Coherent Detected Periodic Brainwave Computer Control

Andrew Junker PhD, Brain Actuated Technologies, Inc
Danise M. Marler, M.A., Sp. Ed., Los Angeles County Office of Education
Bill Hook, Brain Actuated Technologies, Inc

Abstract

The objective of this study was to demonstrate that users with severe muscle control disabilities could use forehead brainwave frequency bio-potentials to obtain computer access by controlling the Cyberlink Brainfingers system with their forehead derived bio-potentials. Four subjects with multiple disabilities participated in this study. They ranged in age from nine to twenty, attended one public special education school, and were restricted in their ability to access curriculum, communication, or leisure activities at the start of this study. At the beginning of the study none of the subjects had meaningful access to switch devices to facilitate communication, curriculum participation, or leisure activities. By the end of the study, the subjects were able to effectively control computers by using their Brainfingers derived brainwave frequency signals at their forehead. The results of this study indicate these subjects achieved effective switch and mouse access by controlling a computer through the Brainfingers system. The subjects reached a level of expertise with Brainfingers that allowed them to interact with the computer and operate software independently from the researcher. During the course of the study, functional and behavioral changes were observed from the four subjects. Likewise, all four learned the Brainfingers system at the same rate even though the experimental protocol was designed to allow independent learning rates.

A second objective was to employ coherent detection of periodic brain waves, taking advantage of the ability of a coherent detection system to reject interference from non-periodic muscle and random brainwave signals. The Brainfingers computer control system was used as the basic building block. Software was modified to operate with full coherent detection. A conventional 2nd order phase lock loop was selected as the design, where the signals were to be hard limited in order to achieve normalized operation.   This design was predicated on the idea that periodic alpha wave signals could be generated by brain wave activity at the control of a disabled person and that interfering muscle signals had no periodic component and therefore would not be detected by a phase lock loop. It was discovered that even strong alpha waves were not generated as continuous waves, but rather as short bursts of about 1 second in duration, and separated by 2 or 3 seconds.   Each burst was at a slightly different frequency, and there appeared to be no coherence between each burst in a series of bursts, thus negating the basic idea of a phase lock loop.   Therefore, the phase lock loop approach to coherent processing was abandoned. Instead a lock-in amplifier approach was used to extract brainwave frequency signals from the forehead.

Introduction

There are over sixty-five million children in the United States between the ages of five and twenty years. Over five million children have at least one type of disability, and within that group, there are over one million children who have two or more types of disabilities, impacting the quality of life and affecting their abilities to enjoy an independent lifestyle. These disabilities include cerebral palsy, skeletal deformities, vision and/or hearing loss, and health impairments, communication disorders, and/or developmental delays.

Children who have two or more disabilities are identified as having multiple disabilities. These children commonly are "…individuals with 1) mental retardation requiring extensive or pervasive supports and 2) have one or more significant motor or sensory impairment and/or special health care needs [1]. Research suggests that children identified with multiple disabilities have the greatest need for extensive support for assistive technology services to limit barriers so the children can be active participants in society [2][3][4][5].

Unfortunately, special education is lagging behind on the implementation and use of high technology computer hardware and software. The findings of Tinker [6] demonstrates this high technology lag in special education due to the need for specialized, non-standard hardware and software that is expensive to purchase and often difficult to learn and operate. Doe [3], Downing [4], Light, Beukelman, and Reichle [5] support Tinker's findings and add that high tech assistive technology can also be more restrictive for individuals' with disabilities by limiting their advancement cognitively and socially. The technology is often slow or slows the individual's use of the equipment, limits choices, does not grow with the individual development, may not be used in many environments, and is often abandoned.

One of the purposes of this study therefore was to ascertain if students, identified with multiple disabilities, would be able to achieve computer and software access by operating Brainfingers. There is a great deal of research on the need for assistive technology for persons with disabilities, but very little on the application of high technology by persons identified with multiple disabilities. Due to this lack of research, it was decided that it would be worthwhile to see if Brainfingers, a high technology system, could be taught to and used by persons identified with multiple disabilities to facilitate communication, curriculum access, and leisure activities.

Students identified with multiple disabilities typically have Cerebral Palsy (CP) as one of the multiple disabilities. CP usually results in either high muscle body tone or low muscle body tone. In either case this results in lack of motor control. This lack of muscle control usually requires that some other means of computer access must be used. Unfortunately, other means of access are not available, leaving the individual "locked inside". The requirement of probably needing to use signals other than forehead muscle signals made these students perfect candidates for the study.

The Cyberlink Brainfingers System

Brainfingers uses brain and body forehead bio-potentials in a novel way to generate multiple signals for computer control inputs. Three silver silver-chloride plated carbon-filled plastic sensors in the Brainfingers headband in conjunction with the Brainfingers amplifier circuit can detect bio-potentials as low as 0.3 micro-volts. Signals are easily and non-invasively obtained and impedance levels are usually below 50 K ohms with little or no skin preparation. The forehead is often the last site to suffer degradation in cases of severe disability and

degenerative disease. For example, in ALS and MD the ocular motor neurons and ocular muscles are usually spared permitting at least gross eye movements, but not precise eye pointing control.

A Brainfingers bio-amplifier separates the forehead signal into three frequency channels. The lowest channel is responsive to bio-potentials resulting from eye motion. It is band pass derived in the frequency range 0.2 to 3.0 Hz. This signal has been used effectively for left/right computer cursor positioning and discrete switch control. Individuals with severe physical limitations such as a near-total loss of facial muscle functionality may retain some degree of control over eye motion, which Brainfingers can exploit.

The second channel is band pass derived between 0.5 and 45 Hz, falling within the most active brainwave region or ElectroEncephaloGraphic (EEG) range. A patented lock-in decoding algorithm [2] subdivides this region into ten component frequency bands with the following frequency centers: three low frequency bands (centered at 0.95, 2.75 and 4.40 Hz), three mid frequency bands (centered at 7.75, 9.50 and 11.45 Hz) and four high frequency bands (centered at 13.25, 16.50, 21.20 and 25.00 Hz). Band-pass magnitude values are derived. For convenience the 10 frequency bands are referred to as Brainfinger 1 through Brainfinger 10 or B1 through B10. The low frequency bands (B1-B3) are sensitive to eye movements, and the high frequency bands (B7-B10) are sensitive to forehead muscle activity. The bandwidths of each frequency band can be user adjusted, giving the user control of the responsiveness of the frequency magnitude value. The default bandwidth has a 3dB point of 0.6 Hz about the center frequency.

Able-bodied participants have shown that continuous control of these frequency bands is often learned first through subtle tensing and relaxing of various muscles including forehead, eye and jaw muscles. After a few sessions, however, participants began to experiment with more efficient, internal and perhaps EEG-based control methods [7] [8]. It was felt this result would be of particular value for the population whose physical limitations often preclude the use of facial and precise eye muscle-based access pointing devices, individuals with multiple disabilities.

The third channel is envelope-detected between 70 and 1000 Hz and is defined as an ElectroMyoGraphic (EMG) signal. For discussion purposes this EMG signal is referred to as Brainfinger 11 or B11. It responds to contractions of the masseter and frontalis muscles and is well suited to discrete on/off switch closures, keyboard commands, and functions of the mouse buttons for users with any significant residual of facial muscle functionality. In a study of B11 discrete control with able-bodied participants [9, response accuracy was found to be extremely high, approximately 98%, and reaction times fell between 0.18- 0.2 seconds, a range considered to be the limit of simple reaction time. Several participants achieved 15-20% faster reaction times with B11 than with a manual button.

The EMG signal, B11, can also be used as an analog control. One-axis continuous tracking studies have shown that Brainfingers able-bodied users can achieve 90%+ accuracy after a few hours of training [8][10]. Five able-bodied participants participated in a target acquisition study to evaluate the Brainfingers mouse as a hands-free mouse replacement [11]. After four 30-minute training sessions, all five participants were able to use the Brainfingers controlled mouse to position and click the cursor on randomly appearing (Windows icon-sized) targets. Their target acquisition times were often under four seconds and compared favorably with their manual mouse performance on the same task, despite far greater experience with the manual mouse. Several participants reported control with the Brainfingers mouse eventually began to

feel more natural and automatic, although it required more conscious effort than the manual mouse initially.

The results of the target acquisition study and other studies with able-bodied participants have positive implications for disabled users. The action of translating and presenting a wide range of forehead bio-signals in an engaging real-time display or through a stimulating training game appears to foster the user to achieve a functional level of conscious control in a very intuitive and efficient manner.

Training Software

A number of video displays and training games were developed that could be controlled with Brainfingers. These displays and games were developed to provide an engaging training experience for the subjects. These included the following:

Brainfingers Display: A window in which 11 Brainfinger frequency bands are displayed as rising and falling colored bars. From this display the subject can observe cause and effect relationships between what they do internally and what they see on the display. The 11 brainfingers are responsive to facial muscle tension and relaxation, later eye movements and perhaps shifts in brainwave resonance between alpha and beta resonance frequencies.

Brain Candy: A game in which the user controlled the display of a three-dimensional "wormhole". Characteristics of the wormhole are responsive to the 11 brainfingers. The display additionally included an insert of a smaller brainfingers display as above. The game was designed to provide a visual compelling experience.

Click Practice: A window in which subjects could practice clicking.   The display included a time history of their click signal plus a click line. Adjustment of click shift, amplify and smooth were made available so the research could tune the Brainfingers software to the individual.

Click Game: A game intended to give the user the ability to practice clicking in response to randomly appearing targets. The objective of this game is to use a Brainfinger to click when a large colored box appears on the screen. When clicked, an auditory feedback sounds, the colored box disappears and another colored box appears somewhere else on the screen.

Grow Game: A simple cause and affect game in which a sphere grows when a user increases the magnitude of their brainfinger and decreases in size when the user decreases the magnitude of their selected brainfinger. Brainfingers in both the up/down and left/right axis can be selected for control. Adjustments are provided to the researcher to tune the shift, amplify and soothing of the user's brainfinger response.

Pong Game: A game in which the subject controls one paddle while the computer controls the other paddle. Scores are made when the ball passes by the opposing side's paddle. The game Pong was created to look like other video games to help create a desire in the subjects to want to continue learning Brainfingers so that they could play video games ("like the other kids").

Cursor Setup Window: This window combines two frequency bands to operate up/down and left/right axes to maneuver a cursor on a blue screen. This window provided the subject with the opportunity to move a cursor on the screen by controlling two Brainfingers, one for up/down and one for left/right.

Two Maze Games, Easy Maze and Labyrinth: Two games in which the subject can practice using two brainfingers to control cursor pointing by maneuvering through a two dimensional maze. The Easy Maze has less walls.

Mouse Practice: A window in which subjects can practice the simultaneous control of cursor pointing and clicking using brainfinger control. Included in the window are displays of the proportional controls used to create the cursor velocity control.

Acquire Game: A game in which subjects can practice using brainfingers for cursor pointing and clicking to acquire randomly appearing targets.

The Cellar Game: A game in which subjects can practice using brainfingers for cursor pointing and clicking to move a hand in a cellar. The objective of the Cellar game is to move the cursor, which is a hand, to one of many bottles and click to pick up a bottle. Once a bottle is in the hand, the hand needs to be moved to an empty space on a wine rack. When the bottle is over the empty space in the wine rack, if the subject clicks the hand will put the bottle into the wine rack. If the subject clicks before the bottle is over the empty space in the wine rack, the bottle falls to the floor and breaks.

Launch Window: A window in which launch buttons can be constructed that allow the mapping of brainfinger actions to computer events. Once a launch button is selected the software "launches" onto the desktop and sends brainfinger activated computer events to 3rd party software that has computer focus.

Coherent Processing using a 2nd Order Phase Lock Loop

One specific object of this task was to modify the basic Brainfingers software to allow real-time coherent processing of the incoming brainwave signals.   A conventional 2nd order phase lock loop was selected as the design, where the signals were to be hard limited in order to achieve normalized operation. This design was predicated on the idea that (i) periodic alpha wave signals could be generated by brain wave activity at the control of a disabled person and that (ii) interfering muscle signals had no periodic component and therefore would not be detected by a phase lock loop.

A significant design effort was carried out in order to modify the Brainfingers software. Additional gain as well as a software hard limiter block had to be added.   For each channel, the I/Q detector block had to be modified in order to provide a coherent output signal to be used in the phase lock loop feedback path, and a software 2nd order loop had to be designed and implemented to provide the proper control feedback to frequency generator block for each channel.

In addition, a software/hardware signal generator had to be implemented in order to test the steady state and transient response of the feedback loop. For initial testing, a less complicated 1st order loop was implemented to allow the measurement of critical loop parameters.

Experimental Approach

Subjects

The four subjects in this study were students attending the same public special education school. The subjects had been assessed in their academic and functional skill areas and were judged to be functioning intellectually at six to eighteen months of age, with an average attention span of thirty seconds, at the start of the project. This level of functioning is considered to be in the severe to profound range of mental retardation. The subjects were dependent for all of their physical, hygiene, and self-care needs. The four subjects experience restricted delayed, and unproductive physical movements and all have seizure disorders and medical issues.

The four subjects were two males and two females, of Hispanic descent and living with their biological families. Subject A was a 9-year-old male and Subject B was a 12-year-old female. Subject C was a 15-year-old male and Subject D was a 20-year-old female.

 Physically, the four subjects were unique to one another. Subject A had spastic quadriplegia cerebral palsy with a head lag to the right, a long delay in the motor planning for arm and hand movement, and intermittent strabismus of the eyes. Subject B had a mixed type cerebral palsy of spastic quadriplegia and asymmetrical tonic neck reflex (ATNR) with a head lag to the left, and was unable to volitionally move her limbs. Subject C had rigid choreoathetoid cerebral palsy with very little movement of the head that was positioned at midline, very little purposeful movements of his limbs, and intermittent strabismus of the eyes. Subject D had atonic choreoathetoid cerebral palsy with little head control, hand tremors, a long delay in the motor planning for arm and hand movement, and nystagmus, as well as intermittent strabismus of the eyes.

The school psychologist, the assistive technology professional, special educators, and California Children Services referred the subjects for this study. The prerequisites to participate in this study were that the subjects had to be identified as having multiple disabilities, be nonverbal but demonstrated ability to answer yes/no questions using facial expressions, blinking, and/or head nodding/shaking, and have shown indicators of eye-gaze use for pointing and/or making choices. The final requirement was that subjects had experiences with switches, computer with switch software, and voice output communication devices. None had meaningful access to switch devices to facilitate communication, curriculum participation, or leisure activities.

Experimental Setting

Training sessions were conducted in the morning, twice a week, over an eight-week period in the researcher's classroom. Procedurally, the subjects worked individually with the researcher in fifteen-minute increments. As the subjects became more proficient with Brainfingers and were able to focus their attention for longer periods of time, the researcher faded the 1:1 instruction so that the subjects developed independence with Brainfingers. Operation time was increased up to one hour, twice a week.

Materials and Re-enforcers

The materials used in the training sessions were two large screen laptop/notebook PC computers with Windows 2000 or XP; two Brainfingers systems that included two headbands and three sensors affixed on each; Cybergel that moisturized the skin where the sensors touched the forehead; two interface boxes which transmit the forehead signals to the computers; and the Brainfingers software.

A wide variety of third-party computer software that ranged from very simple and specialized that taught "cause-and-effect" awareness and choice making, e.g., Soft Touch, Inc., Inclusive Technology LTD., Sensory Software International Ltd., to "over-the-counter" or universal software that utilized mouse operations to explore and/or perform software functions, e.g., Mayer-Johnson, Inc., Gus Communication, Inc., IntelliTools, Inc., Laureate Learning Systems, Inc., Crick Software, Inc., Disney Interactive, The Learning Company School Division, Microsoft Corporation, Davidson & Associates, Inc. This variety of software reinforced the training with the Brainfingers software, created the incentive to continue learning the system, and was adaptable to the subjects' levels of proficiency at operating the software.

Teaching Strategies

The teaching strategies for instruction, support, and redirection varied depending on the subjects' individual needs, and were often combined. Approaches used were modeling, direct verbal instruction, indirect verbal instruction, pointing, choice making, and trial and error applications, and praise for effort and accomplishment.

Modeling the Brainfingers system was briefly utilized the first time the subjects were introduced. The researcher showed and talked about the headband, put it on and played Pong. This modeling of wearing the Brainfingers headband was conducted to minimize the subjects' fears and apprehensions, make evident that the headband would not cause pain or discomfort, and to generate interest to try the system.

Likewise, modeling was utilized throughout the study by way of the researcher manipulating the cursor with the touch pad on the laptop/notebook to show the subjects where to move the cursor for training purposes. For example, while manipulating the cursor on screen, the researcher pointed to the screen and stated, "This thing moving on the screen, this arrow, it's called a cursor. Can you move the cursor to the …" and the researcher moved the cursor to the target, then returned the cursor back to its' initial position. Then the researcher verbally instructed, "Now it is your turn. Move the cursor to the …."

Direct verbal instructions were used for teaching purposes, as well as to do adjustments to the operation signals, e.g., relax, move the cursor to, etc. Incorporated with the direct verbal directions, when necessary, the researcher used pointing prompts to the computer screen to guide the subjects' cursor directional movements. The use of indirect verbal instructions were employed to observe if the subjects were knowledgeable of the implementations, e.g., "How do you exit the program?" and to redirect them back to task, e.g., "Show me what you are working on."

Praise for efforts was utilized to generate interest and motivation by the subjects to learn the system, to decrease the subjects' insecurities and failure anxieties, and to minimize learned helplessness. As the subjects became more proficient, confident, and independent with the

system, praise decreased. Also, as their abilities to operate Brainfingers improved, they were given opportunities to select what software they would operate. The trial and error approach permitted the subjects to experiment with the system to discover their technique of access with the system. As the subjects learned how to control Brainfingers and apply it to software, they had opportunities to discover different methods and approaches, problem-solve, and learn to control software applications.

Training Protocol

The training protocol consisted of the subjects training with Brainfingers for approximately 17 days over an 8-week period of time. Each session was scheduled to last no longer than one hour. In the initial training session times were usually much shorter. The length of a session was predicated on the attention and interest exhibited by the subject. The first day was an introduction day, in which the subjects were first tested with a conventional switch to see if they could control it. They were then shown how Brainfingers works through modeling and through a quick exposure to the various Brainfingers displays and games.

To begin with default controls were used for each subject. The default controls consisted of using B11, muscle control, for clicking and for up/down cursor control. B2 was used for left right cursor control. These Brainfingers were selected as the starting values to see if the subjects could make use of the typically more easily controlled Brainfingers. Knowing that the subjects had CP as one of their multiple disabilities it was hypothesized that subjects might not have success using the B11 muscle for control. If this turned out to be the case alternative Brainfingers would be tried.

In the Introduction session and the Day 1 session the Brainfingers display was used to construct tables of performance of Brainfinger magnitude changes versus facial gestures. The goal of the remaining sessions was to bring the subjects first to click control, then cursor pointing, then simultaneous click cursor control of the various Brainfinger games, then control of third party educational games and finally self selection of 3rd party software.

The Experimental Program Described

The following is a day-to-day description of the experimental program.

Introduction Day

The experimental program began with the subjects being introduced to Brainfingers. Subjects had two fifteen-minute sessions on their first day. In the first session, subjects were asked by the researcher to turn on a radio by way of a physical switch, and were timed, to examine how efficiently and effectively they could do the task. The second session was intended to generate the subjects' enthusiasm and motivation for learning Brainfingers by introducing Brainfingers through the modeling teaching strategy, as well as by giving the subjects an opportunity to direct and control the system.

Moreover, this introduction period was used to observe Brainfinger frequency band activity versus facial gestures. By observing the frequency bands on the Brainfingers display,

researchers were able to estimate which Brainfinger frequency bands would be the best candidates for control. The subjects were asked to perform the following facial gestures.

Relax -
The subjects were directed to relax or to "Make the color bars go down."   If the subjects were unable to perform the action, then the 'Grow Game' was implemented to teach relaxation by directing the subjects to "Make the circle show up. Now make the circle go away."

Stare –
By placing a motivating object in front of the subject at eye level and directing the subject to look at it, e.g., a small brightly colored Koosh Ball that is lightly shaken to keep attention briefly.

Look Right and Look Left –
The researcher, while twiddling fingers to the right or left side of the screen, directed the subjects to look at the fingers.

Close eyes -
The subjects were directed to close their eyes. If unable to follow the direction, the researcher placed a hand over their eyes, which then facilitated the subjects to close their eyes.

Lift eyebrow –
The subjects were directed to lift their eyebrows. If unable to follow the direction, the researcher gently lifted their brows and released them, and then request the subjects "Lift your eyebrows."

Bite –
The subjects were directed to bite as if they were eating.

Clenching jaw -
The subjects were directed to pretend that they did not want to eat.

Finally, the subjects played the Brain Candy game. This game enabled the subjects to discover that their facial actions created a reaction on the computer screen that was observable by both the subject and the researchers.

Day 1

During this day the subjects were again instructed to perform facial gestures while their Brainfinger activity was observed and entered into the Brainfinger/Facial Gesture Tables. The resulting tables are shown in Appendix A of this report.

The session was also designed to generate and encourage the subjects' motivation to learn Brainfingers. The subjects began learning how to click with Brainfinger B11. Again B11 was selected as the click control because it was potentially the easiest signal for the subjects to control, for the researcher to provide instruction in its use, and was observable on the subjects' faces. The Click Practice window was used to start. If the subjects were unable to generate a click or had many false clicks, adjustments were made to improve chances of the subject achieving control.

Once the initial facial muscle signal was established, the subjects played the Click Game.   The researcher utilized the teaching strategy of modeling, verbal instructions, and cues when to

click. Researchers were able to make Brainfinger adjustments to improve subject-Brainfinger connection.

Next the subjects used Brainfinger B11 to control the Grow Game to begin introducing the sense of up/down actions on the computer screen. The researcher utilized the teaching strategy of verbal instruction and praise to instruct the subjects.

Next subjects were given the opportunity to play Pong. The researcher applied verbal instruction, pointing, and praise to instruct the subjects in the game. The trial and error approach was also utilized to offer the subjects opportunity to attempt the game on their own. The paddle and ball were enlarged to maximum, the movement of the ball was slowed and the game ending score against the computer was reduced to eight. Pointing to the subject's paddle, the researcher directed the subject to "Move that paddle like you did to make circles." When the paddle was moved, the subjects were told, "That is you moving the paddle. When you see the ball going to your paddle, try to stop the ball with your paddle."   The same procedure was applied when instructing the subjects on how to play 'Pong' utilizing their left and right eye glances in the left/right axis.

The final step of the first day to engage and motivate the subjects to operate Brainfingers was to give the subjects some experience with Brainfingers cursor control. The subjects played the two Brainfingers maze games; Easy Maze and Labyrinth.   The teaching strategies used were verbal directions, modeling, pointing, and a trial and error approach. The researcher moved the cursor, pointed to the screen, and stated "This thing moving on the screen, this arrow, it's called a cursor. Can you move the cursor to the sun or the house?" as the researcher pointed to the sun and house. Then the researcher released control of the cursor to the Brainfingers software to give the subjects the opportunity to try moving the cursor.

Day 2

Prior to participating in the experiment, all of the subjects had prior experience at attempting to use a single switch to control a computer. They were unsuccessful in their attempts. This was confirmed at the start of the study during the first session, in which the subjects tried and failed to operate a switch. They failed due to their ineffective and slow motor responses. It was unclear what the subjects' success would be using Brainfinger B11 for switch control. On Day 2 the subjects were given the opportunity to control clicking of the same 3rd party switch software they had attempted to use prior to the study.

The Brainfingers Launch window was used to give subjects Brainfinger click control of the computer and the operation of 3rd party software. The researcher offered the subjects choices of software to operate. The switch software offered was the SoftTouch, Inc. Switch Basics (2002), Teach me to Talk (2002), and Teen Tunes Plus (1998); the Inclusive Technology, Ltd. SwitchIt Bundle (1999), Drumkit (2001), and SwitchIt Gadgets (1999); and the Sensory Software International Ltd. Single Switch Connection (2002).

Since the subjects were already familiar with the software, minimal instruction was needed to teach them how to operate the software. Similarly, the switch software has its own computer-generated cues to guide the subjects to click. These cues are either visual, e.g., a hand touching a switch or a switch appears on the screen, and/or auditory cue, or auditory, e.g., clicking sound or voice cues such as "push the switch." The subjects did need occasional

verbal prompt to 'click,' or make the computer go 'bing,' to redirect the subjects' attention back to the computer.

Once the subjects were able to control switch operations with Brainfingers to produce 'cause-and-effect' outcomes, switch access training to make choices was started. Prior to this case study, the subjects had been given opportunities to make choices from two or more visual objects by looking at their choice, by answering yes/no questions to auditory choices, and had experience operating software, by way of a switch, to make choices from two or more options utilizing visual and/or auditory scanning. Prior to this study however, the subjects were unsuccessful in these endeavors. Visual scanning is an option in certain software that highlights, or boxes, an object on the screen for a few seconds then moves to the next object. Auditory scanning is an option in certain software that states what is being highlighted or boxed.

For example, the SwitchIt Bundle 3rd party software has a series called Opposites that can be designed with two to three choices to be scanned visually by a colored box around the object scanned. If working on the opposites of "large and small" by way of three choices, a large ball and two small balls could be displayed on the screen. A computer-generated voice states, "Which is large" and then a square bounces from each ball. When the square is on the correct choice and the subject clicks, a monster character reinforces the correct choice with auditory feedback. If the choice is incorrect, the monster character shakes its' head 'no' with auditory feedback. Similarly, many voice output communication devices and communication software have visual and/or auditory scanning capabilities. If a desired pictorial/auditory/print word or sentence choice is highlighted and/or stated and the switch is triggered, that which was chosen is verbalized aloud to provide a listener a message.

The subjects were instructed as to how to operate the programs and its' scanning design to make choices. Through trial and error, verbal directions, occasional verbal prompts to make a choice, and pointing prompts, the subjects made choices using visual and/or auditory scanning applications featured in specialized software. The researchers selectively offered choices of programs to the subjects based on their prior abilities operating scanning software. Switch software offering visual and/or auditory scanning characteristics that can be obtainable by a switch and setup to be controllable with Brainfingers, was presented for preferences to the subjects. The software was the SoftTouch, Inc. Teach me to Talk (2002), Teen Tunes Plus (1998), and Switch Basics (2002); Inclusive Technology, Ltd. Drumkit (2001), Disco (2000), SwitchIt Gadgets (1999), SwitchIt Bundle (1999), and SwitchIt Arcade Adventure (1999); and the Sensory Software International Ltd. Single Switch Connection (2002).

Day 3

Subjects used Brainfingers for cursor control and to shape a baseline of access. The Cursor Setup window was used to fine-tune the up/down and left/right signal adjustments, as well as for the subjects to practice moving the cursor around the screen. The researchers placed a glittery happy face sticker on a brightly colored post-it and placed the post-it on the computer screen. Then the researcher instructed the subjects to move the cursor to the post-it or the happy face. When the subjects were able to maneuver the cursor near, or touch, the target, they were given the opportunity to play with the Easy Maze, and the Labyrinth maze. When needed, the researcher pointed and verbally directed the subjects "Take the cursor to the house or sun." Otherwise, the subjects maneuvered the cursor through the mazes by way of the trial and error approach.

Day 4

The foundation was set on day three for cursor maneuver control. On Day 4 subjects were given the opportunity to maneuver a cursor in 3rd party software. The software offered to the subjects was the IntelliTools, Inc. IntelliMathics (2001) and IntelliPics Studio (2001), and the Crick Software, Inc. Clicker 4 (2001).   Practicing with the product templates within the 3rd party software, the researcher verbally directed the subjects where to move the cursor on the screen with as needed pointing prompts to facilitate their learning.

After working with the curriculum access software, and being directed what to do, the subjects were given the opportunity to operate the software independently, as well as review their Brainfinger clicking skills on the desktop. Acquainted with the storybook software from watching and listening to the stories, as well as the subjects' prior history of attempting to turn the pages of the stories with a switch, minimal direct instruction was needed. The researcher activated the story and manipulated the cursor on the screen to the icon that turned the pages forward. When the first page being read aloud was completed, the subjects were instructed, "Now, click and go to the next page," and then the subjects were to continue turning the pages of story through trial and error.

The underlying principle of this approach was to explore if and when the page was concluded, if the subjects were attentive to the natural cue when there was no stimuli coming from the computer, to click to continue the story. The software offered to the subjects was the Disney Interaction animated storybooks of "The Lion King" (1998); "Pocahontas" (1995); "Winnie the Pooh and the Honey Tree" (n.d.); and "101 Dalmatians" (n.d.) and The Learning Company School Division Living Books Collection of Dr. Seuss's "Green Eggs and Ham" (1998) and "A B C" (1995); Marc Brown's "Arthur's Birthday" (1997), "Arthur's Computer Adventure" (1998), and "Arthur's Teacher Troubles" (1994); Mercer Mayer's "Just Grandma and Me" (1993), "Just Dad and Me" (1996), "Just Mom and Me" (1996), and "Little Monster at School" (1994); Aesop's Fable's "The Tortoise and the Hare" (1993); Janell Cannon's "Stellaluna" (1996); and Tomie dePaola's "The Art Lesson" (1998).

Day 5

On the fifth day subjects were given an opportunity to attempt to use Brainfingers for cursor directional control, combined with left clicking. The Mouse Set-Up window was used as the training tool and for signal adjustments for each subject. The researcher placed the glittery happy face sticker on the brightly colored post-it on the computer screen and instructed the subjects to move the cursor to the post-it and click, or make the 'bing' sound. This training session encouraged the subjects to attempt the mouse capabilities of Brainfingers.

Recognizing that the subjects were not adept in their cursor maneuvers, and needed refining in their signal adjustments, the researcher had the subjects play the Brainfingers 'Acquire Game.' This game was programmed by the researcher to work on single axes of either up/down or left/right cursor movements. The objective of the Acquire Game, using a trial and error approach, was for the subjects to touch a black box with the cursor. Each time the box was touched, the box disappeared and another black box appeared somewhere else on the screen. The goal was for the subjects to make contact with the boxes ten times, designed for either the up/down or left/right cursor movements.

Day 6

From observing the subjects performance for the previous 5 training days it was obvious that the subjects were not really successful in controlling the cursor and clicking. There definitely was a need for the selection of different Brainfingers for up/down and click control.

The Brainfinger/Facial Gesture tables were reviewed to select candidate Brainfingers. Once selected, the subjects operated the single axes of the Acquire Game, using 'touch point,' the researcher made modifications. After making adjustments to the single axis signals, the subjects practiced maneuvering the cursor using both the up/down and left/right axes in the Acquire Game.

Continuing the training of the single axis of up/down and left/right, the subjects played Pong. The subjects played, without instruction or cues, and the researcher observed to see if the new signals were more effective or if another Brainfinger was needed for cursor control.

Likewise, the subjects' clicking aptitudes were remapped and adjusted due to the continual false clicking affecting their software performance. Ensuring the clicking adjustments were adequate, the subjects briefly practiced clicking in the Click Setup window.

Day 7

Building on the foundation set on day six for cursor maneuver control and left click, the subjects were given Brainfinger control of the desktop and 3rd party software. Practicing with the product templates within the following software, the researcher verbally directed the subjects where to move the cursor on the screen with as needed pointing prompts, as well as offer opportunities for the subjects to utilize the trial and error approach to explore the pictorial pages for communication purposes. The communication software with voice output used was the Gus Communication, Inc. Gus Multimedia Speech System (2002) and Mayer-Johnson, Inc. Speaking Dynamically Pro (2003).

Within the software when the cursor touched a picture, the picture was voiced and highlighted. For example, if the subject maneuvered the cursor to a picture of a school bus and touched the picture, the software would highlight and state "school bus." Then, if the school bus picture was clicked on, the software would either state, "Is it time to go home?" or it would open another window of pictorial choices like a house and a school and if clicked upon, these would state "Is it time to go home?" or "Is it time to go to school?" Hence, the subjects got the opportunity to use two methods of employment for communication purposes.

Day 8

The subjects continued to practice with the communication software. The researcher would either verbally direct the subjects to maneuver the cursor to a particular pictorial, or the researcher would ask a question and the subjects would attempt to answer by way of the communication software and Brainfingers. The subjects continued to have the two approaches of access to utilize for communication purposes; maneuvering the cursor to scan pictorials with voiced meaning and Brainfinger clicking on the pictorials to generated a statement.

Day 9

Prior to day nine, the researcher's focus was to establish the fundamental groundwork with Brainfingers for the subjects to have computer control to operate specialized software. This was accomplished by Day 9. Once accomplished, it was time to move on to develop the subjects' cursor directional controls and clicking control.

In the Brainfingers software is a game called Cellar that fosters the understanding of universal software. It gives the impression of being a video game, but it is actually a training tool to further augment cursor controls and click functions. The researcher utilized the teaching strategy of verbal instructions accompanied with modeling, occasional verbal encouragement to "keep on trying," and praise for effort.

Day 10

The researcher modified the teaching strategy. The subjects' went from working separately with the researcher to small groups of two. This was done so that the subjects could observe each other operating universal software for modeling and motivation purposes. Likewise, the researcher determined that the subjects needed to apply the cursor maneuvers and left click to software that was interesting, stimulating, and more age appropriate to encourage and challenge the subjects to aspire to new experiences. The choices of software the subjects operated, for ages 6-10 years, was the Microsoft Corporation's Scholastic series of The Magic School Bus Explores (2000) of "Inside the Earth," "In the Age of Dinosaurs," "The Ocean," and "The Rain Forest."

The 'Magic School Bus' software gave the researcher an opportunity to observe how the subjects interacted to the experience of using Brainfingers to operate universal software. The teaching strategy utilized by the researcher incorporated pointing prompts with verbal directions, as well as a trial and error approach.

Day 11

Based on the day prior, the researchers determined that the subjects' lacked ease with their left/right cursor maneuverability and adjusted their signals, as well as the speed of the cursor movement on the screen. Going back to Mouse Set-Up, the researcher made the adjustments and modification. Following the revisions, the subjects practiced the changes using specialized software from Laureate Learning Systems called "The Language Activities of Daily Living Series (1997)." This software permitted the subjects to utilize their mouse maneuvers and clicking skills, as well as become familiar with how to explore pages to operate the software. The researcher utilized the teaching strategy of verbal directions, as needed pointing prompts, and a trial and error approach.

Day 12

Using the foundation set on day eleven, cursor maneuver control and left click to explore pages of software was undertaken. From the Launch window, Mouse Control was activated and the launch button triggered so that the subjects had cursor maneuver controls and left click. The researcher began the subjects operating switch software to practice maneuvering the cursor to

targets and left clicking. The switch software gave the researcher the ability to modify the programs by enlarging the target sizes and the numbers of targets. Likewise, due to the subjects' aptitude to operate the software independently the researcher had the opportunity to examine the subjects' software operation and choice making proficiencies. The software offered to the subjects was the Inclusive Technology, Ltd. Drumkit (2001), SwitchIt Bundle (1999), and SwitchIt Arcade Adventure (1999).

Afterwards, the subjects had choices from the following universal "Living Books" software to practice their mouse functions. The researcher utilized the teaching strategy of the trial and error approach, with occasional instructions from the researcher such as; "click here and see what happens." The software offered to the subjects was The Learning Company School Division Living Books Collection of Dr. Seuss's "Green Eggs and Ham" (1998) and "A B C" (1995); Marc Brown's "Arthur's Birthday" (1997), "Arthur's Computer Adventure" (1998), and "Arthur's Teacher Troubles" (1994); Mercer Mayer's "Just Grandma and Me" (1993), "Just Dad and Me" (1996), "Just Mom and Me" (1996), and "Little Monster at School" (1994); Aesop's Fable's "The Tortoise and the Hare" (1993); Janell Cannon's "Stellaluna" (1996); and Tomie dePaola's "The Art Lesson" (1998).

Day 13 – 16

For the final four days the subjects were given the opportunity to perform software exploration to increase their independence at operating universal software. The thirteenth day, the subjects continued developing their independence operating and exploring the "Living Books" software. The subjects then attempted to operate unfamiliar early educational software. The choices of educational software the subjects were offered were; The Learning Company School Division Reader Rabbit Educational Programs of "Toddler" (1998) and "Reading Development 1 Library" (1997), and "Zoboomafoo Animal Alphabet" (2001); Davidson & Associates, Inc. Fisher-Price's "Little People Discovery Farm" (1997), "Sing Alongs Barnyard Rhythm & Moos" Volume 1 (1995), and "Ready for School – Kindergarten Edition" (1996); and the Microsoft Corporation Playskool's "Puzzles" (1995) and "Play-Doh Creations" (1995).

Summary of Results

Coherent Processing using a 2nd Order Phase Lock Loop

A series of tests with the software/hardware signal generator demonstrated that the basic 1st order phase lock loop operated according to design principles, and could acquire and track micro-volt signals in the 7 to 12 Hz region.

The basic apparatus was then tested using human alpha wave activity, but was unable to detect the sort of low-level alpha wave activity that was expected. There was an initial indication that the transient response was not fast enough for the human alpha wave signals.   A parallel investigation was carried out using non-real-time Excel processing on recorded human brainwave activity.   It was discovered that even strong alpha waves are not generated as continuous waves, but rather as short bursts of about 1 second in duration, and separated by 2 or 3 seconds.   Each burst is at a slightly different frequency, and there appears to be no coherence between each burst in a series of bursts, thus negating the basic idea of a phase

lock loop.   Faced with this new information, the phase lock loop approach to coherent processing was abandoned.

Results of Subjects Working With Brainfingers

Drawing from the tally sheets, field notes, and observational data the following figures and tables were created to provide insights into results of this study. Figure 1 illustrates the levels of control subjects achieved with the Cyberlink.

Figure 1

Subjects' Cyberlink Access Occurrences
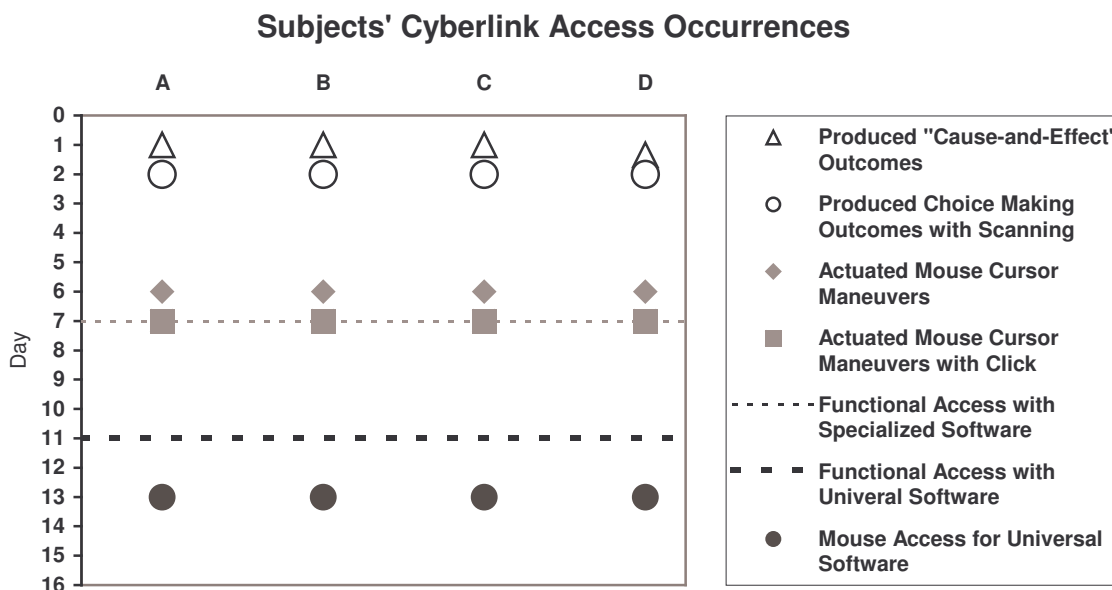
On days 1 and 2, the subjects were able to produce observable "cause-and-effect' behavior. Using switch control the subjects were able to select correct visual and/or auditory scanning choices. The subjects' facial movements were consistent to produce a conscious click when prompted or cued. However, access was not precise or functional due to the subjects' unconscious muscle activity, which caused false clicks.

On day 6 in Figure 1, the subjects continued to produce false clicks while performing clicking control, and continued to have difficulty directing the cursor to targets. This performance suggested some other frequency mapping was needed. Based on data collected from the Brainfingers window during the second session of the Introduction Day (see Appendix A), each subject was given the opportunity to experiment with frequency bands, which were observed to have potential as a control.

By observing the frequency bands on the screen in the Brainfingers window, the researchers were able to uncover frequency bands that could be utilized for various computer functions. These are shown in Tables A1-A4 found in Appendix A. Knowledge gained from prior

experimentation of Brainfingers was used as a foundation from which to propose the format for the tables.

Once clicking and cursor control was mapped to the subjects most effective frequency bands (see Table 2), the subjects improved their performance. The subjects directed the cursor towards, or to, a target no matter where it was on the screen, and continued to lessen their unconscious false clicks.

On day 7 the subjects actuated mouse cursor and mouse left click control, and exhibited functional access to operate specialized software. Based on the subjects' aptitude to operate communication software by moving the cursor to a picture and clicking to voice a statement, otherwise known as direct selecting, the subjects had effective access to specialized software. Yet, occasionally, the subjects continued to have the unconscious false clicks, as well as lose control of the cursor when maneuvering to a target. When control was lost, the subjects would move the cursor back to the initial target to complete the task or activity.

On day 11 adjustments were made to slow the speed of the Brainfinger controlled cursor. With these changes it was observed that the subjects had functional access and control of the Brainfingers system to operate universal software. The subjects gained cursor control and rarely produced the unconscious false clicks. Also, the subjects learned how to operate universal software to execute activities.

On day 13, the subjects demonstrated that they had mouse access to operate universal software, as well as independence to control the software themselves.

Figure 1 suggests an outcome that emerged from this study that was not anticipated. All subjects' rate of improvement and understanding occurred at the same times. This linear occurrence is noteworthy.   The intention of this pilot program was for the subjects to become proficient at their level of performance. Yet, all four subjects learned exactly the same operations and applications at the same time. Subjects used the Brainfingers system on common days, and operated related software at the same times, with the exception of Subject D on the first day of implementation.

Default settings for mouse cursor control and switch control provided as part of the Brainfingers software were used for all subjects at the beginning of the study. The mapping of frequency bands or brainfingers is presented in Table 1. On day 6 it was decided to select a different configuration for the subjects with the hope the new selections would improve the subjects' performance. Subsequent results confirmed this. The final mapping of frequency bands to cursor and clicking control is shown in Table 2.

The decision as to which Brainfingers to try for control in place of up/down and clicking were first made based upon how the subjects' Brainfingers responded to the facial gesture commands in the Brainfingers Display window. Brainfinger performance was tabulated from Day 1 results and the Introduction Day results. Four tables were constructed, one for each subject. The tables are presented in Appendix A.

Table 1

Cyberlink Default Setting

	Subject A	Subject B	Subject C	Subject D
Clicking	Muscle B11	Muscle B11	Muscle B11	Muscle B11
Cursor Up/Down	Muscle B11	Muscle B11	Muscle B11	Muscle B11
Cursor Left/Right	Left/right eye Glances B2	Left/right eye Glance B2	Left/right eye Glance B2	Left/right eye Glances B2

B = Brainfinger or Band, the number following B refers to which band counting from left to right.
B1 – B3 = Muscle activity of eyes left/right glances
B4 – B6 = Alpha brain wave frequency band;
B7 – B10 = Beta brain wave frequency band
B11 = Facial muscle activity

Table 2

Final Cyberlink Settings

	Subject A	Subject B	Subject C	Subject D
Clicking	Muscle B11	Alpha B6	Alpha B6	Alpha B6
Cursor Up/Down	Beta B8	Beta B8	Alpha B6	Beta B7
Cursor Left/Right	Left/right eye Glances B2	Right eye Glance B2	Right eye Glance B2	Left/right eye Glances B2

B = Brainfinger or Band, number following B stands for which band counting from left to right.
B1 – B3 = Muscle activity of eyes left/right glances
B4 – B6 = Alpha brain wave frequency band
B7 – B10 = Beta brain wave frequency band
B11 = Facial muscle activity

Figures 3 and 4 present a mapping of times spent learning Brainfingers for all subjects. For each of the daily sessions, of sixteen days, the subjects were allotted up to 60 consecutive minutes of time-spent learning. Figure 3 is the first eight days of the study. The subjects learned and operated the training tools in the Brainfingers software then applied the training to control specialized software. Figure 4 presents the last eight days of the study (days 9 – 16) during which time the subjects used Brainfingers to operate universal software.

As shown in Figure 3, the subjects' session times steadily increased over the first eight days. There was then a drop on the ninth day (see Figure 4). On the ninth day the subjects applied their control of Brainfingers to operate more intricate and uncommon software compared to the switch software they already knew. This change challenged the subjects by engaging them to concentrate more. Twenty minutes of operation was all the subjects could tolerate then indifference occurred.

Figure 3
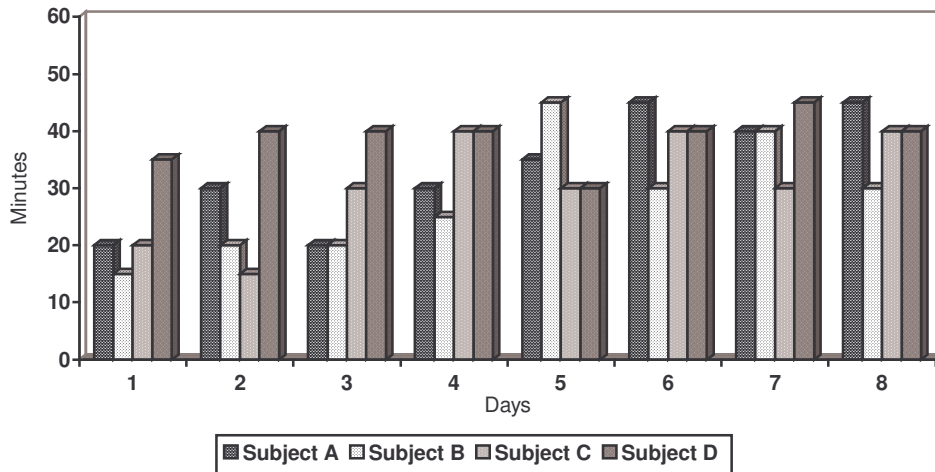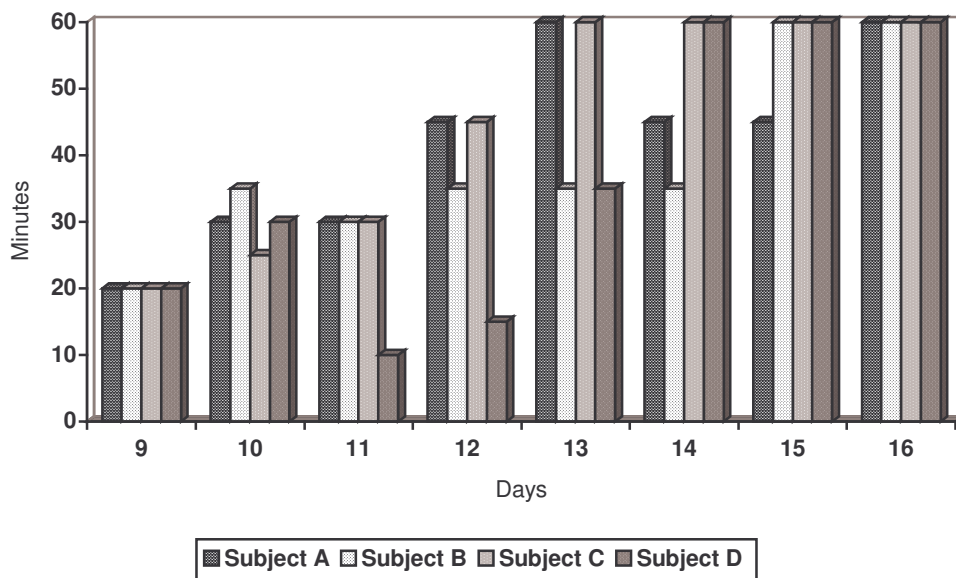
Time Spent Learning the Brainfingers System

Figure 4

Time Spent Applying the Brainfingers System to Universal Software

On day 10 in Figure 4, the subjects continued to be challenged with the Brainfingers system's control when applied to universal software. On day 11 a further refinement in the subject/ Brainfingers connection was made. The change was to slow down the cursor speed.

The software was designed to help the user learn how to perform software functions. Subject A, B, and C could only focus on the software for thirty minutes due to their apparent lack of interest. After the day 11 modifications, the subjects' time spent learning increased progressively to 60 minutes subsequent to the subjects' capability to access universal software. Subject D was ill for day 11 and 12 and is why her operation time dropped.

Another outcome emerged from this study based on the subjects' motivation to control the Brainfingers system and apply the system to operate software. The performance motivation was designed to be encouraging and positive to facilitate independence. For the first eight days each session began with something easy to operate and known by the subjects then ended with something more difficult but stimulating to give the subjects an idea of what was forthcoming in their experience. The last eight days began with challenging tasks, such as operating universal software, to encourage the subjects to experiment with their newly found control and independence. It was observed that the subjects were the most attentive during this time. The sessions ended with something easily accessible to practice and improve the subjects' access controls to ready the subjects for the next session's challenges.

The motivation for the subjects was the opportunities to make selections from forty-four choices of software to operate. The names of choices are listed in Appendix B. Table 3 depicts the subjects' time spent operating each of the software choices they made daily, when the researcher made the choices, as well as the number of prompts or cues needed to focus the subjects' attention back to perform the computer and software functions.

When the researcher made the choice of software, less time was spent on operating the software and more prompts or cues were needed. When the subjects made the choice, more time was spent operating the software and less prompts or cues occurred, with the exception of the "Magic School Bus" software on the 10th day. Likewise, as the subjects became more proficient with the Brainfingers system to operate universal software, they made fewer choices and focused more on each individual piece of software.

Table 3: Software Selected By either the Researcher or the Subjects

	Subject A			Subject B			Subject C			Subject D		
	R/S	Day& Min	# of Cues	R/S	Day& Min	# of Cues	R/S	Day& Min	# of Cues	R/S	Day& Min	# of Cues
Teach me to Talk	S	2/10m.	‖‖‖							R	2/10m.	
Teen Tunes Plus	R	2/10m.	‖‖‖ ‖‖				S	2/5m.	‖‖			
Switch Basics				R	2/5m.	‖	R	2/5m.	‖	S	2/20m.	
Disco				S	12/10m.	‖						
Drumkit							R	2/5m.	‖‖‖			
SwitchIt Bundle	R	12/15m		R	2/5m.	‖‖				R	2/10m.	‖‖
Arcade Adven.	S	4/15m.					R	12/10m.	‖			
Switch Connect.				S	2/5m.	‖‖‖						
IntelliPics	R	4/10m.					R	4/10m.	‖‖‖ ‖			
IntelliMathics				R	4/10m.	‖‖						
Clicker 4	R	4/5m.		S	4/15m.	‖				R	4/10m.	‖‖
Gus Multimedia				R	7/40m.		R	7/30m.	‖			
Speaking Dyn.	R R	7/40m. 8/45m.	‖	R	8/30m.		R	8/40m.	‖‖	R R	7/45m. 8/40m.	
Magic Scl. Bus	S	10/30m.	‖‖‖ ‖	S	10/35m.	‖‖‖‖‖‖‖‖	S	10/25m.	‖‖‖	S	10/30m.	‖‖‖
Laureate	R	11/30m.	‖	R	11/30m.	‖‖	R	11/30m.	‖‖‖	R R	11/10m. 12/15m.	‖‖‖ ‖‖‖ ‖
"ABC"	S	12/30m.										
"Green Eggs"	S	13/15m.		S	12/25m.		S S	4/15m. 14/40m.	‖	S	4/15m.	
"Lion King"							S	4/15m.	‖			
"Pocahontas"										S	4/15m.	
"Little Monster"							S	12/15m.				
"Teacher Troub."							S	12/20m.				
"Discov. Farm"	S	13/20m.										
"Sing Alongs"	S	13/25m.										
"Ready for Scl."				S	13/10m.	‖						
"Tortoise/Hare"				S	13/25m.							
"Puzzle"	S	14/25m.					S	13/20m.	‖	S	13/10m.	‖
"Zoboomafoo" N							S	13/40m.				
"Stellaluna"										S	13/25m.	
"Creations"	S	14/20m.										
RR Toddler	R S	15/45m. 16/60m.		S S S	14/25m. 15/60m. 16/60m.	‖	R R S	3/30m. 15/60m. 16/60m.	‖‖‖	S S S	14/60m. 15/60m. 16/60m.	‖
R												

R = Researcher's Choice. S = Subject's Choice. The day the software was used / Minutes operating software (m.).

Talley marks is how many times the researcher redirected the subject to operate the software

The daily total times spent controlling Brainfingers are listed in Table 4, along with the daily prompts. As the subjects progressed to operate universal software, the subjects increased their time-spent learning Brainfingers and needed less prompt or cues from the researcher to perform.

For this study, odd days were Tuesdays and even days were Thursdays. Looking at the tally marks, on average the odd days needed more prompts or cues. The motivation factor was a major determiner of performance time and increased the subjects' attention span. Even when the subjects operated two to three pieces of software a day, at the end of the study they focused on one piece of software for the full 60 minutes'

Table 4: Subjects' Overall Minutes Comparable To Decrease of Need for Researchers' Prompts

| Allotted Time - 60 Minutes Daily	Subject A		Subject B		Subject C		Subject D	
	Session Minutes	Number of Prompts	Session Minutes	Number of Prompts	Session Minutes	Number of Prompts	Session Minutes	Number of Prompts
Day 1	20	||||| ||||| |||	15	||||| ||||	20	||||| |||||	35	|||||
2	30							20								15										40				
3	20				20						30									40		
4	30		25							40											40				
5	35												45				30							30					
6	45		30		40			40			
7	40				40		30			45	
8	45		30		40					40	
Total	265 m. 4.25 h.	31Xs	225 m. 3.45 h.	26 Xs	235 m. 3.55 h.	39 Xs	310 m. 5.10 h.	18 Xs
9	20			20				20		20	
10	30									35													25							30						
11	30	||	30	|||	30	||||	10¹	|||||
12	45		35			45			15¹							
13	60		35			60				35			
14	45		25²			60		60		
15	45		60		60		60	
16	60		60		60		60	
Total	335 m. 5.35 h.	9 Xs	300 m. 5 h.	19 Xs	360 m. 6 h.	12 Xs	290 m. 4.50 h.	19 Xs
Grand Total	600 m 10 h.		525 m. 9.35 h.		595 m. 9.55 h.		600 m. 10 h.	

Note. m. = minutes; h. = hours; Xs = times. ¹Subject was ill and ²Subject's medication was changed.

Adverse Conditions for number of prompts for all subjects:

Day 1 – First day learning the Brainfingers software
Day 2 – Previously known switch software
Day 3 – Instruction on how to move cursor and signal adjustments
Day 5 – Fine tuning cursor adjustments
Day 10 – Magic School Bus software
Day 11 –Utilizing Laureate software to instruct on software exploration
Days 15 & 16 – Independently operating Reader Rabbit Toddler

Prior to the study, a school psychologist, the assistive technology professional, special educators, and California Children Services had assessed the subjects. The subjects were judged to be performing academically, functionally, and intellectually between six to eighteen months of age. As shown in Figure 5, the subjects' performance levels increased while controlling Brainfingers. This determination was based on what universal software was being operated and the activities, or "games," managed within the software, e.g., matching letters, numbers, shapes, and words. The subjects' performance levels were judged to have increased to 4 - 5.5 years based on the Brigance Diagnostic Inventory IED-II: Inventory of Early Development (2004), for birth to seven years.

Figure 5

**Average Performance Levels Before and After
Universal Access**
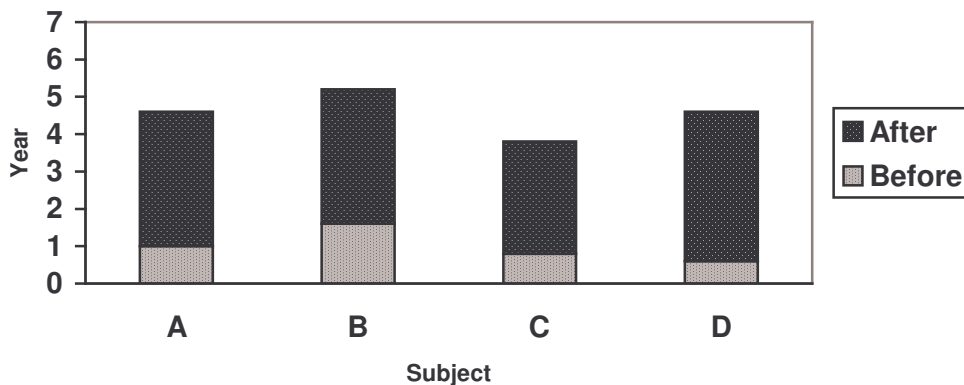
Discussion

The purpose of this study was to examine if the use of the Brainfingers system could be taught and used by persons identified with multiple disabilities to facilitate curriculum access, communication, and leisure activities, and more specifically if brainwave frequency bands could be used for Brainfinger control. The focus was on switch control, cursor pointing, and cursor pointing with clicking, to operate a variety of software to reinforce the training with the Brainfingers system. With the use of tally sheets and field notes, a content analysis was completed describing how each of the subjects operated Brainfingers, and their interactions with software, progress, and obstacles hindering their performance.

The four subjects, who attended the same public special education school, were between the ages of nine to twenty and had been identified as having multiple disabilities. The subjects had

been assessed in their academic and functional skill areas and were judged to be functioning intellectually at six to eighteen months of age with the average attention span of thirty seconds. Likewise, the subjects are nonverbal, but had demonstrated the ability to answer yes/no questions using facial expressions, and/or head nodding/shaking, and could make choices or point using eye-gaze. Finally, the subjects had no meaningful access to switch devices to facilitate curriculum participation, communication, or leisure activities.

The subjects worked individually with the researcher beginning in fifteen-minute increments. As the subjects perfected their control of Brainfingers and were able to focus their attention for longer periods of time, the researcher's instruction faded. The subjects developed independence with the system and the time increased to one hour per session.

As the subjects worked with Brainfingers other abilities began to emerge or were noticed. It became apparent that subjects understood more than previously assessed. Through the various teaching strategies of modeling, verbal directions, pointing prompts, indirect verbal instruction, praise, choice making, and the trial and error approach to teach the subjects how to control Brainfingers and operate software, the subjects demonstrated that they were able to learn. In fact they were able to put into practice everything learned in a very short period of time and demonstrated that they were able to control the computer at an independent level of access.

As the researcher continued to make adjustments of the system and asked the subjects to perform particular tasks so that the adjustments could be made, it became apparent that the subjects learned the computer terminology and demonstrated this knowledge by following the researcher's verbal directions. The terminology used most often by the researcher was; exit program, exit window or program, click, cursor, screen, and main window or page. For example, the researcher would instruct or direct the subjects to "exit the program," and subjects would maneuver the cursor to the icon to exit and click to complete the operations.

On day 6 the choice of Brainfingers used for up/down access and click control were changed. It was determined that better performance occurred when they used brainwave Brainfingers for control. Access became more controlled and the skills learned were able to be applied to 3rd party software. It became apparent that the subjects' motivation for learning the system improved. As the subjects' skills increased they exhibited behavior that they wanted to make choices of what software to operate. They wanted the control and independence. When the subjects had opportunities to make choices of the software to operate, their performance was better. When the researcher made the choices, refusals occurred. The same occurrence transpired after day 11, towards the end of the study when the subjects acquired total control with early education software. In the process of instructing the subjects in how to operate the software, when asked to maneuver the cursor to a target, they often did the opposite in an attempt to get a reaction out of the researcher or as an indication that they wanted to do it themselves. The subjects' motivation to use Brainfingers to operate software, and the use of the teaching strategy of trial and error, developed the subjects' problem-solving skills and encouraged them to use the skills to initiate and perform activities.

The subjects' interest in the computer extended further. When the subjects attended the researcher's classroom for their sessions, it was during the time when class was being conducted. Despite external disruptions of classroom noise and movement, all the subjects remained on task. If the subjects' attention was interrupted, they could independently redirect their attention back to their task. As described in the Brigance Diagnostic Inventory [12], the subjects' demonstrated six-year-old skills.

Finally, there was a result from this study that was not at all expected. Parents and educational professionals verbalized to the researcher about behavioral changes they were observing from the subjects during the course of the study that were not exhibited before the study. All four subjects were more attentive, Subject A, C, and D demonstrated increased alertness, Subject A, B, and C understood what the word 'relax' meant and could display it physically, and Subject A, C, and D initiated social interactions with others.

Conclusions

The performance results of the subjects exceeded the researchers' expectations. The four subjects identified with multiple disabilities achieved computer and software access through hands-free control of Brainfingers in less than sixteen hours over eight weeks. Results suggest that the Brainfingers system could satisfy the needs of persons identified with multiple disabilities who have physical limitations that interfere with computer operations. Brainfingers was found to be safe to use, easily learned, not affected by involuntary body, facial, and/or head movements, or limited vision, and offered specialized and universal computer and software access. For these subjects with multiple disabilities the brainwave frequency bands were better suited for control of up/down and clicking in the computer.

 It is concluded that the Brainfingers system removed access barriers to computers and enhanced the subjects' quality of life by permitting them to operate software for communication, learning, and leisure, and enhanced their abilities to enjoy an independent lifestyle. Brainfingers allowed the subjects to advance their cognitive and social skills. Brainfingers provided the speed needed to use computer technology, made choices available, grew with the individual's development, and could be used in many environments.

Based upon the researcher's perspective and experience, the Brainfingers system would not be usable by persons 1) who are blind and deaf due to the lack of visual and auditory feedback, 2) who seize excessively, and 3) who lack the motivation to learn the system.

The impact of different numbers of days between sessions was noted. Generally the sessions took place on Tuesdays and Thursdays. On Thursdays, because there was one day between sessions, the subjects took approximately a minute to reacquaint themselves to the controls of Brainfingers. But on Tuesdays, five days between sessions, it took approximately two to seven minutes for the subjects to recall how to control the system. It is interesting to speculate what the outcome would have been if the subjects had operated Brainfingers daily.

The subjects did access and use Brainfingers effectively and efficiently and applied the controls to universal software. Longitudinal studies are needed to determine if persons identified with multiple disabilities could achieve further gains with Brainfingers beyond those reported here. There is a need to provide access and instruct individuals in other computer functions like the mouse click-and-drag and double clicks, keyboard functions, and joystick operations. Controls are included in the Brainfingers software but evaluation of these functions was beyond the scope of this study. The plausibility of adding other frequency bands to enhance access would be worthy of exploration.

Studies are needed to examine the possibilities of using Brainfingers as an evaluative tool to determine cognitive awareness and intelligence of persons identified with multiple disabilities.

Brainfingers could be of value in support of day-to-day classroom instruction to facilitate progress in the general education curriculum. Even nonacademic activities could be supported, such as art and music. Further study could be conducted to evaluate Brainfingers as a controller for a voice output communication device in which some of the unique control capabilities of Brainfingers could be optimized.

The research and application possibilities are endless, particularly with advances in technology. Gaining a tool to control a computer, persons identified with multiple disabilities now have the opportunity to operate universal software, access that was conceived of but never made available until now.

Literature Cited

1. Orelove, F., & Sobsey, D. (1996). Educating children with multiple disabilities: A transdisciplinary approach (3rd ed.). Baltimore: Paul H. Brookes Publishing Co.

2 Alliance for Technology Access. (2000). Computer and web resources for people with disabilities: A guide to exploring today's assistive technology (3rd ed.). Alameda, CA: Hunter House Publishers.

3. Doe, T. (2002). Is it working? A review of AT successes and barriers. Sacramento, CA: California Foundation for Independent Living Centers. Retrieved April 4, 2004, from http://atnet.org/CR4AT/home.html

4. Downing, J. (1999). Teaching communication skills to students with severe disabilities. Baltimore: Paul H. Brookes Publishing Co.

5. Light, J.C., Beukelman, D.R., & Reichle, J. (2003). Communicative competence for Individuals who use AAC: From research to effective practice. Baltimore: Paul H. Brookes Publishing Co.

6. Tinker, R. (2001, Fall). Future technologies for special learners. Journal of Special Education Technology 16(4). Retrieved November 11, 2003, from http://jset.unlv.edu/16.4/tinker/refs.htm

7. A. Junker, C. Berg, P. Schneider, M. Terenzio, P. O'Conner, & G. McMillan. *Effects of training and individual differences on performance with the Cyberlink™ alternative control interface* (AL/CF-TR-1995-0109). Technical report, Wright-Patterson Air Force Base, OH: Armstrong Laboratory, December, 1995.

8. A. Junker, C. Berg, P. Schneider, & G. McMillan. *Evaluation of the Cyberlink™ interface as an alternative human operator controller* (AL/CF-TR-1995-0011). Technical Report, Wright-Patterson Air Force Base, OH: Armstrong Laboratory, November, 1995.

9.   W.T. Nelson, L.J. Hettinger, J.A. Cunningham, M.M. Roe, M.W. Hass, L.B. Dennis, H.L. Pick, A. Junker, & C. Berg. Brain-body-actuated control: assessment of an alternative control technology for virtual environments. *Proceedings of the 1996 IMAGE CONFERENCE*, 225-232, 1996.

10.   W.T. Nelson, L.J. Hettinger, J.A. Cunningham, M.M. Roe, M.W. Hass, & L.B. Dennis. Navigating through virtual flight environments using brain-body-actuated control. *Proceedings of the IEEE Virtual Reality Annual International Symposium,* March 1997.

11.   C. Berg, A. Junker, A. Rothman, R. Leininger, & G. McMillan. *The Cyberlink interface: development of a hands-free continuous/discrete multi-channel computer input device.* (AFRL-HE-WP-TR-1999-0191). Technical Report, Wright-Patterson Air Force Base, OH: Alternative Control Laboratory, August, 1999.

12   Brigance, A.H. (2004). Brigance diagnostic inventories IED – II: Inventory of early development. North Billerica, MA: Curriculum Associates, Inc.

APPENDIX A

Table A1: Subject A's Brainfinger Frequency Band Fluctuations:

↓ = Signal goes down   ↑ = Signal goes up

Candidate controls for clicking: B11, B7, B9, and B10
Candidate control for left/right: B2
Candidate controls for up/down: B6, or B8

	LR Glance B1	LR Glance B2	LR Glance B3	Alpha B4	Alpha B5	Alpha B6	Beta B7	Beta B8	Beta B9	Beta B10	Muscle B11
Relax	↓	↓	↓	↑	↑	↑	↓	↓	↓	↓	↓
Stare	↓	↓	↓	↑	↑	↑	↓	↓	↓	↓	↓
Close Eyes		↓		↑	↑	↑		↓			↓
Look Right		↑	↑			↓		↑			↑
Look Left		↑				↓		↑			↑
Lift Eyebrows							↑	↑	↑	↑	↑
Bite							↑		↑	↑	↑
Clenched Jaw							↑			↑	↑

Table A2: Subject B's Brainfinger Frequency Band Fluctuations:

↓ = Signal goes down   ↑ = Signal goes up

Candidate controls for clicking: B11, B7, B6, and B8
Candidate control for left/right: B2
Candidate controls for up/down: B6, or B8

	LR Glance B1	LR Glance B2	LR Glance B3	Alpha B4	Alpha B5	Alpha B6	Beta B7	Beta B8	Beta B9	Beta B10	Muscle B11
Relax	↓	↓	↓	↑	↑	↑		↓	↓	↓	↓
Stare	↓	↓	↓	↑	↑	↑		↓	↓	↓	↓
Close Eyes		↓		↑	↑	↑		↓	↓	↓	↓
Look Right		↑	↑			↓	↑	↑			↑
Look Left		↑				↓		↑	↑		↑
Lift Eyebrows						↑	↑	↑	↑		↑
Bite						↑	↑	↑	↑		↑
Clenched Jaw						↑	↑	↑			↑

Table A3: Subject C's Brainfinger Frequency Band Fluctuations:

↓ = Signal goes down   ↑ = Signal goes up

Candidate controls for clicking: B11, B6, and B7
Candidate control for left/right: B2, or B3
Candidate controls for up/down: B6, or B8

	LR Glance B1	LR Glance B2	LR Glance B3	Alpha B4	Alpha B5	Alpha B6	Beta B7	Beta B8	Beta B9	Beta B10	Muscle B11
Relax	↓	↓	↓	↑	↑	↑	↓	↓	↓	↓	↓
Stare	↓	↓	↓	↑	↑	↑	↓	↓	↓	↓	↓
Close Eyes	↓	↓	↓	↑	↑	↑	↑	↓			↓
Look Right	↑	↑	↑	↑	↑	↓	↑	↑	↑	↑	↑
Look Left	↑	↑	↑	↑	↑	↓	↑	↑	↑		↑
Lift Eyebrows	↑						↑	↑	↑	↑	↑
Bite	↑						↑	↑	↑	↑	↑
Clenched Jaw											

Table A4: Subject D's Brainfinger Frequency Band Fluctuations:

↓ = Signal goes down   ↑ = Signal goes up

Candidate controls for clicking: B6, or B8
Candidate control for left/right: B2, or B3
Candidate controls for up/down: B6, or B8

	LR Glance B1	LR Glance B2	LR Glance B3	Alpha B4	Alpha B5	Alpha B6	Beta B7	Beta B8	Beta B9	Beta B10	Muscle B11
Relax	↓	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑
Stare	↓	↓	↓	↑	↑	↑	↓	↓	↓	↓	↑
Close Eyes		↓	↓	↑	↑	↑	↓	↓	↓	↓	↑
Look Right		↑	↑			↓	↑				↑
Look Left		↑	↑			↓	↑				↑
Lift Eyebrows							↑	↑	↑		↑
Bite							↑				↑
Clenched Jaw							↑				↑