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A Comparison of Gestures for Virtual Object Rotation

Brandon Michael Garner
Brigham Young University

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Brandon Michael Garner

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Master of Science

Derek L. Hansen, Chair
C. Richard G. Helps
Seth R. Holladay

School of Technology

Brigham Young University

ABSTRACT

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Brandon Michael Garner
School of Technology, BYU
Master of Science

The fields of virtual reality and gesture-based input devices are growing and becoming more popular. In order for the two technologies to be implemented together, an understanding of gestures in relation to virtual objects and users' expectations of those gestures needs to be understood. Specifically, this thesis focuses on arm gestures for the rotation of virtual objects.

Participants in the study were first asked to freely perform an arm gesture they felt should execute a task. Next, participants were asked to perform specific rotation tasks with pre-configured arm gestures on four objects. There were two types of objects: those that could only be rotated on one axis and those that could be rotated on two axes. Each object type was represented by a familiar small and large object: combination lock, water wheel, baseball and beach ball. Data on how quickly they could complete the rotation tasks was collected. After performing the tasks on each of the four objects, participants were asked to rate the intuitiveness of each gesture as well as their preferred gesture for the specific task.

The captured data showed that when users were presented with virtual representations of familiar physical objects, most of them expected to rotate the objects with the same gestures they would use on the actual physical objects. Considering 1-axis objects, an arm-based twist gesture outperformed other arm-based gestures in both intuitiveness and efficiency. Also with 2-axis objects, an arm-based horizontal/vertical gesture outperformed others in both intuitiveness and efficiency. Interestingly, those gestures were most efficient for each object type regardless of the size of the object being rotated. This would indicate that users are able to mentally separate the physical and virtual experiences. Larger objects require different rotation gestures than smaller objects in the physical world, but that requirement is non-existent in a virtual world. However, while the mind can separate between the physical and virtual worlds, there is still an expected connection. This is based on the fact that the gestures most preferred for the rotation tasks are the same gestures used for similar physical tasks.

Keywords: gestures, rotation, virtual reality, Unity, Oculus, Myo

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1 INTRODUCTION

1.1 Overview

Virtual reality is a growing field of interest as the Oculus Rift, Samsung's PlayStation VR, Google Cardboard and Google's Daydream are gaining traction. There are many applications for virtual reality from the gaming realm to the medical space. For example, medical professionals have used virtual reality in preparing for and carrying out robotic surgery. With technologies like Microsoft's Kinect, Nintendo Wii, and Thalmic's Myo, the use of gestures is becoming more prevalent as well, however, they may vary in their fields of use. The Kinect can detect gross motor, full-body movement, while the Wii and Myo can detect a combination of gross and fine motor skills. The combination of virtual reality and gestures has enabled medical professionals to manipulate virtual models that make impossible surgeries possible. This technology mixture has unforeseen potential, but there are challenges to overcome for it to be effective.

1.2 Rotational Challenge

One of the challenges of combining virtual reality with gestures is creating a user experience that is intuitive, accurate and efficient. Rotating objects in the real world is done quickly and intuitively. Touching a physical object not only provides a physical perspective of the rotational state, but also a form of feedback while rotating due to weight, position, etc. When users put on a virtual reality headset, they step into a new world where they are unable to physically touch or manipulate the environment they see. In the real world, different types of objects also bring with them different expectations for interaction. For example, people faced with a steering wheel likely expect to rotate it with their hands differently than they would expect to rotate a combination lock. For virtual reality to be most successful, gestures need to be identified that can be intuitive while maintaining speed of execution for virtual object rotation. The purpose of this research is two-fold:

- Identify how the appearance of a physical object affects how users expect to interact with a virtual representation of that object.
- Identify which arm-based gestures are most intuitive and efficient when rotating objects on one and two axes.

1.3 Research Objectives

This research work focusses on the rotational challenges faced with using gestures in conjunction with virtual reality. Here is a list of objectives and questions this research attempts to answer:

- Research Objective 1 (RO1): Develop a system using Unity and the Oculus Rift that allows users wearing the Myo input device to rotate virtual objects, using multiple gestures, along 1 or 2 axes. The system will support an experiment that will evaluate the efficiency of task completion for various virtual objects and scenarios.
- Research Question 1 (RQ1): What is the relationship between the appearance of a virtual object (e.g., a lock or a wheel) and the gesture used to rotate it?
    - Hypothesis 1: Users will attempt to rotate virtual objects using the same gestures they use on the comparable physical object (e.g. they would expect

to “spin” a lock, “turn” a wheel, “palm” a baseball, and rotate a large exercise ball).

- Research Question 2 (RQ2): Which of the following arm gestures are more efficient and intuitive for rotating virtual objects on 1 and 2 axes:
    - Gestures to rotate objects on 1 axis:
        - Arm movement across the horizontal plane in front of the body
        - Arm movement across the vertical plane in front of the body
        - Arm-twisting movement, without horizontal or vertical movement, in front of the body
    - Gestures to rotate objects on 2 axes:
        - Arm movement across the horizontal and vertical planes in front of the body
        - Arm movement across the horizontal plane in front of the body and arm twisting movement in front of the body
        - Arm movement across the vertical plane in front of the body and arm twisting movement in front of the body
- Research Question 3 (RQ3): Is there a common gesture-set across users or are there different gestures that work better for different users?

1.4 Thesis Outline

Chapter 2 outlines related literature on virtual reality, gestures and the technologies used. Chapter 3 outlines the methods used to address the research questions, including a description of the experimental design. Chapter 4 presents the findings of the experiments. Chapter 5 discusses the results and implications.

2 LITERATURE REVIEW

2.1 Overview of Gestures and VR

The combination of gestures and virtual reality can provide new opportunities in video games and the medical field. In video games, virtual reality is already a booming business and gestures, separately, have been growing (e.g. Xbox Kinect, Wii, etc.). Adding gestures to virtual reality enables the player to experience the game on a whole new level. If gestures are intuitively integrated into the games, players can feel more a part of the game by more naturally interacting with the environment.

Combining gestures with virtual reality can also enhance the medical field. Recently, a little girl was born with a heart and lung defect that was never before seen by doctors. Almost all of the left half of her heart was missing. The hospital would normally print a 3D model of the heart in this situation in order to determine the best surgical procedure, but at that time the printer was broken. With the hospital's 3D printer broken, doctors turned to a Google Cardboard to view the girl's heart and decide how to perform an operation to improve her chances of survival. Using a Google Cardboard, the doctor could move around and see the heart from every angle. Once the operation began, the doctor was already very familiar with the physical situation and knew just what to do. Virtual reality in this case made it possible for medical professionals to save the life of the little girl. (Cohen, 2016)

Enabling the use of gestures has also been advantageous in the operating room. Surgeons often need to review their plans during the operation and cleanliness is vitally important in the operating room. For a doctor to clean off his hands, take off the gloves and review their notes just to clean their hands again to get gloves back on to return to the operation, it takes a lot of time that could be the difference between life and death. Research has been conducted in an effort to propose a gesture set "to support basic interaction tasks with radiological images and 3D models." (Hettig et al., 2015) In one case, the Myo armband is being used along with the ADORA Assistant to provide surgeons with an ability to view patient data and images while performing an operation. This reduces risk of infection as well as time needed for anesthesia. (Elaine, 2016)

Remote, robotic surgery is already made possible with the da Vinci Surgical System. The surgeon can be across the room or across the ocean, but they are required to use a console with physical input devices they must hold in their hand. Combining gestures with virtual reality, surgeries could potentially happen remotely with a smaller or non-existent console. A smaller system could increase portability as well as the number of locations it could be used from.

Although these and other promising application areas exist, there are many basic things we do not yet know about how to interact with virtual objects. Researchers are exploring basic interactions such as how to navigate through a virtual space (Cabral, Morimoto, & Zuffo, 2005), how to select virtual objects (Argelaguet & Andujar, 2013), and how to interact with other people in a virtual space (Steuer, 1992). This research will focus on another basic interaction technique that has widespread applicability in virtual reality – namely, how to rotate objects.

2.2 Relevant Research

While researchers have examined virtual reality interactions, as well as rotation techniques, they have rarely been examined together. There are also several papers that discuss how gestures are evaluated, or how test scenarios are effectively created. The following is a list of relevant research or publications used to direct this research.

2.2.1 Frames of Reference in Virtual Object Rotation

Ware and Arsenault conducted research to analyze virtual object rotation using a physically movable input device, similar to a mouse or a joystick. In their research, however, they took steps to hide the object and the research subject's hand from view while solely making the virtual object visible. Figure 2-1, copied from Ware and Arsenault's work, shows the example of how their test environment was set up.

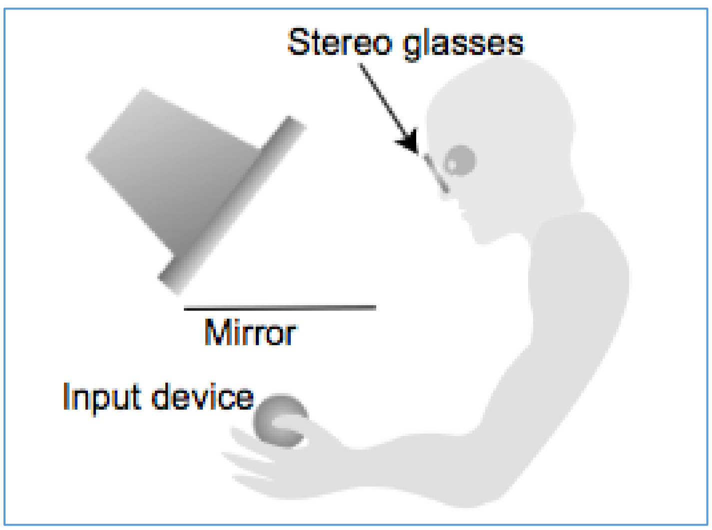

Figure 2-1: Example of the Physical Object Hidden from View

This setup required the user to operate based on feeling rather than a visible reference. The research study in this work does not use palpable objects, but does hide the research subject's arm from view in order to remove the chance of visible reference. Additionally, the subject was asked to rotate the object to a particular orientation. (Ware & Arsenault, 2004) Modeled after the work done by Ware and Arsenault, the research in this thesis used of the Oculus Rift to hide the physical world from the subject, removing the visible reference. This research also required the subjects to rotate the virtual objects to a specific position.

2.2.2 Gesture Recognition Devices

Visual-based (also referred to as camera or vision-based) gesture recognition has been around for several years in many different stages of maturity. Pavolvic, Sharma and Huang describe the difficulties for this type of gesture recognition. One of the challenges they discuss is the need for fast computing that makes real-time vision processing feasible. (Pavlovic, Sharma, & Huang, 1997) Vatavu, Daniel, Pentiuc and Chaillou also mention in their work in 2005 that "camera based or vision trackers make use of video information and video based processing to achieve object tracking." They also point out that a downside to camera based or vision trackers is that "they demand a lot of processing power and depend on computer vision algorithms very much currently under development." (Vatavu, Pentiuc, & Chaillou, 2005)

Three years after Pavolvic, Sharma and Huang published their research, Microsoft released the Kinect, which was based on infrared and camera technology. ("Kinect," n.d.) A Kinect was used during the initial investigation into this research and it was also very processor intensive. It struggled differentiating between certain hand position, such as palm up or palm down when the thumb is not extended. For the purposes of this research, an input device was needed that required less processor power and could more accurately determine certain arm positions.

In 2009, Zhang, Chen, Wang, et al. created an armband device that utilized both electromyography sensors and a 3D accelerometer to realize user-friendly interaction between humans and computers. The sensors allowed the computer to detect hand-gestures as well as arm motions. The authors explain that while vision-based systems can detect gestures, they are affected by ambient lighting as well as background texture. In their experiments, the overall gesture recognition accuracy of the armband was about 91.7% in real application, which is far better than vision-based systems when lighting and backgrounds are not optimal. (Zhang, Chen, Wang, & Yang, 2009)

Only a few years later, a company by the name of Thalmic Labs produced a similar wireless product that is now commercially available. They call it “Myo”. For the purposes of the research in this thesis, a Myo was acquired and implemented as the gesture recognizing input device. More detail regarding the Myo is provided in section 2.3.1.

2.2.3 Assessing Users’ Gestures

The creation of any user interface often benefits from user testing to measure intuitiveness, efficiency, accuracy, etc. When defining gestures for interacting with a virtual world, however, gathering user input can be beneficial if done earlier in the process. For example, in a study done by Ruiz, Li and Lank, test subjects were asked to design and perform a motion gesture that could be used to execute a task with a mobile phone. Smart phones contain sensors that can monitor their three-dimensional movement. Utilizing the smart phone as the input device, test subjects performed gestures that were recorded. The results were later analyzed and common gestures were discovered between the test subjects. (Ruiz, Li, & Lank, 2011)

Wobbrock, Morris and Wilson highlight the need to involve users when creating gestures for computer interaction. In their research, "the final user-defined gesture set was developed in light of the agreement participants exhibited in choosing gestures." In other words, "the more participants that used the same gesture for a given command, the more likely that gesture would be assigned to that command." To gather the most accurate data possible, users were surveyed immediately after performing each gesture. They were asked to rate the gesture on two Likert scales to determine the ease of performance and whether it was a good match for the task. Interestingly enough, Wobbrock, Morris and Wilson state that, "a surprisingly consistent collection founded on actual user behavior" emerged from their testing. (Wobbrock, Morris, & Wilson, 2009)

Both research studies found that involving users in the gesture defining process, rather than only testing the effectiveness of gestures after being defined, helped identify gestures that were common across users. That commonality produced gestures more likely to be successful when implemented for executing a specific task.

In an effort to answer RQ1 of this study, the test subjects were presented with tasks and then asked to freely perform gestures they felt would accomplish the tasks. Those gestures were recorded for further analysis to determine if a common gesture set would emerge.

Later, pre-defined gestures were presented and test subjects were asked to perform those specific gestures. In the study by Wobbrock, Morris and Wilson, they also asked their participants to rate a set of pre-defined gestures on a scale to indicate whether they were "good matches" or "easy to perform". To get the test subject's perspective on the intuitiveness and effectiveness of each gesture, this research study also asked each test subject to rate their experience with each gesture on a scale.

2.3 Technologies Used in this Research

The technologies utilized in this research study include the Myo, Oculus Rift and Unity and they are described in the following subsections.

2.3.1 Myo

Thalmic Labs created a wireless armband, the Myo, that is worn on the forearm just below the elbow. The armband contains the following technology:

- Medical grade stainless steel electromyography (EMG) sensors
- Nine-axis inertial measurement unit (IMU) containing the following sensors:
    - Three-axis gyroscope
    - Three-axis accelerometer
    - Three-axis magnetometer
- ARM Cortex M4 processor
- Haptic feedback via varying length vibrations
- Bluetooth for real time data streaming to another device

The Myo can detect gestures (discrete input) and orientation (continuous input) data because of its specialized, embedded sensors. The EMG sensors can detect electronic signals that cause muscles to contract. (Mayo Clinic Staff, n.d.) Those signals are used to determine which hand gestures are being made from a set of pre-programmed, recognizable gestures. (Thalmic Labs, n.d.)

This research study utilizes only the gyroscope sensors in the IMU to detect arm motion and rotation.

2.3.2 Oculus Rift

The Oculus Rift DK2 headset was used to provide the visual experience. Similar to the research environment described in section 2.2.1, the Oculus hides the physical world from the test subjects in this research while providing a depth-relative view of the virtual world. (Oculus, n.d.)

2.3.3 Unity

The Unity game engine (version 5.3.4p1) was used to develop the environment in which the test subjects experienced the virtual world. Virtual objects were developed in third party software, such as Blender, and then imported into Unity. Support for the Oculus Rift was built into Unity and the Myo had a plugin that could be loaded in order to obtain gyroscope data. (Technologies, n.d.)

3 METHODS

3.1 Overview of Research System

To address the research questions outlined in chapter one, I conducted a within-subjects comparison of the performance of different rotation methods as outlined in later sections.

To conduct the experiment, as described in RO1, a system was developed using Unity, Oculus Rift and Myo to address the research questions. The test subject was seated in front of a computer screen while wearing the Oculus Rift and the Myo armband as shown below in Figure 3-1.

Figure 3-1: Research System Setup w/ Left-handed Participant

Four virtual objects were presented to the test subjects at different stages and each object had three separate controlling gestures. Each test subject experienced all possible combinations of objects and gestures, but in random orders.

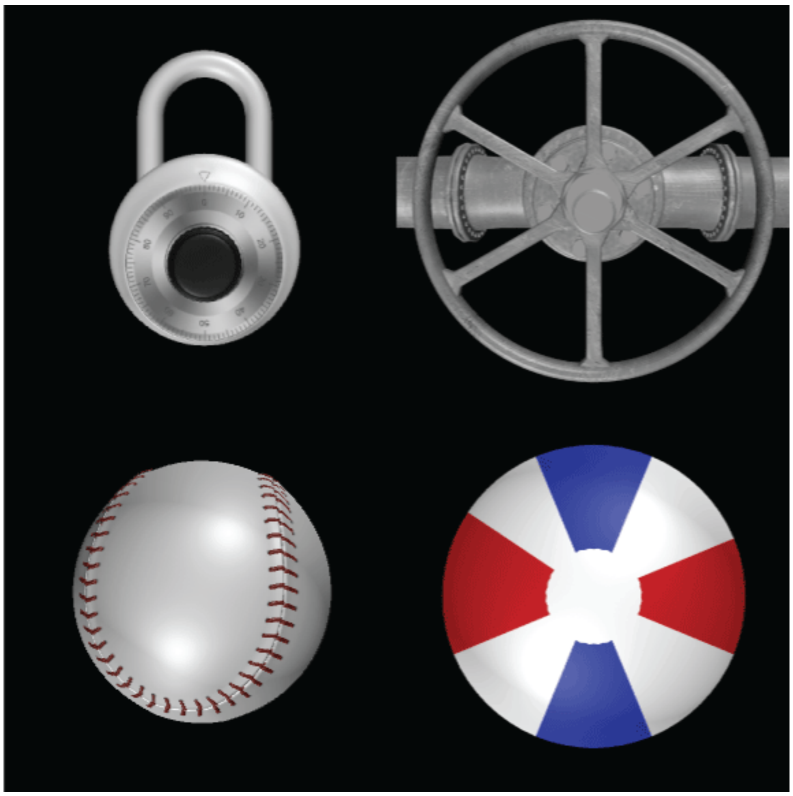

Figure 3-2: Virtual Objects--Lock, Water Wheel, Baseball, Beach Ball

The four virtual objects were acquired from various sources: combination lock (Lyons, 2015), water wheel (Green, 2015), baseball (Walentin, 2013), and beach ball (dotcom461, 2012). The combination lock and the water wheel were chosen because they only rotate on one axis. The baseball and beach ball were chosen because they rotate on two axes. The combination lock and the baseball are smaller objects than the water wheel and the beach ball, which requires different physical movements to rotate in the real world.

3.1.1 Explanation of Gestures and Object Axes

In the experiment, there are only three gestural axes with which the subject can control the object (Figure 3-3):

- Arm movement across the horizontal plane in front of the body – this will be referred to as a horizontal gesture.
- Arm movement across the vertical plane in front of the body – this will be referred to as a vertical gesture.
- Arm twisting movement, without horizontal or vertical movement, in front of the body – this will be referred to as a twist gesture.

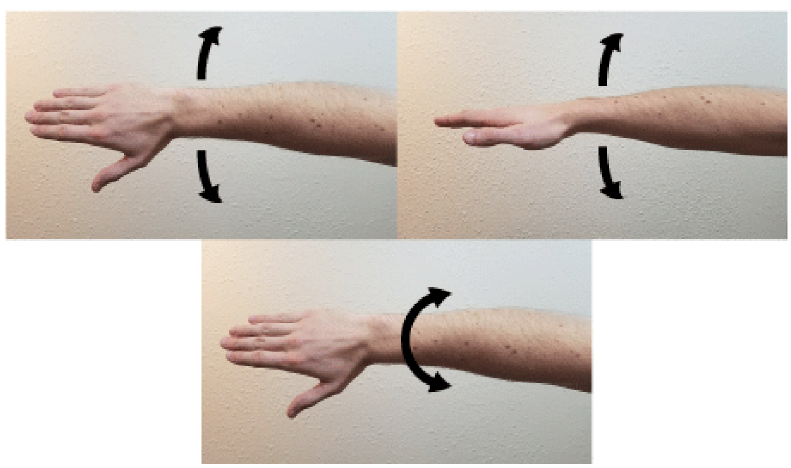

Figure 3-3: Gestures—Horizontal, Vertical & Twist

There are also two different types of objects with specific movement constraints:

- 1-axis rotational objects – these objects will only rotate around one axis:
  - Around the axis outwardly perpendicular to the test subject – this will be referred to as the object's z-axis (Figure 3-4).

Figure 3-4: Rotation Around Object's Z-Axis

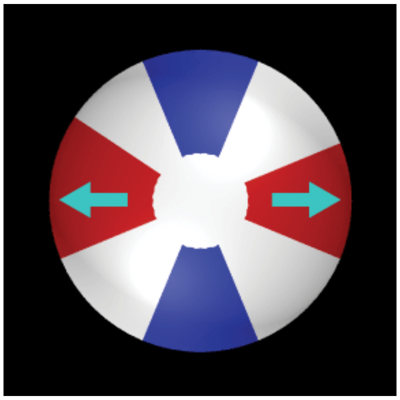

Figure 3-5: Rotation on Object's X-Axis

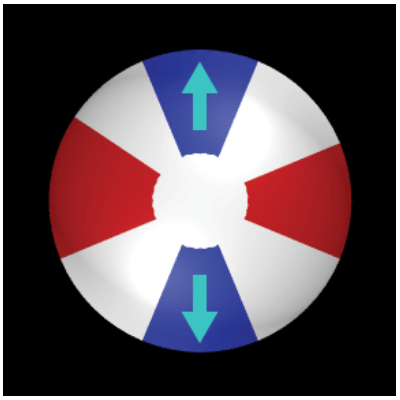

Figure 3-6: Rotation on Object's Y-Axis

- 2-axis rotational objects – these objects will only rotate around two axes:
  - Left and right, or horizontally – this will be referred to as the object's x-axis (Figure 3-5).
  - Up and down, or vertically – this will be referred to as the object's y-axis (Figure 3-6).

3.2 Recruitment Methods

A convenience sample was sought after, which included diversity in age, gender and technical experience/prowess. Only people of ages 18 or older were invited to participate, in line with our Institutional Review Board (IRB) approval. An email was sent to various friends, neighbors, family members, students, faculty members, etc. and recipients were encouraged to forward the email on to others that may be interested. An extra credit opportunity was also provided in a few Information Technology classes should any students in those classes be willing to participate. This specific recruitment method provided for some younger individuals with potentially more technical prowess and experience than the other recruitment methods. Word of mouth was also used as a recruitment method by providing verbal invitations to friends, neighbors, and people passing by the areas where the experimentation was occurring. Each person that expressed a desire to participate in the research was provided with a scheduled time in which they could participate at a pre-determined location.

Because of the novelty of the experience, many people expressed interest and no additional incentive was necessary. Recruitment continued until a total of 50 participants completed the experiment.

3.3 Experimental Procedures

The experimental procedures were discussed with Dr. Hansen and beta-tested on two individuals prior to beginning actual testing. The procedures followed for each test participant are described in detail in Appendix A. This section will describe the different tasks that the test subjects were asked to perform.

3.3.1 Introduction

Once the subject arrived at the research location, they were asked to fill out a consent form and then the research system was explained to them (e.g., how the Oculus fit and how the Myo would be worn and gather data). They would then put on the armband and headset and prepare for the experiment.

3.3.2 User-Defined Rotation Gestures on Static Objects

The first set of tasks randomly presented one of the four objects in a static state (it could not be rotated) to the test subject. The object had a dot at one position and a target at another as shown below.

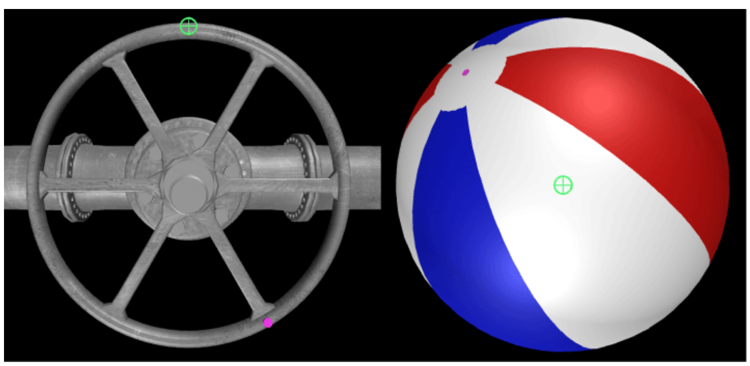

Figure 3-7: 1-Axis & 2-Axis Objects w/ Pink Dot & Green Target

The test subject was then asked to freely perform one gesture they thought should rotate the object to place the dot into the target. The user-defined gesture was recorded according to Figure 3-8 below, which was created to represent the gestures as they were performed by the test subjects.

This process was repeated for the remaining three objects. The data collected from this set of tasks helps to address hypothesis 1 of RQ1. The gestures performed by the participants are referred to as user-defined gestures.

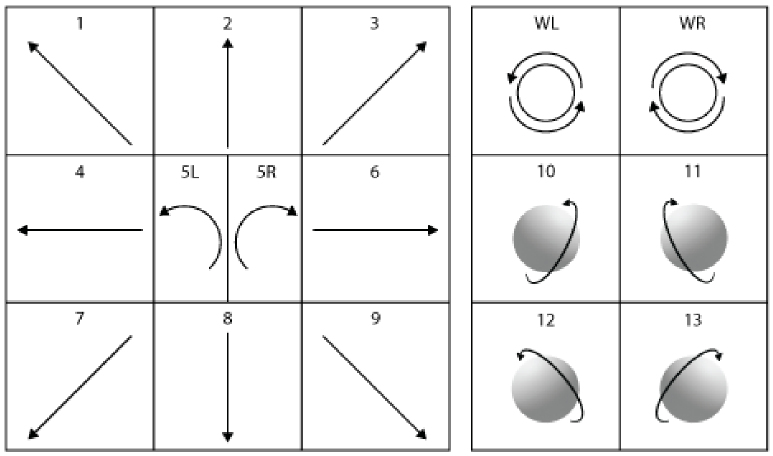

Figure 3-8: Chart to Record Gestures Used During Static Tasks

3.3.3 1-Axis Rotational Objects

Of the four objects, the combination lock and the water wheel could only be rotated on one axis, meaning that the dial of the combination lock or the wheel would only rotate as if they were the actual physical object. One of those two objects were randomly presented to the test subject and one of the three control gestures (e.g., horizontal gesture, vertical gesture, twist gesture) were randomly selected to control the object's rotation on its z-axis. The test subject was then given an opportunity to discover the gesture required to rotate the object by trying different arm motions and provide a verbal indication when they felt they had. The test subject pressed the spacebar to activate the gesture control and released it to indicate they were done rotating the object.

With the test subject now feeling they had discovered the gesture, they were presented with four tasks in succession. Similar to the static object task, the object again had a dot in one position and a target in another. The task required the test subject to perform the gesture in such a way that the object would rotate, moving the dot into the target. Once they had the dot located in the target, they released the spacebar. The system would record the time it took to complete the task. At that point, the next task for that object began until all four tasks had been completed for that object with that specific control gesture.

Next, one of the remaining two control gestures was selected with the same object and the test subject again attempted to discover the control gesture and complete four tasks. This was again repeated with the remaining control gesture.

After completing the four tasks, the test subject was asked questions to determine the intuitiveness and level of preference of each control gesture for that specific object. This data was later used to address RQ2 and RQ3.

This process was repeated for the remaining 1-axis object.

3.3.4 2-Axis Rotational Objects

Of the four objects, the baseball and beach ball could be rotated on two axes simultaneously: the x-axis and the y-axis. In the test scenarios, one of the three control gestures were mapped to each of the two object rotational axes.

One of the two 2-axis objects were randomly presented to the test subject and one of the mappings shown in Table 3-1 were randomly selected to control the object. The test subject was then provided with an opportunity to discover how the object was controlled and then asked to complete four rotational tasks. This was again repeated with the remaining control gesture mappings and then a survey was given. This process was then repeated for the remaining 2-axis object.

Table 3-1: Mapping of Control Gestures to Object's Rotational Axes

Gesture Title	Object's x-axis	Object's y-axis
horizontal/vertical-axis	horizontal gesture	vertical gesture
vertical/twist-axis	twist gesture	vertical gesture
horizontal/twist-axis	horizontal gesture	twist gesture

3.3.5 Final Survey

At the conclusion of the experiment, the test subject was asked to complete an eight-question survey that took approximately 1-3 minutes to complete. The survey included demographic questions regarding gender and age, questions to assess the final nausea and fatigue levels of the test subject, and several questions assessing their familiarity with technical equipment similar to what was used in this experiment.

A unique ID was assigned to each test subject when the experiment began. That unique ID was used to link the data from the survey to the data recorded by the research system. No names were ever recorded in correlation to the unique ID to ensure anonymous participation.

3.4 Analysis Methods

A simple analysis was done in Microsoft Excel while SAS v9.4 was used for deeper statistical analysis reporting significance at the 0.05% and 0.01% level. The analysis compared data on the efficiency and the participant-rated intuitiveness of each gesture. We also examined variations across participants. To assess the statistical significance of differences in gestures, we used a mixed-model analysis of variance with blocking on subject. The gesture and object are independent variables while task duration is the dependent variable. Accuracy was not measured directly because the objects had to be rotated to a highly accurate degree in order to complete each task.

4 FINDINGS

4.1 Demographic Information of Test Subjects

Gender and age varied across 50 participants. 69% were males while 31% were females over a range of ages from 18-54 as shown in (Figure 4-1). Only 32% had used virtual reality while 64% had used a gesture-based input device. The survey data showed that participants had experience with virtual reality on a few different platforms as shown in Table 4-1. The higher percentage of experience with gesture-based input devices could very likely be attributed to the Nintendo Wii being so common (which remotes are gesture-based input devices). However, because of the newness of the Myo and virtual reality in general, most participants had not used the combination of the two.

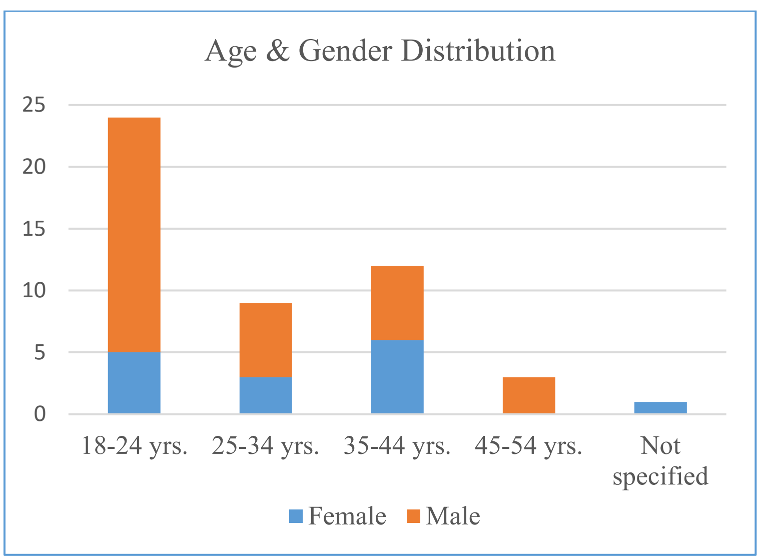

Figure 4-1: Demographic Breakout of Participants

Table 4-1: Participants' Experience with VR Decives

Google Cardboard	7
Oculus Rift	5
Samsung VR	4
HTC Vive	1
2k Rapture	1
Unknown	1
No Experience	34

4.2 User-Defined Gestures on Static Objects

As described in chapter 3, a randomly selected object was presented to each participant; and they were asked to freely perform any gesture to rotate the object in such a way that the dot on the object would rotate into the target. In this section, we report on the user-defined gestures performed by participants.

Based on the data presented in Table 4-2 below, there were only 2 gestures commonly tried for the lock. The gestures expected for each object, based on the gesture used to rotate the physical object, are indicated by the presence of a star in the table. 60% of participants tried to rotate the virtual lock with a twist (gesture 5L in Table 4-2), the same gesture that would be used to rotate the physical object. This confirms hypothesis 1 for 1-axis objects, which states that users will attempt to rotate virtual objects using the same gestures they use on the comparable physical object. It is also worth noting that 30% of participants tried rotate the virtual lock the same way they would a large water wheel (gesture WL in Table 4-2). This does not support hypothesis 1.

The water wheel yielded unexpected results. Only 20% of participants tried to rotate the virtual wheel the same way they would the physical object (gesture WL in Table 4-2) while 36%

of participants tried to rotate the water wheel the same way they would rotate a physical combination lock (gesture 5L in Table 4-2). This does not very strongly support hypothesis 1. As a side note, gesture 1 (a straight arm movement toward the upper left) was tried by 22% of participants. This is believed to be due to a misunderstanding of the instructions. Several participants, despite the directions given to rotate the wheel, commented later that they had been trying to move the dot in a straight line to the target as if it was not attached to the wheel.

Table 4-2: Actual & Expected User-defined Gestures for Each Object

Gesture	Lock	Water wheel	Baseball	Beach ball
1	2	11		27*
2				
3		1	19*	
4				
5L	30*	18	1	
5R	1	2	3	
6				
7				
8				
9				
10			1	
11		3	11	3
12	1	3		20*
13		1	15*	
WL	15	10*		
WR	1	1		

With regards to both the baseball and the beach ball, 2 gestures were expected for each object, based on the gesture used to rotate the physical object (indicated in Table 4-2 by the star). This is because the gesture could start with the hand in different positions on the balls.

Depending on the position where the participant's hand started, one of the two gestures would have been expected.

Most participants tried to rotate the virtual objects the same way they would the physical objects: 68% and 94% for the baseball and the beach ball respectively. This confirms hypothesis 1 for 2-axis objects. As an unexplainable side note, 22% of participants used an unexpected gesture for the baseball (gesture 11 in Table 4-2). This does not support hypothesis 1.

Analyzing this data with respect to hypothesis 1, many participants did not try to rotate the 1-axis virtual object with the same gesture they would the physical object. However, in regards to 2-axis objects, most participants did try to rotate the virtual object with the same gesture they would the physical object. Based on this data, a separate single rotation gesture should be implemented for type of object (1-axis or 2-axis). Likewise, a single rotation gesture should not be implemented across both 1-axis and 2-axis objects.

4.3 1-Axis Object Rotations

The following subsections will discuss the participants' gesture preference and intuitiveness ratings with respect to each 1-axis object. An analysis of task completion times, to determine gesture efficiency, will also be discussed.

4.3.1 Participant Preference and Intuitiveness Ratings

Data about preference of gesture type for the lock and wheel was captured after all the tasks for an object were completed. Based on the data in Table 4-3, about half of the participants preferred the twist gesture for rotating both 1-axis objects, despite the size difference between them. Participants also rated the intuitiveness of each gesture on a scale from 1 to 5 (where 1 was not intuitive and 5 was very intuitive) and the twist gesture was rated higher (see Table 4-4). These findings, shown below in Table 4-3 and Table 4-4, correspond to the expected gestures for the 1-axis objects displayed in Table 4-2.

Table 4-3: Gesture Preference for Each 1-Axis Object

Gesture	Lock	Water Wheel
Horizontal	15	10
Vertical	10	18
Twist	25	22

Table 4-4: Gesture Intuitiveness Rating for Each 1-Axis Object

Gesture	Lock	Water Wheel
Horizontal	2.38	2.82
Vertical	3.26	3.44
Twist	4.5	4.34

4.3.2 Analysis of Task Completion Times

Data on the efficiency of task completion (i.e., how quickly the participants could rotate the object to the specified position) was also captured and statistically analyzed for the 1-axis findings. Participants performed 4 rotation tasks for each object. The analysis looked the median (i.e., the average of the middle two sorted task completion times), minimum (i.e., the fastest of the 4 tasks), and the average of the task completion times. Results were similar across these different methods. In this section, the reported data is based off the median because it removes outliers.

A statistical analysis was done to look for an interaction effect between the efficiency of the gestures and the objects (lock versus water wheel). The interaction between the gestures and the objects was found to be insignificant (p-value = 0.2273). There was also not a statistically significant difference in task completion time between objects (p-value = 0.4554). Therefore, the rest of the statistical analysis in this section combines data for the two objects.

Table 4-5: Avg. of Median Task Completion Times for 1-Axis Objects

Participants' w/ Best Time	**Horizontal**	**Vertical**	**Twist**
Lock	6	14	30
Water Wheel	6	13	31

Percentages of Best Time	**Horizontal**	**Vertical**	**Twist**
Lock	12%	28%	60%
Water Wheel	12%	26%	62%

Average Time	**Horizontal**	**Vertical**	**Twist**
Lock	10.8	6.41	5.16
Water Wheel	9.68	7.74	6.73

Std. Dev. of Avg. Time	**Horizontal**	**Vertical**	**Twist**
Lock	12.96	3.92	3.25
Water Wheel	6.03	3.87	4.46

Table 4-5 shows which gesture was the most efficient for the various participants as well as the average time and standard deviation of the task completion time. As shown, the twist gesture outperformed the other gestures 60% and 62% of the time. Additionally, the average time to complete the tasks using a twist gesture was faster than the other two gestures for both objects. The twist gesture was statistically significantly faster than the horizontal gesture by 4 seconds on average (p-value < 0.0001). The vertical gesture was also statistically significantly faster than the horizontal gesture by 3 seconds on average (p-value = 0.0011). The difference between the twist and vertical gestures was not statistically significant (p-value = 0.3875), though the twist gesture performed better for both objects.

For 1-axis objects, the relationship between the virtual object and the gesture needed to rotate it is one where a common gesture, the twist or vertical, can be used to rotate 1-axis, virtual objects. To answer RQ1, participants were able to use the twist or vertical gesture to efficiently perform the rotation tasks regardless of the size of the object.

Based the data presented above, the answer to RQ2 is that there are two gestures which are most efficient but one is most intuitive for rotating 1-axis objects: the arm-twisting movement, without horizontal or vertical movement, in front of the body, or the twist gesture.

Based on the data presented above, the answer to RQ3 is that there is a common gesture set for rotating 1-axis objects that works for all participants: the twist or vertical gestures.

4.4 2-Axis Object Rotations

The following subsections will discuss the participants' gesture preference and intuitiveness ratings with respect to each 2-axis object. An analysis of task completion times, to determine gesture efficiency, will also be discussed.

4.4.1 Participant Preference and Intuitiveness Ratings

Data about preference of gesture type for the baseball and beach ball was captured after all the tasks for an object were completed. Based on the data in Table 4-7, over half of the participants preferred the horizontal/vertical gesture for rotating both 2-axis objects, despite the size difference between them. Participants also rated the intuitiveness of each gesture on a scale from 1 to 5 (where 1 was not intuitive and 5 was very intuitive) and the horizontal/vertical gesture was rated higher (see Table 4-7). These findings, shown below in Table 4-7 and Table 4-7, correspond to the expected gestures for the 2-axis objects displayed in Table 4-2.

Table 4-6: Gesture Preference for Each 2-Axis Object

Gesture	Baseball	Beach ball
Horizontal/Vertical	27	26
Vertical/Twist	5	7
Horizontal/Twist	18	17

Table 4-7: Gesture Intuitiveness Rating for Each 2-Axis Object

Gesture	Baseball	Beach ball
Horizontal/Vertical	4.42	4.56
Vertical/Twist	2.26	2.22
Horizontal/Twist	3.62	3.36

4.4.2 Analysis of Task Completion Times

Data on the efficiency of task completion (i.e., how quickly the participants could rotate the object to the specified position) was also captured and statistically analyzed for the 2-axis findings. Participants performed 4 rotation tasks for each object. The analysis looked the median (i.e., the average of the middle two sorted task completion times), minimum (i.e., the fastest of the 4 tasks), and the average of the task completion times. Results were similar across these different methods. In this section, the reported data is based off the median because it removes outliers.

A statistical analysis was done to look for an interaction effect between the efficiency of the gestures and the objects (baseball versus beach ball). The interaction between the gestures and the objects was found to be insignificant (p-value = 0.1091). There was, however, a statistically significant difference in task completion time between objects (p-value = 0.0240), although that difference was only 2 seconds. The rotation tasks involving the baseball were faster on average than the beach ball for every gesture used. Given no significant difference between gestures across objects, the rest of the statistical analysis in this section combines data for the two objects.

Table 4-8: Avg. of Median Task Completion Times for 2-Axis Objects

Participants' w/ Best Time	**Horizontal/ Vertical**	**Horizontal/ Twist**	**Vertical/ Twist**
Baseball	43	7	0
Beach ball	47	2	1

Percentages of Best Time	**Horizontal/ Vertical**	**Horizontal/ Twist**	**Vertical/ Twist**
Baseball	86%	14%	0%
Beach ball	94%	4%	2%

Average Time	**Horizontal/ Vertical**	**Horizontal/ Twist**	**Vertical/ Twist**
Baseball	4.31	7.13	13.3
Beach ball	4.7	8.14	17.7

Std. Dev. of Avg. Time	**Horizontal/ Vertical**	**Horizontal/ Twist**	**Vertical/ Twist**
Baseball	3.89	7.34	9.45
Beach ball	2.33	4.36	16.96

Table 4-8 shows which gesture was the most efficient for the various participants as well as the average time and standard deviation of the task completion time. As shown, the horizontal/vertical gesture outperformed the other gestures 86% and 94% of the time. Additionally, the average time to complete the tasks using a horizontal/vertical gesture was faster than the other two gestures for both objects. The horizontal/vertical gesture was statistically significantly faster than the vertical/twist gesture by 11 seconds on average (p-value = 0.0336). The horizontal/twist gesture was also statistically significantly faster than the vertical/twist gesture by 8 seconds on average (p-value < 0.0001). The horizontal/vertical gesture was also statistically significantly faster than the horizontal/twist gesture by 3 seconds on average (p-value < 0.0001).

For 2-axis objects, the relationship between the virtual object and the gesture needed to rotate it is one where a common gesture, the horizontal/vertical gesture, can be used to rotate 2-axis, virtual objects. To answer RQ1, participants were able to use the one horizontal/vertical gesture to efficiently perform the rotation tasks regardless of the size of the object.

Based the data presented above, the answer to RQ2 is that the most efficient and intuitive gesture for rotating 2-axis objects is the arm movement across the horizontal and vertical planes in front of the body, or the horizontal/vertical gesture.

Based on the data presented above, the answer to RQ3 is that there is a common gesture for rotating 2-axis objects that works for all participants: the horizontal/vertical gesture.

4.5 Nausea and Fatigue

In the final survey, questions were asked to determine the level of nausea and fatigue the participants had experienced during the experiment. The levels were rated on a scale from 0-5, with 0 being none and 5 being extreme nausea or fatigue (see Figure 4-2). Only one participant reported experiencing extreme nausea while 90% experienced none. Over 50% did not experience fatigue while 44% ranged from 1-4.

4.6 Summary of Findings

The data presented in this chapter provides answers to the research questions and addresses the hypothesis in each respective sub section. As a summary for this chapter, the following conclusions can be made based on the data presented.

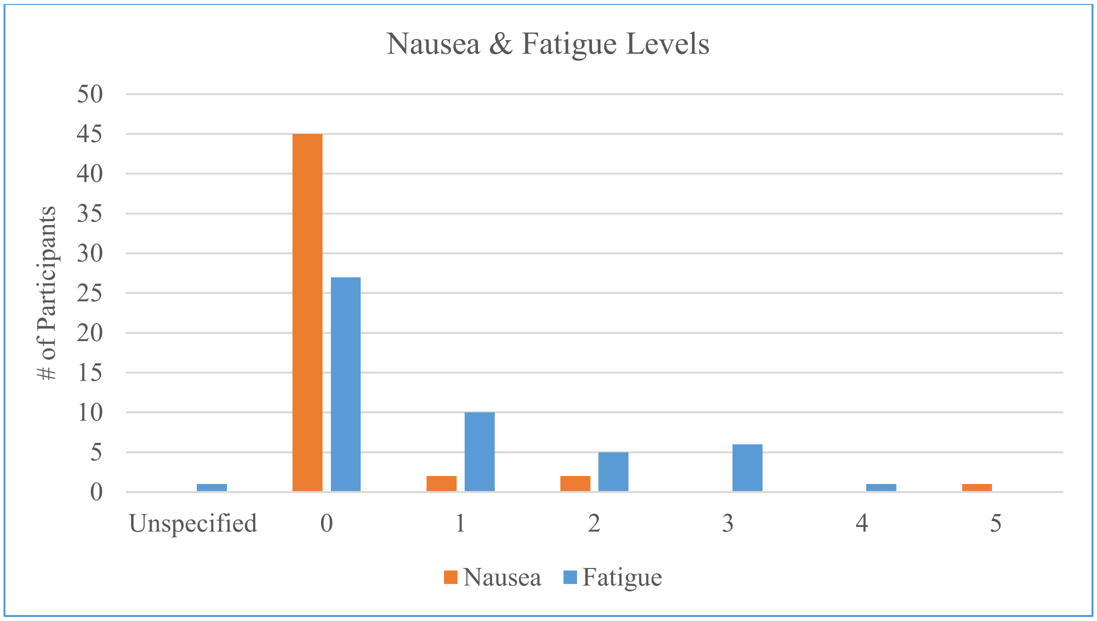

Figure 4-2: Participants' Nausea and Fatigue Levels

4.6.1 Response to Research Question 1

Taking both the 1-axis and 2-axis objects into account, there is a relationship between the appearance of a virtual object and the gesture needed to rotate it. The size of the object did not impact the gesture used. Instead, the gestures predominately used for both object types were understood/intuitive/efficient for each object type regardless of the size of the objects within each type. In other words, the gesture used to rotate a small combination lock was also efficiently used to rotate a large water wheel; and the gesture used to rotate a small baseball was also efficiently used to rotate a large beach ball.

- Hypothesis 1 – Again, participants attempted to rotate both types of virtual objects with a gesture that would be used on a comparable physical object with size ignored.

4.6.2 Response to Research Question 2

There was no single gesture more efficient or intuitive for rotating both 1-axis and 2-axis objects, but there was a specific gesture(s) that was most efficient and intuitive within each object type. For the 1-axis objects, the twist and vertical gestures were most efficient while the twist gesture was the most intuitive. For 2-axis objects, the horizontal/vertical gesture was the most efficient and intuitive.

4.6.3 Response to Research Question 3

There is a common gesture-set across participants that works for both 1 and 2-axis objects:

- 1-axis objects: twist or vertical gesture, with twist having a slight advantage in both efficiency and preferability
- 2-axis objects: horizontal/vertical gesture

This specific set of gestures were statistically efficient for completing the rotation tasks no matter the participant.

5 DISCUSSION

5.1 Summary of Findings and Resulting Implications

As more and more people use virtual reality headsets and gesture-based controls, it is important to understand which arm gestures are most intuitive. Although virtual reality is already becoming mainstream, our understanding of basic user interactions, such as how to rotate an object, is lacking. The work presented in this thesis helps fill this void by examining the intuitiveness, efficiency and user preference of a set of gestures used specifically for virtual object rotation. Two different types of objects were used: two objects that rotated only on one axis (a combination lock and a waterwheel) and two objects that rotated on two axes (a baseball and a beach ball). Additionally, the size varied between objects within each object type to determine if there was an impact on the participant's efficiency and preference.

Participants tended to prefer those gestures that were found to be most efficient for each virtual object type. Interestingly, most participants seemed to be able to separate the physical and virtual experiences. This was done in such a way that the varying sizes of objects did not impact their interaction expectations or their ability to map non-physically natural gestures to those objects (e.g., using a gesture for a smaller physical object, such as a lock on a larger water wheel). The human mind appears to have the ability to adapt to the different environments and situations it is presented with. In the virtual world presented to the participants, the mind adapted and found different ways to employ smaller gestures for larger tasks, likely because there was no physical need to perform a larger gesture. A positive side effect of performing smaller gestures is the preservation of energy while a possible negative side effect is a cognitive disconnect between the virtual and physical tasks (i.e., this is a less authentic experience).

5.2 Connections to Reviewed Literature

This research identified a specific gesture set for rotating objects in virtual reality. The method for discovery followed a procedure recommended by Wobbrock, Morris and Wilson as described in section 2.2.3. Similar to their work, this research began by eliciting gestures from participants in a static environment (objects would not move) and then by having participants try a specific set of gestures on objects that did move. As found in Wobbrock, Morris and Wilson's study, a "final user-defined gesture set was developed in light of the agreement participants exhibited in choosing gestures" (Wobbrock et al., 2009). But this research did not stop there. The data captured from the same participants executing the gestures to perform tasks further proved that the user-defined gesture set was efficient and intuitive in most cases.

5.3 Implications for Designers

There are potentially many types of objects that virtual reality participants may need to rotate. One interesting question for designers is: Should the same rotation technique be used for different types of 1-axis objects (likewise for 2-axis objects)? For example, in a virtual reality game, should a player use a twist motion to rotate a small lock (which mirrors the natural world motion), as well as to rotate a large object like a steering wheel (which would not mirror the natural motion)? There are pros and cons of using different rotation gestures for different sized objects.

Depending on the device used, a larger range of motion may produce more granular control, but larger ranges of motion also increase fatigue more rapidly. A potential con to assigning a large range gesture is an inverse of intuitiveness. For example, most participants in this research preferred and excelled at rotating a large water wheel with a gesture intended for rotating a small combination lock. If a game were developed requiring a player to rotate a large water wheel with the large, physically natural gesture, it would not be the most efficient and the user experience would likely suffer. Furthermore, users may become accustomed to using just one rotation gesture for all rotation tasks in a specific environment. Thus, it would be more intuitive to use a "less natural" gesture (i.e., a twist motion on a large wheel) because users are already using it for other rotations.

Additionally, as mentioned in the 5.1, the human mind appears to be able to adapt to the situation it is in with regards to virtual reality. When in a virtual world, this research showed that participants adapted by attempting and excelling at rotating a large beach ball using the same gesture they would a small baseball. There is no evidence from this research that would suggest that a new gesture should be developed simply because the size of the object has changed.

It should also be noted, however, that while one gesture may be more efficient, it may not be the only intuitive or effective gesture. This research proved that the vertical gesture was almost as efficient in performing a rotation task on a 1-axis object as the twist gesture. Looking at the difference in average task completion times, either gesture could feasibly be implemented in a game or other use case with efficient results. However, the entire gesture set must be considered in conjunction with the tasks that need to be performed. To reduce confusion, it is best not to attach the same gesture to two very different tasks. For example, while the vertical gesture could be used for rotation, it may make more sense to use the vertical gesture to control an object that moves vertically (such as a lever that moves up and down) and the twist for rotation.

The low average task completion times of the gesture set described in section 4.6.3 for 1 and 2-axis objects would indicate that there is also very little to no learning curve for these gestures among the majority of users. To further that point, the gesture set aligns with the gestures participants had designed in section 4.2, indicating that the gestures would be natural for most users.

Therefore, it seems the best approach for developers would be to use a single rotation gesture that is already natural to the users. This research provides a possible gesture set. The more intuitive, simple and efficient the required gestures, the more likely the market success of the developed product.

5.4 Limitations

Some limitations to this research are as follows:

- Limited sample set of participants – This research only had fifty participants, most of whom had a familiarity with technology but were new to gestures and virtual reality.
- Newer technologies – The Myo armband is fairly new and virtual reality is also a budding field. Uses for the technologies, especially the armband, are still being developed. Familiarity with these technologies is not very widespread today and future studies may find new integration or implementation possibilities.

- Single gesture type – Only arm-based gestures were used in this research. Other gestures involving hand, eye, head, etc. could also be used as single or multi-gestural input methods to rotate objects.
- Single input device – This research only utilized the Myo gestural input device. No other input devices were used for the sake of comparison.
- Single handed gestures – This research only implemented and evaluated the use of one-handed gestures. It is feasible that for an object that rotates, a second hand could make sense.
- Limited research on fatigue – Testing sessions were relatively short and only one data point was recorded at the end of the study.
- Only studied gestures with the physical world obscured from view – No comparison was done with the physical world (i.e., the subject's arm or other surroundings) being visible vs. obscured.
- No evaluation or examination of learning effects over a long period of time – The test window was kept short with only four attempts to use a gesture for a specific object. The tasks performed by the participants were also very quick. Therefore, an opportunity to evaluate the learnability of a gesture for a given object was not available.
- There was no representation of the participant's arm (or arms) in the virtual space. Displaying virtual arms that mirror the physical arm movement may change results.

5.5 Future Work

Both virtual reality and gestures are still actively evolving and developing technologies and the combination of the two is fairly new. Below are several areas where future research could be conducted:

- As the technologies continue to develop, becoming more widely used, new integration and interaction methods may be discovered. For example, as the Myo is further developed, it may be possible to research more gestures in connection with rotating objects such as moving the extended thumb, index, and middle fingers as one would do to rotate a small combination lock.
- Further research could be conducted on fatigue as it relates to these rotation gestures.
- Gesture learnability could be researched. Is it possible for non-intuitive gestures to be learned and then utilized in a manner that is as efficient, if not more efficient than intuitive gestures?
- This research only looked at single-handed gestures. Two-handed gestures could also be evaluated especially in connection with objects that rotate on two or more axes.
- Research could be conducted to evaluate the effects of presenting the user's physical hands and/or arms in the virtual world. Would this impact the gestures used? For example, consider trying to rotate a large water wheel with hands and arms visible. Would users still attempt a twist gesture even though it is not the natural gesture when manipulating the physical object?
- Other gestural input devices exist today like Microsoft Kinect, Leap Motion (Weichert, Bachmann, Rudak, & Fisseler, 2013), Ring Zero (Logbar, n.d.) and FlowMouse (Wilson

& Cutrell, 2005). How does the Myo compare with other technologies for detecting gestures? Should gestures change for the same virtual action based on the input device used?

- Would enabling multi-gesture input require the development of new gestures? Would the gesture set identified in this research still be applicable if a user could also make hand gestures at the same time to control other aspects of the virtual interaction experience? For example, what if the user made a fist instead of pressing the space bar to begin rotation? Would the gesture set proposed in this research still be the most efficient?

5.6 Conclusion

As virtual reality and gesture-based interactions become more prevalent, research that helps us understand how they work together will become increasingly important. This thesis was a first step at examining how intuitive and efficient different arm-based gestures are for rotating objects in a virtual reality environment. Hopefully it will help prompt additional research in this area.

REFERENCES

Argelaguet, F., & Andujar, C. (2013). A Survey of 3D Object Selection Techniques for Virtual Environments. *Computers and Graphics (Pergamon)*, *37*(3), 121–136. https://doi.org/10.1016/j.cag.2012.12.003

Cabral, M. C., Morimoto, C. H., & Zuffo, M. K. (2005). On the Usability of Gesture Interfaces in Virtual Reality Environments. *Proceedings of the 2005 Latin American Conference on Human-Computer Interaction - CLIHC '05*, (OCTOBER 2005), 100–108. https://doi.org/10.1145/1111360.1111370

Cohen, E. (2016). Google Cardboard Saves Baby's Life - CNN.com. Retrieved October 22, 2016, from http://www.cnn.com/2016/01/07/health/google-cardboard-baby-saved/

dotcom461. (2012). Beach Ball. Retrieved from http://www.blendswap.com/blends/view/45572

Elaine. (2016). Using Myo During Surgery with ADORA Assistant™. Retrieved October 22, 2016, from http://developerblog.myo.com/using-myo-during-surgery-with-adora-assistant/

Green, A. (2015). The Valve. Retrieved from http://www.blendswap.com/blends/view/80585

Hettig, J., Mewes, A., Riabikin, O., Skalej, M., Preim, B., & Hansen, C. (2015). Exploration of 3D Medical Image Data for Interventional Radiology using Myoelectric Gesture Control. *Eurographics Workshop on Visual Computing for Biology and Medicine*. https://doi.org/10.2312/vcbm.20151221

Kinect. (n.d.). Retrieved October 24, 2016, from https://en.wikipedia.org/wiki/Kinect

Logbar. (n.d.). Ring ZERO. Retrieved November 12, 2016, from http://ringzero.logbar.jp

Lyons, J. (2015). Combination Lock.

Mayo Clinic Staff. (n.d.). Electromyography (EMG). Retrieved October 27, 2016, from http://www.mayoclinic.org/tests-procedures/electroconvulsive-therapy/basics/definition/prc-20014183

Oculus. (n.d.). Oculus Rift Development Kit 2. Retrieved October 31, 2016, from https://www3.oculus.com/en-us/dk2/

Pavlovic, V. I., Sharma, R., & Huang, T. S. (1997). Visual Interpretation of Hand Gestures for Human-Computer Interaction: A Review. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, *19*(7), 677–695. https://doi.org/10.1109/34.598226

Ruiz, J., Li, Y., & Lank, E. (2011). User-Defined Motion Gestures for Mobile Interaction. *Proceedings of the 2011 Annual Conference on Human Factors in Computing Systems - CHI '11*, 197. https://doi.org/10.1145/1978942.1978971

Steuer, J. (1992). Defining Virtual Reality: Dimensions Determining Telepresence. *Journal of Communication*, *42*(4), 73–93. https://doi.org/10.1111/j.1460-2466.1992.tb00812.x

Technologies, U. (n.d.). Unity - Game Engine. Retrieved October 31, 2016, from https://unity3d.com

Thalmic Labs. (n.d.). Myo Gesture Control Armband. Retrieved January 1, 2016, from https://www.myo.com/

Vatavu, R. D., Pentiuc, Ş., & Chaillou, C. (2005). On Natural Gestures for Interacting with Virtual Environments. *Advances in Electrical and Computer Engineering*, *24*. Retrieved from http://www.eed.usv.ro/~vatavu/papers/advances_2005.pdf

Walentin, T. (2013). Baseball. Retrieved from http://www.blendswap.com/blends/view/67352

Ware, C., & Arsenault, R. (2004). Frames of Reference in Virtual Object Rotation. In *Proceedings of the 1st Symposium on Applied perception in graphics and visualization* (Vol. 1, pp. 135–142). https://doi.org/10.1145/1012551.1012576

Weichert, F., Bachmann, D., Rudak, B., & Fisseler, D. (2013). Analysis of the Accuracy and Robustness of the Leap Motion Controller. *Sensors (Switzerland)*, *13*(5), 6380–6393. https://doi.org/10.3390/s130506380

Wilson, A. D., & Cutrell, E. (2005). Flowmouse: A Computer Vision-Based Pointing and Gesture Input Device. In *HumanComputer Interaction-INTERACT 2005* (Vol. 3585, pp. 565–578). https://doi.org/10.1007/11555261

Wobbrock, J. O., Morris, M. R., & Wilson, A. D. (2009). User-Defined Gestures for Surface Computing. *Proceedings of the 27th International Conference on Human Factors in Computing Systems - CHI 09*, 1083. https://doi.org/10.1145/1518701.1518866

Zhang, X., Chen, X., Wang, W., & Yang, J. (2009). Hand Gesture Recognition and Virtual Game Control Based on 3D Accelerometer and EMG Sensors. *Proceedings of the 14th …*, (September 2015), 401. https://doi.org/10.1145/1502650.1502708

APPENDICES

APPENDIX A TESTING PROCEDURES

A.1 Preparation

1. Test subjects will be provided a consent form. Testing will only follow if they provide signed consent.
2. Test subjects will be shown into the testing room and seated.
3. The function and desired use of the equipment will be explained (e.g., the Myo will be described as a device that will collect data from the movement of their arm and the Oculus Rift will provide the virtual reality experience.)
4. The subjects will be able to see a test scene in the Oculus Rift headset to make sure they are comfortable before continuing.
5. At this point, if the test subject has no objections, then they will be ready to begin the tests.

A.2 Tests

Testing will be administered in three phases: the static tasks, the 1-axis tasks and the 2-axis tests. Following the testing, a final survey is given.

1. Static Tasks

    a. Within the virtual reality application, the subject will be presented with an object and asked to use their arm to rotate the object with one gesture. The researcher will take note of the observed gestures. This will be repeated for all 4 objects (combination lock, valve wheel, baseball and beach ball) that are presented in a random order. We will tell them, “You will see an object in the headset. For this first part of our study, you won’t actually rotate the object, but we will record the movements that you make to better understand how you would like to have moved it. Please try only one gesture per object."

2. 1-Axis Tasks

    a. We will tell the participant, “For the next set of tasks, you will rotate an object to a specific point. After each test, we will change the arm movement that rotates the object. You will have a learning time to get used to each arm movement, then you will rotate the object to a specific point as fast and as accurately as you can, four times. Let us know if you have any questions as we proceed.”

    b. Upon beginning this test, the application will randomly select one of two objects: combination lock or valve wheel.

    c. The application will randomly select one of three control gestures (horizontal, vertical, or twist) and the subject will be given time to determine which arm rotation will cause the object to rotate. Once they are comfortable with the movement, they will verbally indicate they are ready for the rotation task.

d. They will be shown the object with a dot that they will then rotate to a desired position (e.g., place the dot in the target) as quickly and as accurately as they can. The application will record the time it took to rotate the object to the desired position.

e. They will rotate the same object four more times. The application will record the speed of task completion each time.

f. At this point, the subject will go through the same tasks, starting at 2.c., this time with a different control gesture. This will be repeated three times until all three control gestures have been tested.

g. At the completion of the tasks, the headset will be removed and a brief survey will be filled out.

h. Now the steps above will be repeated, starting at 2.b., with the other object.

3. 2-Axis Tasks

a. We will tell the participant, "We are now going to have you rotate objects on two axes, meaning it will take two of the control gestures you were using before. The recommendation would be to learn what gesture will rotate the object up and down, and then which gesture will rotate the object left and right. The procedure will be the same as those you just completed. Let us know if you have any questions as we proceed."

b. Upon beginning this task, the application will randomly select one of two objects: baseball or beach ball.

c. The application will randomly select one of three, 2-axis control gestures that will control the object rotation (horizontal/vertical, horizontal/twist, or vertical/twist) and the subject will be given time to get used to the chosen arm rotation.

d. Once they are comfortable, they will be asked to rotate the object to a specific point displayed in the application. The application will record the time it took to rotate the object to the desired position.

e. They will rotate the same object four more times. The application will record the speed of task completion each time.

f. At this point, the subject will go through the same tasks, starting at 3.c., this time with a different 2-axis control gesture. This will be repeated three times until all three 2-axis control gestures have been tested.

g. At the completion of the tasks, the headset will be removed and a brief survey will be filled out.

4. Final Survey

    a. At the end, the test subject will be asked to remove the Oculus headset and fill out the remainder of the survey to acquire fatigue, nausea, demographic and technological experience data.

5. Closing

    a. Upon completion of the survey I will thank them for their participation in the study and lead them out of the room.

APPENDIX B SURVEY QUESTIONS

B.1 Post-Task Survey Questions

1. Likert scale questions (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree):
    a. For the first gesture: The gesture was intuitive, it made sense?
    b. For the second gesture: The gesture was intuitive, it made sense?
    c. For the third gesture: The gesture was intuitive, it made sense?
2. Rank order the gestures from the most preferred (at top) to least preferred (at bottom).
    a. First
    b. Second
    c. Third
3. Briefly, why did you prefer the gesture you selected in the last question? (free text answer)

B.2 Final Survey

1. During the study, did you experience fatigue due to the gestures?
    a. 0 (none), - 5 (extremely fatigued)

2. During the study, did you feel nausea?
    a. 0 (none) - 5 (extreme nausea)
3. Age range:
    a. 18-24 years old
    b. 25-34 years old
    c. 35-44 years old
    d. 45-54 years old
    e. 55-64 years old
    f. 65-74 years old
    g. 75 years or older
4. What is your gender?
    a. Female
    b. Male
5. Have you used virtual reality headsets before such as PlayStation VR, Google Cardboard, Oculus Rift, etc.?
    a. Yes
        i. Open text: What device(s) have you used in the past?
    b. No
6. Have you used gesture-based interfaces before such as Microsoft Kinect, Myo, Wii Remote, etc.?

a. Yes

b. No

7. In a typical week, how often do you interact with a virtual world such as Minecraft, BioShock, Halo, etc.?

a. 0 times per week

b. 1-2 times per week

c. 3-5 times per week

d. 6 or more times per week

8. Do you have any additional comments on this virtual reality research study? (free text answer)