The Effects of Egocentric Interaction Techniques and User-performed Task on Problem Solving in Virtual Reality

by

Talal Alothman

(Under the Direction of Kyle Johnsen and Maria Hybinette)

Abstract

As we find further applications of Virtual Reality (VR) in the field of education, a need to understand the core facilities of a virtual experience becomes vital. Few have studied the impact of interaction techniques on problem solving. In this thesis, we study the effect two egocentric, interaction techniques (virtual hand, raycast pointer) have on problem solving, recognition, and timing, all core learning outcomes. Additionally, we observe how these outcomes vary in relationship to the type of user-performed task (selecting, sorting). We describe a study in which participants ($N = 107$) are presented 30 questions that challenge their ability to alphabetically order English words. Questions are presented as interactive interfaces in a Virtual Environment (VE) and participants answer these questions using the interaction technique they’ve been assigned. Performance variables were recorded in addition to testing participants for their ability to recognize words that have already appeared. Results point to both interaction technique and the type of user-performed task as having statistically significant effects on performance, recognition, and timing.

Index words: Virtual Reality, Egocentric Interaction, User Interface
The Effects of Egocentric Interaction Techniques and User-performed Task on Problem Solving in Virtual Reality

by

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B.Sc., University of Sharjah, 2013

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

Master of Science

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2017
THE EFFECTS OF EGOCENTRIC INTERACTION TECHNIQUES AND USER-PERFORMED
TASK ON PROBLEM SOLVING IN VIRTUAL REALITY

by

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The Effects of Egocentric Interaction Techniques and User-performed Task on Problem Solving in Virtual Reality

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Dedication

To Yummah, Yabah, Hala, Saba, and Saif. I love you all dearly and could never have done this without all of you. You are the roots that hold me high and strong.
Acknowledgments

I’d like to thank Dr. Kyle Johnsen for his continued mentoring, support, and patience in the last couple of years. He sparked my interest the first day I took his Virtual Reality class and I have been hooked ever since.

Thank you Dr. Maria Hybinette, Dr. Khaled Rasheed, and Dr. Lakshmish Ramaswamy for all of your motivation, enthusiasm and support at my time here at UGA.

And to Jackie Tachman, thank you for being my anchor. Sometimes I start a sentence and I don’t even know where it’s going. I just hope I find it along the way. Thanks for helping me find so many sentences along the way.
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Chapter 1

Introduction

1.1 Motivation

Virtual Reality (VR) has a long history of facilitating and enhancing educational practices. For years, VR simulations have allowed us the ability to save lives, money and time. Nonetheless, access to VR technologies has been limited to academic and large budget entities due to the high cost of entry that came with procuring hardware and software able to run VR experiences. In the last four years, advancements have brought costs down and with it a renewed and expanded interest in VR. This has also added more interest in the role VR has in enhancing the educational and learning processes.

Research in the field of VR and education has focused on less immersive forms of VR. This goes so far as to include Virtual Environments (VE) such as video games and digital interfaces as part of the VR field. While this usage is common within the education literature, we will avoid using it that way. VR will be defined as “a computer-generated digital environment that can be experienced and interacted with as if that environment were real.” [8]

Based on this definition, our focus is to study the role VR has on problem solving. Our objective is to experiment with interaction techniques common in the field of VR and their
role in facilitating or even enhancing the learning process. Additionally, another goal is to understand the role user-performed task has.

We build on the projection that VR will have a large role to play in the field of both education and learning technologies. We attempt to utilize our understanding of VR interaction to further optimize VR education.

Figure 1.1: Cloned student with VR headset
1.2 Thesis Chapters Description

The following chapters are organized in the following structure. Chapter 2 will delve into a further description and the existing literature on VR and it’s relation to the fields of Human-Computer Interaction and education.

Chapter 3 describes the interfaces we’ve designed and enumerates the different design decisions we’ve taken in an attempt to answer our research questions. In chapter 4, the study design is presented and explained. Chapter 5 presents our results. In chapter 6, we discuss the implications, limitations, future avenues. Finally, chapter 7 summarizes this thesis.
Chapter 2

Literature Review

2.1 Overview of Virtual Reality

2.1.1 Defining Virtual Reality

Lavalle [9] defines VR as that which induces “targeted behavior in an organism by using artificial sensory stimulation, while the organism has little or no awareness of the interference.” In [3], the authors choose to ignore the term Virtual Reality and replace it with the term Virtual Environment (VE). They define a VE as “a synthetic, spatial world seen from a first-person point of view. The view in the VE is under the real-time control of the user.”[4] Jerlad [8] defines VR as “a computer generated digital environment that can be experienced and interacted with as if that environment were real.”

There does not seem to be a lack of definitions for VR. In this study, we will use Jerlad’s definition[8]. This definition fits with our goals to build an environments that is computer-generated and attempts to remove the user from where they are by placing them in a computer generated environment. Having said that, we acknowledge that not every interaction in VR we study will feel real. This is an ideal goal and one that many are working towards but acceptance of our current limitations is important to note. Additionally, we will use the
term virtual reality and virtual environment synonymously throughout this study.

2.1.2 Immersion and Presence

As mentioned above, a goal for a VR system is to provide an environment that the user begins to believe is real. There might still exist a sense that what one is seeing doesn’t look as real as the “real” world, but an acceptance of one’s ability to interact with this environment in ways that almost demonstrate it’s existence is the objective.

To that matter, we introduce the term Immersion. “Immersion is the objective degree to which a VR system projects stimuli onto the sensory receptors of users.”[8] Some of the variables we consider when looking at the level of immersivness of a VR system are [8]:

- extensiveness: range of stimuli modalities (visual, audio, tactile) projected
- matching: congruence between virtual stimuli and user expectations
- vividness: the quality of the stimuli
- interactability: the ability for the user to interact with their virtual environment
- surroundness: the extent to which stimuli are panoramic

These variables describe what you might think of as a specification sheet for a VR system. While the better the specs, the more hopeful we are of convincing the user that they’re in another reality, how they subjectively experience this immersion is what we aim to direct. This subjective experience is called Presence.

“Presence is a psychological state or subjective perception in which even though part or all of an individual’s current experience is generated by or filtered through human-made technology, part or all of the individual’s perception fails to accurately acknowledge the role of the technology in the experience.”[8] Presence is an internal psychological and physiological
state of the user; it’s the sense of “being there” inside a space even when physically located in a different location. This is one the main variables that differentiate a VR experience from a traditional 2D desktop experience. The more presence a user feels inside a VE, the more the user feels they’ve been transported to another reality.

2.1.3 Health Effects

A important part of the discussion with VR, as is with other systems, is what health effects it has on it’s users. Research in this field has shown that there are multiple factors that can contribute to adverse health effects on a VR user. System, individual user, application design are all possible contributing factors to an uncomfortable VR experience.

System factors are those that are a result of technical shortcomings of the technology. This includes latency, tracking accuracy, tracking precision, display response time and persistence. 

Application design factors stem from how our bodies respond to how the VR content was designed. Duration of time in VR, vection which is the illusion of self-motion when one is not actually physically moving, and luminance of a VE are examples.

Individual user factors include age, gender, prior history of motion sickness, migraine history. These factors are obviously harder to avoid and hence a focus on system and application design factors are key when developing VEs.

2.2 User Interfaces and Interaction

2.2.1 Concepts and Taxonomy

“User interfaces (UI) are mediums through which the communication between users and computers takes place.” The command-line interface (CLI) and the graphical user interface
(GUI) are examples of UIs that we are more familiar with. This study focuses on 3D interaction techniques; interaction in which tasks are performed directly in a 3D spatial context.[4] Unless specified, all mentions of the word interaction in this thesis refer to 3D interaction.

Interaction techniques are a core component of the VR experience. "An interaction technique is a method allowing a user to accomplish a task via the user interface."[4] Without a proper interaction technique, we cannot efficiently select or manipulate objects in a VE. There exists a large number of interaction techniques but in this study, we focus on 3D interaction techniques that have been utilized and studied in VEs.

Throughout this section, we utilize the taxonomy of Poupyrev et al. [11] to classify the interaction techniques we use. There exists other taxonomies that describe different VR interaction techniques, the Poupyrev taxonomy shown in 2.1, defines two main groups: egocentric and exocentric. Egocentric interaction is interaction from the first person view or from within the virtual environment. An egocentric reference frame is defined relative to a certain part of the human body.[4] Exocentric is interaction from a 3rd person or a frame of reference defined relative to something in the virtual environment.[4]

![Poupyrev Interaction Taxonomy](image)

Figure 2.1: Poupyrev Interaction Taxonomy [11]
In this study, we focus on egocentric interaction techniques. To further describe egocentric techniques, they are split into Virtual Hand metaphors and Virtual Pointer metaphors. Here a metaphor refers to a mental model of a technique: an understanding of what the user can do (accordances) and what they cannot do (constraints) with that technique. [4]

Metaphors attempt to facilitate the user’s ability to perform canonical manipulation tasks. [4] These tasks are selection, positioning, rotation. Selection is the task of identifying a particular object from the entire set of objects. Positioning is changing the position of an object in the virtual environment. Rotation is changing the orientation of an object in the virtual environment. [4] Metaphors build on the user’s understanding of the real world to allow the user to quickly learn and apply these tasks in a VE facilitating better usability.

There exists a number of interaction techniques under each metaphor type but a discussion into all of them is beyond the scope of this study. Instead, we focus on describing two main techniques of interest: the classical virtual hand (under virtual hand metaphors) and ray-casting (under ray metaphors).

With the classical virtual hand technique, users can grab and position objects by “touching” and “picking” them with a virtual representation of their real hand. “Classical” virtual hand technique attempts to provide one-to-one mapping between the real and virtual hands. [11]

With the raycast technique, the user selects and manipulates objects by pointing at them. A pointer emanates from the user’s hand and when the the virtual pointer intersects with an object, it can be picked and manipulated. [11]

The following section describes some of the empirical results that have come out studying these interactions techniques.
2.2.2 Empirical Evaluations

Researchers have found significant effects of interaction techniques on canonical manipulation tasks. Variables such as time needed, accuracy vary significantly based on which interaction technique we use to for selection and positioning.

In [3], the authors find a significant difference between the time needed to position an object using a hand metaphor technique versus a pointer metaphor technique. The hand metaphor technique required significantly more time to achieve the task. The hand metaphor technique was also less efficient at selecting objects at further distances. [3]

Additionally, in [1], researchers conducted a large survey on various interaction techniques and found that there were limitations in hand metaphors techniques to successfully select objects at further distances while ray metaphor techniques are more successful at this task. They also found that hand techniques require higher depth perception than pointer techniques. With regards to user fatigue, the authors also found that hand techniques would require more arm effort than pointing techniques, while pointing techniques required more wrist effort.[1]

On the other hand, results from [11] point to hand metaphor techniques performing better when more accuracy is required (selection of small objects). Their results also suggest that while hand metaphor techniques provide effective manipulation of objects in 3D space (6-DOF), pointer metaphor techniques are more effective at manipulating objects in 2D space (3-DOF). The authors conclude by resolving to not being able to find the “best” interaction technique and refer to task conditions as the main cause of this variability. [11]

2.3 Virtual Reality in Education

There has been extensive work in the education and instructional design fields to try and understand how VR can facilitate various learning objectives. One of VR’s strengths is it
allows for the ability to experience situations that would otherwise be inaccessible.[7] Time, physical and safety constraints can usually be circumvented by building VR experiences that remove those constraints while simultaneously immersing the user. This has allowed students to visit historical periods, observe our solar system up close, and journey depths of the earth. Adult training is another core application that allows for applications to train pilots, firefighter, factory workers.[7]

Beyond VR’s effectiveness ability to immersively place a user in a different location, it’s important to try and evaluate what role VR has on learning outcomes. A number of studies have attempted to do this.

In [2], the author studies the role of dimensional symmetry on learning bimanual psychomotor skills. Dimensional symmetry is the correspondence between a virtual interaction metaphor to the real-world equivalent. The bimanual psychomotor skills were a set of tools the subjects were asked to use after having experienced the VR intervention. Results included no significant effect of reduced degrees of freedom on learning outcomes. Additionally, 6-DOF interaction better precision for the subjects. At the same time, more participants felt that they could not complete their task when using a 6-DOF interaction technique over a 3-DOF interaction technique. The authors seem to think this is due to the steeper learning curve associated with the 6-DOF technique. [2]

Additionally, a study [6] that attempted to assess knowledge retention and recognition in a VE compared to printed information safety cards, has also pointed to the important role VR can have in knowledge retention. Recognition, in psychology, is a form of remembering characterized by a feeling of familiarity when something previously experienced is again encountered.[5] The authors found that an immersive VE is more effective in the long term in the retention of safety knowledge. Additionally, subjects using the printed information safety cards suffered from significant knowledge loss between the post-test and retention-test conducted in comparison to the group that was administered the VR intervention. The
authors attribute this to the larger engagement and emotional arousal that was caused by the VR intervention. [6]

This study [10] compared an immersive VR experience with that of a desktop setup experience. Results showed that the VR experience provided better results when testing for learning outcomes such as the student’s ability to analyze, synthesize, and evaluate the knowledge they were exposed to. The same study also showed that users spent more time exploring their surroundings when in the VE over the desktop setup. Nonetheless, a consistent finding was an increase in the time needed to finish the tasks assigned to the users.[10]

In summary, the benefits of VR in enhancing learning goals are many and an exhaustive compilation would be beyond the scope of this thesis. Nonetheless, a mention of interesting studies is key to helping us direct our research. While the first cited paper in this section attempts to observe the role an interaction technique has on learning outcomes, we find research interested in the study of the role interactions techniques have in education lacking. Most of the studies we have come across study the role VR as a medium has but do not focus as much as the role the type of interaction technique has. We aim to further add to the literature by attempting to understand what role VR interaction techniques have in facilitating learning objectives.
Chapter 3

Experiment

3.1 Hypotheses

The hypotheses we have setup out to explore are the following:

- The virtual hand interaction technique facilitates higher performance scores in the sorting task.
- The virtual hand interaction technique facilitates higher performance scores in the recognition task.
- More interactive user-tasks such as a sorting task enhances recognition.

3.2 System Description

To be able to test our hypotheses, we designed and implemented a VR experience that attempts to test the variables we’re interested in. The experience is dependent on both effective hardware utilization and efficient software implementation.
3.2.1 Hardware

For our Head-Mounted Display (HMD), we utilize the Oculus Rift CV1, a consumer off the shelf VR system. In addition to the headset, we also use the Oculus Touch controllers. We utilize a 2 camera setup.

Figure 3.1: Participant with Oculus Rift and holding Touch Controllers
3.2.2 Software

To develop the software that runs on the HMD, we use the Unity3D game engine. Unity allows us to iterate quicker by providing a stable development environment that facilitates prototyping, a great asset pipeline, and support for numerous VR platforms.

Additionally, we utilize the Virtual Reality Toolkit (VRTK), a library of extensible C# classes that provide core VR functionality such as implementations of basic interaction techniques.

3.2.3 Design

Attempting to answer the questions above, we implemented a user interfaces that would be used to ask questions in a VE. This interface differ in two main aspects: the interaction technique, and the interaction task. The interaction techniques we utilized are Raycast and Virtual Hand.

The user-performed task is also split into two types: Selection and Sorting. These two tasks are both solved using either interaction technique mentioned above. The two tasks require the user to either select the correct answer or order a set of possible options into the correct order.

All subjects are exposed to a introductory VR tutorial where they are asked to look around their environment and use their controllers to move their hands. Subjects are then split into two main groups. The Raycast group and the Virtual Hand group. All participants are added by random using a random number generator that begins the appropriate interfaces.

Subjects are then presented with a number of demographic questions that they answer using their assigned interaction technique. Interaction technique differs based on group and but the questions remain the same. This phase also functions as a tutorial to introduce the
users to our system.

Figure 3.2: Screenshots of the Selection Tasks. Top: Selection using the Raycast technique. Bottom: Selection using the Virtual Hand technique.

3.3 Method

3.3.1 Participants

Participants (N = 107) consisted mainly of undergraduate Computer Science students at the University of Georgia. While the majority of the subjects came from an undergraduate,
Computer Science background, the study was open to anyone who fit our qualifying criteria: the subjects needed to be at least 18 years old and have completed their high-school education. These conditions were defined to avoid any extra steps involved in approving an IRB for underaged subjects and to attempt to set a baseline for a participant’s educational background.

In order to encourage participation, two main forms of incentives were provided. The
first was a bonus grade added to participating student from the CSCI 1302 class. The other incentive was a consumable snack.

### 3.3.2 Study Description

There were two main independent variables that we are interested in. The interaction technique which consisted of two factors: the Raycast Pointer technique and the Virtual Hand technique. The other independent variable is the user-performed task that consisted of two factors: Selection and Sorting. To study how these variables influence other dependent variables in our system, we designed a mixed-factorial study: a between-subjects component for the Interaction Technique variable and a within-subjects component for the User-performed Task variable.

To insure the validity of our randomized-experiment, participants are randomly added to one of the interaction technique groups (Raycast Pointer, Virtual Hand). This is done at runtime with a constant likelihood of 50/50 for each group throughout our study. This randomization determines which of the between-subjects group the participant will be added to.

The within-subjects portion of the experiment presents to the subjects two main factors: the first is 10 selection tasks and the second is 10 sorting tasks. Participants will be presented with both types of tasks. To insure we control for order effects in our repeated measures, within-participants portion, we counter-balance the selection tasks and the sorting tasks based on the interaction technique group the subject has been assigned to. Subjects in the raycast pointer group are subjected the selection tasks first while subjects in the virtual hand group are subjected to the sorting tasks followed by the selection tasks.

Additionally, to further reduce any order effects we randomize task order for both selection tasks and sorting tasks.
3.3.3 Material

All the tasks mentioned above involve the subject answering a question. Questions are at the core of our interface design and choosing what questions to ask was key to attempting to understand the effect our independent variables have on our dependent variables.

To avoid having to expose subjects to new knowledge and to lessen the effect background knowledge has on their ability to answer our questions, we focused on questions that inquire about alphabetical order. The two questions are:

• Select the nth word sorted alphabetically? (Select Task)

• Sort the words alphabetically from left to right? (Sort Task)

These question items follow a multiple choice question layout. Each item consists of a stem (the question text itself), and 4 words. For both types of questions, there is only one correct answer. The correct answer for the select task is one of the possible words (each word functions as possible answers). The correct answer for the sort task is the word set ordered alphabetically from left to right (each permutation of the set is a possible answer).

How a subject goes about selecting or sorting depends on the interaction technique group they’ve been randomly assigned to. The raycast pointer group utilizes pointers that extend from the controller in the Virtual World and allow for selection and sorting. The virtual hand group use their controllers that are represented as hands in the virtual world to physically select and sort.

To further lessen order effects, each question presented in the Select or Sort stage was randomized. Additionally, the initial order if the 4 words was randomized. Each question was presented only once.

We also utilize a “Submit” button that subjects can use to allow for some measure of learner control and pacing, an positive variable in learning interfaces.
3.3.4 Measures

Demographics

Variables are age, gender, educational level, and previous gaming experience.

Correct Answer

This variable is collected for each question the subject answers and provides information about whether they answered the question correctly or not.

Timing Variables

- Time to Tutorial Completion: This variable presents us with the amount time it took the participant to complete the initial tutorial phase which also functions as the demographic collection stage.

- Time to Question Completion: This variable represents the amount of time the subject spent on each question.

- Time To First Interaction: This variable represents the amount of time it took the subject to first interact with the interface.

Interaction Frequency

This variable keeps count of the amount of times the subject interacted with the interface. This can mean how many time they’ve either selected or attempt to move a sortable object.

Simulator Sickness and Comfort

This is a value that represents how comfortable or not the subject was throughout the experiment. This value can range from 1 to 5.
Immersion

This is a value that represents how immersed or not the subject was throughout the experiment. This value can range from 1 to 5.

Immediate Recognition

This value represents how many correct word recognitions the subjective able to recognize in the memory questions phase.

3.3.5 Procedure

Participants are exposed to a set of stages that consist of questions that guide their progression through the experiment. Together, the number of questions is equal to 30. These stages consist of the following:

1. The VR Introduction

2. Tutorial + Basic Information Questions

3. Selection Questions (3rd Raycast Pointer, 4th Virtual Hand)

4. Sorting Questions (3rd Virtual Hand, 4th Raycast Pointer)

5. Memory Questions

The VR Intro

Two main substages are included in this stage. The first is before the subject puts on the headset. The second, after the subject puts on the headset.

• In Reality: Subjects are first asked to fill out the consent form that describes the project, it’s objectives, and the tasks they would be exposed to. Subjects are then shown how to hold the controllers and put on the headset.
• In Virtual Reality: This stage provides a simple introduction to the subject’s ability to move in 6 degrees of freedom in addition to a simple introduction to their controllers and the randomized interaction technique.

**Tutorial + Basic Information Questions**

In this stage, subjects answer demographic questions using the interaction techniques introduced to them in the previous stage. This also functions as an applied tutorial for the interface and interaction technique.

**Main Tasks**

As described in the Materials section of this document, this stage is made up of selection task questions and sorting task questions. Subjects use what they have learned in the previous two stages to answer the questions they are presented.

**Memory Questions**

These questions ask the subject to select which words have appeared in the Main Tasks stage. This will be used to measure recognition. Both order of questions and initial order of possible answers are randomized to reduce order effects.
Chapter 4

Results

4.1 Interaction Technique Results

**Sorting**  We group all data by user and conduct a Welch Two Sample t-test. We find that there is no significant difference \( t(85) = 1.61, p = 0.11 \) between raycast pointer and virtual hand.

**Selection**  We group all data by user and conduct a Welch Two Sample t-test. We find that there is no significant difference \( t(104) = 0.153, p = 0.88 \) between raycast pointer and virtual hand.

**Memory**  We group all data by user and conduct a Welch Two Sample t-test. We find that there is a significant difference \( t(102) = 2.16, p = 0.03 \) with raycast pointer \( (M = 8.02, SD = 1.56) \) performing better than virtual hand \( (M = 7.41, SD = 1.35) \).

Additionally, we found significant effects of interaction technique on all timing and number of interaction variables. See table 4.1.
4.2 User-task Results

A chi-square test with Yates’ continuity correction was conducted to compare number of correct responses for the sorting task versus the selection task. There was a significant difference ($\chi^2(1) = 67.199, p < 0.001$) with sorting questions being answered correctly at a higher rate ($M = 101.5, SD = 5.11$) than selection questions ($M = 89.7, SD = 3.34$). See figure 4.1.

A chi-square test with Yates’ continuity correction was conducted to compare number of correct responses for memory questions associated with the sorting task versus the selection task. There was a significant difference ($\chi^2(1) = 70.41, p < 0.001$) with memory questions associated with the selection task being answered correctly at a higher rate ($M = 90.4, SD = $...
<table>
<thead>
<tr>
<th>Interaction Technique</th>
<th>Tutorial Time (sec)</th>
<th>Time Taken Per Question (sec)</th>
<th>Time to First Interaction (sec)</th>
<th>Number of Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virtual Hand</td>
<td>$M = 57.69, SD = 17.69$</td>
<td>$M = 18.16, SD = 13.08$</td>
<td>$M = 11.37, SD = 9.83$</td>
<td>$M = 2.65, SD = 2.99$</td>
</tr>
<tr>
<td>Raycast Pointer</td>
<td>$M = 39.19, SD = 12.96$</td>
<td>$M = 14.79, SD = 9.98$</td>
<td>$M = 9.24, SD = 7.67$</td>
<td>$M = 3.19, SD = 3.79$</td>
</tr>
</tbody>
</table>

Table 4.1: Interaction technique effect on Timing and Interaction variables

17.85) than memory questions associated with the sorting task ($M = 74.6, SD = 18.38$). See table 4.2.

Figure 4.2: Percentage of Correct Memory Answers Based on associated User-task
<table>
<thead>
<tr>
<th>Time Taken Per Question (sec)</th>
<th>Time to First Interaction (sec)</th>
<th>Number of Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select</td>
<td>( M = 19.62, SD = 12.49 )</td>
<td>( M = 1.24, SD = 1.16 )</td>
</tr>
<tr>
<td>Sort</td>
<td>( M = 22.09, SD = 10.35 )</td>
<td>( M = 6.39, SD = 3.92 )</td>
</tr>
<tr>
<td></td>
<td>( p &lt; 0.001 )</td>
<td>( p &lt; 0.001 )</td>
</tr>
</tbody>
</table>

Table 4.2: User-performed task effect on Timing and Interaction variables

### 4.3 Other Results

#### 4.3.1 Gender

Gender did not have a significant effect on the time needed to complete the tutorial \((t(38.17) = 2.0134, p = 0.051)\). Additionally, gender did not have a significant role on the number of interactions \((t(66.21) = 1.58, p = 0.12)\).

#### 4.3.2 Previous Gaming Experience

A Kruskal Wallis test revealed a significant effect of Previous Gaming Experience on Tutorial Time \((\chi^2(3) = 163.14, p < 0.001)\). A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences. See table 4.3.2, figure 4.3.

<table>
<thead>
<tr>
<th>Noob</th>
<th>Casual Gamer</th>
<th>Core Gamer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional Gamer</td>
<td>( p &lt; 0.001, r = 0.14 )</td>
<td>( p &lt; 0.001, r = 0.14 )</td>
</tr>
<tr>
<td>Core Gamer</td>
<td>( p = 0.03, r = 0.5 )</td>
<td>( p &lt; 0.001, r = 0.11 )</td>
</tr>
<tr>
<td>Casual Gamer</td>
<td>( p &lt; 0.001, r = 0.14 )</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4.3: Results of Mann-Whitney tests with Bonferroni correction between Previous Gaming Experience Groups and Tutorial Time

A Kruskal Wallis test revealed a significant effect of Previous Gaming Experience on Time Taken per question \((\chi^2(3) = 12.255, p = 0.007)\). A post-hoc test using Mann-Whitney tests with Bonferroni correction showed significant differences between noob and core gamer groups \((p = 0.02, r = 0.05)\). See figure 4.4
Figure 4.3: Tutorial Time based on Previous Experience Group
Figure 4.4: Mean Time Taken per Question based on Previous Experience Group
Chapter 5

Discussion

5.1 Hypotheses

5.1.1 The virtual hand interaction technique facilitates higher performance scores in the sorting task

As described in the results section, there was no significant difference between the virtual hand group and the raycast pointer group in terms of performance. Even though the virtual hand interaction technique manipulates objects in 6-DOF, in comparison to the raycast pointer technique which manipulates in 3-DOF, subjects using virtual hand performed slightly but insignificantly better in the sorting task. We expect this is due to the similarity of how we sort items in the real world versus the interaction technique, where the virtual hand technique is more similar to how we naturally do it.
5.1.2 The virtual hand interaction technique facilitates higher performance scores in the recognition task

We found a significant difference between the two interaction technique groups in terms of their ability to answer the recognition questions. The virtual hand technique performed worse than the raycast pointer technique, negating our hypothesis. We are not exactly sure why raycast pointer performed better on the recognition task but expect it might be due to the ability for the user to better observe their possible answers from further away. This is due to the nature of the raycast pointer technique that allows the user to interact from a further distance, possibly giving them a better vantage point of all their options.

5.1.3 More interactive user-performed task such as a sorting task enhances recognition

While we found a significant difference between the selection sorting tasks, the selection task resulted in better performance on the recognition questions associated with it. We expect this is due to the user having to consider thoroughly every possible answer when conducting the selection task. The sorting task on the other hand, provides for the ability to cognitively offload much of the thinking into physical space; 2D space for raycast pointer and 3D for virtual hand.

An interesting finding is the effect of user-performed task on recognition for the virtual hand technique. While there is no significant difference of user-performed task on the raycast pointer group, varying user-performed task on the virtual hand group results in a significant ($\chi^2(1) = 94.51, p < 0.001$) difference with selection performing better than sorting. See figure 5.1. From this observation, it seems that the virtual hand interaction technique significantly reduces recognition when paired with a sorting tasking while the raycast pointer technique does little to change recognition in either tasks.
We can see this more clearly if you remove the raycast pointer data and focus on the virtual hand data. 5.2.

Another observation from the results is that users performed better on sorting tasks in comparison to selection tasks even when possible answer come from a larger set. The answer in the sorting task comes from a larger possible answer set than that of the selection task. Nonetheless, we found a significant difference in performance between the two groups. The sorting tasks had a significantly higher number of correct answers when compared to the selection group. We expect that this is due to the sorting task facilitating more cognitive offloading by allowing users to keep track of order states by visualizing them in space (2D and 3D). On the other hand, in the selection task, users must keep track of the order state in their heads, increasing the cognitive load but mostly likely requiring students to activate their ability to recognition the words they’re ordering.

![Figure 5.1: Percentage of Correct Memory Questions based on User-performed task](image)

Figure 5.1: Percentage of Correct Memory Questions based on User-performed task
5.2 Limitations and Future Work

A core limitation to this study is that our sample mainly consisted of undergraduate, computer science students. While this helped us increase our sample size, it’s important to consider how participants from outside the computer science department and others from different educational levels respond to varying interaction techniques and user-performed
tasks. As VR expands into the classroom, its role in elementary education also becomes of great importance.

Additionally, the questions we asked focused on the task of ordering English words in alphabetical order. We did not experiment with the effect of interaction technique or user-performed task on others types of questions or other languages. These variables could have role on the type of results we find. While recognition was a core focus, delving it the role interaction technique and user-performed task have on inducing higher forms of learning such as the ones defined in Bloom’s Taxonomy is an obvious way forward.

Finally, our focus on two main egocentric VR interaction techniques is in no way comprehensive of the large number of interaction techniques in the literature. Possible future work could extend our experiment to many of other egocentric and exocentric methods of interaction found in the literature.
Chapter 6

Conclusion

Interaction techniques remain a core research interest for many in the Virtual Reality community. With continuous attempts to find newer ways to interact in a Virtual Environment, an understanding of how these interaction techniques effect the user is vital to optimizing their efficiency in different applications.

Education is poised to be a core application of VR in the coming years. With adoption of VR technologies growing, we expect to see more and more classrooms with access to head-mounted displays. These tools will not replace traditional learning environments but will attempt to enhance them by providing immersive, educational experiences augmenting traditional learning.

What we attempted to do in this thesis was to study what role interaction techniques and user-performed tasks have on problem solving. We believe these are important questions to ask as we attempt to optimize VR as a learning tool.

We’ve found significant effects of both interaction technique and user-performed task. We hope that these results better inform researchers, developers, and designers when attempting to build VR educational experiences. We hope to add to the vast literature in the hopes of facilitating VR adoption as a core asset to our daily lives in the years to come.
Chapter 7

Appendix

7.1 Sorting Questions

Select the 3rd word sorted alphabetically? craftsman crank cranky craft
Select the 1st word sorted alphabetically? trapeze trapper treatment traveler
Select the 2nd word sorted alphabetically? skyline skiing skyscraper skunk
Select the 4th word sorted alphabetically? breeze breathe breezy bread
Select the 1st word sorted alphabetically? larva leaflet learn lake
Select the 3rd word sorted alphabetically? measure maze mayor measurement
Select the 2nd word sorted alphabetically? sloth slime slouch slither
Select the 2nd word sorted alphabetically? laughing lately lasting later
Select the 3rd word sorted alphabetically? airmail alternate amaze aluminum
Select the 4th word sorted alphabetically? allowed alternative allowance airplane
7.2 Sorting Questions

Sort the words below alphabetically, from left to right? craft craftsman crank cranky
Sort the words below alphabetically, from left to right? trapeze trapper traveler treatment
Sort the words below alphabetically, from left to right? race ran runner rush
Sort the words below alphabetically, from left to right? oak oar owl own
Sort the words below alphabetically, from left to right? daffodil daisy dandelion dark
Sort the words below alphabetically, from left to right? sandal scare seen send
Sort the words below alphabetically, from left to right? rain rainbow rainy robin
Sort the words below alphabetically, from left to right? east easy end enter
Sort the words below alphabetically, from left to right? garden grass green grow
Sort the words below alphabetically, from left to right? trek truck truncate truly

7.3 Memory Questions

Select the word that has previously appeared? crane crank crang crack
Select the word that has previously appeared? trapeze cheese freeze keys
Select the word that has previously appeared? scout stuck sunk skunk
Select the word that has previously appeared? breen breed breezy bee
Select the word that has previously appeared? ache crake bake lake
Select the word that has previously appeared? raft crake daft craft
Select the word that has previously appeared? runner stunner gunner forerunner
Select the word that has previously appeared? clone own drone bone
Select the word that has previously appeared? lazy glazy daisy crazy
Select the word that has previously appeared? scare air care glare
Bibliography


