Developing Tests of Visual Dependency

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Individual Project Report submitted to the International Space University in partial fulfillment of the requirements of the M.Sc. Degree in **Space Studies**

August, 2011

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ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. Jacob Bloomberg, for his support, guidance, and encouragement that he has so generously given to me over the course of my internship and the weeks prior. I am very grateful for the amount of time he has spent explaining to me various concepts, helping me organize my project, and discussing my experiments. His involvement in this project has been indispensable to me.

I wish also to thank Dr. Ajit Mulavara for his direction and support during my internship, as well as my ISU mentor, Dr. Gilles Clément, for his encouragement and optimism.

I am grateful to my co-investigators: Matthew Fiedler, Raquel Galvan, Patricia Santana, and Igor Kofman for their constant willingness to lend a hand. I am also appreciative to laboratory colleagues Chris Miller and Crystal Batson, and to all members of the NASA JSC Neuroscience Laboratory for their friendship.

I am grateful to Rachel Brady for her technical/scientific input and her excellent proof-reading skills on both this report and my final presentation.

I would like to thank my family in Montreal, Canada, for their inspiration and continual motivation.

I wish to acknowledge the Ninety-Nines International Organization of Women Pilots, the Social Sciences and Humanities Research Council of Canada, the Canadian Foundation for the International Space University, the European Space Agency, and the International Space University for fellowships awarded to me over the course of my studies at the International Space University.

ABSTRACT

Astronauts develop neural adaptive responses to microgravity during space flight. Consequently these adaptive responses cause maladaptive disturbances in balance and gait function when astronauts return to Earth and are re-exposed to gravity. Current research in the Neuroscience Laboratories at NASA-JSC is focused on understanding how exposure to space flight produces post-flight disturbances in balance and gait control and developing training programs designed to facilitate the rapid recovery of functional mobility after space flight. In concert with these disturbances, astronauts also often report an increase in their visual dependency during space flight. To better understand this phenomenon, studies were conducted with specially designed training programs focusing on visual dependency with the aim to understand and enhance subjects' ability to rapidly adapt to novel sensory situations. The Rod and Frame test (RFT) was used first to assess an individual's visual dependency, using a variety of testing techniques. Once assessed, subjects were asked to perform two novel tasks under transformation (both the Pegboard and Cube Construction tasks). Results indicate that head position cues and initial visual test conditions had no effect on an individual's visual dependency scores. Subjects were also able to adapt to the manual tasks after several trials. Individual visual dependency correlated with ability to adapt manual to a novel visual distortion only for the cube task. Subjects with higher visual dependency showed decreased ability to adapt to this task. Ultimately, it was revealed that the RFT may serve as an effective prediction tool to produce individualized adaptability training prescriptions that target the specific sensory profile of each crewmember.

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CHAPTER I

INTRODUCTION

The Human Research Program at the NASA Johnson Space Centre (JSC) in Houston, Texas, was created in 2005 with one of its missions as “discovering the best methods and technologies to support safe, and productive, human space travel” (Human Research Project, 2011). With this mission in mind, researchers at JSC design and conduct many different types of experiments, in all domains of human research, including cardiovascular studies, exercise science, bone, blood, and neuroscience research, to name only a few, to better understand and promote safe and productive space travel, and to also aid in the preparation and training of future astronauts.

As part of this mission, astronauts are required to undergo intense training that spans many years in order to properly prepare them for a future space mission. Besides tasks related to their specific assignment, astronauts undergo rigorous training that is not limited to survival classes, piloting aircraft and simulators, medical training, and learning the different components of each system, whether on the Shuttle or on the International Space Station (ISS). In addition, astronauts must also endure, among other activities, training for Extra-Vehicular Activities where they will be free-floating in space. Undeniably, during their time between selection and travelling into space, astronauts receive thousands of hours of training and are required to undertake numerous classes to prepare them for their mission.

As in any learning environment, including astronaut training, learners excel when instruction is delivered in a manner that is suited best to their style of learning or personal strengths. This is also true for astronauts: training programs designed with the individual astronaut in mind will surely benefit and be most efficient in properly training the astronaut. In the typical educational context, determining whether an individual is a visual, auditory, or other type of learner is very important for effective instruction. Indeed, tailoring learning programs to an individual’s personal strengths aids in the learning process and allows for the learner to use their strengths to better adapt to any situation.

It is well documented that one’s ability to adapt to any situation can vary among individuals (ref). For example, gender differences can imply benefits for one sex over the other in specific tasks (ref). Moreover, certain individuals may possess skills that enable them better to adapt to a low-gravity environment, while for others, the manner in which they have become accustomed to their intrinsic senses in space can give them an advantage (ref). Recognizing inter-personal differences in inter-personal abilities and knowing how to support these individual differences is key to success in any activity, whether space flight or other.

Differences in adaptability to varying situations between individuals can be based on many things: one's past experiences, one's personal physiology, the manner in which an individual has become accustomed to adapting to differing environments, prior training, and even culture can all have an important impact on the manner in which an individual can adapt to a situation. With regard to the Human Research Program at JSC, the Neuroscience Laboratory is one of the main fields where important research continues to be undertaken to better understand the underlying factors surrounding adaptability differences between individuals.

The Neuroscience Laboratory at JSC

The Neuroscience Laboratory at JSC is deeply involved in research that aims to understand how the brain functions and reacts to changes in central nervous system functions. Many investigations regarding the effects of space flight on the human nervous system, with an important focus on posture, gait function, the coordination of eye and head movement, perception, motion sickness in space, and vestibular system function (NASA Human Adaptation and Countermeasures, 2011) are conducted in the laboratories. In effect, the main mission of the Neuroscience Laboratory is to mitigate and investigate physiological effects associated with the adaptation to space flight and the micro-gravity environment, as well as re-adaptation to the Earth' s gravity on return from space flight. The laboratory is involved in ground and in-flight investigations, the monitoring of crew health, as well as mitigating risks, evaluating countermeasures currently in use, and validating existing research. It is comprised of several different laboratories: Motion, Neuroautonomic, Off-vertical Access Rotator, Postural Control, Preflight Control, Preflight Adaptation and Virtual Reality Training, Sensorimotor, Short-arm Centrifuge, and Visual-Vestibular (Gaze) (NASA Human Adaptation and Countermeasures, 2011). All of these laboratories play a critical role in the understanding of the central nervous system's ability to adapt to a variety of environments and situations. Studies in these laboratories aim to investigate the sensory functions that are important in space flight.

Sensory Functions

All living organisms have intrinsic abilities to sense what is going on and react to their environment. Relying on one's senses in any organism is critical to its survival. In terms of humans, every day we are faced with numerous sensory stimuli that we must interpret, react, and adapt to. We are able to do this using our sensory organs, which include vision, auditory (hearing), olfaction (smell), gustation (taste), and somatosensation. Of these senses, the first four are relatively obvious to the common individual. However, somatosensation, which is less well known in common language, refers to the use of scattered nerve endings located everywhere on the human body that innervate muscles, joints, skin, and tendons, as well as other regions on the interior of the human body (Clement & Reschke, 2008).

In addition to the above mentioned sense, one last sense is the sense of self-motion which refers to one's ability to maintain balance while reacting and adapting to body movements (Clement and Reschke, 2008). This sense requires the integration of many senses including vision, vestibular organs in the ear, and somatosensory inputs, as well as inputs from visceral and auditory systems. In concert, these sensory systems react and adapt to any environment an individual may encounter.

Changes in Sensory Motor Function During and Post-Flight

The sensory motor system is a network that includes the sensory organs, as mentioned above (eyes, ears, skin, vestibular, and proprioception), the nervous system, as well as the manner in which body uses its motor controls. It is in charge of one's ability to sense and react to external stimuli from the environment. Once an astronaut is in space, the sensorimotor system must adapt to microgravity, and then re-adapt once the astronaut returns to Earth and its 1-g environment. During both of these time frames, numerous perturbations in sensorimotor function have been documented (ref).

To be safe during space flight, it is important that astronauts be aware of the changes that their sensory motor systems undergo. In the future, astronauts will likely travel to Mars or other places that require an extended duration in a microgravity environment and therefore understanding how one's sensory systems change and adapt to these new environments is of critical importance. Without this understanding, alterations in sensory motor inputs can have serious consequences for astronauts whose sense of balance, equilibrium, and general orientation may be altered.

Sensorimotor changes related to space flight include alterations in control of movement, spatial disorientation, space motion sickness, postural control, problems with gait, visual acuity, balance, gaze control, proprioception, locomotion, hand-eye coordination, and the vestibular system in general (Figure 1).

Studies at JSC aim to mitigate or reduce sensorimotor deficits that arise as a result of these changes. Many of these studies have focused on exercise, self-assessment tools, and adaptation countermeasures. Additional studies are needed, however, to design and implement in-flight measures that will help astronauts identify and facilitate their own abilities in adapting to decreased gravitational environments.

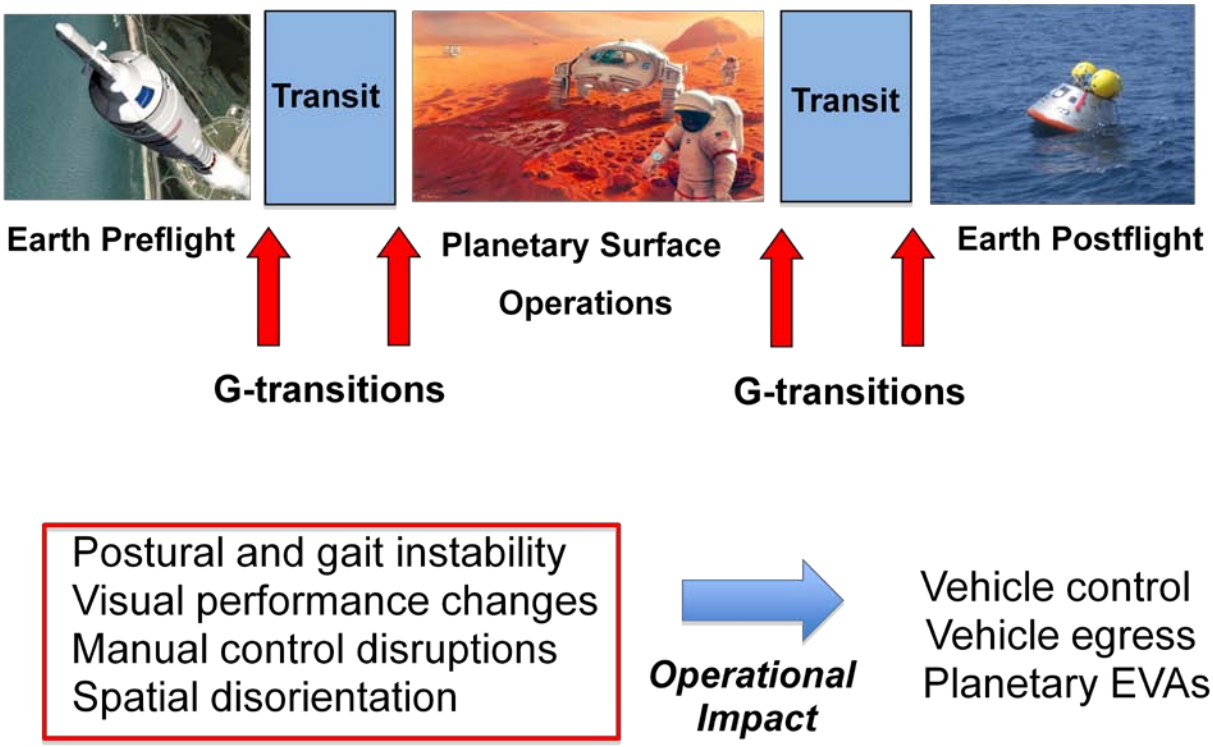

Figure 1: Sensorimotor Disturbances Occur During and After G-transitions

Adaptability Training at JSC

Astronauts develop neural adaptive responses to microgravity during space flight. Consequently these adaptive responses cause maladaptive disturbances in balance and gait function when astronauts return to Earth and are re-exposed to gravity. Current research in the Neuroscience Laboratories at NASA-JSC is focused on understanding how exposure to space flight produces post-flight disturbances in balance and gait control. The laboratory is also developing training programs designed to facilitate the rapid recovery of functional mobility after space flight to improve performance of astronauts after return to Earth and during exploration class missions.

The human brain is highly adaptable enabling individuals to modify their behavior to match the prevailing environment. Subjects participating in specially designed training programs can enhance their ability to rapidly adapt to novel sensory situations. By applying these concepts for training astronauts we can enhance their ability to “learn how to learn” to adapt when transitioning to new gravitational environments. The adaptability-training program the laboratory is developing entails manipulating the sensory conditions of treadmill exercise to systematically challenge the balance and gait control systems. This enhances the overall adaptability of balance and gait control enabling rapid recovery of function in different gravitational environments. By mounting a treadmill on a six degree-of-freedom motion base and providing variations in the flow of virtual scenes during exercise we have created a multifaceted balance and gait adaptability training system.

Exposure to visual flow variation during treadmill exercise can be an effective way to challenge and train the balance control system (Richards et al. 2004; Mulavara et al. 2005; Richards et al. 2007; Mulavara et al. 2009, Batson et al, 2011). Studies have also been conducted to determine if balance training using variation in visual flow during treadmill exercise improves functional mobility in healthy older adults who were experiencing age-related postural instabilities (Buccello-Stout et al. 2008). The results showed that subjects who were exposed to varied visual flow during treadmill walking significantly improved their ability to negotiate an obstacle course after training compared to another elder group who only walked on a treadmill for the same amount of time. This study confirms that adaptability training developed for use by astronauts can also be used to improve balance and gait performance in elder subjects and points to the general applicability of this type of training in different clinical populations.

Vision Studies

With regard to the studies I am currently undertaking in the Neuroscience Laboratory, they are focused on vision as part of the central nervous system, and the manner by which different individuals rely differently on their vision to perform a variety of tasks. In the context of my research, it is therefore important to review studies that deal with vision and the important changes it undergoes as it adapts to the space environment and back to Earth.

Vision

Along with the otolith organs and semicircular canals of the vestibular system, as well as one's ability to sense position, the eyes are also an important source for the brain to synthesize a sense of body orientation and movement. (Buckey, JC, 2006)

Information regarding balance is integrated between many centers. These senses complement one another while providing information to the central nervous system, which is capable of synthesizing its own representation of the individual's body and movement. In space, the manner of how these senses continue to integrate information despite changes in gravity is a subject studied by many (Figure 2).

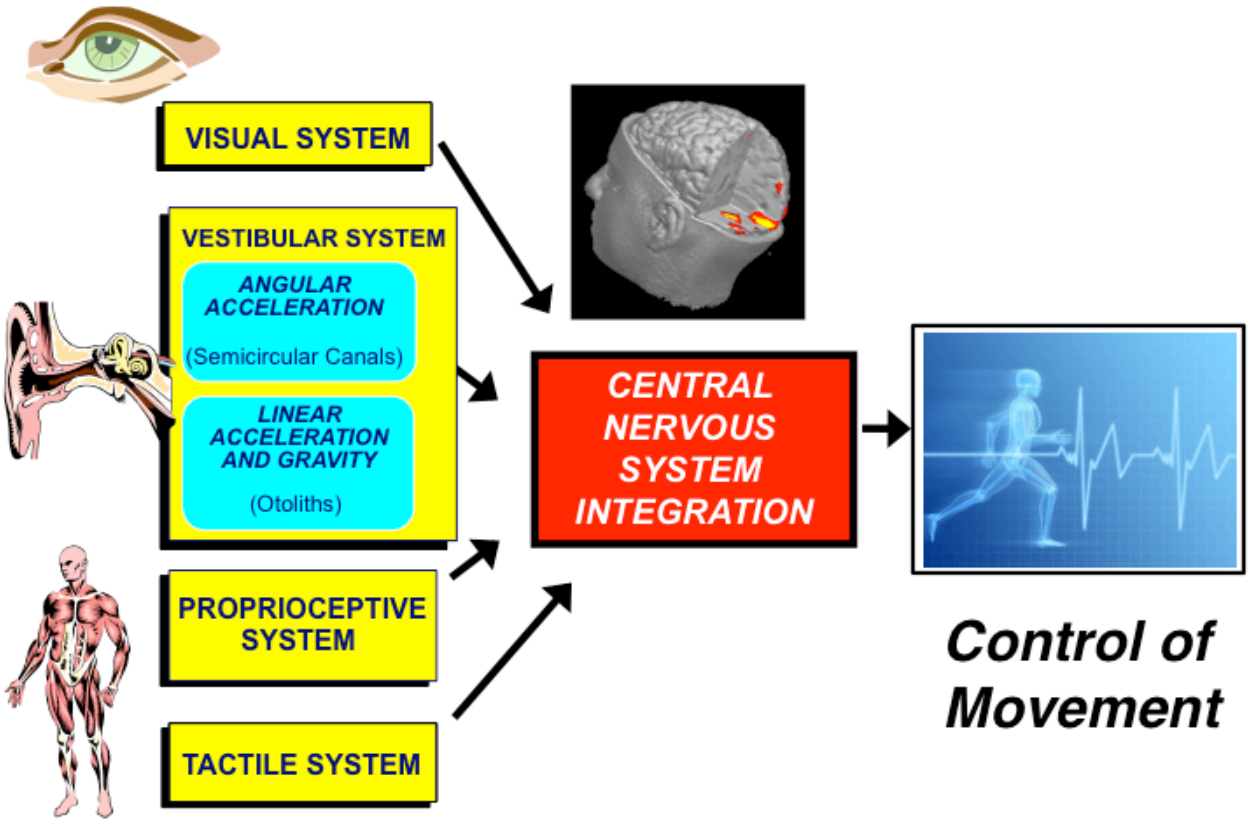

Figure 2: Central Nervous System Integrates Multiple Sensory Inputs

It is well known that vision plays a critical role in balance (Manchester et al., 1989; Riley et al, 1999) as well as the ability to perform specific tasks (Pisella et el., 2006). Subjects' ability to remain in an upright position when standing position on a tilted platform is decreased when their eyes are closed versus when their eyes remain open. In addition, subjects walking on a stationary treadmill while viewing a hallway scene in front of them have increased difficulty once the hallway begins to oscillate (ref). Despite there being no additional movement from the treadmill, the change of motion of the hallway has important consequences in being able to alter the walking abilities of subjects. Indeed, vision has an important role in an individual's ability to adapt and perform in any environment. In terms of space flight, understanding how the visual system functions is important for ensuring successful missions.

Vision and Space Flight

Visual-vestibular integration is known to be disturbed in weightlessness. Studies conducted by Young et al. (1986, 1996), investigated visual-vestibular integration with regard to spatial orientation. Studies were conducted on crewmembers, both on Earth and in space, in which subjects were asked to insert their heads into a polka-dotted drum that rotated about the visual axis. Crew members were to indicate the amount of rotation that they sensed. On Earth, subjects in an upright position indicated that they had a mild sensation of rolling or tilting. In space, the majority of astronauts indicated that they felt they were rotating to a greater level than on Earth. Astronauts that used a harness to secure them to the space craft deck indicated that they experienced decreased rotation in comparison. From this experiment, Young suggested that crewmembers are more visually dependent in a microgravity environment as their sense of angular speed was increased in space in response to the rotation of the visual scene.

Since during adaptation to 0g the vestibular information may be altered, the astronauts' visual abilities seemingly were more dominant, and thus gave the perception of increased rotation. Interestingly, when tests that evaluated one's visual dependency were administered post-flight, astronauts displayed a mild increase in visual dependency in comparison to pre-flight (Buckey JC, 2006).

In a 0g environment such as during space flight, input from gravitational cues is diminished. As a result, the otolith organs of the inner ear, which are responsible for detecting linear acceleration, become unloaded. Signals from these organs to the central nervous system are therefore absent. Information regarding one's orientation, other than voluntary or passively imposed information regarding head movements is relayed to the brain. Therefore, despite linear acceleration in space, astronauts must their other senses to detect linear acceleration. Vision is one of these senses upon which astronauts become very dependent as a result.

Visual Dependency on Earth

Visual dependency plays an important role not only in space, but also on Earth. Several studies have been conducted in the aim of better understanding individual differences in visual dependency. Such studies are discussed below.

The Rod and Frame Test (RFT)

To assess an individual's visual dependency, Herman Witkin, an American psychologist, developed several tests. In 1958, he designed and created the Rod and Frame Test (RFT) and this test is still instrumental today in determining whether an individual is more or less visually dependent.

The RFT consists of a screen where a rod is viewed in a number of different degrees of tilt. A tunnel-like frame that surrounds the rod is projected towards the subject (Figure 3). Both the degree of tilt of the tunnel frame and the degree of tilt of the rod can be altered. The subject sits in the dark, with the tunnel framing their face, thus removing all peripheral vision. The subject is then required to align the rod to the upright vertical position by the use of a manual controller similar that of a video game (Figure 4). For the subject to be successful in aligning the rod to upright, s/he must ignore the tunnel reference frame, and use solely their own intrinsic cues.

Figure 3: Subject positioned at the RFT

Figure 4: RFT Controller

A subject able to successfully align the rod to upright is said to be visually independent or field independent, as they use multiple sensory senses to align the rod. Conversely, if a subject is unable to align the rod to upright, they are said to be visually dependent/field dependent, as they require their vision to be successful at the task.

The RFT has been very useful in attempting to categorize individuals according to their visual dependency. Isableu et al, (1997; 2010) studied visual dependency with relation to balance and stability. In general, the research demonstrates that once categorized as visually dependent or independent via the use of the RFT test, individuals who are visually independent were significantly more stable in any experimental condition to which they were subjected. This included experiment tests related to postural stability, balance, body stability, among others.

In other studies, Hodgson et al. (2010) determined that visual dependency can play an important role in one's ability to be successful at certain sports. Hodgson et al. (2010) hypothesized that visually independent individuals (as categorized by the use of RFT studies) would be more successful at activities that included a large proportion of closed skills. Closed skills are classified as activities such as gymnastics or trampoline activities, where a participant is required to rely less on their vision, and more on other internal cues. Hodgson et al. (2010) undertook studies to determine if the kayaker's hip-snap maneuver (a skill where the kayaker must move from an inverted underwater position to an upright above water position while positioned in their own kayak) would be easier for a visually independent individual than a visually dependent one. It was revealed that this maneuver is also performed with increased success in visually independent individuals compared to those who require a visual field of reference. This maneuver is classified as a closed skill as the kayaker is upside down, immersed in water, and is subjected to little or no external visual reference frame.

Once participants completed a skill teaching session splitting the maneuver into several different tasks, they were assessed on each of the tasks as well as their ability to complete the entire maneuver successfully. Subjects were assessed on their number of trials to complete the task.

The results indicated that field independent individuals were associated with much better performance of the sub-skills as well as the acquisition of these skills. It was concluded that visually independent individuals may have an advantage when acquiring closed sport skills that require cognitive restricting and internal cues for success.

The Embedded Figures Test (EFT)

Herman Witkin found the RFT to be difficult and time consuming so he later developed the EFT (Figure 5), also used to assed visual dependency. It requires that the subject be able to locate images that are obscured within a greater complex image. It is thought that the RFT and EFT can both give important information regarding visual dependency (Witkin, 1948; Witkin & Asch, 1948). According to the research performed by Witkin et al. (1948), individuals who are more field independent will be able to find the embedded figures faster than individuals who are field dependent.

The studies conducted also act as a manner which to correlate the data from both the RFT and EFT, and suggest that a subject who takes a longer time to complete the EFT is also likely to indicate that the rod is aligned properly in the RFT, when actually, the rod is quite tilted. It can be said that for an individual who is visually dependent, their sense of perception is strongly dominated by their vision and the overall organization of the field surrounding them. Conversely, visual independent individuals are able to disassociate parts of a given field, and organize pieces as discrete elements (Witkin et al., 1948).

Both the EFT and RFT are useful tests to assess visual dependency and continue to be used in concert with other similar tests.

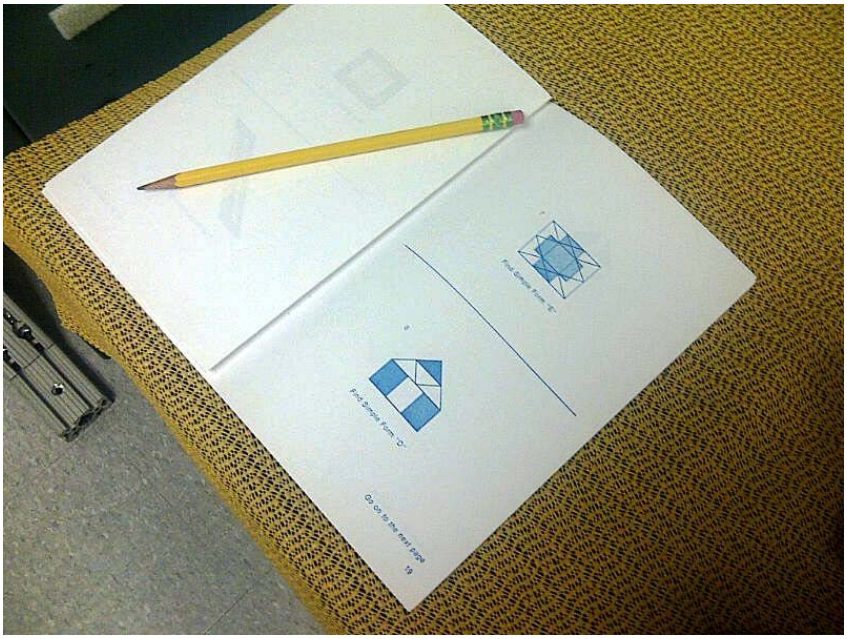

Figure 5: The Group Embedded Figures Test

Implications of RFT and EFT for Space Flight

As described previously, vision plays a critical role during space flight, as the otolith organs of the vestibular system become unloaded in 0g. While astronauts train for the mission, having information about their individual visual dependency attributes is important in order to tailor their program to their specific needs. The manner by which every individual learns and adapts to a new environment or situation is person specific, and training astronauts to use their strengths or improve on their weaknesses with regard to visual dependency can have important implications for their adaptation in space.

My Research at JSC

In the attempt to improve the training that astronauts receive prior to their mission, my studies at JSC involve visual dependency and its applications for adaptability on several tasks. In the following section, I will discuss the experiments I have undertaken as part of a pilot study to determine the best conditions under which the RFT can be administered, the correlation between the RFT and EFT, and an individual's ability to adapt to a task when a visual impairment is present.

CHAPTER II

RESEARCH PROJECT

Astronauts rely on their intrinsic senses to provide them with a sense of their environment, as well as their location within that environment. As it is well documented by several studies (ref), astronauts become more dependent on their vision and less on their vestibular systems, as gravitational cues upon which the vestibular system relies upon are significantly reduced. As such, one's ability to adapt a dependency upon one's own visual system is important in space.

Research conducted with the aim of understanding how visual dependency changes in space is, in fact, limited. Studies regarding how visual dependent individuals on Earth adapt to the space environment compared to individuals who rely less on their vision on Earth are needed to assess the role of visual dependency in space.

With the goal of better understanding visual dependency and its adaptability in space, ground based studies with astronauts are first needed to assess their dependency before traveling into space. These studies will hopefully not only allow for a better understanding of visual dependency on earth and in space, but also allow for crew training to account for interpersonal differences in visual dependencies.

With this in mind, the Research Project I have undertaken has with a long-term goal of improving astronaut training by adapting training programs to a crew member's strengths. These strengths are not limited to all of their senses, as discussed previously. However, as the study of human senses is a vast scientific domain, my Research Project will focus on visual dependency.

Developing Tests for Visual Dependency

The Research Project I have conducted as part of my internship is part of a larger study being conducted in the Neuroscience Laboratory at JSC. The large study at JSC is focused on better understanding how the visual system is important in balance and other sensorimotor systems, and also has an ultimate goal of better adapting training programs to specific individual strengths.

Within this pilot project, visual dependency is assessed using a variety of methods that include a number of studies. The following briefly describes the various tests currently being undertaken as part of the pilot study devoted to studying human motor and visual disturbance as well as countermeasures for astronaut training and adaptation to the novel space environment. Included in this section is general information regarding the studies performed via Visual Locomotor Treadmill, and the Group Embedded Figures

test. Further to this general description, I will describe studies I have personally conducted via the use of the Rod and Frame Test, the Cube Construction Test, and the Pegboard Test as part of the pilot study on Visual Dependency.

Visual Locomotor Treadmill (VLT)

The VLT is a useful tool in that it allows the investigation of an individual's visual dependency in a number of ways. It consists of a treadmill that is able to move with six degrees of freedom, as well as a large screen placed in front of the treadmill that is capable of presenting a variety of scenes (Figures 6 & 7). In the past, experiments have been conducted with many different combinations of treadmill movement and scene perturbations. For example, as the treadmill moves from side to side, the hallway scene projected on the screen can also move by oscillating from side to side with the same period but out of sync with the treadmill. While dealing with staying balanced on the treadmill while visualizing the moving treadmill, subjects are also required to complete a cognitive task consisting of pressing a button when they hear a series of tones. In these studies and others (Lajoie et al. 1993), when presented with challenges of postural stability and responding to the series of tones, subjects have demonstrated that postural stability is a more important task. In addition, individuals who were evaluated as being visually independent performed better than their visually dependent counterparts, as their performance on the moving treadmill was more stable.

Other studies also performed in the Neuroscience Laboratory at JSC (Batson et al., 2011) have attempted to investigate whether prior training has an impact on one's ability to maintain postural stability on the VLT. According to Batson et al. (2011), it is suggested that highly visually dependent individuals performed tasks differently than visually independent individuals with regard to stability, gait, and balance. In still unpublished data, despite (after training) being comparable to visually independent counterparts on previously-trained tasks, visually dependent individuals had more difficulty with novel VLT tasks presented to them in comparison to visually independent subjects who underwent the same training. This suggests that highly visually dependent subjects benefited from training in gait adaptability but this training was not able to be generalized and successfully incorporated into a novel challenge. These results mirror those found by studies conducted by Haart et al. (2004), which suggest that an individual, with enough training, can be comparable to a visually independent individual, but also reveals that new studies would be beneficial in understating how one's improved ability to complete a task does not carry over into novel tasks.

Indeed, the VLT in the Neuroscience Laboratory is very useful in gaining a better understanding of visual dependency.

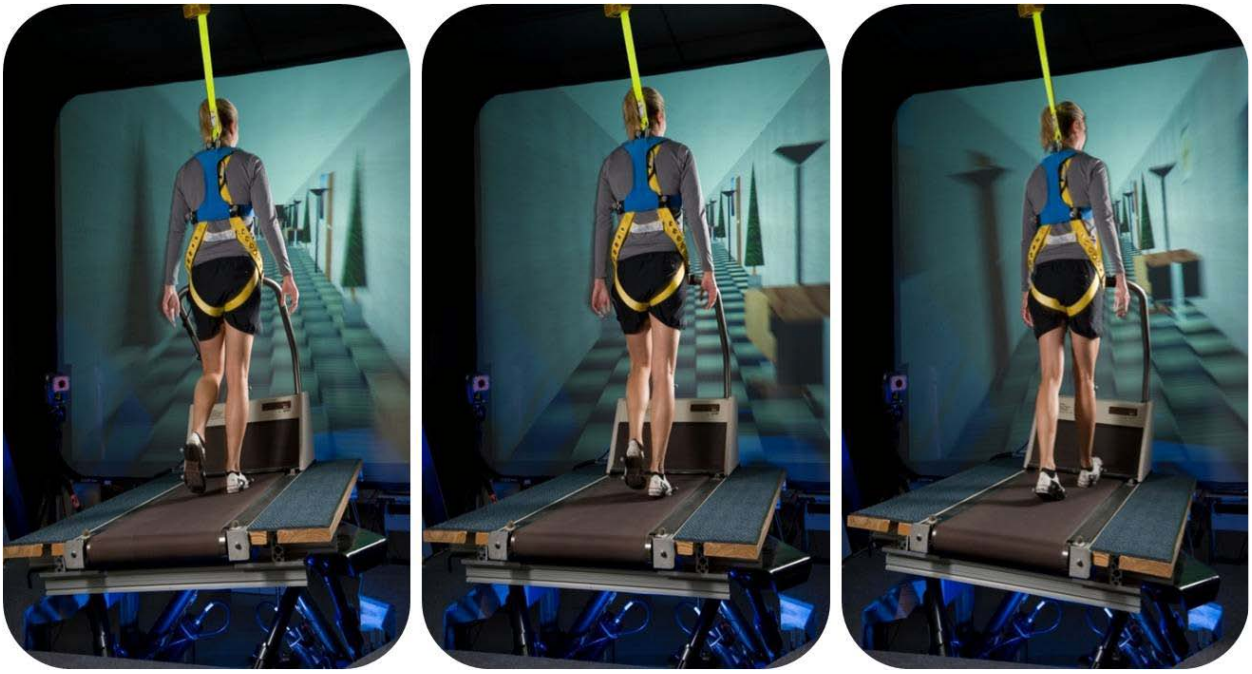

Figure 6: Visual Locomotor Treadmill (VLT)

Figure 7: Visual Scene used with VLT

The Group Embedded Figures Test (GEFT)

As described previously, the GEFT is also used to assess an individual's visual dependency. The test relies on a booklet that features a variety of complex patterns. The subject's task is to locate a simple figure from within a complex design.

Nine subjects were required to trace the specified figure from within the design, and that size, proportion, and direction were to be maintained between the figure and design images. The GEFT is made up of three sections consisting of 26 tasks.

Although this test was led by a colleague in the Neuroscience Laboratory, the methodology and administration of the test was performed by three interns, including myself.

The GEFT was evaluated based on the GEFT Manual by Witkin, Oltman, Raskin, and Karp. The test is scored based on the total number of simple figures traced correctly within a specified time frame in the second and third sections of the test.

It has been suggested that individuals who are more field independent will be more successful in locating images, and will locate them faster than individuals who are field dependent.

Results of GEFT

When the results of the GEFT were analyzed, no correlation was found between the subject's scores versus their time of completion, as indicated in the following graph.

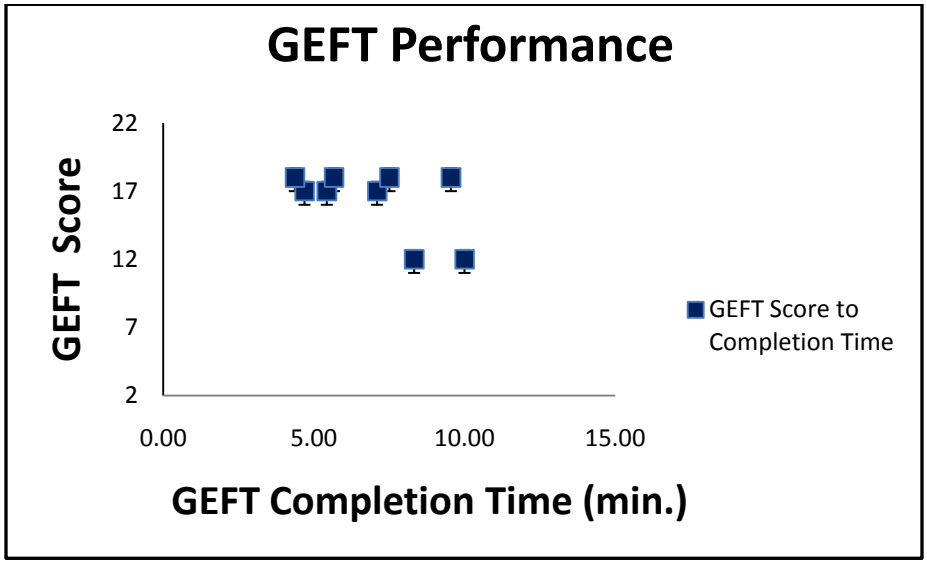

Figure 8: GEFT Performance

However, more interesting than correlating GEFT performance and GEFT score is the relationship between the GEFT score and the RFT results. According to the GEFT manual, “reflecting in each case the strong influence of the immediately surrounding field upon the way in which one of its parts is perceived, the person who takes very long to discover the simple figure in the complex EFT design is also likely to tilt the rod far toward the tilted frame and his own body far toward the tilted room” (Witkin et al., 1971).

In the following sections, this correlation will indeed be discussed. However, prior to this discussion, it is important to describe the RFT that was conducted as part of the pilot study in the Neuroscience Laboratory, as there were indeed many variable factors that were explored in order to make the RFT as accurate and as representative in assessing visual dependency as possible.

The Rod and Frame Test (RFT)

The RFT is a test used to assess an individual’s visual dependency by the use of a tunnel reference frame and a rod projected on a screen.

Figure 9: RFT Set-up

As this test is novel to the Neuroscience Laboratory at JSC, many different variables were introduced while performing this test in order to assess which of these variables, or a combination of variables, would allow for the best assessment and be most representative of an individual's visual dependency.

These variables include

1) the material (wood, foam, or no material) placed below the chin of the subject ;

2) the use of ±9° versus ±18° tilt in frame angle;

3) the appearance of a dot in the center of the RFT screen versus the appearance of a curtain-like effect on the screen (consisting of the entire viewing field being blanketed in white.

4) the adjustment of the frame angle whether as four rod adjustments in the positive direction and four to the negative; or two to one direction, and two to the other, repeated for a total of eight rod adjustments.

The following section discusses in detail these three sets of variables.

General Methods for RFT

For all of the studies conducted, the following general methods were applicable:

Subjects viewed an image of a tilted rod projected on a screen, as discussed previously, while blocking out their reference to vertical via the use of a tilted rectangular tunnel frame structure (measuring xx by xx by xx), through which the subject observed the rod. Rods were 20cm in length, and 1cm in thickness. The length of the tunnel was 0.6m, and therefore the subject was this distance from the screen.

For each different variable tested, a few of the methods differed between tests, as shall be discussed in turn.

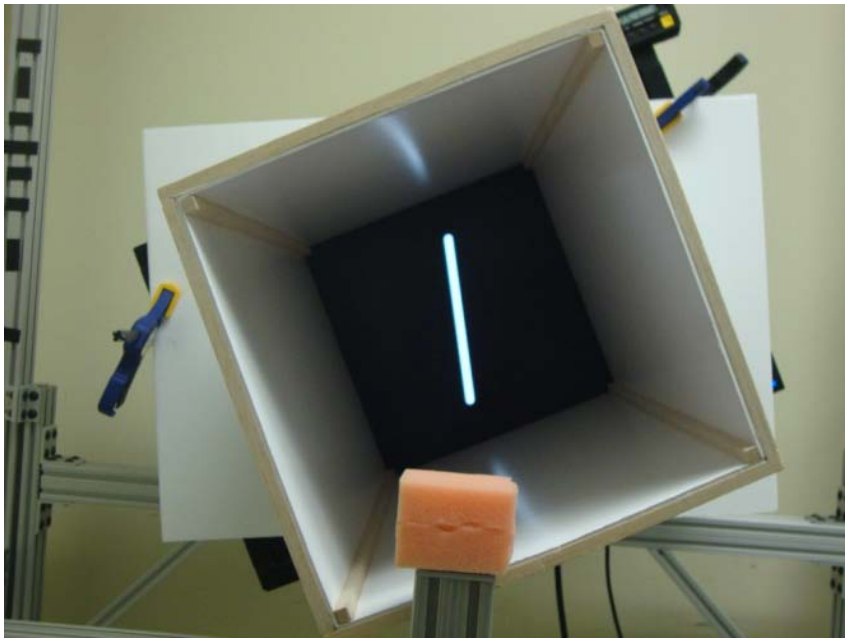

Figure 10: RFT with Rod

Variables 1 & 2: Material and Frame Angle

For this portion of the pilot study, the RFT was administered with the aim to investigate whether visual dependency was affected by the material placed below the subject's chin. It is unknown to us whether the presence of a hard surface (wood), a malleable soft surface (foam) or no material would have an effect on how subjects performed the RFT. Additionally, in conjunction with the material testing, I also investigated if ±18° was sufficient for assessing visual dependency, or if ±9° was also necessary. As a result of the three different materials, the subjects had three sessions with the RFT, and all three sessions were completed with a one week time period.

Seven subjects placed their chin on one of the three materials at the far end of the rectangular tunnel reference frame. Throughout the test, they were asked to remain still so as to avoid any vestibular cues or motion parallax. At the beginning of the trial, the rectangular tunnel was aligned to vertical. Subjects were instructed to close their eyes, following which the frame was adjusted to 18 degrees (CCW) to vertical, and the lights were closed. Subjects were then told to open their eyes, and viewed a tilted rod (tilted to approximately ±18 degrees), projected on the screen, at the far end of the rectangular tunnel. This was repeated four times. Via the use of a controller device similar to those used in video games, the subject was asked to align the rod to vertical to the best of their ability. The controller had two fine adjusters that allowed a movement of 0.1°, and two coarse adjusters with movements of between 0.5° and 1.0°, so that the subject could not rely on the number of adjustments as a reference for vertical. The subject was required to press two other buttons simultaneously to indicate that they had aligned the rod to vertical.

At the conclusion of the four trials, the subject was instructed to close their eyes. The subject repeated the above procedure with the rectangular reference frame was adjusted to 9°, -9°, and -18°. In total, the subject viewed 16 rods in one session. As previously indicated, subjects returned to the laboratory to repeat the test two more times over the course of the following seven days.

Material and Frame Angle results

Seven subjects took part in this part of the pilot study. Although every best effort was made to have all subjects assessed for all three materials, scheduling conflicts did not allow for all seven subjects to complete all trials. When evaluating foam as a material, all seven subjects completed testing. For wood, five subjects completed testing at 18°, 9°, and -9°, but one subject was unable to complete the -18° testing as they began coughing during testing and the test was terminated.

The following graph (Figure 11) plots the Rod Angle Average Vs Frame Angle for each material used. The Rod Angle Average is a parameter that is an average of four different rod adjustments within a given material and a given frame angle. For example, when foam is used as a material, and the frame angle is adjusted to 18°, the subject

adjusted 4 rods. The Rod Angle Average is the average adjustment (in degrees) of the four rods combined.

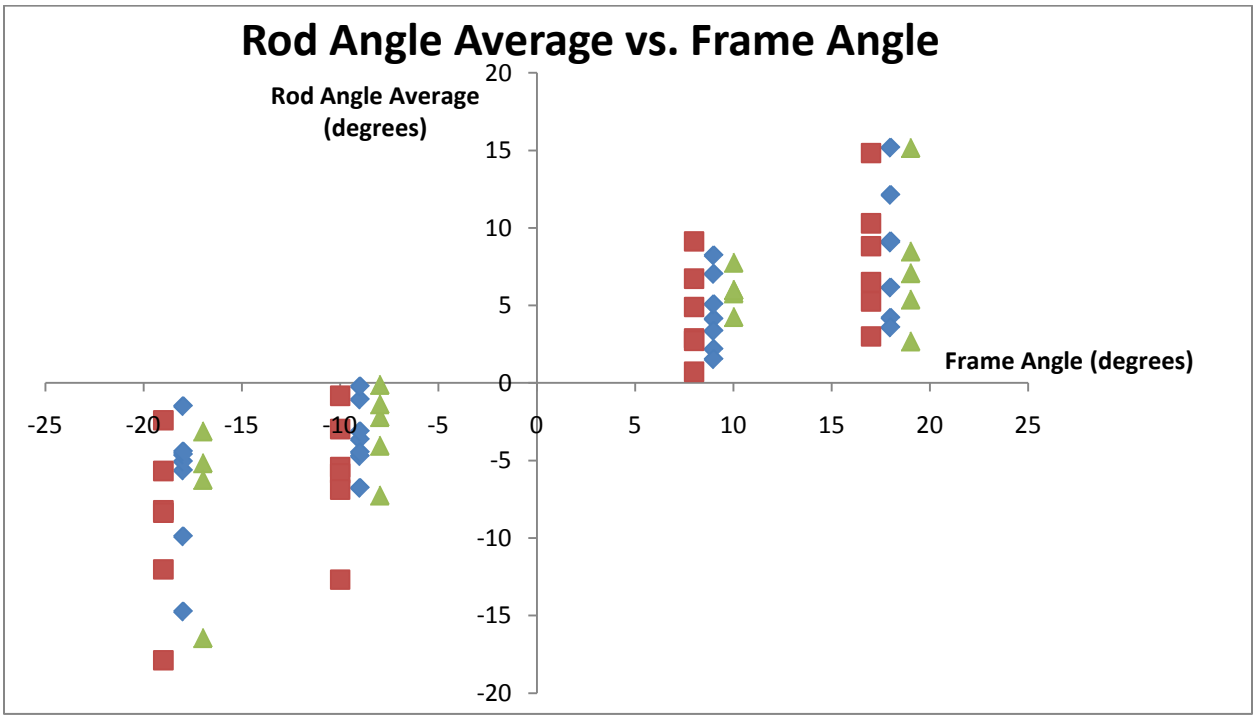

Figure 11: Rod Angle vs. Frame Angle Graph.
Neither chin support nor degree of frame tilted affected RFT scores.

As evident in the above graph, as for any given material, as the degree of Frame Angle was increased away from vertical (0°), the average rod adjustment was also shown to increase despite changes in material. There is no significant diffidence in the average rod from adjustment performed by the subjects across different materials. Whether foam, wood, or no material, the subjects' individual results, nor combined group results, differed significantly from one another. It was therefore suggested that the material below a subject's chin was not of great importance when being assessed for visual dependency with the RFT.

With respect to this same study, the results were also analyzed in terms of what degree of tilt of the frame would be best. As previously indicated, 18°, 9°, -9°, and -18° frame angles were all evaluated. As evident in the graph, subjects adjusted the rods with the same absolute error to vertical regardless of whether the reference frame angle was set initially to 18°, 9°, -9°, and -18°. It is evident that there are indeed some outliers, as some individuals performed with more accuracy if the frame was adjusted initially closer to 0°, but for the most part, there was no difference.

It is interesting to note through this testing that if the rod displayed was angled in a positive direction, final rod placements also were slightly positioned to positive, and vice-versa.

Material and Frame Angle Conclusions

Based on these results, it was decided that 18° and -18° would be selected for future experimentation, as previous studies (ref) had also selected these values. In addition, it was also suggested that the foam surface would be best suited for the experiment as it allowed the subject to place their chin in the right place to perform the experiment, but without a hard surface that could potentially bias the results. Thus, all subsequent pilot studies were conducted using foam as the material below a subject's chin, and ±18° were used as frame tilt angles.

Variables 3 & 4: Dot vs. Curtain, and Sequence of Frame Tilt

For this part of the pilot test, nine subjects were evaluated on three different RFT protocols, as described:

1) Subjects viewed four rods with the frame being tilted to 18°, followed by which they viewed another four rods with the frame being tilted to -18°. At beginning of each trial, and between each rod, a while dot appeared in the center of the screen.

2) Subjects viewed four rods again with the frame being tilted to 18°, followed by which they viewed another four rods with the frame being tilted to -18°. However, at beginning of each trial, and between each rod, a while curtain effect was displayed on the screen. (figure x).

3) Subjects viewed two rods with the frame being tilted to 18°, then two rods viewed with a frame tilt to -18°, then again two at 18°, and finally two rods at -18°. At beginning of each trial, and between each rod, the while curtain effect was displayed.

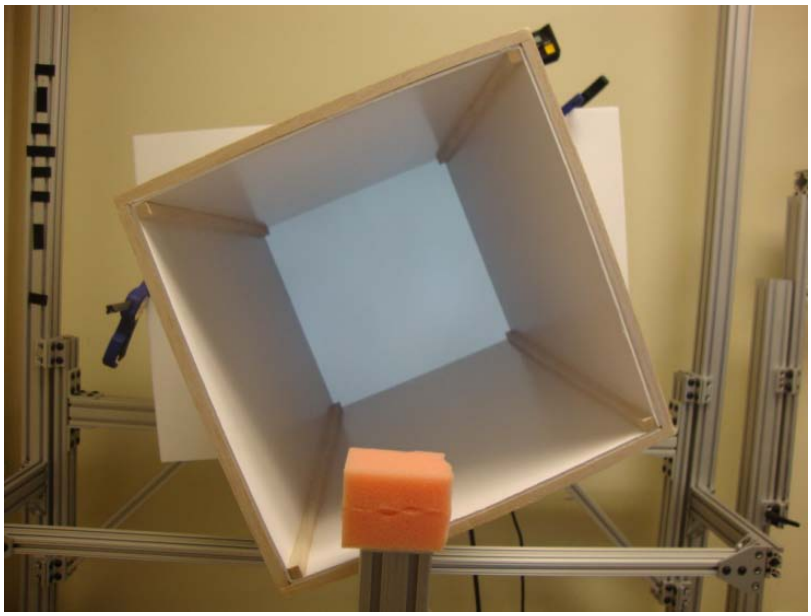

Figure 12: RFT with white screen to prevent afterimage effect.

These variations in protocol were conducted for a variety of reasons. The change of protocol from the frame being tilted four times or two times in a given direction was undertaken in order to understand if there were differences in results based on an individual's ability to become accustomed to viewing rods with the frame tilted to one direction through four rods. The two in the same direction protocol was designed to mitigate the subjects' potential ability to become used to aligning the rods from a given frame tilt angle.

The introduction of the curtain versus the dot when conducting the RFT arose from trials undertaken from the material pilot study, as described previously. Several subjects reported having an aftereffect of the previous rod on the subsequent rod. This phenomenon was suggested to potentially have a biasing effect on aligning the subsequent rod, as this may have introduced the possibility of aligning the subsequent rod to the previous rod, and not to one's own novel perception of vertical.

Results of Dot vs. Curtain, and Sequence of Frame Tilt

The following graph (Figure 13) displays the absolute deviation from vertical in degrees for each of the subjects. This data was obtained in the following manner:

1) For the first trial, indicated by blue markers on the graph (with white dot and where subjects viewed four rods with the frame being tilted to 18°, followed by which they viewed another four rods with the frame being tilted to -18°), data for the first four rods was average per subject, and data for the second four rods was also averaged per subject.

2) In the second trial, indicated by red markers on the graph (with curtain and where subjects viewed four rods again with the frame being tilted to 18°, followed by which they viewed another four rods with the frame being tilted to -18°), data was processed in the same manner as for the previous trial.

3) For the final trial, indicated by blue markers on the graph (with curtain and where subjects viewed two rods with the frame being tilted to 18°, then two rods viewed with a frame tilt to -18°, then again two at 18°, and finally two rods at -18°), data across -18° was averaged, as was data across 18°, despite the change of frame angle after two rods.

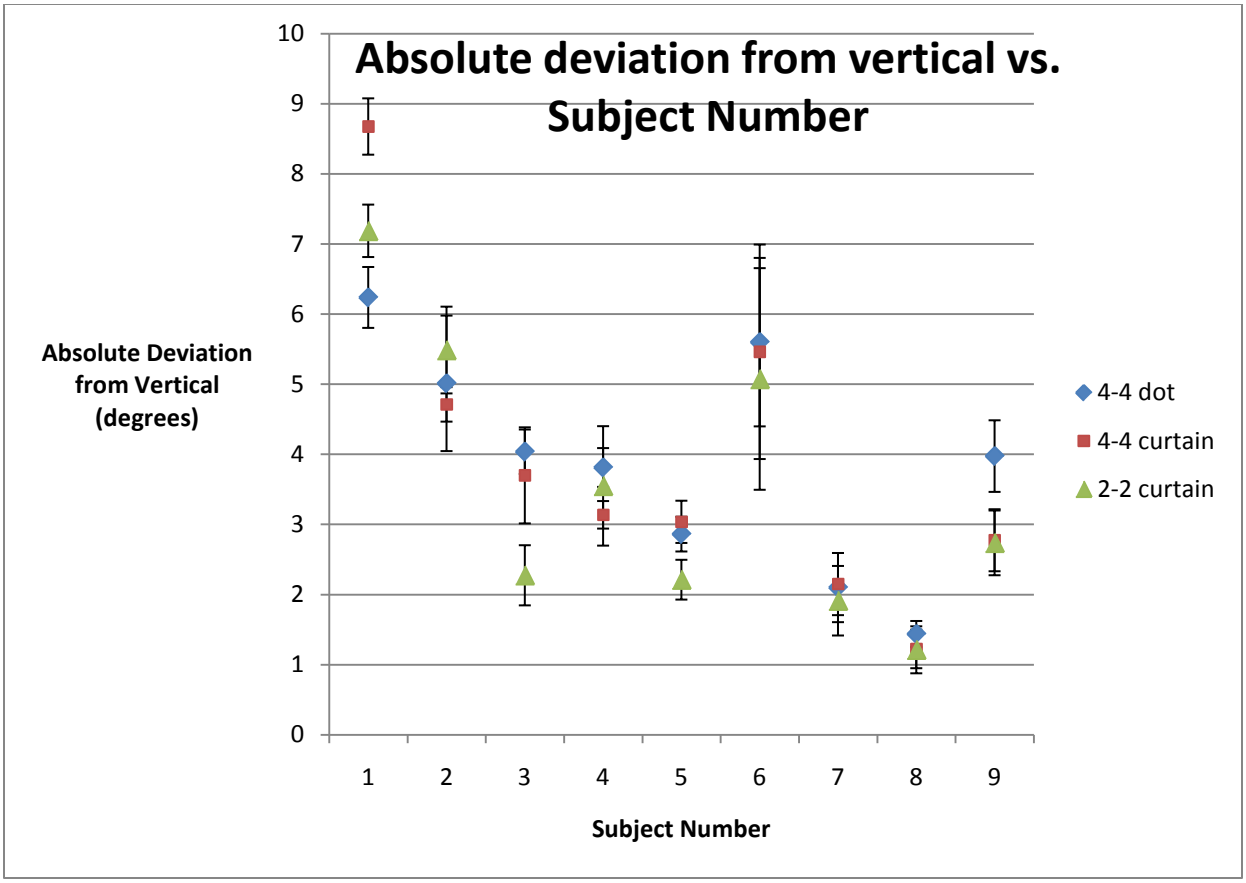

Figure 13: Absolute deviation for vertical vs. Subject number.

As displayed in the graph (Figure 14), for all conditions, the data suggests that there is no difference in the absolute deviation from vertical across all the subjects. Indeed, there are cases where it may seem that there may be a difference, such as for Subject #1, but in general, there is no trend for one set of conditions over another.

The following graph presents the Change in Rod Angle Average versus Subject Number for all nine subjects. All subjects have two entries on the graph, one to indicate their Change in Rod Angle Average at -18° frame tilt, and the other at +18° frame tilt.

Indeed, there are certain subjects who are able to align the rod to near vertical and therefore their change in rod angle average is decreased and presents itself as a shorter column on the graph.

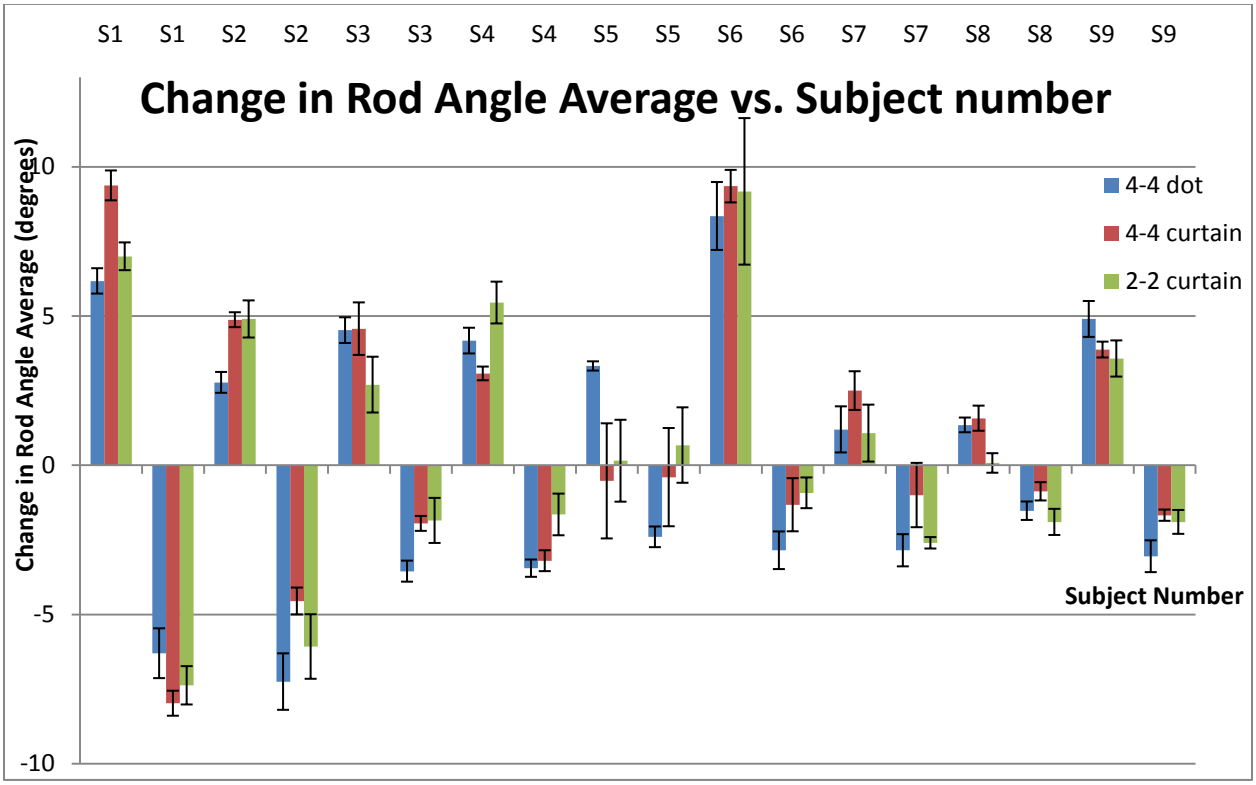

Figure 14: Change in Rod Angle vs. Subject Number. Generally, subjects' scores did not differ no matter the order of frame tilt or with the presence of a dot or white screen curtain effect.

In general, most subjects aligned the rod with a bias towards the side to which the frame was tilted. Subject #5, however, was able to align the rod very close to vertical for some of his/her trials, and as a result, went past vertical very slightly. Thus, this subject seemed to be able to adapt themselves to the tilted environment and end up with virtually perfectly aligned rods despite the ±18° frame tilt.

Dot vs. Curtain, and Sequence of Frame Tilt Conclusions

As discussed, there was no apparent difference in result across the nine subjects whether a dot or a curtain-like effect was displayed don the screen. Despite the effect of a rod after-effect reported by certain subjects, this issue did not seem to result in variations in subjects' ability to align the rods.

In addition, the sequence of frame tilt did neither seem to affect the ability of the subjects to align the rod. Whether the subjects were asked to align four rods with a given frame tilt sequentially, or two alignments in either direction, this presented no general trend as to one variation being better than the other.

Relationship between the RFT and the GEFT

It has been documented that there is a relationship between the RFT and the GEFT, as they both are assessments of an individual's visual dependency.

The results I obtained from the initial RFT test (using dot and four alignments in one direction) were analyzed with respect to the GEFT to see if there was an indeed a relationship between the two test scores.

For this analysis, time of completion was used to compare both tests. GEFT, though a test of visual preference, does not take in account the visuo-vestibular sensory integration as well as the RFT. It is clear that GEFT and RFT may contribute different aspects of visual preference by the negative linear relationship ($r = 0.39$) of the completed times represented in Figure 15.

Moreover, taking in to account the absolute average rod angles as a dominant measure of visual preference and the completion time of performing the GEFT (Figure 16) significantly displays no correlation. Thus, suggesting that RFT and GEFT measure different skills within the ability to use visual preference.

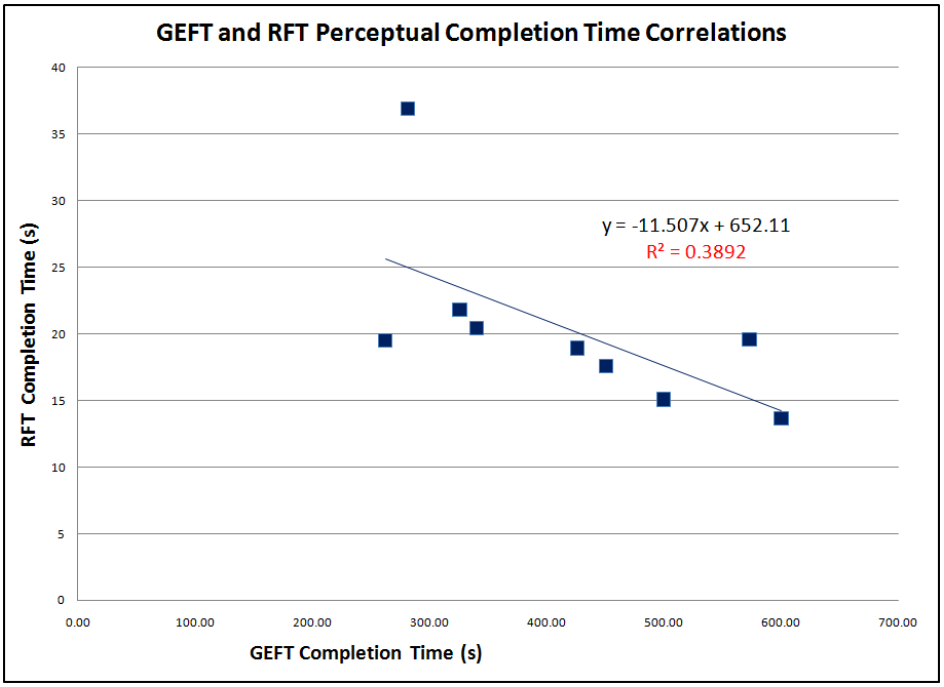

Figure 15: Correlation between GEFT and RFT Completion Times

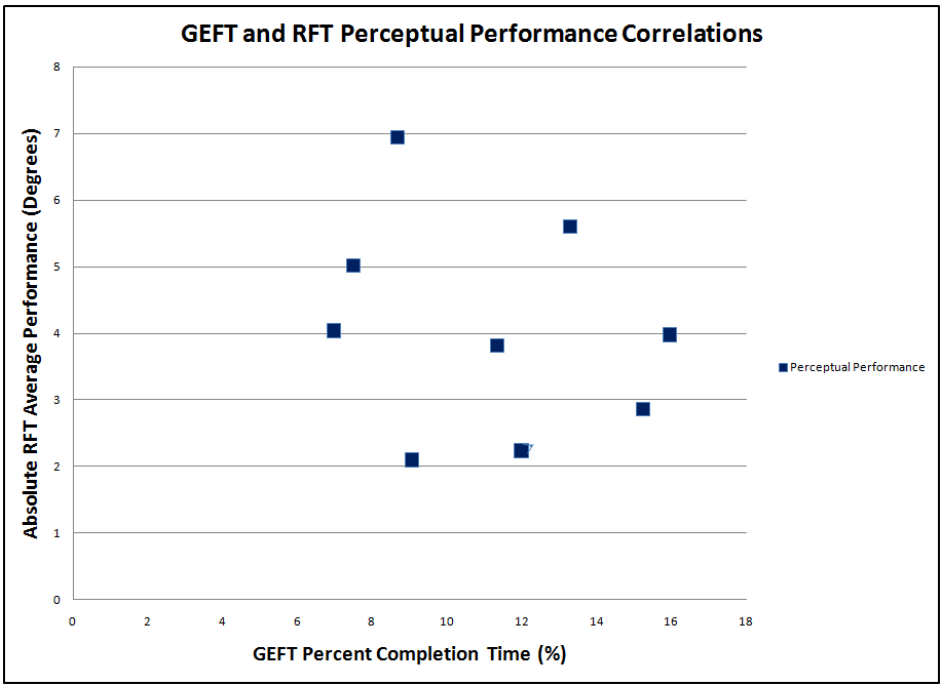

Figure 16: Correlation between GEFT and RFT Performance

RFT and Novel Visual Transformation

Once the RFT were complete, the laboratory was interested in understanding whether there was a correlation between the RFT and a novel visual transformation (ie a novel task). This information would be useful in understanding whether the RFT could serve as a predictor for one's ability to perform a new task.

We subjected subjects to two series of novel visual transformations: the Pegboard test and the Cube Construction test. The following sections describe these tests and their relation to the RFT.

The Pegboard Test

In the attempt to investigate one's ability to adapt to visual perturbations, the Pegboard test was conducted.

Nine subjects underwent the pegboard test (Figure 17), whereby their ability to place pegs in a board with and without visual impairment was assessed.

The pegboard is a white flat board, measuring xx by xx, with two columns of 25 vertical holes. The objective of this test was to measure the rate of inserting pegs into one of the vertical columns and to determine the difference in speed of completion when wearing sham goggles, versus maximizing goggles.

Five groups of five pegs each were placed surrounding the pegboard. The subject was instructed to close their eyes, to put first the sham goggles, and to place their dominant hand on the starting position, which was on the right of the pegboard for individuals who were right handed, and on the left for the converse.

Once instructed to begin, the subject would open their eyes, and take one peg from the first pile, and place it in the top hole, then a second peg from the second pile and place it in the second hole, and so on until 5 pegs (one from each pile) had been placed. The time to complete 5 five peg placements was recorded. Subjects were instructed to place their hand on the starting position following the placement of 5 pegs. This was performed 5 times, with the subject inserting a total of 25 pegs. The same procedure was repeated with maximizing goggles.

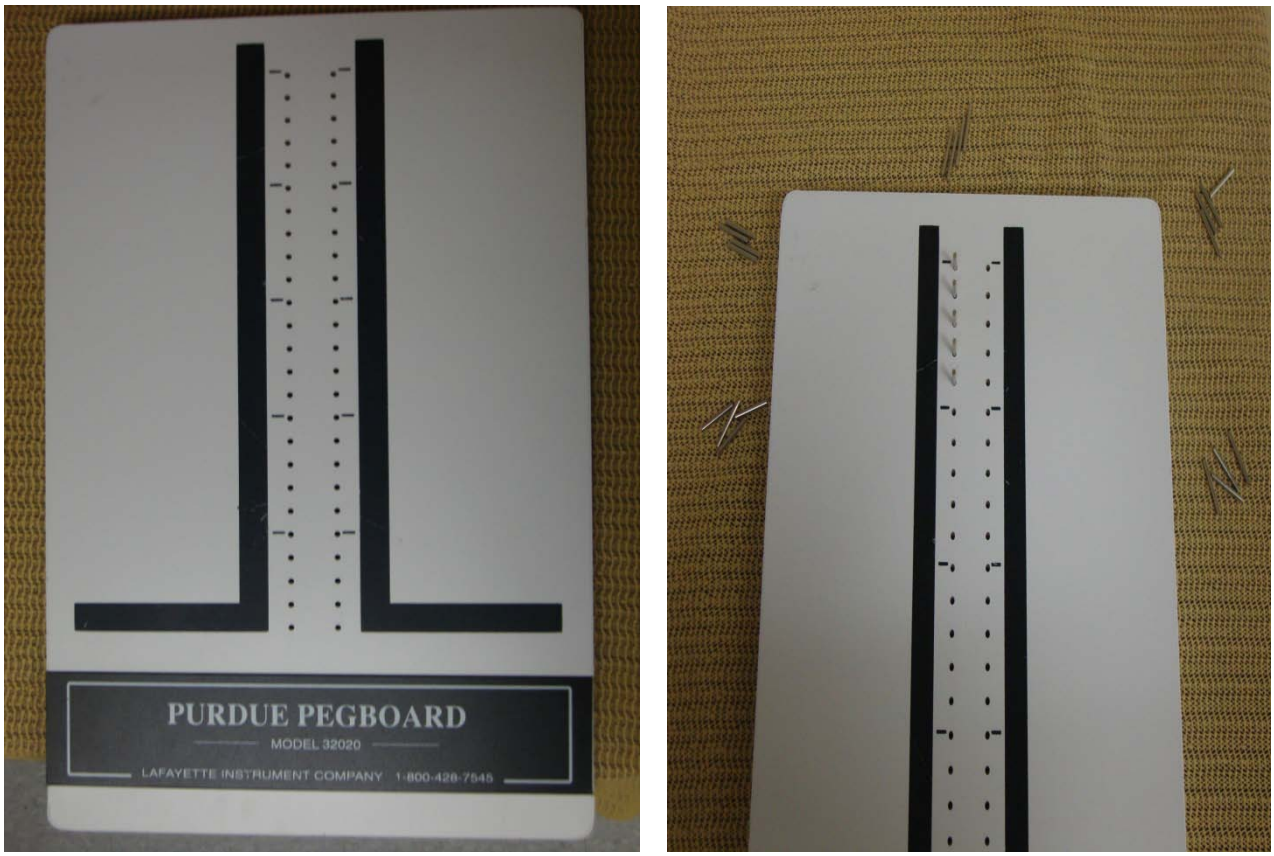

Figure 17: The Pegboard Test

Results of the Pegboard Test

The following graph (Figure 18) is the results obtained from one of the subjects, although all subjects displayed generally the same results. As indicated, individuals performing the task with wearing sham goggles were constant in the time it took them to complete the task. Conversely, subjects wearing the maximizing goggles had an initial time to complete that was longer, and were generally able to adapt with each subsequent trial. Importantly, subjects did not reach the same low completion times as their sham goggle counterparts, but it is likely that had the number of trials increased, their completion times would have continued to decrease.

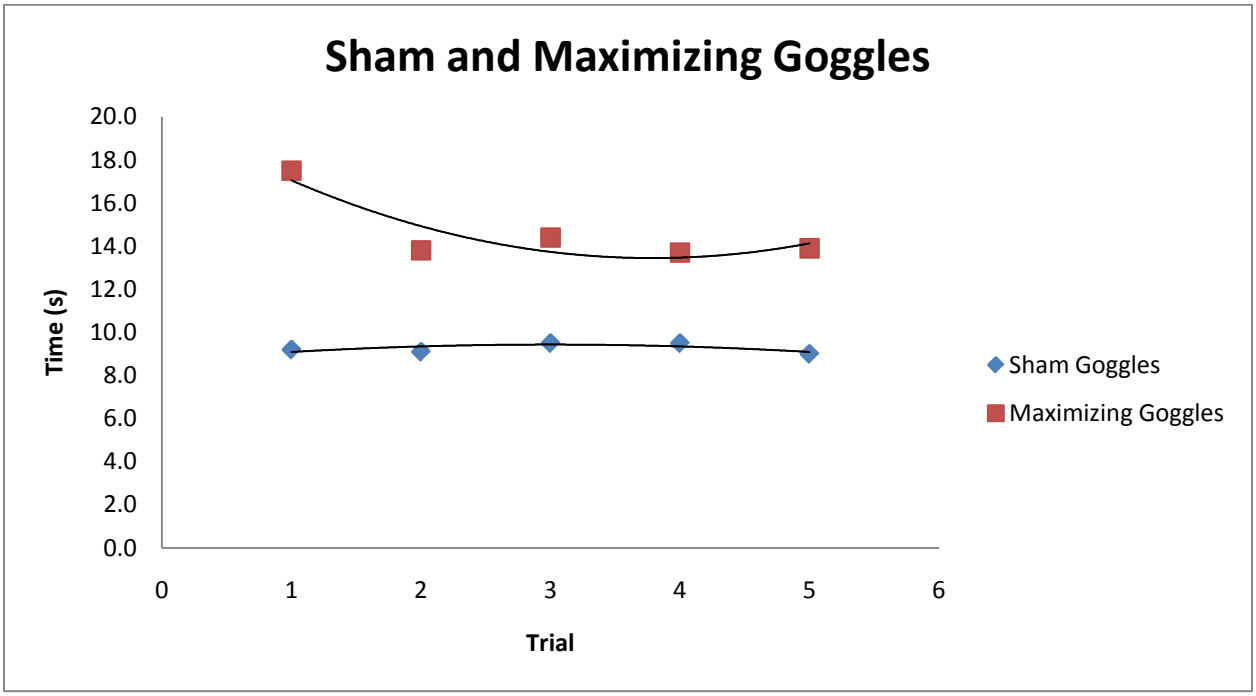

Figure 18: Graph showing Adaptability over time with Pegboard Test

Cube Construction Test

Nine subjects underwent the cube construction test (Figure 19) whereby they were required to construct a cube using rods and connectors while wearing first sham, and then minimizing goggles. Their times of construction were recorded following each construction. This test was performed to assess if a learning curve exists between individual trials, as well as the adaptability of the subject to a new visual environment, and his/her dependence on vision for task completion.

To begin, subjects were asked to assemble the cube 5 times with no goggles in order to familiarize themselves with the different cube pieces. Their times were not recorded.

Next the subjects were asked to close their eyes and put on the sham goggles. The subjects were instructed to open their eyes, and were required to construct the cube 5 times. Their time to complete was recorded after every trial. The subject was given a 2 minute rest period following the construction of these 5 cubes.

The same procedure was done a second time, with the subject wearing maximizing goggles.

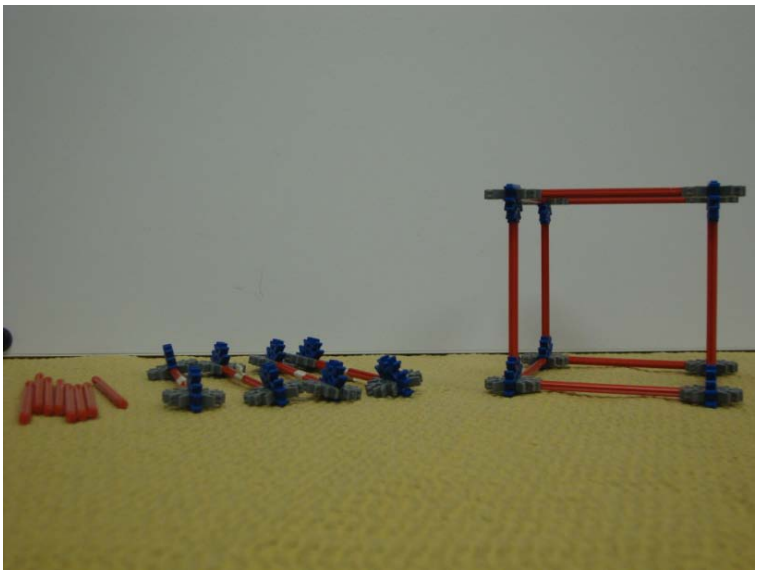

Figure 19: The Cube Construction Test

Results of the Cube Construction test

The following graph (Figure 20) is the results obtained from one of the subjects, although all subjects displayed generally the same results. As indicated, individuals performing the task with wearing sham goggles were constant in the time it took them to complete the task. Conversely, subjects wearing the minimizing goggles had an initial time to complete that was longer, and were generally able to adapt with each subsequent trial. Compared to the Pegboard test, the adaptability is quite pronounced, with this particular subject adapting completely by the fifth trial.

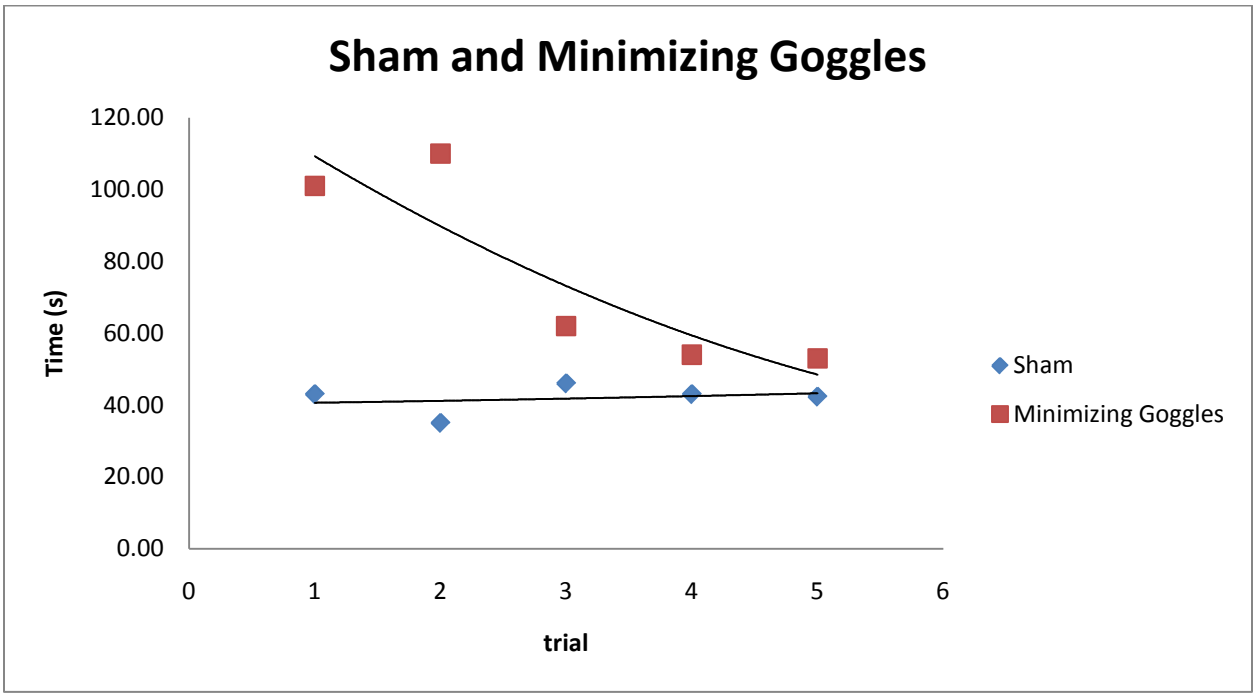

Figure 20: showing Adaptability over time with Pegboard Test

RFT, Pegboard, and Cube Construction

When the RFT scores were correlated with both the Pegboard test times and the Cube Construction test times, respectively, interestingly, the results reveal that there is a correlation between the RFT and the Cube Construction test, with an r^2 value of 0.767 (Figure 21). This result suggests that the RFT is able to predict how an individual will perform on the Cube Construction test.

Alternatively, no such correlation existed between the RFT and the Pegboard test. It is suspected that the Pegboard test was too easy for the subjected to perform, and thus did not actually assess their adaptability on this novel visual transformation.

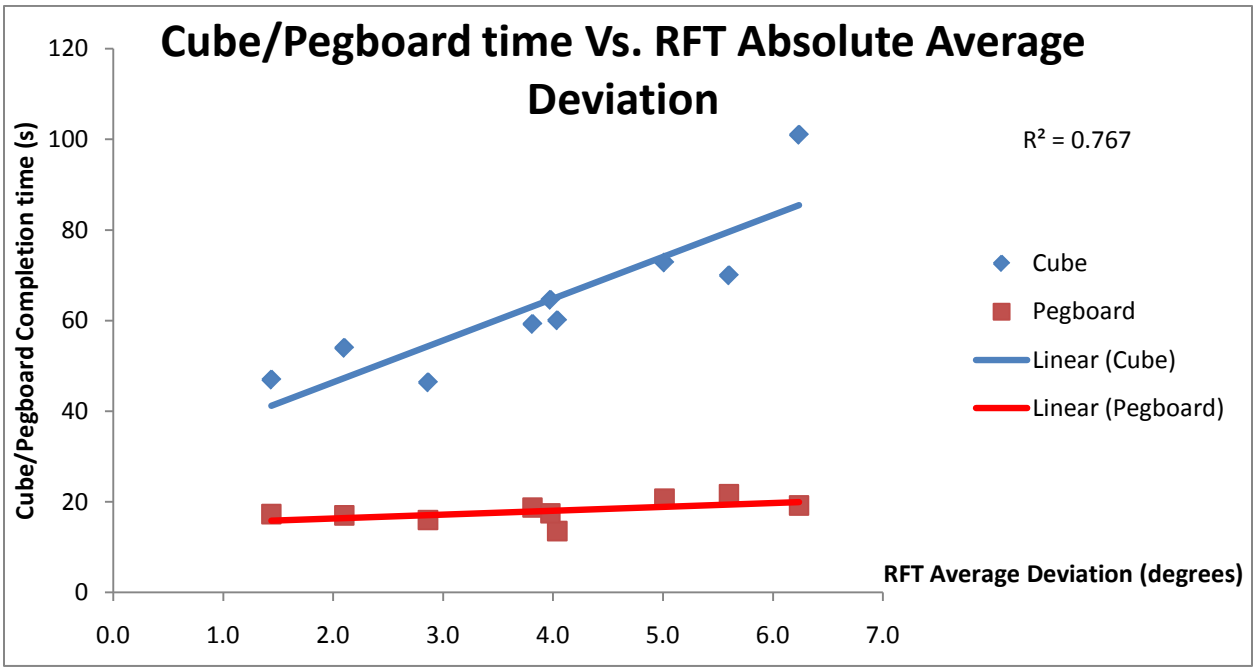

Figure 21: Correlation of RFT with Cube Construction, and with Pegboard Test.

CHAPTER III

CONCLUSION

Understanding the ways in which individuals adapt to their surroundings is of utmost importance whether in space flight, or in one's everyday tasks. As described previously, individuals typically show signs of sensory bias in their everyday lives, favoring one, or some, of their senses above others.

In terms of astronaut training, the Neuroscience Laboratory has focused its research on training designed not only to assure that astronauts remain in good health while during their mission, but also conduct investigations that aim to improve an individual's ability to adapt to any environment.

Studies to further understand the benefits of adaptability training are currently underway in the Neuroscience Lab. As previously discussed, the Visual Locomotor Treadmill is an effective way in which to train individuals to adapt t a variety of different challenges. It also allowed for the assessment of an individual's visual dependency, as individuals who were evaluated as being visually independent performed better than their visually dependent counterparts, since their performance on the moving treadmill was more stable.

Adaptability Training

Training with task variability along with exposure to repeated sensorimotor adaptive challenges leads to faster adaptation to new environments and readaptation to the normal environment. Adaptive generalization of motor skills can be enhanced through training including both manual control (Welch et al. 1993; Roller et al. 2001; Bock et al. 2001; Seidler, 2004; Shadmehr and Moussavi, 2000; Stroud et al. 2005) and locomotion (Lam and Dietz, 2004; van Hedel et al. 2002; Cohen et al. 2005). This type of training is effective in rehabilitating patients with balance control problems (Pavlou et al. 2004; Suarez et al. 2006, Silsupadol et al. 2006), gait disturbances (Baram and Miller, 2006; Fung et al. 2006) and manual control and perceptual-motor disturbances (Holden, 2005; Rizzo et al. 2004; Adamovich et al. 2004; Krakauer, 2006). Other work has shown adaptive generalization to the same sensorimotor arrangements while performing a criterion task that has critical features that are different from the training task such as prism adaptation during walking generalizes to reaching, (Morton and Baastiance, 2004); from a pointing task to a tracking task and vice versa (Abeele and Bock, 2003). These studies and other work all support the notion that performers who practice solving a class of motor problems improve their ability to adapt or "learn to learn". Hence, they may learn to generalize better than performers who practice generating only one solution.

By applying these concepts for training astronauts we can enhance their ability to adapt to new gravitational environments (Bloomberg et al. 2001). A training program exposing crewmembers to variation in sensory input and balance challenges with repeated adaptive transitions among states will enhance the ability to learn how to assemble and reassemble appropriate motor patterns in novel sensory environments. The central nervous system (CNS) can produce voluntary movement in an almost infinite number of ways. For example, locomotion can be achieved with many different combinations of joint angles, muscle activation patterns and forces. The CNS can exploit these degrees of freedom to enhance motor response adaptability during periods of adaptive flux like that encountered during gravitational transitions. Ultimately, the functional goal of SA training is not necessarily to immediately return movement patterns back to "normal". The training program should facilitate the process of adaptive re-assembly of available sensory and motor sub-systems to achieve immediate performance goals.

Final Outcomes

For my research project, I also performed tests that assessed individual's visual dependency via the RFT, and investigated whether the results of these tests could be correlated to the results of a novel visual transformation task. Essentially, it was hypothesized that individuals that were more visually dependent would have a longer time to complete the novel visual transformation tasks.

Before correlating the RFT to the novel transformation task, studies conducted revealed the following:

- Head position cues did not alter RFT performance;
- Initial visual test conditions did not alter RFT performance.

Furthermore, it was also demonstrated that subjects gradually adapted to both the Pegboard Test and the Cube Construction tasks despite their impaired vision.

Importantly,

- Individual visual dependency correlated with ability to adapt to a novel visual distortion for the cube task. Subjects with higher visual dependency showed decreased ability to adapt.

Moreover,

- The RFT may serve as an effective prediction tool to produce individualized adaptability training prescriptions that target the specific sensory profile of each crewmember.

Final Conclusion

The results in this report indicate that indeed adaptability training is a necessary and useful method to prepare astronauts for space missions. By using the RFT in concert with novel transformational tasks, it is now suggested that predications can be made regarding which individuals would benefit most from adaptability training and vision.

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