

**Creating an Appropriate Experimental Design to Study the Learning Process in  
A Computer Maze Task**

by

Sarah Howie

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Honors Bachelor of Science in Exercise Science with Distinction

Spring 2015

© 2015 Howie  
All Rights Reserved

**Creating an Appropriate Experimental Design to Study the Learning Process in  
A Computer Maze Task**

by

Sarah Howie

Approved: \_\_\_\_\_  
Dr. Nancy Getchell, Ph.D.  
Professor in charge of thesis on behalf of the Advisory Committee

Approved: \_\_\_\_\_  
Dr. Christopher Knight, Ph.D.  
Committee member from the Department of Department Name

Approved: \_\_\_\_\_  
Dr. Elizabeth M. Orsega-Smith, Ph.D.  
Committee member from the Board of Senior Thesis Readers

Approved: \_\_\_\_\_  
Michael Arnold, Ph.D.  
Director, University Honors Program

## **ACKNOWLEDGMENTS**

I would first like to thank Dr. Patricia Shewokis and Dr. Hasan Ayaz for their assistance with MazeSuite and fNIRS. I would additionally like to thank my fellow classmates Nicole Gomes, Autumn Cohen, and Tim Kelly, who also worked in the Developmental Motor Control Lab. I would like to thank my second and third readers Dr. Christopher Knight and Dr. Orsega-Smith. I would also like to thank Dr. Lynn Liang for her constant support and guidance throughout the senior thesis process. Lastly, I would like to thank my thesis director and advisor, Dr. Nancy Getchell. I would not have been able to complete my thesis without her guidance and her commitment to helping me succeed.

## TABLE OF CONTENTS

LIST OF FIGURES .....	vi
ABSTRACT .....	vii
1 Introduction .....	1
2 Methodology.....	6
Learning fNIRS .....	6
<u>Instrumentation</u> .....	6
<u>Learning fNIRS</u> .....	6
Developing Mazes .....	8
<u>Protocol</u> .....	9
Testing Participants .....	9
<u>Participants</u> .....	10
<u>Task</u> .....	10
<u>Protocol</u> .....	10
<u>Data Analysis</u> .....	11
3 Results .....	12
Oxygenated Hemoglobin vs. Trials .....	12
Path Length vs. Trials.....	14
Oxygenated Hemoglobin vs. Path Length.....	16
4 Discussion.....	19
Analysis of Data .....	19
Future Directions .....	21
REFERENCES .....	22
APPENDIX	

A	Learning fNIRS .....	24
	Data Collection.....	24
	Data Processing .....	25
B	Developing Mazes .....	25
	Designing Mazes .....	25
	Creating MazeList .....	27
C	Testing Mazes.....	28
	Prior to Participant Entering Room .....	29
	While Participant is in the Room.....	29
	When Participant leaves the Room.....	30

## LIST OF FIGURES

Figure 1	Final maze that was tested on participants. ....	9
Figure 2	Average change in oxygenated hemoglobin versus trial number for participant one. ....	13
Figure 3	Average change in oxygenated hemoglobin versus trial number for participant two. ....	13
Figure 4	Average change in oxygenated hemoglobin versus trial number for participant three. ....	14
Figure 5	Path length versus trial number for participant one. ....	15
Figure 6	Path length versus trial number for participant two. ....	15
Figure 7	Path length versus trial number for participant three. ....	16
Figure 8	Average change in oxygenated hemoglobin versus path length for participant one. ....	17
Figure 9	Average change in oxygenated hemoglobin versus path length for participant two. ....	18
Figure 10	Average change in oxygenated hemoglobin versus path length for participant three. ....	18

## **ABSTRACT**

Motor learning is a set of processes associated with practice that leads to improvements in performance or execution of a task. The prefrontal cortex plays an important role in learning as it is associated with planning and assisting motor tasks. The purpose of this study is to create a perfect experimental paradigm using MazeSuite and Functional Near Infrared Spectroscopy (fNIRS) in order to evaluate the learning process. Three adult participants completed an online virtual maze in blocks of 10 trials until the maze was mastered. fNIRS recorded the participant's oxygenated hemoglobin in the prefrontal cortex and MazeSuite recorded the participant's path lengths. Data analysis looked at the relationship between oxygenated hemoglobin and trial number, path length and trial number, and oxygenated hemoglobin and path length. Overall, as trial number increased, oxygenated hemoglobin decreased. The same relationship was seen when comparing path length with trial number. Lastly, as path length decreased, oxygenated hemoglobin also decreased. Future researchers can go into more detail with the data collection process, study the Contextual Interference Effect, and study kids with developmental disabilities such as Dyslexia.

## **Chapter 1**

### **Introduction**

Motor learning is a set of processes associated with practice or experience leading to relatively permanent gains in the capability for skilled performance<sup>12</sup>. According to Fitts, there are 3 stages of learning<sup>13</sup>. The first stage is the cognitive stage, where the learner's first issue is cognitive and largely verbal<sup>13</sup>. In this stage, the main concerns are identifying goals, evaluating performance, and figuring out what to do, when to do it, and how to do it<sup>13</sup>. The main purpose of this stage is to figure out what you are looking at in the environment and coming up with a correct movement attempt<sup>13</sup>. It is proven that gains in proficiency during this stage are very rapid and large<sup>13</sup>. The second stage of motor learning is the fixation stage<sup>13</sup>. During this stage, the learner is now focused on organizing the most effective movements to produce the pattern<sup>13</sup>. This stage is characterized by performance improving steadily, inconsistency at times due to attempts at new solutions, and smoother and less rushed movements<sup>13</sup>. The third stage of learning is known as the autonomous stage where the person attains expert performance<sup>13</sup>. This means that less attention is necessary to complete the task, allowing for higher order cognitive functions such as strategizing<sup>13</sup>. The most common way to evaluate the learning and the progression through these three stages is by using a performance curve<sup>13</sup>.

Performance curves are plots of individual or average performance against practice trials<sup>12</sup> (See Figure 1). These curves can either slope upwards or downwards, depending on whether the measured data increases or decreases with practice and

experience<sup>12</sup>. A nearly universal principle of practice states that early on in learning, improvements are large and rapid, although later on in learning, improvements are slower and more gradual<sup>12</sup>. There are various practice schedules that researchers look at to generate performance curves, one of which is known as the Contextual Interference Effect.

The Contextual Interference (CI) effect offers insight into two different practice schedules, random and blocked<sup>9</sup>. The CI effect refers to the levels of interference found in a practice situation, blocked or random, and the extent to which these varying degrees of interference have on learning<sup>9</sup>. Random practice represents a learning strategy where the tasks to be learned are in an unpredictable order and therefore occur with high levels of interference<sup>2</sup>. In blocked practice however, the tasks are presented in a predictable order and therefore occur with low levels of interference<sup>2</sup>. There are three phases that are used to assess the CI Effect<sup>2</sup>. The acquisition phase constitutes the first time the individual performs the given tasks, either in a blocked or random order<sup>2</sup>. To best assess the effectiveness of blocked and random practice on learning, the CI effect has two additional phases<sup>2</sup>. During the retention phase, each task performed during acquisition is completed using a random practice schedule in order to assess an individual's memory of the task<sup>2</sup>. During the transfer phases, new but similar tasks are created in order to assess an individual's generalizability of the task<sup>2</sup>. It has been proven that during a random practice schedule, individuals perform worse during the acquisition stage although better on retention and transfer stages<sup>15</sup>. The results are reversed during a blocked practice schedule, demonstrating that individuals learn and retain information better using a random practice schedule<sup>15</sup>.

While the Contextual Interference effect has been demonstrated in previous research using typically developing individuals, there is no research done thus far regarding the CI effect in individuals with learning disabilities such as Dyslexia<sup>2,15</sup>. Dyslexia is a persistent, chronic condition that affects 5-17% of school aged children and 40% of the entire population<sup>14</sup>. It is a learning disability that causes an individual to have difficulty with the speed and accuracy of word decoding, reading comprehension, and spelling<sup>14</sup>. Research shows that while Dyslexia is complex and difficult to define, there is a clear neurological basis<sup>4</sup>. Several researchers have found that in terms of the dyslexic brain, there are deficits in the frontal lobe, specifically in the inferior frontal gyrus and the primary motor cortex<sup>4,11</sup>.

A portion of the frontal lobe, the prefrontal cortex (PFC), plays an important role in controlling our thoughts and actions in order to meet our internal goals<sup>2</sup>. It is associated with goal representation, planning, and performance monitoring<sup>10,16</sup>. Research shows that the PFC is key to motor learning and assisting in planning and completing motor tasks<sup>16</sup>. Previous research suggests that during a continuation-tapping task, children with dyslexia were more variable in their results, suggesting an underlying issue with motor planning<sup>6,7</sup>. What is unknown however is the source of this variability<sup>7</sup>.

In order to discover what is occurring in the brains of individuals with dyslexia that results in a greater variability during motor tasks than typically developing individuals, we need to develop the perfect experimental paradigm. I intend to do so by evaluating the CI effect in individuals with dyslexia compared to typically developing individuals. The participants will complete a task using the software Maze

Suite and I will analyze their PFC activity using a device called Functional Near Infrared Spectroscopy (fNIRS).

fNIRS is a safe, noninvasive, portable, and effective brain imaging technique<sup>2,5</sup>. This technology has been used to measure brain activity while participants undergo motor activities, visual activation, auditory stimulation, and the performance of cognitive tasks<sup>5</sup>. While several other neuroimaging modalities exist, including EEG, fMRI, and PET, fNIRS has several advantageous characteristics, especially in comparison to fMRI<sup>5</sup>. fMRI requires that participants lie within the confines of a magnet bore and it is also extremely sensitive to movement artifact<sup>5</sup>. fNIRS on the other hand enables participants to sit upright and work on a computer, which is what is required during MazeSuite, and is less susceptible to movement artifact<sup>5</sup>. Altogether, fNIRS is especially useful when testing populations not able to remain sufficiently still, such as children, and studies that require repeated, low cost neuroimaging<sup>5</sup>. Functional Near Infrared Spectroscopy measures relative changes in the concentration of deoxygenated hemoglobin, which results in an indirect measure of neural activity<sup>5</sup>. fNIRS also measures relative changes in oxygenated hemoglobin, and therefore using a differential equation, total blood flow is able to be calculated<sup>5</sup>. In recent history, brain activation research using fNIRS has found that there have been localized increases in oxygenated hemoglobin in response to functional challenge<sup>8,17</sup>. Altogether, fNIRS has been proven to be effective in assessing hemodynamic changes that occur during brain activation.

MazeSuite is a complete toolset that enables researchers to create and test 3-D virtual mazes in order to perform spatial and navigational experiments<sup>1,2</sup>. MazeSuite

can synchronize with external devices such as fNIRS which in turn leads to physiological and neuroimaging measures<sup>1,2</sup>.

In conclusion, fNIRS can be used in conjunction with MazeSuite in order to analyze the CI effect and PFC as well as generate performance curves.

## **Chapter 2**

### **Methodology**

#### **Learning fNIRS**

##### Instrumentation

The Portable fNIRS System is comprised of three primary components: 1) an LED-based sensor that covers the participant's forehead, 2) a control module with an integrated power supply for sensor control and data acquisition, and 3) a desktop computer for the data analysis software (See Figure 2).

The sensor pad consists of four LED light sources with 10 detectors which cover the forehead using 16 voxels. There is a source-detector separation of 2.5 cm, allowing for approximately 1.25 cm of penetration depth. The LED light sources emit infrared light at wavelengths of 730 nm and 850 nm, and this light is absorbed mainly by deoxygenated and oxygenated hemoglobin. The flexible sensor design enables the pad to adapt to the curvature of the participant's forehead. The investigator will place the sensor pad onto the participant's forehead, just above the eyebrows. The center of the sensor pad will be aligned with the vertical axis of the participant's nose. Cognitive Optical Brain Imaging (COBI) Studio software will collect raw fNIRS signals while the device is running.

##### Learning fNIRS

Beginning in the Spring of 2014, I began learning how to use the fNIRS device. People in the Developmental Motor Control Lab at the University of Delaware were already in the process of running their own experiments using this device. Therefore, I was taught the steps of running the fNIRS device and practiced using it on several participants. Throughout this time, I learned several important details about running fNIRS that enabled me to ensure the best quality results during my experiment. Firstly, I learned how to manipulate the device settings. Our lab agreed that prior to running an experiment, we need to ensure that the baseline at each of the 16 sensors was between 400-4000 wavelengths. If in fact I were to turn on the fNIRS device and notice that the wavelengths were higher or lower than these values in any given sensor, I now know how to change the gain of the device in order to adjust the wavelengths to be in this range. Throughout this time, I also learned how to correctly apply the sensor pad. We found that excess light was interfering with our results, and therefore we now apply a purple headband over the sensor pad to keep this light out. In addition, we turn off the lights in order to minimize interference. Although fNIRS is relatively successful in accommodating movement, we have our participants sit in a stationary chair to avoid excessive motion. One issue that we encountered during this time involved manual versus automatic event markers. Usually, the fNIRS device is able to sync with MazeSuite and automatically place event markers when an experiment starts, ends, and in between trials. We experienced difficulties however due to the fact that the automatic event markers were not working. We ordered a new cable to sync the device with MazeSuite although found that this did not work either. It was at this point that we decided to manually place event markers when necessary. While this is not an ideal situation, it worked for the purpose of our experiment. Prior

to testing any of my actual participants, I completed a proficiency exam to demonstrate that I mastered the fNIRS device.

### **Developing Mazes**

Upon returning to University of Delaware in the Fall of 2015, I began learning how to operate the software MazeSuite. During this time I learned about the three applications: MazeMaker, MazeWalker, and MazeAnalyzer. When we received the MazeSuite software from Drexel University, we also received mazes that they had created along with an orientation maze and a maze list. Throughout our evaluation of the mazes they sent us, we found several issues in using these mazes for our own experiments. For one, the mazes were too easy and we felt that in order to see an actual learning curve, we would need to create harder mazes. We also found that there were too many trials. Drexel sent us MazeLists in blocks of 50 trials and upon testing participants, we felt that asking our participants to do 50 trials in a row was excessive and unattainable. At this point in the process, we discovered that you could generate your own standardized mazes using MazeMaker and we therefore decided to give that a try. We created several mazes of varying dimensions, and found the ideal dimension to be 11x10. While creating mazes, you are able to input objects such as couches or chairs in order to provide landmarks for your participants to judge their location off of. We put in a couple of objects although found that this made the mazes too easy. We decided that we would only put a door at the start of the maze and an exit sign at the end of the maze. During the initial testing stages, we found that several of our participants were experiencing motion sickness, and we therefore expanded the width of the walls. We also put in a two minute time limit as opposed to unlimited time in

order to decrease the occurrence of motion sickness and frustration. In addition, we changed the trial number from 50 to 10-20 or until the participant mastered the maze. Once all of these needs were addressed, I created a final maze and tested it on 3 participants (See Figure 3).

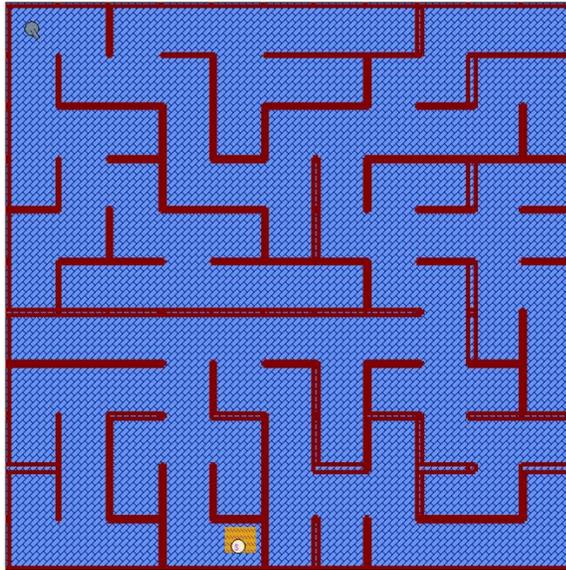


Figure 1 Final maze that was tested on participants.

### Protocol

Maze Suite consists of three applications: MazeMaker which is an editing program to construct a maze environment, MazeWalker which is a visualization/rendering module, and MazeAnalyzer which is an analysis and path visualization tool.

### **Testing Participants**

### Participants

The participants consist of two males and one female over the age of 18. They were recruited from the University of Delaware community via word of mouth.

### Task

One maze task will be used, developed from the program MazeSuite. MazeSuite is a complete set of tools that enables researchers to perform spatial and navigational behavioral experiments within interactive, easy to create, 3-D environments.

### Protocol

Upon entering the Developmental Motor Control Lab, the participant will be handed an informed consent form for them to read and fill out. After the participant signs the form, they will be given an alcohol pad to clean their forehead while the experimenter cleans the fNIRS device. The experimenter will place the fNIRS sensor pad on the participant's head and place the purple headband over the device. The experimenter will turn off the light and start the fNIRS device, ensuring that the wavelengths are between 400-4000 nm. When all device settings are correct, the experiment will begin. The experiment will consist of two orientation mazes in order to provide the participant with an opportunity to test out the software prior to attempting the actual maze. During this time, the participant is free to ask the experimenter any questions they might have about navigating the maze. Upon completion of the two orientation mazes, the experimenter asks that the participant please refrain from speaking since the actual experiment is about to begin. The participant will then complete 10 trials of the actual maze. Regardless of whether or not the participant gets to the exit sign, the

maze will shut out and restart after two minutes. Following the 10 trials, the experimenter will determine whether or not the participant needs to complete 10 more trials based on whether or not they have mastered the maze. The experiment will continue in blocks of 10 until the participant fully masters the maze. When this occurs, the experimenter will turn off the fNIRS device and remove the sensor pad from the participant's head. At this point in time, the participant is free to leave.

### Data Analysis

The experimenter will analyze the data using COBI software. The experimenter will analyze the results looking at path length and oxygenated hemoglobin.

## **Chapter 3**

### **Results**

#### **Oxygenated Hemoglobin vs. Trials**

Figures 2-4 examine the relationship between oxygenated hemoglobin and trial number for each of the three participants. Figure 2 shows that oxygenated hemoglobin increases rapidly at first for participant one and then shows a steady decline until leveling off at a value of ~1.5 micromoles. Figure 3 shows that oxygenated hemoglobin fluctuates between ~3-6 micromoles although shows an overall decreasing general trend. Figure 4 shows that oxygenated hemoglobin starts off relatively steady, increases rapidly, and then decreases rapidly until the last trial.

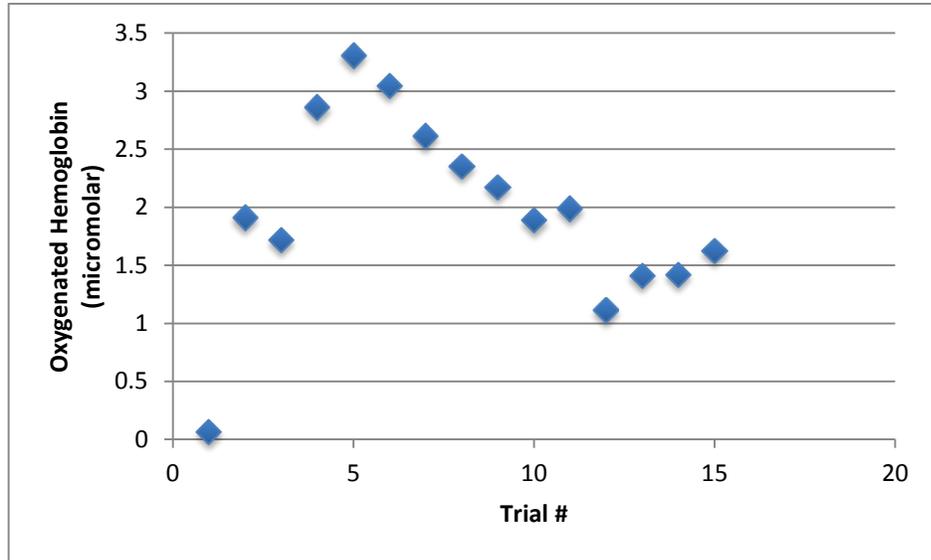


Figure 2 Average change in oxygenated hemoglobin versus trial number for participant one.

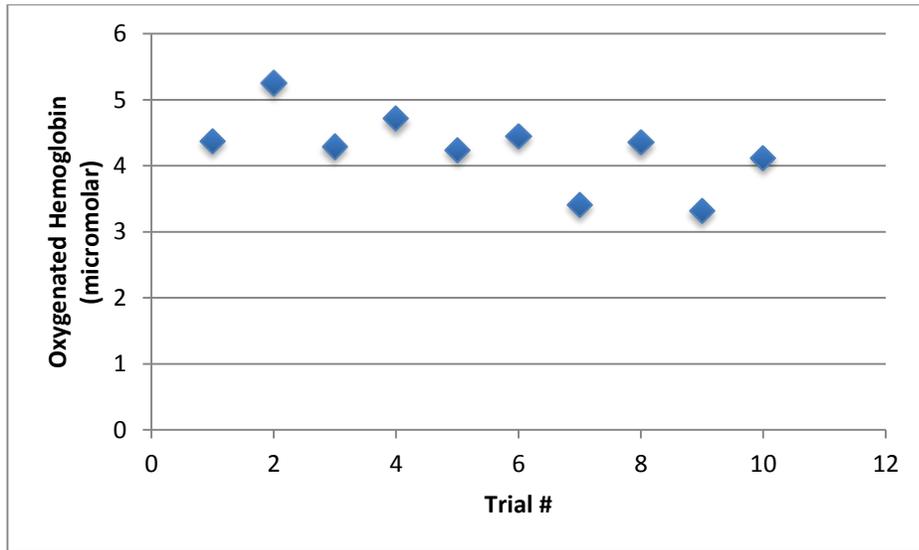


Figure 3 Average change in oxygenated hemoglobin versus trial number for participant two.

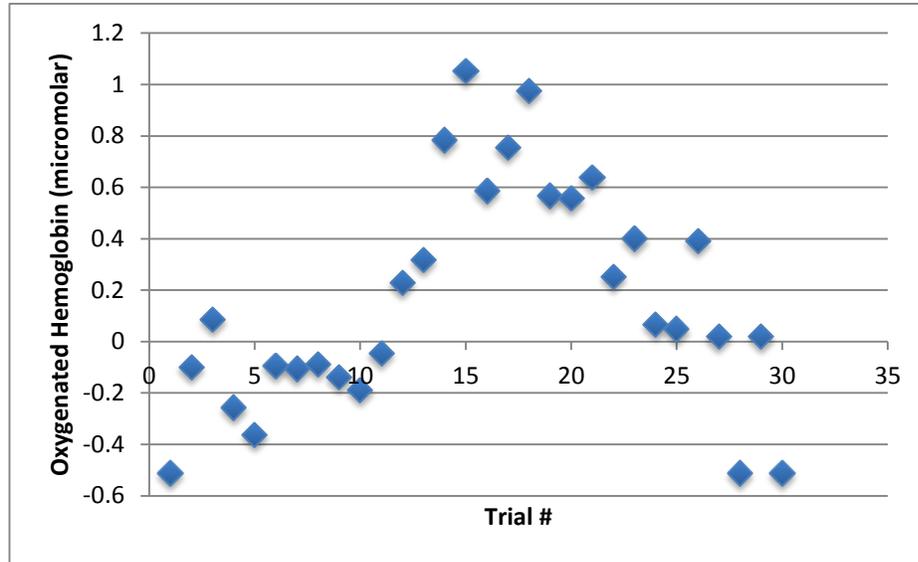


Figure 4 Average change in oxygenated hemoglobin versus trial number for participant three.

### Path Length vs. Trials

Figures 5-7 examine the relationship between path length and trial number for each of the three participants. Figure 5 shows that for participant one, the path lengths are long for the first 7 trials except for trial 3 when the participant randomly completed the maze. Following the 7<sup>th</sup> trial, the path lengths decrease and level off at an average length of ~70 maze units. Figure 6 shows that for participant two, the path lengths are long for the first 5 trials at a length greater than 200 maze units. Following the 5<sup>th</sup> trial, the path lengths decrease rapidly and level off at ~70 maze units. Figure 7 shows that for participant three, the path lengths fluctuate between ~80-180 maze units and do not follow any particular pattern. The last few trials on the graph however demonstrate an overall decrease in path length.

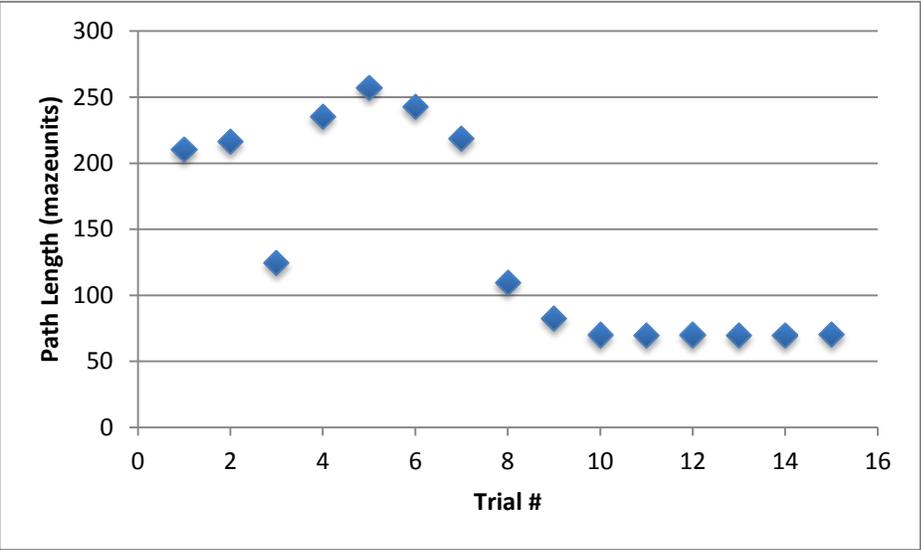


Figure 5 Path length versus trial number for participant one.

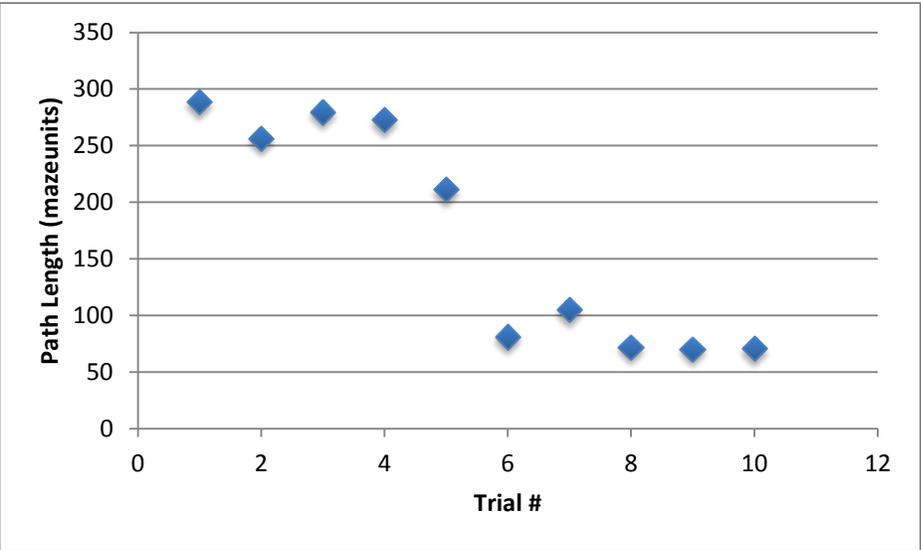


Figure 6 Path length versus trial number for participant two.

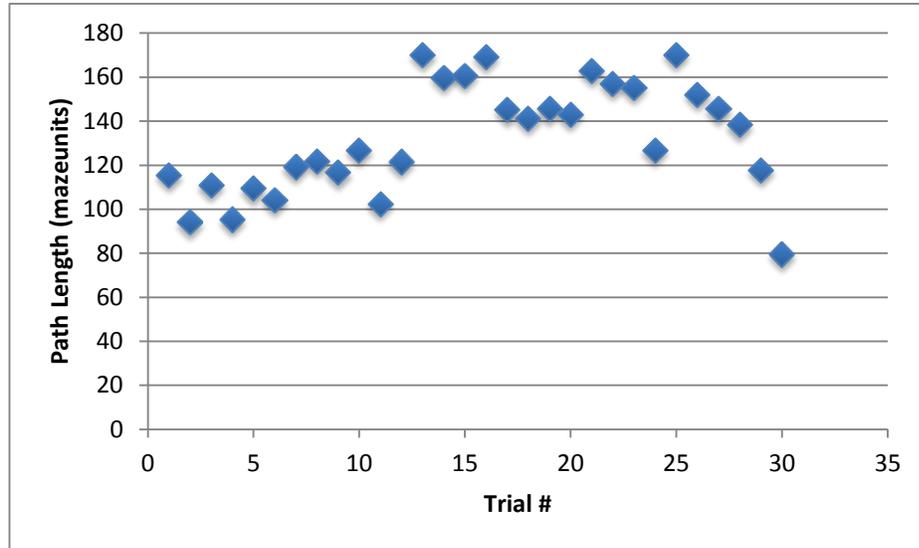


Figure 7 Path length versus trial number for participant three.

### Oxygenated Hemoglobin vs. Path Length

Figures 8-10 examine the relationship between oxygenated hemoglobin and path length for each of the three participants. Figure 8 shows that overall, for participant one, as path length decreases the average concentration of oxygenated hemoglobin also decreases. The  $r^2$  value of this graph is .68412 and the r-value of this graph is .827115. Figure 9 also shows that for participant two, as path length decreases the average concentration of oxygenated hemoglobin also decreases. The  $r^2$  value of this graph is .32401 and the r-value of this graph is .569219. Figure 10 is similar to figures 8 and 9 and shows that for participant three, as path length decreases the average concentration of oxygenated hemoglobin also decreases. The  $r^2$  value of this graph is .47477 and the r-value of this graph is .689036.

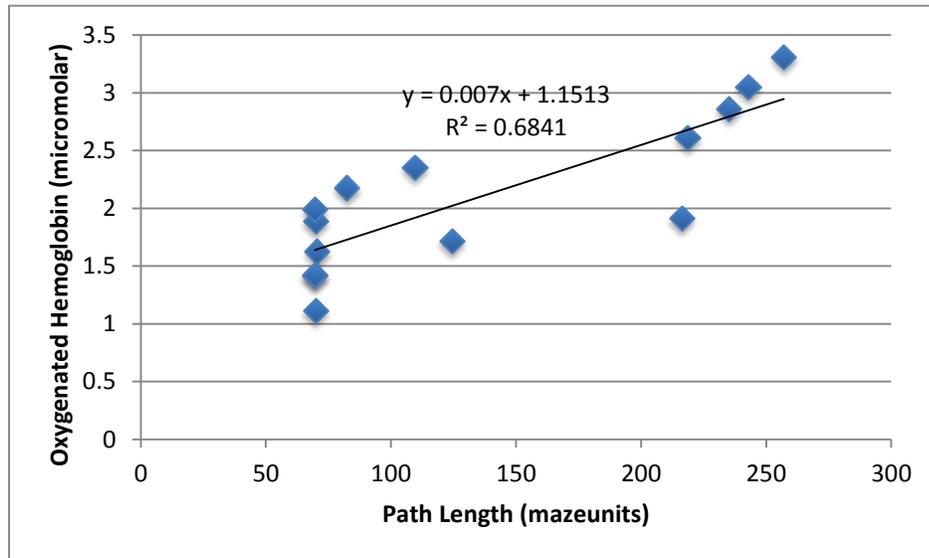


Figure 8 Average change in oxygenated hemoglobin versus path length for participant one.

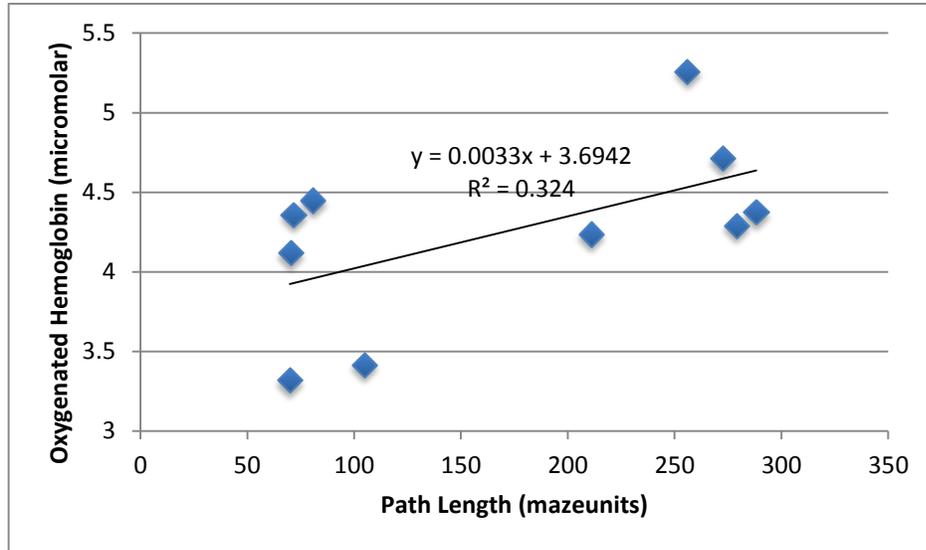


Figure 9 Average change in oxygenated hemoglobin versus path length for participant two.

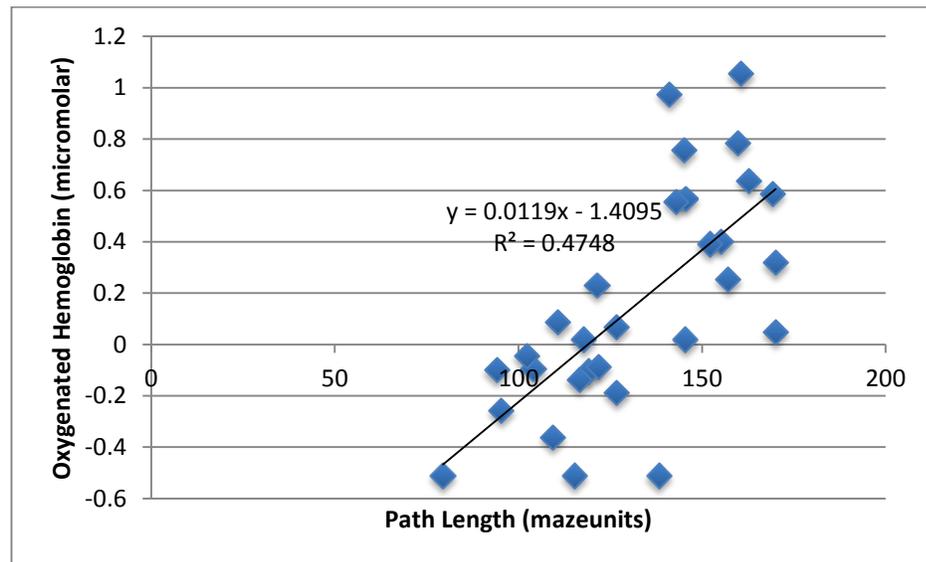


Figure 10 Average change in oxygenated hemoglobin versus path length for participant three.

## **Chapter 4**

### **Discussion**

#### Analysis of Data

For figures 2-4, my hypothesis was that as trial number increased, oxygenated hemoglobin would decrease. In figure 2, oxygenated hemoglobin increases at first during the first few trials, and then decreases until leveling off. The same trend is seen in figure 4. I believe that the reason oxygenated hemoglobin was lower at first was because participants were becoming accustomed to the MazeSuite function and were not experiencing stress at that point. It was clear through observation that participants were more relaxed during the first few trials and then became much more frustrated and focused on completing the maze. While the decrease in oxygenated hemoglobin is not as steep and rapid in figure 3, there is still an overall general decline in oxygenated hemoglobin. I believe that the reason the graph does not show such a quick decrease is due to the fact that this participant only completed 10 trials whereas the other two participants completed 15 and 30 trials.

For figures 5-7, my hypothesis was that as trial number increased, path length would remain high at first, have a rapid decline, and then level off upon mastering the maze. Figures 5 and 6 demonstrate this performance curve perfectly, however there are a few outlier points. In figure 5, the dot on the graph showing trial 3 shows a much shorter path length, although trial 4 shows a much longer one. This is because the participant randomly found the exit sign during trial 3, however they did not master the maze at this point. Figure 5 demonstrates that the participant mastered the maze

following trial 7, and figure 6 demonstrates that the participant mastered the maze following trial 5. Figure 7 does now show the exact performance curve that I was looking for. For almost all 30 trials, path length varies although it shows a general increase. The participant began to solve the maze during the last 5 trials, and the results demonstrate this seeing as the points on the graph do show a decrease in path length over these last few trials. If the participant completed 10 more trials, I believe that the graph would show the curve I was looking for, however due to time constraints, this was unable to occur.

For figures 8-10, my hypothesis was that as path length decreased, oxygenated hemoglobin would decrease. This is because upon mastering the maze, the participant does not have to exert as much effort and the movements become more automatic. As a result, path lengths would get shorter and oxygenated hemoglobin, or activity in the PFC, would decrease. Overall, all three figures support my hypothesis. The line of best fit for figure 8 produced an  $r^2$  value of .68412 and an R-value of .827115. This value indicates that there is a strong positive correlation between oxygenated hemoglobin and path length, supporting the hypothesis that as path length decreases, oxygenated hemoglobin decreases. The line of best fit for figure 9 produced an  $r^2$  value of .32401 and an R-value of .569219. This value indicates that there is a positive correlation between oxygenated hemoglobin and path length and also supports my hypothesis. The line of best fit for figure 10 produced an  $r^2$  value of .47477 and an R-value of .689036. This value indicates that there is a positive correlation between oxygenated hemoglobin and path length and also supports my hypothesis.

## Future Directions

Due to time constraints and several obstacles that I faced while completing our research, I did not get to everything that I planned. In terms of analysis, it would be beneficial to not only analyze all 16 sensors together, but to break them down into different regions. This would allow me to observe medial vs. lateral regions of the prefrontal cortex as well as left vs. right. My research also only looked at oxygenated hemoglobin. It would be beneficial to analyze the data looking at deoxygenated hemoglobin as well, and then do a comparison between them. A huge issue that I encountered was not being able to use the automatic event markers setting. In order to eliminate this source of error, it is necessary to figure out exactly how to use automatic event markers and stop doing them manually. Now that I have produced a baseline study on typically developing individuals, the next goal is to test the Contextual Interference effect and progress into researching children with developmental disabilities such as dyslexia.

## REFERENCES

1. Ayaz, H., Allen, S., Platek, S., & Onaral, B. (2008). MazeSuite 1.0: A complete set of tools to prepare, present, and analyze navigational and spatial cognitive neuroscience experiments. *Behavior Research Methods*, *40*(1), 353-359.
2. Ayaz, H., Shewokis, P., Curtin, A., Izzetoglu, M., & Onaral, B. (2011). Using MazeSuite and functional near infrared spectroscopy to study learning in spatial navigation. *Journal of Visualized Experiments*, (56)
3. Brady, F. (2004). Contextual interference: A meta-analytic study. *Perceptual and Motor Skills*, *99*(1), 116-126.
4. Brown, W., Eliez, S., Menon, V., Rumsey, M., White, C., & Reiss, A. (2001). Preliminary evidence of widespread morphological variations of the brain in dyslexia. *Neurology*, *56*(6), 781-783.
5. Bunce, S., Izzetoglu, M., Izzetoglu, K., Onaral, B., & Pourrezaei, K. (2006). Functional near- infrared spectroscopy: An emerging neuroimaging modality. *IEEE Engineering in Medicine and Biology Medicine*, , 54-62.
6. Diamond, A. (2000). Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Development*, *71*(1), 44-56.
7. Geuze, R., & Kalverboer, A. Tapping a rhythm: A problem of timing for children who are clumsy and dyslexic. *Adapted Physical Activity Quarterly*, *11*(2), 203-213.
8. Lloyd-Fox, S., Blasi, A., & Elwell, C. (2010). Illuminating the developing brain: The past, present, and future of functional near infrared spectroscopy. *Neuroscience and Biobehavioral Reviews*, *34*(3), 269-284.
9. Magill, R., & Hall, K. (1990). A review of the contextual interference effect in motor skill acquisition. *Human Movement Science*, , 241-289.
10. Miller, E., & Cohen, J. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*, 167-202.

11. Richlan, F., Kronbichler, M., & Wimmer, H. (2009). Functional abnormalities in the dyslexic brain: A quantitative meta-analysis of neuroimaging studies. *Europe PMC Funders Group*, 30(10), 3299-3308.
12. Schmidt, R., & Lee, T. (2014). Motor learning and performance: From principles to application *Human Kinetics*.
13. Shaywitz, S., & Shaywitz, B. (2001). The neurobiology of reading and dyslexia. *National Center for the Study of Adult Learning and Literacy*, 5(A)
14. Shea, J., & Morgan, R. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory*, 5(2), 179-187.
15. Taylor, J., & Ivry, R. (2014). Cerebellar and prefrontal cortex contributions to adaptation, strategies, and reinforcement learning. *Progress in Brain Research*, , 217-253.
16. Villringer, A., Planck, J., Hock, C., Schleinkofer, L., & Dirnagl, U. (1993). Near infrared spectroscopy (NIRS): A new tool to study hemodynamic changes during activation of brain function in human adults. *Neuroscience Letters*, 154(1-2), 101-104.

## **Appendix A**

### **Learning fNIRS**

#### Data Collection

1. System Set Up
  - a. Turn on the computer that has the fNIRS and COBI software
  - b. Ensure that the power cable of fNIRS is plugged into the surge protector
  - c. Ensure that the sensor pad is connected to the fNIRS correctly, wire 1 to port 1, and wire 2 to port 2
  - d. Ensure that fNIRS is connected to the computer with a USB cable
  - e. Ensure that the wires of the sensor pad are untangled and easy to apply
2. Apply the Sensor Pad
  - a. Do not strain the wires on the sides of the sensor pad. Use the strips.
  - b. Using an alcohol swab, clean the fNIRS sensor pad and the participants forehead
  - c. Ensure that the hair of the participant is not in the way
  - d. Ensure that the orientation of the sensor pad is correct: cable 1 is on the left, the words are not upside down.
  - e. Ensure that the fNIRS sensor pad is matched to the midpoint between the eyebrows and the nose
  - f. Ensure that the lower edge of the sensor pad is right above the eyebrows
  - g. Tighten the strips
  - h. Clip the wires using a binder clip
  - i. Have the participant move their head to ensure the sensor pad is stable and not moving
  - j. Place the purple winter head band around the sensor pad to ensure optimal tightness
3. Run COBI and collect data
  - a. Open COBI software
  - b. Start new experiment
  - c. Turn off the lights in the room before starting the device
  - d. Start current device
  - e. Check the light intensity: acceptable range is 400 mV to 4000 mV
    - i. If the light intensity is too high, the sensor pad is not in contact with the forehead

- ii. If the light intensity is too low, the hair might be in the way
- f. Change the LED current if necessary: currents should be between 5 mA to 20 mA
- g. Change the gain if necessary: initial gain should be 1,5,10,15, or 20
- h. Wait for the light intensity to be stable before collecting baseline
- i. Click on baseline (the data is collected automatically after the baseline is collected)
- j. Add markers accordingly
- k. Stop the device when the experiment is complete
- l. Save files

### Data Processing

1. Obtain data from fNIRSoft
  - a. Click on Lightgraph
  - b. Load data by clicking on load file
  - c. Load marker file by clicking yes when the prompt box opens
  - d. Refine data using default filter
    - i. Click raw data, select the next button, then press apply
  - e. Calculate oxygenation data (by clicking Oxy) using refined data (select refined data)
    - i. Select calculate oxygenation
  - f. Define blocks correctly
    - i. Select start of a block and end of a block, hit run, then hit save
    - ii. Repeat this procedure for all blocks
  - g. Save all blocks
    - i. Select save, click all blocks, click raw or refined data depending on whether the data was refined again, then select save
  - h. Export data from Dataspace to the designated folder
    - i. Select all variables → separate files → hit next → select output folder
  - i. File of each block will be saved separately
2. Process Data in Excel
  - a. Calculate averages using equation function
  - b. Create necessary graphs

## Developing Mazes

### Designing Mazes

1. Open MazeMaker

2. Click on Create New Maze using Wizard
3. Select appropriate width and height of cells
  - a. For my purpose I select width of 11 cells, height of 10 cells
4. Scroll through maze selections, clicking regenerate maze until you find one you like, select finish
  - a. Press on Options at the top of the screen and continue to select Shrink until the entire maze is visible on the screen
5. Click on Collections → Texture Collection
6. Click on Add from Standard Library
  - a. Select a ground pattern, wall pattern, and ceiling pattern
7. Click on the blue floor of the maze
  - a. A sidebar will appear on the right
    - i. Under **Floor Properties**, click on Texture Floor and select the pattern chosen from the standard library for the floors
    - ii. Under **Ceiling Properties**, click on Texture Ceiling and select the pattern chosen from the standard library for the ceiling
8. On the left hand side under Maze Items, click on **Walls**; this should highlight all walls of the maze
  - a. A sidebar will appear on the right
    - i. Under **Texture**, click on Texture and select the pattern chosen from the standard library for the walls
9. Click on the start position in the top left corner of the maze
  - a. A sidebar will appear on the right
    - i. Under **Options**, select Angle in order to rotate the start position
10. Click on End Region at the top of the screen
  - a. A white cross will appear in the maze
    - i. Move the cross to where you would like the end of your maze to be and drag the cross until an orange rectangle appears
11. Click on Collections → Model Collection
12. Click on Add from Standard Library
  - a. Select any objects necessary for your maze
    - i. Select a door and an exit sign for my maze
13. Select the Static button at the top of the screen
  - a. A little hand will appear in the maze
    - i. Click on the location where you would like to place the door; this should be right on top of the start position
    - ii. Click on the location where you would like to place the exit sign; this should be at the chosen end region of your maze
14. Select the Pointer at the top of the screen
15. Click on the nude colored circle at the start position that appeared as a result of Step 12
  - a. A sidebar will appear on the right

- i. Under **Model**, click on Model and select the door that you chose from the Standard Library
        - I. Under **Model**, click on Rotation and change the coordinates of the door to the correct orientation
- 16. Click on the nude colored circle at the end of the maze that appeared as a result of Step 12
  - a. A sidebar will appear on the right
    - i. Under **Model**, click on Model and select the exit sign that you chose from the Standard Library
      - I. Under **Model**, click on Rotation and change the coordinates of the exit sign to the correct orientation
- 17. Click on the white area outside of the maze
  - a. A sidebar will appear on the right
    - i. Under **Timeout**, click on Timeout Value and enter a time limit in seconds for your maze; for my purposes, type in 120
    - ii. Under **Timeout**, click on Message Text and type in a message that will appear when the maze shuts out; for my purposes type in \_\_\_\_\_!
- 18. Select File → Save As → Select Folder → Enter File Name

### Creating MazeList

- I. Select the Tools button at the top of the screen, then click MazeList Builder
- II. Insert Mazes
  - a. Click on the dropdown menu and select Maze File if not already selected
  - b. Select the Add button
    - i. Select the folder in which the mazes are saved; for my purposes, select the Maze Wizard folder
      - 1. Click on Orientation Maze, then click Open
        - a. For my purposes, repeat 2 times since the participant will complete two orientation mazes prior to the actual trial
      - 2. Click on the actual maze you are testing
        - a. For my purposes, repeat 10 times since the participant will complete the actual maze for 10 trials
- III. Insert Text
  - a. Click on the dropdown menu and select Text Display
  - b. Prior to Maze 1, enter Text Display
    - i. A sidebar will appear on the right

1. Under **General**, click on Value and type in: Welcome!  
You will perform a few trials of an Orientation Maze
  2. Under **Display**, click on LifeTime and type in a value of 5000; click on Text Display Type and select OnFramed Dialog
- c. Following Orientation Maze 1, enter two Text Displays
- i. A sidebar will appear on the right
    1. For Text Display 1
      - a. Under **General**, click on Value and type in: Take a few moments to relax.
      - b. Under **Display**, click on Lifetime and type in a value of 5000; click on Text Display Type and select OnFramed Dialog
    2. For Text Display 2
      - a. Under **General**, click on Value and type in: Ready? Here is another try at the orientation maze.
      - b. Under **Display**, click on Lifetime and type in a value of 1000; click on Text Display Type and select OnFramed Dialog
- d. Following Orientation Maze 2, enter Text Display
- i. A sidebar will appear on the right
    1. Under **General**, click on Value and type in: Congratulation! You have successfully completed the orientation. The experiment will start momentarily.
    2. Under **Display**, click on Lifetime and type in a value of 1000; click on Text Display Type and select OnFramed Dialog
- e. In between Maze Trial 1 and Maze Trial 2, enter Text Display
- i. A sidebar will appear on the right
    1. Under **General**, click on Value and type in: Relax.
    2. Under **Display**, click on Lifetime and type in a value of 5000; click on Text Display Type and select OnFramed Dialog
- f. Repeat Step E, entering the exact same Text Display in between the remaining maze trials and following Trial 10 of the actual maze
- g. The MazeList is now complete → click Save As, select folder, and type in file name

### **Testing Mazes**

#### Prior to Participant Entering Room

- I. Set Up fNIRS following the steps listed above under **Learning fNIRS** → Data Collection → System Set Up
- II. Using the computer that has MazeSuite, select MazeWalker
  - a. Under Video Settings, leave the Resolution at 800x600 (4:3) and the Color Dept at 32 bits
    - i. Ensure that the Full Screen box is checked off
  - b. Under Control Settings, click on the box that indicates the way in which the participant will be navigating through the maze
    - i. For my purposes, check the box that says Use Mouse
  - c. Under General Settings, check the box that says Enable Shaders
  - d. Under Open Maze, click on the box that contains (...) and select the actual maze that the participants will be navigating through.
  - e. Under Keep Log, select the MazeList that was created for the maze being tested
  - f. Leave MazeWalker open while waiting for your participant; you will return to this screen later

#### While Participant is in the Room

1. Upon the participant entering the room, give them the informed consent form and have them read and fill it out while sitting on the stable chair facing the MazeSuite computer
  - a. Ask them if they have any questions and answer them accordingly
2. Apply the Sensor Pad following the steps above under **Learning fNIRS** → Data Collection → Apply the Sensor Pad
3. Turn on and set up Cobi Studio following steps a-i listed under **Learning fNIRS** → Data Collection → Run Cobi and Collect Data
4. When baseline is complete, select Start on MazeWalker on the Mazesuite computer
5. Complete steps j-l under **Learning fNIRS** → Data Collection → Run Cobi and Collect Data
  - a. Select Marker 1 when the participant starts a maze, and select Marker 2 when the participant gets to the exit sign of a maze or when the time runs out
6. When the experiment is over, turn on lights and remove the fNIRS device from the participant
7. Turn off fNIRS device
8. At this point, the participant is free to leave

When Participant leaves the Room

1. Analyze data following the steps under **Learning fNIRS** → Data Processing