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# Investigating the Use of Brainfingers in Children with Cerebral Palsy for Spatial-Motor Education

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# Investigating the Use of Brainfingers in Children with Cerebral Palsy for Spatial-Motor Education

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# Abstract

Cyberlink:Brainfingers is a human–computer user interface that supports hands-free computer access. This is especially valuable technology for disabled individuals who lack the motor skills necessary to use a keyboard and mouse easily. Over the course of two months, four students with cerebral palsy, a motor-disorder, used Brainfingers to play a variety of spatial software. The primary aims were to see if use of Brainfingers with spatial software could improve the spatial-motor abilities of students with cerebral palsy, as well as to assess any apparent behavioral changes. Two of the students showed a large increase in spatial abilities when assessed, and all students displayed improvement or no change in positive behavioral attributes. All students improved their control of Brainfingers over time, and expressed their desire to use Brainfingers in the future over other methods of accessing a computer. The implications of these results are discussed, as well as issues for further study.

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# Chapter 1

# Introduction

## 1.1 About Brainfingers

Cyberlink: Brainfingers is a hand-free device developed and distributed by Brain Actuated Technologies of Yellow Springs, Ohio which allows one to control a computer by detecting the electrical signals produced by one's brainwaves and facial muscles. The unit consists of an interface box that can be connected to a computer either through a USB or serial port, and a thin headband which attaches around the user's forehead with a velcro strap.

On the headband are three plastic sensors which, after a small amount of vaseline jelly is applied to increase conductance, can read the electrical signals produced from a user's brain waves (Electroencephalography-EEG), muscle contraction from lateral eye movement (Electrooculography-EOG) , and facial muscle activity (Electromyography-EMG) These signals are transmitted through a wire embedded in the headband to the interface box, and then decoded for use with different mouse functions.

Research in the area of brain–computer user interfaces has been conducted for at least the past 30 years. A longtime forerunner in this field is IBVA which claims to have been one of the first groups to investigate the use of brain-software applications. IBVA markets a semicommercially available device which, like Brainfingers, reads a variety of neural signals to affect computer use, through the emphasis seems to be more on experimental applications of brain waves to software, such as music composition and biofeedback, rather than direct control of more mundane functions, i.e. cursor movement.

The computer science department of Colorado State University (Ander-

Figure 1.1: An image demonstrating the user interface of Cyberlink:Brainfingers (from `http://brainfingers.com`)

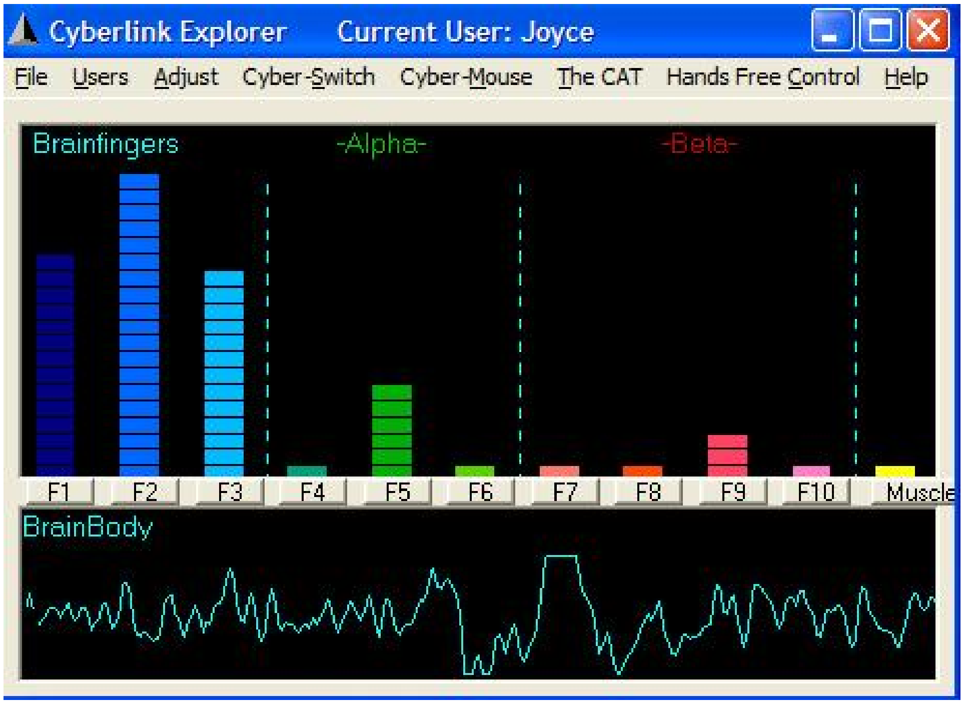

Figure 1.2: A screenshot of Brainfingers' calibration mode (from `http://brainfingers.com`)

son, 2007) is one group that appears to be heavily involved in EEG research related to computer control. On their web site, they detail their equipment setup and list various publications that may be of interest to the reader. Furthermore, such products are on the verge of being seized by companies for entertainment purposes. Emotiv and NeuroSky are but two companies who are planning to release commercial brain-computer interfaces for use with console and computer games in the near future. The emergence of Brainfingers as a viable brain-computer interface will likely be one of many competing devices in this sector. Any function that can normally be accomplished with the use of a computer mouse can be done with Brainfingers. This includes directional cursor movement and clicking functions normally associated with a mouse. Brainfingers accomplishes these actions by dividing sensory information into 11 different channels—"brainfingers"—and mapping them to different functions, which can be altered based on the user's preference. The first three brainfingers (B1–3) are for lateral eye movement. Brainfingers 4-6 (B4–6) detect alpha waves, which is a name for brainwaves in the frequency range between 8–12 Hz and are often associated with relaxed mind states. Usually, these channels are mapped to control either vertical or horizontal cursor movement. Brainfingers 7–10 (B7–10) also have the default setting of controlling multidirectional cursor movement, but utilize beta waves to do so instead of alpha waves. Beta waves are a classification for any brainwave frequencies above 12 Hz and are associated with active concentration. The role of the alpha and beta waves in brainfingers are not mutually exclusive, and a user may achieve more skillful use in one before the other to perform the same actions. B11, the last brainfinger, maps to facial muscle activity, and it is often used to perform clicking actions. Upon using Brainfingers for the first time, the user's baseline values for each of these brainfingers are automatically calibrated. However, within the software's settings, each of these brainfingers can be modified to alter their sensitivity. In addition to trial and error in the operation of any piece of software, there are several simple games bundled with Brainfingers to calibrate each of the channels more finely. Ideally, one should exert as little effort as possible while still feeling in control of cursor movement and clicking actions. Each brainfinger can also be mapped to different functions. For instance, if a disabled individual who lacked facial movement ability could not utilize B11 well, clicking might instead be mapped to one of the brain-state controlled brainfingers, B4–10.

## 1.2 The Danbury School

Naturally, this technology is of strong interest to those who are disabled and lack the motor abilities to operate a computer with a mouse and keyboard. One of the obvious potentials of technology such as Brainfingers is communicative. For individuals who lack speech ability, Brainfingers allows the ability to type using an on-screen keyboard, moving the cursor to each key and clicking to produce meaning.

The Danbury School is an elementary school in the Claremont Unified School District (Claremont, CA) for disabled children, many of whom have cerebral palsy. The school has expressed interest in how Brainfingers can be used to augment the education of their students. This interest arose from observing an 11-year-old student, A, who recently obtained her own Brainfingers and sometimes uses it at school. In a visit to Danbury School, I, Darryl Yong, and Maria Klawe, observed her using the device to operate a variety of children's software, much of which involved communication and language skills. With a teacher encouraging her and engaging her with various questions about herself and her life, A was able to use one program to indicate her mood and discuss topics like the weather and her family in simple terms by moving the cursor on screen to pictures and words and clicking to indicate her preferences.

## 1.3 Cerebral Palsy and Spatial–Motor Development

Cerebral palsy (CP) is a term used to describe a variety of nonprogressive, noncontagious motor disorders that are a result of some type of brain damage to various motor-related areas of the brain, such as the motor cortex, the cerebellum, or the pyramidal tract. It is not thought to be genetic, and most cases occur during pregnancy, although traumatic incidences after birth can also be a cause if they result in brain damage. Individuals with CP usually lack much motor control over their bodies and may either be unable to move their muscles much, as they are spastic and in a perpetual state of contraction, or may have a great degree of involuntary motion. They may also have balance and coordination problems (NINDS, 2007). This study is focused on the use of Brainfingers for children with cerebral palsy at the Danbury School. Specifically, I am interested how Brainfingers can be used to enhance mathematical–spatial skills in such individuals, as well as to potentially improve motor capability. As motor and spatial areas of the brain are intricately woven together, it is logical that the deterioration or improvement of either type of perception would influence the other (Zabalia, 2000). The noted developmental psychologist and philosopher, Jean Piaget, has said,

> Motor activity is of enormous importance for the understanding of spatial thinking. (Copeland, 1970)

Because children with CP lack the *experience* of interacting with the environment, they lack the intuitive sense of spatial understanding that the healthy individual develops in the first few years of life. The objective of this research is to determine if the process of using brainfingers for the exploration of 2-D and 3-D virtual space and geometry can improve students' spatial perception, and subsequently, motor ability.

## 1.4 Related Research

Several studies to date have focused on using Brainfingers for educational purposes (Marler, 2004; Redstone, 2006), though none primarily for mathematics education, to my knowledge.

The most notable has been done by Dani Marler (2004). In her study, four disabled individuals between the ages of 9 and 20, thought to be operating at various low cognitive levels (between six to eighteen months), learned to use Brainfingers to play various third-party children's software.

By experimenting with different settings for each user and carefully guiding her participants (but still allowing the subjects full latitude in their choice of software after the first few sessions), Marler helped her students to attain a high degree of proficiency in using Brainfingers (all could move cursor and click to operate universal software). Furthermore,

> prior to the study the subjects were judged to be performing academically, functionally, and intellectually between six to eighteen months of age. 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.

These results are quite significant. They demonstrate that use of Brainfingers may aid in the realization of substantial cognitive improvement that can be gauged in a variety of arenas. Additionally,

> 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.

These findings have greatly aided me in creating the conceptual framework for my project. To see cognitive development reflected both in academic, performance-based metrics, as well as in overall positive behavioral changes suggests that the potential for brain–computer devices is high, and goes far beyond just the classroom.

## 1.5 Pilot Study

During the summer of 2007, Katie Eliseo, a Harvey Mudd College Student, conducted a preliminary study (2007). She worked with two students: B, a 9 year old male, for 6 sessions over a period of 3 weeks, and D, a 9 year old female, for 7 sessions over a period of 5 weeks. She had the students play the built-in Brainfingers software, as well as Luxor, a third party game. During this study, both students were able to control all brainfingers, except that D had trouble with B11 due to poor muscle control. A spatial test designed by Eliseo was sporadically given, with D answering most questions correctly, and B answering only questions of lower difficulty correctly consistently. Based on assessments by the students' teachers, both students showed a large improvement in positive behavioral attributes such as "not frustrated," and "time on task."

# Chapter 2

# Procedures

## 2.1 Selection Criteria

In the process of picking students for the study, we (I, Maria Klawe, Darryl Yong, and Stephen Hamilton, principal of Danbury School) discussed what kinds of students would be most well suited for this research. The most relevant student characteristics were: age level, cognitive level, gender, language ability, extent of prior computer use, and extent of motor ability. One of our first priorities was deciding whether we would like to solely involve students who have a lower degree of motor skills relative to their peers and lack the ability to operate software via physical switches (such as a joystick or button) or use students who have a wider range of motor abilities. In the second case, the result would be a comparative study.

Although this approach is not without merit, due to the complex and multivariable nature of the study, we thought that it would be best to reduce as many of the variables as possible. Based on the relatively short time scale (several months) and small sample size (probably no more than six students total) of the study, making meaningful comparisons will likely be extremely difficult. Furthermore, we felt that it would be more interesting and potentially more meaningful to have students who previously had little experience using a computer, now using Brainfingers to access software, possibly for the first time. Although it is not the primary focus of this study, it goes without saying that one of the principal benefits of technology such as Brainfingers is to allow communication through software (either through an on-screen keyboard or other linguistic or pictographic morphemes) in individuals who may lack any means of communication beyond eyegazing.

Among other criteria, we preferred to keep a close age range between participants, and use individuals who speak English as a first language (to facilitate ease of communication between participants and myself/staff), both genders, and a range of cognitive abilities. Upon communicating these criteria to Stephen Hamilton, he and other teachers at Danbury Elementary produced a list of nine students, ranked by priority for use in the study, as well as a small amount of information about each child. We then narrowed this list and picked four students for the study.

## 2.2 Subjects in the Study

1. Subject C: 11 years old, male, uses a wheelchair. We had met with this student on a previous visit to Danbury. He seemed very interested in gaining others' attention and was described as having a disparity between the general ability he attempts to display he is capable of and his actual (lower) performance ability. He can use a switch with his hand to operate simple software, with varying degrees of success, as his motor movement is often too slow to effectively control switch function.

2. Subject H: 8 years old, male, uses a wheelchair. He can use a mouse and is very bright, but does not speak English as a first language (mother tongue is Farsi).

3. Subject E: 14 years old, uses a walker, female, can use software called Dynavox to generate speech as well as use a touch screen.

4. Subject J, 11 years old, uses a wheelchair, male. He was described as "bright," has some computer access, and is able to use a keyboard to some degree.

## 2.3 Protocol

The study lasted from September 17, 2007 to November 19, 2007, and included four students with cerebral palsy from Danbury Elementary School. I went to the Danbury school three times per week for between 1–1.5 hours per visit depending on the availability and attention span of the students on that day. Subjects H and J had relatively long attention spans—H was usually able to use Brainfingers for 30–40 minutes per session before becoming tired or disinterested, and J, for up to an hour, so that they usually each had their own days. Subjects C and E had much shorter limits of attention and endurance, typically 10–20 minutes each, so that I usually saw them both on the same day. Thus, on average, each subject was seen once a week, but their sessions may have been of very different lengths.

Spatial testing was done once in the beginning of the study and once at the end. There are five levels of difficulty and corresponding point values (refer to the appendix).

1. Obvious topological differences between objects.
2. Euclidian differences.
3. Euclidian differences with rotation.
4. Shape fitting without rotation.
5. Shape fitting with rotation.

The original idea was to use adaptive spatial testing: If a child gets a question right, move on to next level, if the child answers two questions incorrectly, he/she drops back down to the previous level, 10 questions total. However, after discussion and further research into standard testing protocol, we decided it is more consistent to have all subjects cover the same number of questions at each level. To correct for using adaptive testing with the first two subjects, we also gave adaptive tests for the remaining two subjects, and then for the second session, gave a nonadaptive test of 10 questions, 2 of each level, in order of increasing difficulty. For the two basic types of question (1–3 and 4–5) an example was first given so that the objective of the task was clear. It was not revealed to the subjects whether their answers were correct. For 1–3, the prompt is: "Which of the black shapes has the same shape as the blue shape?" For 4–5: "Which of the green shapes fits inside the white shape?"

During sessions, each subject used Brainfingers with a variety of Spatially-involving software from 15 to 60 minutes a session or as soon as participants become too tired or disinterested. Participants were observed and video taped for the purposes of ascertaining their ease of use with Brainfingers, their Interest Level, their degree of Positive Emotional Expression and their level of frustration.

Each session was videotaped (but subjects were always asked at the beginning of a session if it was all right to record it). During sessions, encouragement was given as needed and Brainfinger settings adjusted for easier use when it appeared necessary. I attempted to gauge the need for both types of intervention based on the student's performance and body signals (degree of concentration and relaxation), as well as occasionally asking about the difficulty of the current activity. After the initial calibration of Brainfingers, the subject is asked what game he/she wants to play, or asking, "Do you want to play game X?" In the beginning of the study, when subjects were not very familiar with the choice of software, I cycled through available software, suggesting possible choices to them. While monitoring the student's progress and interest with a particular game, every few minutes, or when it appeared subject was becoming disinterested or losing focus, he/she was asked "Do you want to keep playing this game or do you want to play a different game?" If neither question received a positive answer, I asked, "Do you want to stop using the computer?" or "Do you want to keep using the computer?" Children were typically quick to indicate when they wanted to stop without needing any further enticement.

We expected very minimal risks to the participants. Participants did not experience any physical discomfort as only concentration and calmness are required to use the Brainfingers device effectively. A staff members from the Danbury school was present at all times to make sure that students were comfortable, not tired, and participating voluntarily. In private consultation with us, Danise Marler, a special-education teacher who wrote a master's thesis on the effect of Brainfingers on children with cerebral palsy, indicated that a few of her students have at times been uncomfortable using the Brainfingers device in her classroom. Her speculation is that these children might feel some embarrassment at wearing a headband in the presence of other children who are not. Because the participants were working individually with the principal investigators and Danbury staff members, they were not in the presence of other children and these difficulties never arose.

The expected benefits to participants in the study included increased communication and computer-use abilities, increased spatial understanding, and increased motor ability. The knowledge gained from the study could be used for educational and therapeutic purposes for those who suffer from cerebral palsy and other motor disorders.

A limited number of quantitative measurements were taken. In any game-like piece of software, the accuracy and duration of time it takes to fulfill built in or user defined objectives can be recorded. However, after much discussion between me and my advisors, as well as Stephen Hamilton, we all realized that focusing too much on such measurements would not necessarily be informative. We expected that the more students used Brainfingers, the better they would get at using it and at performing tasks.

Recording these data may best serve as comparative measures of progress between students of different abilities. However, looking at such data alone may not tell us much about the development of each individual.

Stephen Hamilton devised a scale (refer to chapter 4) to estimate interest level/focus, degree of positive emotional express and level of frustration for each child in using computers. The teachers of each child decided upon their approximate baseline values for these categories. Therefore, much of the recorded data was qualitative, to capture, as fully as possible, the state of each child at a given time in the course of using Brainfingers, and the way we perceived them to be interacting with the software in conjunction with our help.

For the first few sessions, it was necessary for the user to become acquainted with the basic functions of the Brainfingers device. Although there is a range of 11 possible brainfingers for use in Brainfingers, any particular piece of software does not require more than four (one for movement in the horizontal plane, one for movement in the vertical plane, one for left click, one for right click), and many only need three. One of the principal aims of these first few sessions was be figuring out which brainfingers were most effective for each individual, and then using these for software use, fine-tuning them as necessary.

# Chapter 3

# Software

## 3.1 Packaged Software

Originally, we had thought to use Brainfingers to guide a small robot around the floor, such as the Roomba [1]. The advantage of this approach is to allow participants to get a tangible sense of movement and spatial orientation that a virtual environment may not necessarily produce. Although navigating either an actual or virtual environment both requires spatial perception, it is obvious that the actual environment is more "real" and therefore more desirable. As Brainfingers is set up to move a cursor along two axes at variable speeds, as well as clicking actions, it seems reasonable that these functions could be mapped to robotic movement via the computer's interface. Although such an interface has been studied in the past for purely technical research (Choi and Sasaki, 2001), we ultimately decided that there were a number of limitations to this approach and did not pursue it. As our subjects are young children, we needed to make the study as enjoyable as possible. From a larger perspective, we are engaging in mathematics education, and we strongly believe that education should be a stimulating experience. We decided to use Brainfingers with purely internal software because we believe the variety and Interest Level to be higher than what moving a robot can produce for an extended study.

Brainfingers comes with a variety of built-in software. Some of the software is very useful as a diagnostic for ascertaining which frequency bands a given user is most easily able to control, as well as what settings need to be changed to make a person's use of Brainfingers more effective. One such piece of software is "Brain Billiards."

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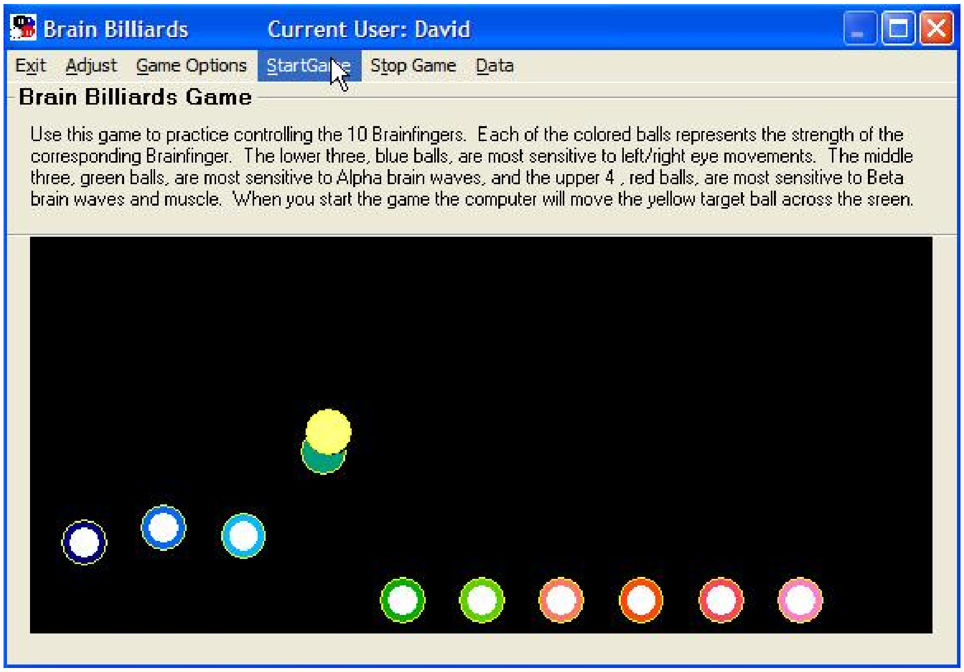
[1] `http://www.irobot.com/sp.cfm?pageid=122`



Use this game to practice controlling the 10 Brainfingers. Each of the colored balls represents the strength of the corresponding Brainfinger. The lower three, blue balls, are most sensitive to left/right eye movements. The middle three, green balls, are most sensitive to Alpha brain waves, and the upper 4 , red balls, are most sensitive to Beta brain waves and muscle. When you start the game the computer will move the yellow target ball across the sreen.

Figure 3.1: A screenshot of Brain Billiards (from `http://brainfingers.com`)

In this game, each of a user's 11 brainfingers is represented by a different colored billiard ball, evenly spaced along the horizontal axis. Activation of a given brainfinger will cause the associated ball to rise. If there is no activity in a brainfinger, the ball will stay at the bottom of the screen. A white ball moves straight across the screen at a given height, repeating its movement at different heights at each crossing. The objective is to raise each brainfinger at just the right height to hit the white ball. Upon doing so, the user is rewarded with a dinging sound and data is recorded to let the user know how apt one is at manipulating each brainfinger. This activity allows one to get a very visual idea of brainfinger activity and so is an excellent training tool. Certain brainfingers may be less responsive than others for different users. This exercise is good way of discovering which brainfingers work best for a given user.

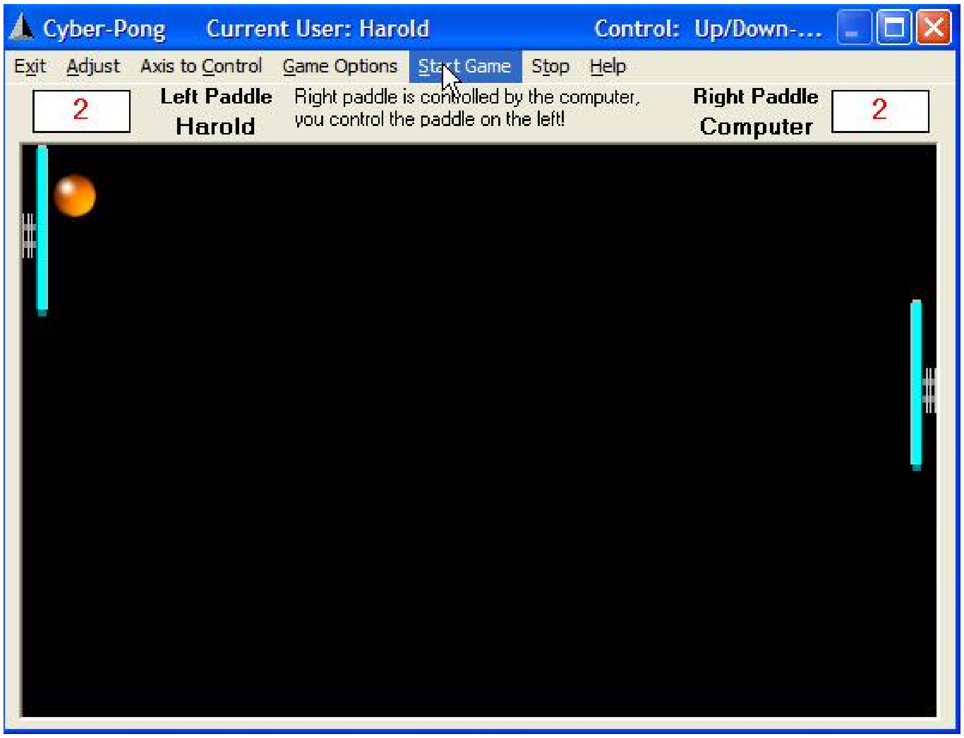
Although I find "Brain Billiards" to be one of the best diagnostic games built into Brainfingers, there are several similar ones. The "Grow Game" is another visual display of expanding concentric rings when brainfingers are activated. It also allows one to attain a visually pleasing understanding of how to use Brainfingers. "Brain Candy," creates a first-person display of moving through a tunnel. Activation of different brainfingers may create different colors and shapes and change the speed of movement through the tunnel.

There are also a number of more sophisticated games that allow the user to map different brainfingers to different functions. The simplest of these is the classic "Pong," the virtual version of ping pong in which a ball is released from a given direction and one must move a paddle along one axis to hit it at the right moment towards an opponent.

Failure to move the paddle in front of the ball results in a point for the opponent (in this case a computer). This is a nice way to get acquainted with Brainfingers, as it requires the use of only one brainfinger. The default option is B11, facial movement, which is not very difficult to control, but any one of the seven alpha or beta wave brainfingers can be used instead. It is very likely this game is one of the ones that will be used in the beginning of the study for its ease of use as well as containing some spatial properties.

Another favorite, "Tetris," is also included. The objective is to move and rotate tetrominoes (a geometric shape composed of four squares, connected orthogonally) so that when stacked, they will fit together and subsequently form filled in sections that disappear. The tiling of different shapes is a clear spatial activity, and in this case, two brainfingers can be used to accomplish this in the game.

"Labyrinth," as its name implies, is a game in which one must guide



Right paddle is controlled by the computer, you control the paddle on the left!

Figure 3.2: A screenshot of Pong (from `http://brainfingers.com`)

Figure 3.3: A screenshot of Tetris (from `http://brainfingers.com`)

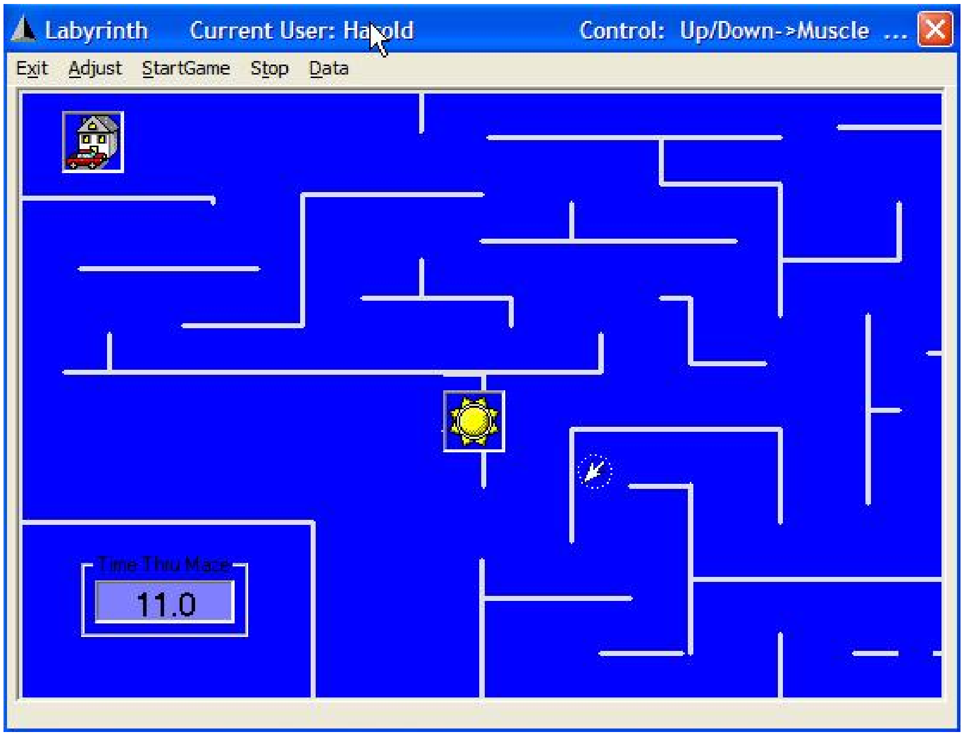


Figure 3.4: A screenshot from Labyrinth (from `http://brainfingers.com`)

a cursor through a maze to get to a specified destination. It is an effective way of using different brainfingers to create 2-D movement.

In "The Cellar," the objective is to move a cursor around the screen to pick up wine bottles and put them in an empty slot in the wine cabinet. Three brainfingers are used: one for horizontal movement, one for vertical movement, and one to pick up/release a bottle, the equivalent of the left button on a mouse. The faster one puts all the wine bottles in the cabinet, the higher the score, but there is no time pressure. This is a useful distinction, as one of our concerns has been finding games that are be playable without necessarily having to worry about completing objectives within a specified time limit. In a later stage, various insects move across the screen and the cursor must be directed to just the right place to squash the bugs with a hammer. This requires considerably more control and could be considered a kind of time pressure. In the final stage, the player must perform fine-tuned actions such as turning a safe to the right combination, requiring subtle activation of the left-click brainfinger.

Finally, a game which somewhat simulates the 3-D movement of skateboarding, ”Cosmic Skateboarder,” is also included. In contrast to the other games, there is no explicit objective or time constraints, which makes it a good opportunity for a user to gain control without artificial pressures. Three brainfingers are used to turn a skateboarder left, right, and move him forward around a track. There are a number of bumps and curves along the way, and moving over them quickly will often cause the skateboarder to fly into the air; although vertical movement is not explicitly controlled, it can be induced.

## 3.2 Third Party Software

One game we briefly attempted to use is Luxor (MumboJumbo, 2005), a 2-D puzzle game. In the game, multicolored balls roll through tubes curving in various directions, moving from one side of the screen to the other. The objective is to move a cursor along the $x$ axis and shoot the moving balls with similarly colored balls from the cursor’s position. Doing so causes the balls to disappear; shooting a ball next to differently colored balls will add it to the stack, creating more work for the player. Depending on where and when the control ball is shot, the moving line of balls may split up into different parts that move at different speeds. At later stages, multiple lines are shot out at different times. The game thus provides the use of two brainfingers ($x$-axis movement and left click), as well as requiring an understanding of 2-D movement and timing.

Counting on Frank (Electronic Arts, 1994) is a game which incorporates a variety of simple puzzles into a storyboard format. The one game we attempted to use was magic squares, in which one is given a number from 1–9, and must play it on a 3x3 grid. To win, a row add up to a particular number before the opponent (computer) does. Unfortunately, the software is quite old, and we experienced run-time, resolution and sound problems from running it on a relatively modern computer (Windows 2000).

Pandora’s Box (Microsoft, 1999) contains a variety of different types of well-designed puzzles. We used two of these games, focus point, and rotatoscope. In focus point, the user is presented with a jumbled picture broken into rectangles of different sizes. One must exchange images between boxes by clicking on two of the boxes until the picture looks normal. If a piece of the picture is in a box of incorrect size, it will appear out of focus. When a piece moves into its correct box, it will be in focus. Rotatoscope has similar constraints, as the user is given a series of fragments from a picture,

Figure 3.5: A screenshot of Luxor (from `http://www.share2.com`)

except in concentric rings. One must swap pieces in and out of the sections of the rings to form a picture with all the pieces in their correct sizes and positions.

Figure 3.6: A screenshot of Pandora's Box (from `http://microsoft.com`)

# Chapter 4

# Results

## 4.1 Teacher–Student Input

Each week of the study, from September 17, 2007 to November 19, 2007, the teachers of the students involved in the study were asked to quantify any changes they had seen in the behavior of the child. Below is the form the teachers used.

Behavioral Activity Rating Scale

First Name of Child: ________ Date: ________

Scale: 1=None 2=Some 3=Moderate 4=Good 5=Significant

| | | | | | |
|---|---|---|---|---|---|
| Interest | 1 | 2 | 3 | 4 | 5 |
| Time on Task | 1 | 2 | 3 | 4 | 5 |
| Not Frustrated | 1 | 2 | 3 | 4 | 5 |
| Positive Emotional Expression | 1 | 2 | 3 | 4 | 5 |
| General Attentiveness toward Computer Activities | 1 | 2 | 3 | 4 | 5 |
| General Attentiveness in the Classroom Overall | 1 | 2 | 3 | 4 | 5 |

For each subject, the overall trend is indicated by A:B, where A is the score given for the category on 9/17, and B the score given on 11/19. If there is only one number, the score did not change.

At the end of the study, two questions were asked:

1. For the Teacher: “What if any changes have you seen since the student has been involved with the Brainfingers study?”
2. For the Student (asked by the student’s teacher): “In the future, when you use your computer, would you rather use the computer with brainfingers or without brainfingers?”

**Subject E**

(Teacher A)
Interest Level: 3:4
Time on Task: 3:4
Not Frustrated: 3:4
Positive Emotional Expression: 4
General Attentiveness toward Computer Activities: 4:3
General Attentiveness in the Classroom Overall: 4:3

1. Not seen any significant changes.
2. Brainfingers

**Subject J**
(Teacher A)
Interest Level: 4
Time on Task: 4
Not Frustrated: 4
Positive Emotional Expression: 4
General Attentiveness toward Computer Activities: 4
General Attentiveness in the Classroom Overall: 4

1. No significant changes.
2. Brainfingers.

**Subject H**
(Teacher B)
Interest Level: 4:5
Time on Task: 2/3:3 (to 11/5):2 (to 11/19)
Not Frustrated: 4:5
Positive Emotional Expression: 4:5
General Attentiveness toward Computer Activities: 4 (to 11/5):2 (to 11/19)
General Attentiveness in the Classroom Overall: 4:5

1. No changes in general. Great attitude though.
2. Brainfingers

**Subject C**
(Teacher C)
Interest Level: 3:4

Time on Task: 2:4
Not Frustrated: 2:4
Positive Emotional Expression: 2:4
General Attentiveness toward Computer Activities: 2:5
General Attentiveness in the Classroom Overall: 3:5

1. Shows more interest in ′job time′ (using internet to find ′weather for day′ and ′this day in history′). Now views self as having access to the internet and more capable with it.

2. Brainfingers

## 4.2 Spatial Test Scores

**Subject H**
Beginning:17
End:16
**Subject E**
Beginning:12
End:12
**Subject C**
Beginning:5
End:8
**Subject J**
Beginning:16
End:25

## 4.3 Subject–Specific Findings

**Subject H**

H showed a high aptitude for learning how to use Brainfingers from the beginning. He quickly gravitated towards more complex games that allowed a variety of movement, especially Cosmic Skateboard, and to a lesser extent, the cellar game. He also exhibited a relatively high attention span, as his sessions usually lasted around half an hour. However, like J, the other most advanced student in the study, he did not develop fine enough control of Brainfingers to play the more sophisticated third party software (Pandora's Box, Counting on Frank), as it requires one to be able to rest the cursor around the middle of the screen and move back and forth between small areas which must be clicked on to play the games. Because of his high intelligence and curiosity, and his interest in Brainfingers, I am sure H would have been capable of completing more difficult puzzles and spatial tasks if he had more time to develop the necessary control.

From his teacher's perspective, H showed slight increases in all positive behavioral traits, although actually exhibited a decrease in "time on task" and "general attentiveness toward computer activities" during the last two weeks of the study. His spatial aptitude test did not show any improvement, and was actually one point lower at the end of the study than at the beginning. I believe these results reflect H's frustration towards not being challenged sufficiently. Although he continued to be enthusiastic about Cosmic Skateboard, I could sense that H was disappointed by not being able to effectively play Pandora's Box, and by apparent software-compatibility problems preventing him from playing Luxor.

H is easily physically agitated, especially when frustrated with his progress. He had a tendency to move his body much more than the other students, sometimes raising his hands up when desiring an action to take place. That he managed to quickly attain a relativity high ability for using Brainfingers is admirable, considering that this tensing behavior interfered with the signals, preventing progress. During these times, H also gave verbal commands towards the screen; while these verbalizations may have distracted him from effectively concentrating, it is also possible this verbal determination may have given him an impetus to change his thought patterns.

**Subject J**

J was enthusiastic about the project and avid about computer use. He was often inquisitive about the workings behind brainfingers, asking how to perform an action when having trouble, as well as directly interested in exploring the limits of the software. A notable example of this was during a session in which he was playing the maze game and discovered an error in the software—the ability to move the cursor through a section of an apparently not totally impenetrable wall. He was very pleased with himself for discovering this, and amused himself for awhile by exploiting this loophole. Another time, while playing the cellar game, he made the comment, "I get it—you have to be on top [of the bottle in order to pick it up]."

Over the course of the study, J proved to have an incredible endurance, increasing the time of his sessions from about 30 minutes initially, to a consistent length of about an hour. This ability to concentrate for long periods of time was already high initially, matched possible only by subject H, but quickly became greater than any of the other subjects. In the beginning of the study, J preferred to switch around between many different games, but as the study progressed, he was able to focus his energies on a particular game for much longer periods of time, usually preferring to play Pong, Cosmic Skateboard, and the Cellar game. If not for apparent software issues of responsiveness, I believe he would have also spent more time playing Tetris, as we came back to it a number of times, but usually not with much success. However, it is worth pointing out that in his final session, he requested to play Tetris, and was able to do so with much greater success than either he or any of the other subjects had managed in the past. He appeared to have a decent understanding of where to fit the various tetrominoes, and would have doubtlessly performed much better at it were it not for the lack of control experienced by all subjects when playing Tetris.

J's control of Brainfingers certainly improved considerably over the course of the study. Although his progress was often very discrete, over time, he exhibited greater ease with cursor movement, as well as clicking. J did not usually need a lot of encouragement, instead preferring to figure out problems on his own. Often, he would sit in an apparent deep concentration for several minutes, with no affect on cursor action, as if trying out different possibilities in his mind, until the cursor suddenly moved, as the case of a skateboard quickly moving across the screen after being stationary.

Physically, J was usually more relaxed than the other subjects, but had some tendencies to tense his body during Brainfingers, especially when faced with a time-dependent activity. During Pong a reoccurring tendency was to tense his body upwards when the ball's trajectory was moving towards the top of his screen. As the paddle's default position is to rest at the bottom of the screen, it was understandable that an upwards tension in his body sometimes occurred in response to a necessary upwards movement in the game. However, J made some progress on relaxation over the study, gradually tensing up during these moments less frequently as he began to understand, through explanation and experience, how Brainfingers works. When using B1–3, J sometimes utilized yawning, smiling, and laughing to have the desired affect, which often provoked further laughing in him!

J expressed interest in the games within Pandora's Box when he was showed them, and I strongly believe he would have enjoyed the puzzles and was capable of solving them. Unfortunately, the puzzles of Pandora's Box, like much commercial software, require finer cursor control than J had time to develop during the length of the study. He was able to move the cursor back and forth between extremes, but had difficulty continually maintaining the cursor in a given position, which screen-centered puzzles necessitate to perform any kind of extended action.

J was the only one of the subjects to have no change in scores on the behavioral chart filled out by his teacher, though he started with high marks. His attitude was generally very positive and attentive, and did not appear to fluctuate much. He showed a marked improvement in spatial test score, increasing from 16 to 25 (one 5 point question short of a perfect score). This improvement may be reflected in J's high total amount of time spent using Brainfingers (relative to the other subjects) to play spatially related games, which appears to have possibly increased both his spatial understanding and level of concentration. It is not surprising that he indicated his preference to use Brainfingers in the future when using a computer, as he had indicated to me during the study his desire to use Brainfingers to play familiar software.

**Subject E**

I saw only a modest level of change in E over the length of the study. Her total attention span for using Brainfingers did not fluctuate much throughout the study, almost always between 10–15 minutes per session. After the first couple sessions, she opted to spend the majority of her time playing Brain Billiards, which was surprising to me, due to its very simple nature, which I thought would become boring quickly. While playing this game, she was usually quite focused; when her attention lapsed, it usually meant that she was ready to end her session. She also occasionally expressed an interest in playing Pong.

Her control of Brainfingers certainly improved over the course of the study, though the speed of her responsiveness was usually low. She sometimes swayed while using the computer, but upon gradually gaining greater ease with Brainfingers, she did this less by the end of the study when playing a game familiar to her (mostly with Brain Billiards), and was able to move her body less while using Brainfingers.

A number of times, E inquired about the purpose and function of several on-screen settings, as well as why I wrote down notes during our sessions. Although her measured and observed responses were modest, and her teacher saw only minor fluctuations in aspects of her behavior during the study, she clearly had an active interest in Brainfingers, and opted to use it in the future when asked. Her spatial aptitude score did not change, though she answered different questions correctly. This constancy is perhaps not surprising given that she decided to stick mostly to Brain Billiards, a highly predictable, purely one-dimensional game that I was planning on using mostly as a diagnostic. Though I sometimes asked if she would like to play a different game, I allowed her to continue to play the Billiards game, as I did not want to discourage her from computer use.

**Subject C**

C was recommended for the study with uncertainty. I was told that he sometimes exhibited a high degree of intelligence, yet was easily distracted, and it was difficult for his teachers to ascertain what he was actually capable of. He was often slouched over and looking off to the side, and did not verbalize very frequently, so it was indeed challenging to tell what percentage of the time he was actually engaged in Brainfingers. However, like all the students in the study, he appeared excited to use Brainfingers, and indicated that he would prefer to use it in the future over other means of accessing software.

C had a short attention span, usually playing no longer than 10 minutes at time, and had to be continually encouraged. He gravitated towards Pong and Cosmic Skateboard, and somewhat improved his control in these games during the study, but I was often unsure how much progress he was actually making. However, from the vantage point of his teacher, C made large strides. His spatial score went from 5 to 8 (he was not even able to finish the test the first time, losing interest), and his behavioral activity scores went from 2s and 3s to 4s and 5s. His teacher commented that he seemed more confident and interested in computer use. By these measures, it would appear that the study was very beneficial for C.

# Chapter 5

# Software Issues

## 5.1 General

There were a number of problems with the Brainfingers software. For one, it was not always stable, or compatible with other software. Several times while switching between the built in games, visuals disappeared (such as the paddles in Pong), or a game would not start correctly until the program had been restarted. Neither the built in version of Tetris nor Luxor were not very responsive to Brainfingers. When playing Tetris, it was very difficult to move the pieces across the screen, regardless of the brainfingers mapped to this function. In Luxor, cursor movement was possible to a limited degree, but clicking functions could not be accessed at all.

Within Brainfingers, there is a main window from which a number of the games and settings are accessed, and a separate "Launch" window which must be opened separately to play several of the games, as well as any third party software. An annoying feature of the Brainfingers that could be easily corrected, is that anytime one switches between these windows, the lowest-alphabetically user in the list of users is automatically selected, even if one had just set it to another user. As each user preference records the auto-adjusted settings for that user, as well as the most recent Brainfinger settings for each game (which are preserved upon exiting Brainfingers), one must be very sure to check which user is selected when switching between windows.

## 5.2 Cursor Movement

A recurring issue in the study was how to best change the way a signal is interpreted for cursor movement. If a student is having trouble moving the cursor in a certain direction, the signal controlling that direction of movement can be amplified—but this sometimes results in choppier movement across the screen, not really achieving better control. The signal can also be shifted towards a direction, but if it is shifted too much, it can be difficult to move the cursor back in the other direction.

The way Brainfingers is designed for cursor movement is unidirectional. If a given brainfinger is mapped to L/R motion, then a signal from this brainfinger will cause the cursor to move right (or left, depending on user's preferences), and will otherwise rest towards the left (or right) hand side of the screen. This kind of binary directional movement works fine for game such as Pong, which only require one to move a paddle up a certain amount of the screen for a short amount of time, as where the signal can then be relaxed until the ball moves to the player's side of the screen again, but makes playing many games frustrating. This was the case when both J and H tried to play some of the puzzles in Pandora's Box. Because the puzzles require the cursor to be continually held around the middle of the screen and make many fine movements, they require a much finer degree of control with Brainfingers. Effectively, the signal must be maintained at moderate amplitudes; the tendency of the students was generally towards an "all-or-nothing" approach when activating the signal. If the study was longer and/or sessions were more frequent, I believe J and H could have developed this kind of control, but Brainfingers should be ideally configurable so that one can master this kind of control relatively quickly.

One possible solution would be to use more brainfingers such that instead of say, an activation of B3 corresponding to upwards cursor movement, and total inactivity of B3 leaving the cursor at the bottom of the screen, one could set B3 to move rightwards, B2 to move leftwards. Although this approach would also take a degree of training, it may be more feasible than the current setup. Using the example of B2/B3:L/R, one could use B3 to move the cursor towards the middle of the screen, and then, if neither B2 nor B3 were being activated (or if both were being activated roughly equal amounts), then the cursor would stay in the middle of the screen without any additional effort. This is a more accurate mouse-like setup. It should be possible to keep the cursor at a position on the screen without exerting any energy. Effort should only be necessary when moving the cursor, as when moving a mouse.

Otherwise, it is very taxing to continuously maintain a signal over a long period of time using Brainfingers. Another application, Brainfingers-Gaming, has been developed by the makers of Brainfingers, and allows one greater freedom to map brainfingers, specifically allowing one to place different threshold markers on a given brainfinger (i.e. activating B3 at 50 % of its maximum threshold causes cursor movement left, 75 % percent causes cursor movement right), but there are problems with this setup (it is undesirable to have to move left every time before moving right), and it is only compatible with games which strictly use a keyboard and/or joystick, so inapplicable for mouse movement.

# Chapter 6

# Conclusion

This study was concerned with a number of aims, but at the core of the project was the question: “can a hands-free device such as Brainfingers be used to teach mathematics concept to students with cerebral palsy?” The answer that emerged is positive if not entirely conclusive. On the spatial test administered, subjects H and E showed no change in score, C improved his score by 60 percent, and J improved his score by 56 percent. These results are understandable in light of my observations: J amassed by far the highest amount of time using Brainfingers due to his long attention span during sessions, at least a factor of two in total time over H, who had the closest level of endurance. C was initially assessed at a low level and so had the most to gain. Although he was still the lowest performer in absolute terms, if total time during sessions, ability of control attained, and spatial test score are taken as the primary metrics, both his teacher, and Frank Ramirez, who was present at almost all of the sessions to aid me, commented on the noticeable improvement in his attitude and focus. E’s progress was very slight, exhibiting a moderate attention span and control of Brainfingers relative to her peers, and her comments and test scores reflect this lack of any noticeable change. I believe H has a high potential for change, but was not challenged enough, due to his high intelligence and curiosity. Although he often displayed a higher ability to use Brainfingers than any of his peers, but became frustrated by some of the control issues in Brainfingers, preventing him from playing more interesting third party software.

However, it is important to note that it is very difficult to establish a firm causal link between use of Brainfingers and changes in spatial-motor or behavioral characteristics of the children in this study. First of all, our study was small, consisting of only four students. Low sample sizes are invariably fraught with uncertainty, and we lacked a control group (one could debate for some time whether this would consist of other disabled students playing the same spatial software without the use of Brainfingers, using Brainfingers on non-spatial software, students without cognitive disabilities using Brainfingers to play spatial software, or something else entirely). Furthermore, there was a great deal of variability in the cognitive and behavioral characteristics of our students. This is especially acute among disabled students, who may share an umbrella neural disorder (in this case, cerebral palsy), yet humans and brains are immensely complex, and these disorders will certainly affect children to varying extents, such that it is impossible to ever pick an "identical" group of students. Since I spent only spent a short amount of time with the students each week, the changes in their spatial and behavioral attributes could have resulted from many different sources, such as classroom activities, their respective home environments, playing other games that do not use Brainfingers, or other kinds unrelated cognitive breakthroughs. In short, in a study such as this, there are a very large number of variables outside the control of the researchers, so we must be prepared to scrutinize our findings and continue research in this area to further develop our insight.

Brainfingers is a remarkable tool that allows disabled people who would otherwise not have the chance to have computer access. Although it was not the focus of my study, Brainfingers has obvious potential of making communication for people with cerebral palsy possible in a way that might otherwise never exist for them. The world of cerebral palsy is often a frustrating one for both those the disease it afflicts and the people around them, as it interferes with all muscle coordination, including those necessary to produce coherent speech. Through the use of on-screen keyboards and icons, one can write and express thoughts, as easily (if not as quickly), as typing on an actual keyboard. This work has already been done successfully in the past, notably by Dani Marler, and I hope it will be pursued at Danbury and other institutions with speech- and muscle-impaired individuals. Most notably, all the subjects of the study were generally excited to use Brainfingers, and emphasized their desire to use it in the future over other methods of accessing a computer. Hands-free devices such as Brainfingers can allow individuals with CP to learn in an interactive way, not just mathematics, but any discipline. However, I believe mathematical ideas are particularly well suited for this endeavor, considering the role that spatial representation plays in all levels of study. I would recommend that another spatial-oriented study with Brainfingers be done in the future, but with a longer time span, and more frequent sessions. If some of the control issues are worked out, students could access games which required a much higher degree of spatial reasoning than the subjects in this study had an opportunity to engage in.

Upon beginning this study, I did not know what to expect. I am far from an expert in human–computer interaction, psychology, neuroscience, mathematics education, or special education, yet this study included elements of all these disciplines. Furthermore, I had never spent any amount of significant time in a disabled classroom. Initially, I was very unsure how to approach the students or treat them due to their disabilities. From the vantage point of a "healthy" person, such individuals are often seen as unfortunate, but what I experienced during my time at the Danbury School contradicted these societal norms; instead I saw a happy, vibrant community of staff, volunteers and students who created a supportive, upbeat atmosphere for all. All four of the students I had the pleasure of interacting with were almost always in good spirits, eager to share their lives with me. I saw that, although they faced challenges that most of us would not wish our children to face, they were essentially still like any group of children, capable of enjoying life on a daily basis.

## Epilogue: A Story

One day at the end of a session with H, I observed him trying to retrieve an item from his backpack, which was looped around the back of his wheelchair. I pondered helping him for a moment, but then decided to let him do it himself. After several seconds of scrambling, he finally managed to obtain the object, a yellow lollipop wrapped in plastic. He jerkily maneuvered the lollipop into his lap, and then successively moved his hands towards the plastic, using quick, choppy grabs to unwrap it. Finally, he successfully unwrapped the plastic, and maneuvered the lollipop into his mouth, via a slightly strange path, repeatedly correcting his overcompensated motion. Rarely have I seen a child smile so widely. Most of us would not think anything of putting a lollipop into our mouths, but for H and other individuals with CP, it was a challenge—yet it held a reward I couldn't possibly appreciate. Many times while at Danbury, I gained a new appreciation for the everyday magic of existence through my students. Enjoy every lollipop.

# Appendix A

# Structure of the Spatial Reasoning Test

There are five types of questions on the spatial test:

1. Obvious topological differences between objects.
2. Euclidian differences.
3. Euclidian differences with rotation.
4. Shape fitting without rotation.
5. Shape fitting with rotation.

# Appendix B

# Example Questions

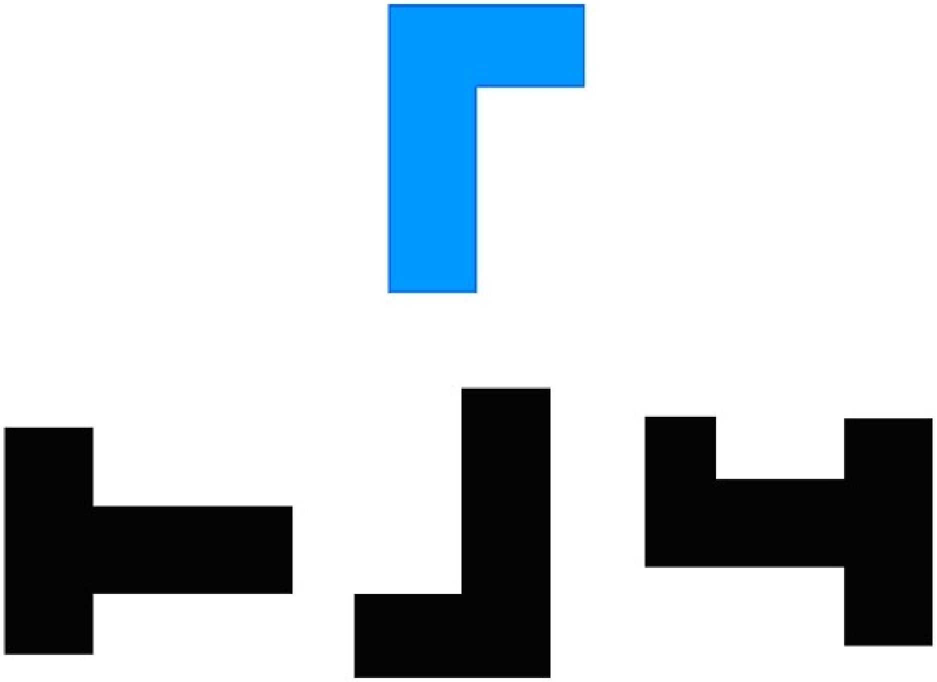


Figure B.1: A question from a 3-point question (Euclidean differences and rotation). The test-taker must reason which of the black shapes is the same shape as the blue shape.

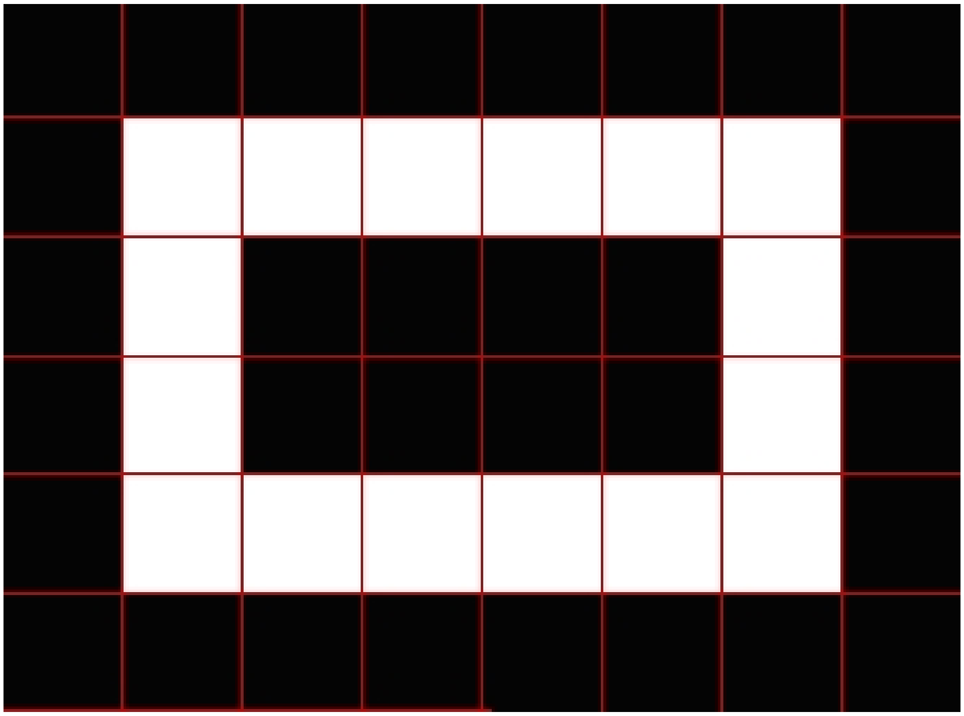


Figure B.2: A question from a 4-point question (shape fitting with no rotation). The test-taker must reason which of the green shapes shown in the next free figures will fit entirely within the white area.

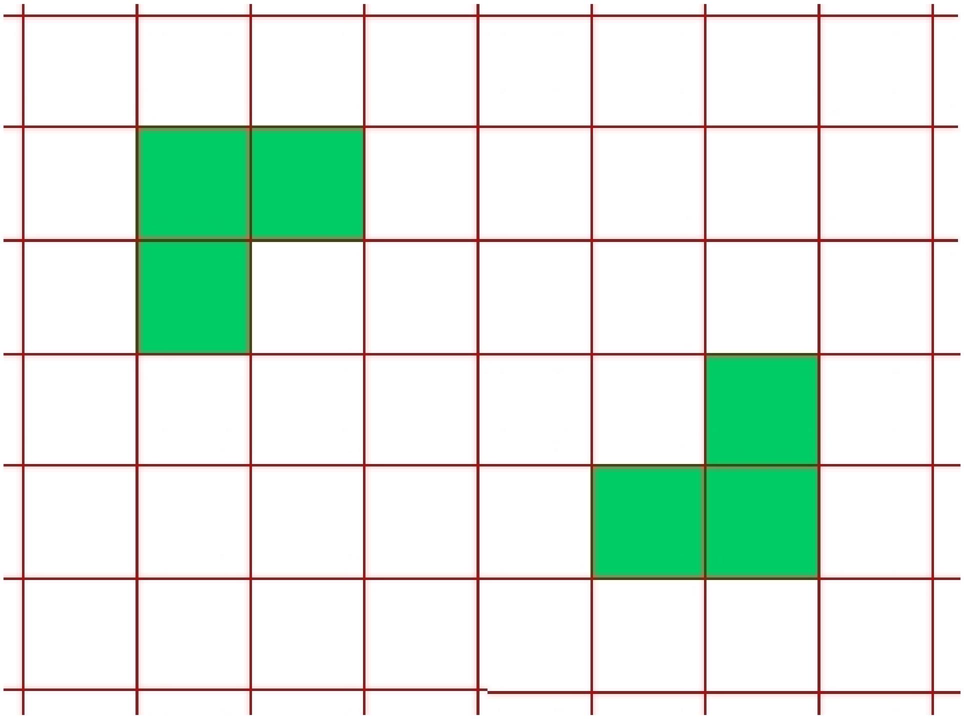


Figure B.3: A choice for the 4-point question.

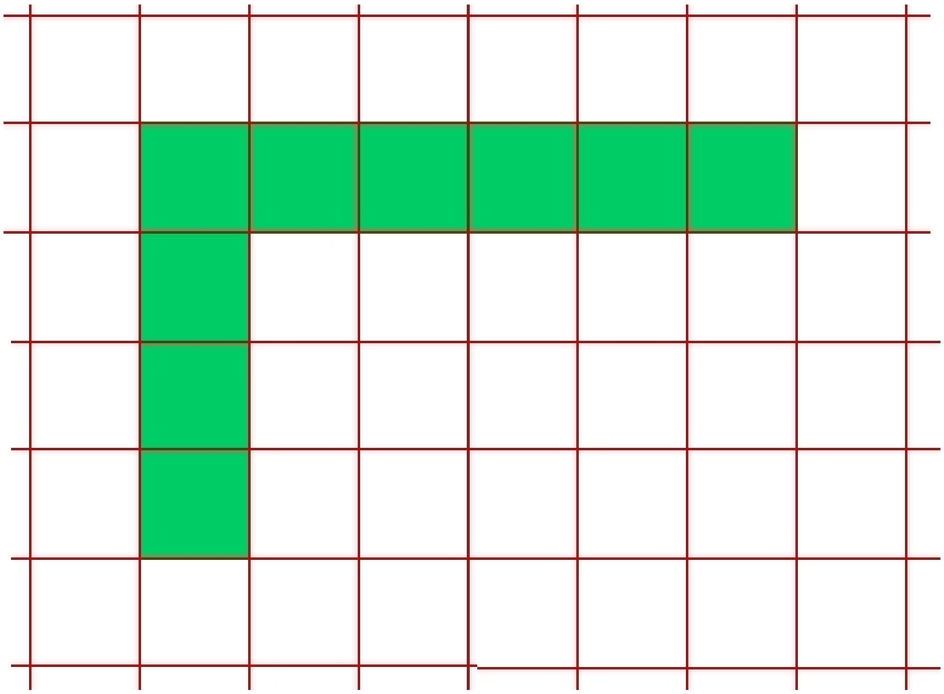


Figure B.4: A choice for the 4-point question.

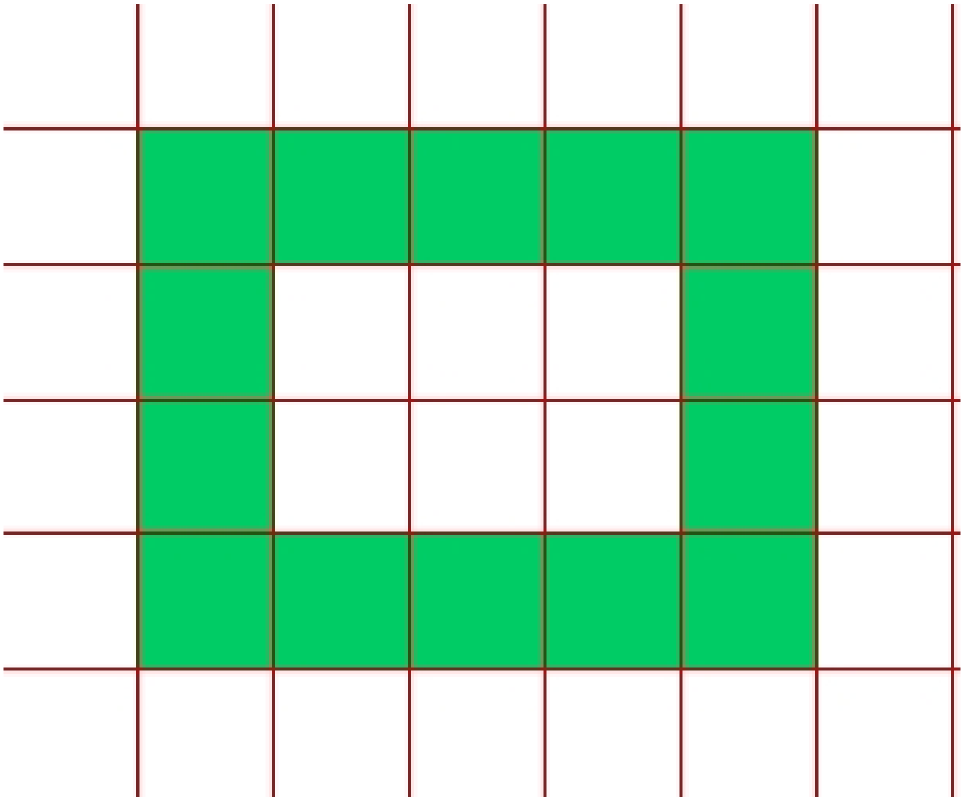


Figure B.5: A choice for the 4-point question.

# Appendix C

# Field Notes

Abbreviations: U/D: Up/Down L/R: Left/Right F: Forward B1-11: Brainfingers 1-11

**Subject H**

9/17 Scores on adaptive test: 1 2 3 3 3 3 3 3 3 3-we decided to not test on 4th and 5th levels as that morning we decided their meaning needed to be changed. He was very quick and eager at answering all questions, all correctly, too easy for him. In wheelchair. High attention span, very affable, though began to move head and body more as he became more excited and/or agitated. Roughly understandable speech ability. Able to move arm and hands haltingly to rest on answer in spatial test. Started out w/ auto-test and blue bars, weak on B11 and B1-3 until further explanation and encouragement, then there was improvement. Told to follow blue bar with eyes, relaxed, without moving body (for all). First played billiards game for several rounds. High success and good control of brainfingers. Tried B7 on pong with ok success, then tried B5 which worked better. Lowered amplification by 1 point for finer control. 5 minutes. Then played maze-pretty good success. Settings: L/R: B2, U/D: B5. Strong w/ alpha but trouble lowering. Tried labyrinth-a harder maze, switched L/R to alpha, U/D to B11, played for 2 minutes. Cellar game, some difficulty moving up, but able to pick up bottles within the first few minutes. All in all, played BF for around 30 minutes. Generally, we gave continual encouragement and every few minutes would ask, "Do you want to keep playing this game? Do you want to play a different game?"

9/27 Non-adaptive test 1 1 22 3 3 0 0 (got one right) 5 0 Did a review of BF and its functions. Played B. billiards, especially strong with alpha but also with B. Raises arms a lot when concentrating. Pong: B5, high success.

Very verbal when trying to achieve action: “go down/up, go!” Good at activating levels but more difficult to decrease on demand within a range. Easy maze: U/D B11, L/R B5, quickly solved, switched to Cellar game: Alpha L/R, Beta: U/D. Me: “Use your brain, not your arm”-good success Good at grabbing bottles, but tendency towards excess clicking. Played for 5 minutes, very determined. 15-20 minutes for total session.

10/8 Started off with pong, B5, enthusiastically. Slow ball, all other settings normal. Tetris-click B8, L/R B5, good at rotating, but B5 very active, hard to keep to left. After a round or two had him try b. candy as a break. He enjoyed it, seeing how he could vary speed of tunnel, very engrossing. Very verbal, as always: “Go, go! Move up!” Cellar game: lost some of skill from last time. Tried billiards twice then tetris again, still tough. Back to cellar game, B8 L/R B5 U/R with difficulty, then back to pong with a bigger ball for about 5 minutes, just ok results. Back to billiards. I believe he needs to be challenged with new games to keep up with his interest and high intelligence. Asked if he wanted to play a different game, he says, “new game.”

10/15 Today there were many software/computer problems. I attempted to have H play the game “Luxor,” mapping L/R movement of cursor with B1-3, and left click (shoot balls) first with alpha, and then with other channels, but was unable to get the balls to shoot/activate left-mouse click within Luxor. L/R movement was possible, although very choppy, and all functions worked normally using a mouse. Accessing Luxor using the “launch” window from within BF directly, as well as activating “hands-free use” to control the desktop and then open Luxor both had the same problem. This was particularly confusing as all the normal functions of BF (L/R and U/D movement, left click, click and drag) worked fine on the desktop. I later attempted to play Luxor with BF on my own computer but ran into the same problems. After realizing that we were not going to get Luxor working during our session with H, I had him play some of the familiar software instead. First tried the cellar game: slow at first, but then did a little better. “Slow speed” option was somehow triggered within the game. Still has a tendency to lean forward and touch the screen when frustrated and verbalize his desired actions, such as telling the cursor “go!” In response, I urged him to “use your brain.” After a few minutes with the cellar game, he played Brain Candy for a short time, which he was absorbed in.

10/29 We installed a new game, Counting on Frank, which contains a variety of math puzzles. We tried one of these, magic squares, in which one is given a number from 1-9, and must play it on a 3x3 grid. To win, one must have a row add up to a particular number before the opponent (computer) does. Unfortunately, the software is quite old, and we experienced run-time, resolution and sound problems from running it on a relatively modern computer (Windows 2000). It was difficult to move the cursor in the right place and click on one of the squares, so we decided to not use the software. Skateboard: L:B8, F:B5, R:B2. Good success, able to move the skateboard very fast. Left turns are easy, shown a preference over right. After a few minutes, he became very concentrated, leaning forward in his chair. Capable of making very large jumps and rotating in midair, and pleased with himself about this. Still issuing verbal commands ("Go!") Whether deliberately or accidentally, almost pressed a button on the monitor. 15 min. Maze: U/D: B7:L/R: B4: Too hard, seemed easily tired. Pong x1: U/D:B7-requested increased ball and paddle size, other settings lowest. Brain Candy 3 min. Head forward and very concentrated. Exclaimed, "Ooh, wow!"

11/5 Very active at pressing clicker and monitor buttons. P.Box: Focus pt. L/R:B2, U/D:B4, B11 click. Explained the game to him, initially demonstrating with mouse, then handed control over to him. Difficulty moving cursor to correct location. Skateboard: L:B8, F:B5, R:B2. Pressed monitor buttons several times while playing. Leans forward, very concentrated, prefers to turn right, likes making big jumps, still gives verbal direction towards game when he wants some action to occur. Said, "Ow!" jokingly when skateboard hit the wall. Told me, "I want to go outside [the in-game boundaries of the arena]." Tried Focus Pt. again. Still difficult to control cursor accurately. I asked him what he did to move the skateboard in an attempt to see the parallels in cursor movement, but it didn't help. Pong: U/D:B4/B5, low settings, big ball and paddle. Some success with narrow misses causing H to say, "oh my god.." (as in, "how could I miss that shot?") Labyrinth: U/D: B4, L/R:B2, not very good, switched to U/D:B5, L/R:B7, no noticeable improvement. Billiards: Generally high success. Cellar game: L/R:B4, U/D:B8, Click: B11. Rapid and discrete movement. Difficulty, but better than previous settings: L/R:B2, U/D:B4. H briefly squeezed my hand while playing.

11/15 Skateboard: Previous settings. Signals were inexplicably found to be shifted +8, changed to default. Moved board very quickly and pleased with himself over making huge jumps. Occasionally verbalized and touched screen. Got tired earlier than normal. Was grabbing door handle shortly after the end of session. 10 min.

**Subject E**

9/19 Glasses were broken, not sure how much this affects visual performance. Adaptive test scores: 1 2 3 0 0 3 3 0 3 3 Compared to H, took much longer on test and attention began to wander halfway through. B2-4 strong, played billiards for a few minutes. Also played pong for a few minutes. Encouraged her and asked her if she wanted to keep playing in addition to asking game preferences. 10-12 minutes into the session she decided she was done. Her attention span was much shorter than H's. She had similar control of arm to H. Uses a walker. Likes to swing back and forth.

9/24 Non-adaptive test: 1 1 2 2 3 3 0 0 0 0 (for last three questions, correctly fit one shape, but incorrectly fit other shapes). After auto-adjust (lower B11 than first time-138) immediately asked her if she wanted to play the pong game, which she did, so she played for several minutes. w/ B5, good concentration, relatively relaxed. Asked her if she wanted to play a different game: yes, chose "easy maze," with B5 for L/R, B7 U/D, not a lot of success, difficult for her. After a few minutes, she indicated that she was ready to be done.

10/3 Expressed interest in B.billiards when I asked her if she wanted to play it. Control much improved, hit 1-10 on 2nd try, looks down sometimes, and sways. Asked if she wanted to keep playing thrice and said, "yeah!" both times. Leans forward sometimes but still relatively relaxed. Played billiards for a full 10-12 minutes before indicating she wanted to finish by trying to remove the headband.

10/11 Very enthusiastic for BF! Wanted to touch sensors and gel, and I let her (she squirted out a bunch of gel). Asked her if she wanted to play the billiards game again and she said yes. Good control overall. Switched to pong-novice settings, B6 U/D moderate success. Attention seemed to be drifting at times, encouragement helped. 12 min. total.

10/24 Seemed especially talkative today and asked me why I video tape and write. She expressed an interest in the start up screen, asking what the waves corresponding to frequencies represented. I attempted to give a simple explanation. She was eager to play the billiards game again, hitting almost every ball on the first run.. Fairly focused and good control of BFs except for B11. Began to move arms and legs around when distracted. 14 min.

10/31 Difficulty with adjustment-excessively high B11. Billiards: 5 min. Pretty decent performance. Briefly reached hand out to press a blue switch while playing. She played a few times and then indicated that she wanted to take off the headband.

11/15 Pong: x1. U/D:B8. As I was changing the in-game options, she asked me what I was doing, and I said, "making it easier." She told me, "I want it hard," so I made the ball speed normal, keeping lowest difficulty, big paddle and medium ball. Got a few hits, touching clicker while playing. I changed speed to slowest. She had difficulty moving paddle up all the way to the top of the screen when the ball was directed there.

**Subject C**

9/24 Adaptive test: 1 2 3 0 0 0 0 started losing concentration/interest halfway through test, so stopped Easily distracted, uses wheelchair, capable of slow movements. Has a tendency to lean forward and look around the room. Unsure sometimes how much was looking at screen from strange angle or not paying attention. Strong in Beta waves, high w/ 11 After start up and auto-adjust, moved head around not necessary at screen. Played billiards for a couple minutes, appeared to lose interest, and asked if he wanted to play a different game. He said yes and we switched to pong with moderate success using B7 for U/D. Used a strap to keep him in his chair so he doesn't fall forward. Played for ¡ 5 minutes before appearing disinterested, so we ended the session.

9/27 -Used a stick to stay up straight Did non-adaptive test, : 1 0 2 2 quickly lost interest, so we stopped. Pong using B5, used big paddle, big ball, novice skill, slow ball to make it easier for him-some success. Played for 3 min. Moves tongue and mouth a lot. Switched to easy maze: B2 L/R, B5 U/D, worked pretty well, took him a few minutes. Sometimes gets very distracted. Switched to brain candy for a break 2 minutes, emphasized using channels to control speed of motion. Billiars: strong alpha and B3. 3rd time through got all except B10-B11 (very weak on B11). Tried Tetris 2-3 minutes L/R B5, B11 rotate, small success, but very hard. Explained objective is to fit pieces together, tried to have him move to the right, but it seems very difficult to keep them there and not move back. Cellar game: 2-3 minutes, quite difficult for him.

10/3 B.billiards 2 minutes, very fluctuating Pong-difficult, put on lowest settings. B5-6, not good, B7 a little better. Shifted and amplified +1 with better results. Switched to easy maze-slow at first then rapid progress. X2. U/D B7, L/R B2. Labyrinth: B5 L/R quickly lost interest. Brain candy-2 minutes, seemed to enjoy. Tetris-B5 L/R B8 click, hard, lack of ability to move pieces horizontally and keep them there as they fall. Switched again to b.billiards and to maze briefly before he lost interest.

10/11 B. Billiards, good at hitting balls, but lots of flux (overshooting-poor control). Quickly lost interesting-switch to pong B7, amp down from 6 to 5. Played for a short time but lost interest and indicated that he wanted to stop.

10/24 Very high B11 rating (greater than maximum allowed), so used previous value. Pong-previous BF settings. Lowest difficulty and speed, big ball and paddle. Hit some of the balls, performed better with encouragement. Skateboard: B8:L, B5:F, B2:R. Enjoyed, but was getting tired and wanted to stop, but appeared to have easy movement forward. 10 min. total. 11/7 Pong: Low settings, big ball and paddle, U/D:B7, moderate success, but wanted to switch after one game. Skateboard: previous settings. Prefer right turn. Sometimes whispering to self. Occasionally looks at me, perhaps awaiting a reaction or encouragement. He sometimes moved his hands and arms around, head often in a downwards position, and/or towards the side. 5 min. B.Candy: 2 min. At the end of the session he thanked me and smiled effervescently. 11/15 Pong: x1. Low settings, big paddle, medium ball, U/D:B7. Small amount of success. Skateboard: Previous settings. Nothing at first, then motionless turning following by some forward motion. a few minutes B.Candy:Very briefly, wanted to stop ¡ 2 minutes.

**Subject J**

9/26/07 Adaptive test: 1 2 3 0 3 3 3 3 3 0 (answered one fit correctly but others, incorrectly) Auto-adjust-B11: 49, more relaxed than others. In wheelchair but doesn't move body around a lot. Appears focused but always wanted to change games when I asked-but maybe they're just boring. Played billiards for 2-3 minutes. Sometimes clenches body when concentrating. Pong: B4-B6 not great, B7 worse, back to B5 with some success, increased paddle and ball size (as well as decreasing speed to minimum, which I did for all children.) After a few minutes moved on to easy maze, mapped U/D B-11, and L/R with B5. After some encouragement and direction ("move your eyebrows to go up", "use brain to move to right") had quick success. After completing once ( 3 minute) moved on to tetris. B8 L/R, B11 rotate, pretty difficult to keep pieces to right. Not very much success. After 1.5 full games asked if he wanted to be done, and he said yes. Tetris game has a tendency to not respond to changed settings.

10/1 Non-adaptive: 1 1 2 2 3 3 0 4 0 0. I described a shape fitting as "not in the black part." Auto adjust: low B11, (35-40) relaxed B billiards: good 1-3, high alpha, good control of Beta. Pong: B7, lowest settings, ok, back to B5, better, moves head up when trying to move up, smiles easily, which sometimes affects controls. Verbal action: "come on.." to self. Used Amplify+1 with B5 for some additional success. Easy maze: U/D B11, L/R B4, very playful and seemed to have pretty good success, found great amusement in exploiting a boundary in the maze and trying to move it through this gap towards the sun (shortcut). I emphasized relaxing his face to move the cursor down, which worked, except that he was joyful and laughing, which used muscles in his face! Played for about 4 minutes. B. Candy as a good break for 2 minutes: Enjoyed manipulating speed, very involved. Cellar game-"too hard" so we stopped. Tried tetris: B5 L/R, B11 rotate, told him to use brain to move right, and was able to do it for a few pieces, but the overall low success with tetris for all children so far makes me question if it is really just unresponsive for some reason. Switched back to pong: decreasing speed to 3 rather than to 2 with moderate success using B5, keeping paddle big, ball size normal, novice skill, switched to B6-good, switched to B4-best, better control, easier to move up. Even managed to score a point against computer! Played two full games and then told us "One more game," and we ended. 25-30 minutes for session, long attention span.

10/10 Played very long time: 55 minutes Pong: B4: U/D at novice (previous) settings, good results. Still has a habit of clenching body and tensing up when moving cursor up or down, possibly thinking there is a connection. Improved control from last time. Verbal cueing for movement of cursor: "Come on.." Played twice then expressed interest in cellar game: B4 U/D, B7 L/R. Moved cursor very discretely: jumpy. Picked up one bottle then dropped it. 2 min. later picked up another. Concentrating very hard, about 5 minutes total. Billiards: strong alpha and B1-3. Tetris: B5 L/R, B8 rotate-hard. B candy-3 minutes, likes a lot. Bars fluctuate a lot. Back to pong-played 4 full games (8 balls/game). Novice settings except for normal ball speed B4 U/D. Hunches forward when concentrating. Amp, shift +1 seemed to help. Cellar game: 10 minutes. Long period of inactivity: B4 U/D good, B3 L/R not great, but less clunky movement than before. Me: "Use your eyes to make it go to right." Him: "I'm trying." Difficult. L/R: Sudden progress and then none.

10/18 Total time: 1 hour. Expressed interest in "The tennis game." Played pong using B4: Novice difficulty, normal (3) ball speed, medium paddle, medium ball. Good concentration and control. Two games over four minutes Easy maze: U/D B4, L/R B3. Reminded him that L/R corresponds to eye movement. He took his time moving the cursor to the shortcut (the image of the sun), and then rejoiced, before guiding cursor to final goal point. Wanted to play the game "in the tunnel." (Brain Candy). Served as a nice break, he was all smiles and very focused, 3 min. total. Introduced him to Cosmic Skateboard: B11 forward, B4 turn right, B3 turn left. Really enjoyed playing it, and was very deliberate in the movement of the skateboard. Sometimes gripped handlebar of wheelchair for a few seconds-related to perceived control of game? J: "When I yawn it works." Briefly adopted a "thinker" pose while concentrating and occasionally purposefully tried yawning to cause movement in the game. Expressed interest in tetris, but once again, it seems very unresponsive. Returned to pong, moving the paddle from a low to high position fast enough is a reoccurring difficulty-possibly became overexcited. Seemed very amused and was laughing after hitting the ball. After the 3rd set of games, I increased the paddle size to "big." Also increased amplification and shift by one, seemed to help a bit. He thought there was a connection between moving his eyebrows and the paddle moving, so I reiterated that, at the current setting (B4), he had to use his brain to move the paddle. I asked him, "Is it hard to move paddle up?" J: "A little hard." After increased the amp. +1 again and then asked him if it felt easier to move it now and he said yes. Cellar game: I reminded J of the current controls (use eyes to move L/R, brain to move up, eyebrows to grab a bottle). Lots of false clicking (i.e. use of B11 when there is no bottle to pick up). Very discrete movement-sometimes no movement of cursor, and then very rapid movement and grabbing of bottles. Somehow kept turning "slow speed" option on and off. Sometimes almost had a bottle but wasn't quite able to align the cursor in the right position and activate B11 to pick it up. J: "I get it-you have to be on top [of the bottle]."-An insightful realization on the limits of the software!

10/25 (Note: Had just seen speech therapist and seemed tired, though perhaps this meeting was not the cause). Pong: x3. B4-shift+1, Lowest settings and speed. Some difficulty, movement was sometimes choppy, made signal +.05 smooth but didn't seem helpful. I asked, "Is it easy or hard to move up?" and adjusted accordingly. Maze: U/D: B4, L/R:B3. No movement for several minutes, until he yawned, which caused him to smile. Slow and intermittent progress. 9 min. Brain Candy 2 minutes. Skateboard: L:B4, F:B7, R:B2. Hesitating at first and then gradually more skillful movement. 30 min.

11/1 Told me about a Playstation game at his home-NBA Live. I asked if he could play it with BF, if he would like that, and he said he would. Pandora's Box: L/R:B3, U/D:B4, click:B11. Focus point: Cursor kept towards NE corner of screen. Too difficult to control cursor. He asked, "Can I play skater game?" Skateboard: L:B8, U:B5, R:B2. Good control and likes to play very much. Adept at turning both directions, like doing jumps and experimenting with ramps. 20-25 min. Pong: B4:U/D, novice difficulty, medium ball, paddle, speed. Switched to B8. Me: "Is it easier or harder than before?" J:"Easier." Shift+1, ballspeed-medium (his preference). Billiards: Strong: B1-2, B7-11, concentrated. B.Candy-3 min. Labyrinth-U/D:B8, B5:L/R. Not much success, cursor stuck to right/up direction (same problem as in Pandora's box).

11/8 Pong: Previous settings (B8). Got a point on the first try. x1. Skateboard: Previous settings. Only turning right, and did not move forward at first. Appeared to be concentrating for several minutes before forward movement occurred. Seemed to be trying to jump up the ramps. Part way in, he turned around and asked what time it was, as he didn't want to stop. P.Box: Focus pt. Movement only towards upper right hand corner of screen-lack of cursor control. B.Candy: 3 min. Shifted L/R and U/D signals -5 and tried Focus pt. again at hopes of overcoming the stray cursor movement problem, but was not successful-there was only a brief moment when the cursor was in the SW corner of the screen. Cellar game: Same problem with cursor. Shifted signals back to default settings, cursor went between extreme SW and NE corners of screen. J remarked, "Every time I try to get it [a bottle], it doesn't get it." I switched U/D from B8 to B5. When I asked him if it was easier now, he said, "a little."

11/21 45 minutes total Pong x5: U/D:B5, low difficulty, medium speed, paddle, ball. Had some good saves but not always fast enough. Briefly manipulated control for wheelchair. On the 4th game he got a point. Skateboard: Previous settings. "I did three jumps over that thing [the middle barrier]." Easy movement. 20 min. Expressed an interest in tetris. Rotate:B11, L/R:B3. Tendency for pieces to naturally move towards right, but was able to move them to the left enough to make it to level 3. Rotation without difficulty and decent fitting abilities even though he did not manage to delete any lines due to lack of movement all the way to the left side of the screen.

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# Bibliography

C. Anderson. EEG pattern analysis. Website, viewed 2007., 2007. URL `http://www.cs.colostate.edu/eeg/`.

K. Choi and M. Sasaki. *Mobile Robot Control by Neural Networks EOG Gesture Recognition*. Gifu University, Gifu, Japan, 2001.

R. Copeland. *How Children Learn Mathematics: Teaching Implications of Piaget's Research*. Macmillan, 1970.

Electronic Arts. Counting on Frank. Computer game, 1994.

K. Eliseo. Investigating the use of Brainfingers in children with cerebral palsy for spatial-motor education, May 2007. Senior thesis, Department of Mathematics, Harvey Mudd College.

IBVA. IBVA Technologies website. Website, 2007. URL `http://www.ibva.com`. Viewed 2007.

D. Marler. Cyberlink: Computer access for persons identified with multiple disabilities. Master's thesis, CSU Northridge, Northridge, CA, 2004.

Microsoft. Pandora's Box. Computer game, 1999.

MumboJumbo. Luxor. Computer game, 2005.

NINDS. The National Institute of Neurological Disorders and Stroke. Website, 2007. URL `http://www.ninds.nih.gov/`. Viewed 2007.

F. Redstone. A training program for the use of the Cyberlink control system for young children with cerebral palsy. *Technology and Disability*, 18:107–115, 2006.

M. Zabalia. The role of action in the representation of moving shapes in children with cerebral palsy. *Current Psychology Letters—Behaviour, Brain and Cognition*, 2:71–78, 2000.