid tool for BK as part of his optimal assistive technology solution. He was marginally faster and more accurate using Brainfingers over a manual switch. Future interfaces will include social elements at the forefront, to encourage engagement with the system and to increase usefulness as a communication tool for BK. We concur with Marler (2004) and Scott (1998) that any solution which utilizes direct selection will facilitate more autonomy and satisfaction for BK's outcome, as well as increase both his attention span and engagement level. The strongest conclusion demonstrated is that his current manual switch scanning assistive technology is not working.

Appendix A

List of questions used for each session

1 are you a Buckeye fan? (yes)
2 is your horse's name little Dee? (yes)
3 is your brothers name Jeremy? (yes)
4 do you have a dog named ginger? (yes)
5 do you live on Kirkwood drive? (yes)
6 are your grandparents Dotta and Paw paw? (yes)
7 do you like to ride in the van? (yes)
8 do you like peas? (no)
9 are you a girl? (no)
10 are you a Michigan fan? (no)
11do you have a twin? (yes)
12 are you in 8th grade? (yes)
13 do you like Alan Jackson? (yes)
14 do you like getting out of the car? (no)
15 do you hate school? (no)
16 do you have a beard?(no)
17 does sierra mist make you sick? (no)
18 do you like to eat cold things? (no)
19 does ginger bark a lot? (yes)
20 does ginger like cats? (no)
21 do mom and dad tuck you in at night? (yes)
22 did you take a long vacation this summer? (no)
23 have you been to Disney world? (no)
24 have you ever been to kings island? (no)
25 have you ever lived outside Vandalia? (no)
26 do you speak Spanish? (no)
27 is Carrie your speech therapist? (yes)
28 is blue your favorite color? (no)
29 are the lights off? (yes)
30 is dad here? (no)

Appendix B

T-test and Kruskal Wallis Analyses Results

MS vs. BS	**BS vs. BC**	**MS vs. BC**	
0.021903	0.042394	0.148359	Paired t-test (2 tail)
MS vs. BC correct	**BS vs. BC correct**	**MS vs. BC correct**	
0.024308	0.113197	0.097784	Paired t-test (2 tail)
MS3 vs. BS3	**BS3 vs. BC3**	**MS3 vs. BC3**	
0.018936	0.101447	0.371886	Paired t-test (2 tail)
MS3 vs. BS3 correct	**BS3 vs. BC3 correct**	**MS3 vs. BC3 correct**	
0.733315	0.423308	0.846391	Paired t-test (2 tail)

KW comparison	**Adjusted H**	**d.f.**	**P value**
MS avg vs. BS avg	6.542	1	0.011
BS avg vs. BC avg	3.018	1	0.082
MS avg vs. BC avg	1.102	1	0.294
3rd sessions all data	5.525	2	0.063
3rd sessions correct	3.739	2	0.154
All sessions all data	17.791	8	0.023

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