An Immersive Virtual Reality: The Effect of Haptics on Agency in a Virtual Environment

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Table of Contents

ACKNOWLEDGEMENTS

Firstly, I would to thank Dr. Victoria Interrante for her guidance while learning about and virtual reality in her lab. The experience I had under her guidance with the high-tech equipment and software I used in lab as well as the design and implementation of a project is invaluable.

In addition, I would like thank Mr. Zhihang Deng for his help in learning how to create and use virtual environments. He helped me troubleshoot and overcome many issues in my project and the knowledge and experience that he was willing to share with me was greatly appreciated.

Finally, I want to thank Mrs. Neelima Potlapalli for her help with the statistical analysis. Confronting hundreds of numbers after the experiment was a daunting task however with her help and knowledge of SAS software I was able to analyze the results and draw conclusions.

PROJECT OVERVIEW

My project began with a meeting with Dr. Victoria Interrante, in which she went over various projects that her graduate students were doing, and described related projects that I could possibly do. I decided to do a project regarding hand-tracking and haptics in virtual reality, similar to what her Ph. D. student, Zhihang Deng, was doing. However, before I could start my project, there was a lot I had to learn about the software and equipment that was being used.

For my first few weeks of lab I began learning how to use UnrealEngine4 to create virtual environments, and how to use the Oculus Rift and Leap Motion sensor to view the virtual environment with hand tracking capabilities. Learning how to use this technology was difficult since a lot of times the devices would not act the way I wanted them to. In addition, UnrealEngine4 uses an uncommon way of creating virtual environment using “blueprints” which is a form of coding I had to learn how to use. After completing many tutorials online, reading through instructions and lessons online, and receiving help from Zhihang, I was able to successfully create a virtual environment to use in my experiment.

Furthermore, I ran into difficulties when designing and implementing my experiment. I had to do a lot of background research before understanding how agency and ownership could be measure and how haptics could be tested. After creating a research plan and getting it approved by Dr. Interrante, I had to start creating the materials needed for the project.

One difficulty I ran into was that the Oculus Rift Head Mount Display did not have an attachment for the Leap Motion sensor which needed to be fixated onto it in order for the virtual environment to have hand tracking capabilities. To solve this problem, I manually created a way to attach the Leap Motion sensor using strings and tape, but also designed an attachment on autocad that can be 3D printed and used.

Another difficulty I ran into while creating the experiment dealt with trying to measure the subjective qualities of agency and ownership. I had to do some research into how psychology could play a role in measuring these qualities and after looking at some examples from other research papers, I came up with statements regarding agency and ownership that I could have the user's rate on a 7 point Likert scale.

A larger challenge presented itself when I was statistically analyzing the results. The results were not as I expected and they were quite counterintuitive and unexpected. I had a hard time drawing conclusions based on such results. Even though my original hypothesis was not supported, I was able draw various conclusions about my results after doing some research and careful thought.

Many more challenges that I faced throughout the experimental design and implementation of my project were overcome. Although at times this research project could feel overwhelming, I was always able to push through the challenges and come to a conclusion.

ABSTRACT

With an increasing number of virtual reality applications, more research must be conducted regarding human interaction with virtual environments. Various studies have researched agency and ownership over a virtual avatar and others have researched haptics in virtual reality (VR). This experiment combines these two sects of VR studies to determine if haptics in a virtual environment alters the perception of agency or ownership a user feels over their virtual hands. Unreal Engine 4 and an Oculus Rift with an attached Leap Motion sensor were used to create an immersive virtual environment with hand tracking capability. Human subjects were individually tested in 3 tasks. First, they were to touch and lift a block with their virtual hands, then they did the same with an identical block in front of them so they would be interacting with a real and virtual block simultaneously, finally they did the same action with just a real block and without a virtual block being seen. A questionnaire was given afterwards to measure the user's agency and ownership over the virtual hands during each task. The results show that haptic feedback may decrease one's agency over virtual hands, but also increase one's agency absent a visual display. This suggests that the proprioceptive response related to feeling an object with a person's actual hands may decrease the effectiveness of the illusion that the hands on the screen actually belong to the user, meaning a more immersive virtual environment could be created with less haptic feedback. More research should be conducted verifying the impact tangible virtual objects have on a user's virtual experience, but overall this research could have far-reaching implications. Instead of augmenting virtual environments with real ones, an environment with less interaction with reality could allow for better VR applications.

PROJECT INTRODUCTION

Background/Rationale:

Much research has been conducted regarding the ownership illusion over an alien appendage. The rubber hand illusion is a well-known example. In the rubber hand illusion experiment a rubber replica of a test subjects hand was placed in front of the subject in a life-like position while the subject's real hand was hidden. Researchers measured how the subject responded to simultaneously tactile stimulation of their hand and the rubber hand. The results showed that the users created a sense of agency over the rubber hand and reacted as if it was their own hand when the hand was threatened (Botvinick & Cohen, 1998). This is significant because it leads the way to a whole new psychophysical area of study concerning the basis of bodily self-identification.

Since the advent of immersive virtual reality, the inquiry into this self-perception illusion has gained much more traction. It is now possible to model a person or their body part in a virtual environment and determine how they respond. Studies have been conducted detailing how various feats of virtual reality can be manipulated to further create an illusion. For example, Argelaguet et al. (2016) researched how the realistic look of a user's hand in virtual reality can affect that user's ownership and agency in a virtual setting. Further studies have altered the skin color (Kilteni et al, 2013), shape of a person's body (Priyankova et al., 2014), or even number of fingers on a hand (Hoyet et al. 2016) in virtual reality and measured the user's response to such alterations.

In addition to self-perceptual studies in virtual reality, haptics is becoming a larger research area. After it was discovered that hands could be modeled in virtual reality, researchers started conducting experiments to determine how the user responds to a virtual environment that is haptically different from the physical environment. This sort of study in pseudo-haptics involves the manipulation of what a user is feeling in real life and what it looks like they are feeling in virtual reality to determine how much the virtual environment can be altered until the user does not think they are in a virtual environment. An example is Lecuyer et al. (2000) experiment using a Spaceball device to simulate the compression of the spring, while the user was shown a differing view of how much the spring was being compressed. It was determined that the visual feedback given to the user created an illusion that the spring took a different amount of force to compress than it actually did. This haptic disconnect hints at the potential to which virtual reality can manipulate proprioception.

The research conducted in this experiment combines the advances in the ownership illusion with haptic feedback to determine if a user’s agency or ownership over a virtual hand can vary depending on the haptic feedback they receive.

Hypothesis and Support:

How does haptic feedback effect one’s sense of agency in virtual reality? It was hypothesized that the more one feels with their hands in the real world while immersed in virtual environment, the less they will associate the virtual representation of the hands to actually being theirs, i.e. they will feel less agency and ownership over their virtual hands. Note a distinction between agency and ownership made by Argelaguet et al. (2016). Agency describes motor control and awareness of one’s actions whereas ownership describes the feeling that one’s body is the source of where sensations are being felt. It is important to measure both when conducting an experiment, so they are not mistaken or confused even though they are two separate qualities that will not affect each other during the experiment.

Many researchers have shown some counterintuitive results in regards to agency and virtual representation. Argelaguet et al. (2016) determined that the more like a real hand the virtual representation looks, the less agency a person feels because the hand has a larger chance of acting imprecisely, however the more ownership the user feels since it looks like their real hand.

In addition, many haptics studies observed that pseudo-haptic feedback effectively causes a false impression, indicating that a visual stimulus usually outweighs haptic feedback. Ban et al. (2012) using a viseo-haptic system, determined when a user touches an object that has horizontal edges different from the angled edges shown on the screen displaying their hands, most of the users believed that the actual object's edges had some angles like the one shown on the screen.

A combination of the idea that the realism decreases agency and haptics can be illusory support a hypothesis for this experiment that if the user can feel an object that they are seeing on the screen with their own hands in real life as well, their agency and ownership of the hands on the screen would be less.

MATERIALS AND METHODS

Setup and Preparation

A simple virtual environment was created using Unreal Engine 4 in which the user is placed in a first-person perspective in front of three blocks. An Oculus Rift with an attached Leap Motion sensor was used to provide an immersive virtual environment in which the users can see and use their hands in virtual reality. In order for the experiment to work, the virtual environment must be able to create the illusion that the virtual hands are part of the person using them. The setup described is almost guaranteed to be effective enough to create this illusion as per the research of Maselli & Slater in 2013. They tested different variations of a virtual environment outlining a sufficient threshold at which the illusion of ownership or agency can take place with virtual hands. They concluded that the virtual environment must be in first person perspective to create and sustain the illusion and that when using hands the fake hand does not necessarily need to be realistic for the illusion to take place. The experiment conducted uses a first-person perspective and the Leap Motion Floating Hands character that has a consistent appearance between the tasks, meaning an agency or ownership illusion should be possible and the effects on one's agency over his/her hands can only be attributed to the haptic difference between the tasks.

Experimentation

This experiment consisted of three separate tasks. In the first task, the user was told to move or lift any of the virtual blocks present in front of them. In the second task, the user was told to move lift a virtual block while a replica in size and shape was in its position in the real world. In the third task, there was no block in the virtual environment, however the user was told to move or lift a real block with their real hands. Before each test subject went through the tasks, they were initially given time to move their hands around in virtual reality and look around to experience how the leap motion hand tracking works. This control run, allowed the user to feel what an immersive virtual environment with their hands being tracked felt like, before assessing the agency and ownership of their hands while doing tasks.

In this experiment 10 random test subjects at various ages above 18, with little to no previous experience in virtual reality were used. Each test subject was guided individually through each task. Afterwards, they were given a short questionnaire. The questionnaire consisted of 10 questions (Figure 1), rated on a 7-point Likert scale (Figure 2). The questions were made as specific as possible to the situation the participants were immersed in, and was used to determine the agency each user felt over the virtual hands.

A1	It felt like I was actually holding something when I was holding the virtual block.
A2	I felt that I was not able to manipulate the blocks in the way I wanted to.
A3	Manipulating the blocks (ie moving, touching, lifting, grabbing...) was difficult.
A4	Using the virtual hands to move the block felt no different from using my real hands.
A5	I felt like I had control of my virtual hands as if they were my own hands.
A6	Manipulating the block felt realistic (ie similar to manipulating a block in real life of similar size and shape).
AD	The block in the virtual environmnet looked very realistic.
O1	When using the virtual hands, it felt as if they were a part of my body.
O2	The virtual hands accurately portrayed my real hands.
O3	I felt like I was losing control of my own hands when the virtual hands did not respond properly.
O4	It felt like the virtual hands were going through the virtual object.
OD	The virtual hands were the same size and in the same location as my actual hands.
OD	It felt like I was wearing white gloves.
	Flipped Questions: A2, A3, O3 and O4

Figure 1: 10 questions give to the user. A questionnaire is a common and effective way to measure embodiment in virtual reality, also used by Argelaguet et al. (2016), Kilteni et al. (2012) and many others.

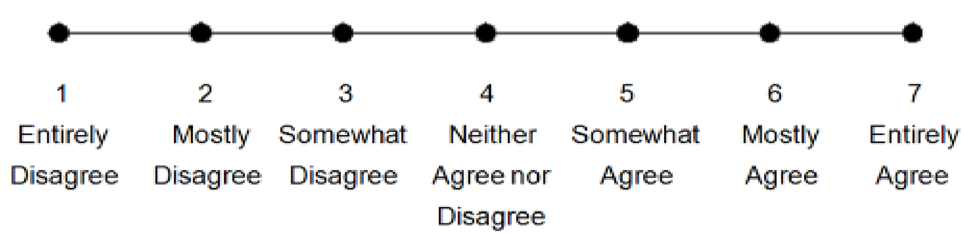

Figure 2: 7-Point Likert Scale. A common method to measure one's attitude or opinion from one's cognitive or affective components of attitude (McLeod, 2008).

Analyzing the Responses

A1 through A6 were used to measure agency and O1 through O4 was used to ownership. The questions were designed so that the larger the 1-7-point value they assigned the larger the agency or ownership the user felt over their virtual hands. However, a few of the question were flipped, so that a lower rating meant a higher score. In addition, AD and OD were distractor questions and the questions were given a randomized order without the labels A or O on them. These techniques of flipping questions, using distractors, and randomizing the order was to prevent bias in participant answers and assure accurate results. The distractor questions were not used during analysis and the opposite of the users' answers for the flipped questions were used during analysis, so if the user had entered a 2 for the flipped question, the answer was analyzed as a 6 and if they had entered a 3 their answer would have been analyzed with a 5.

Afterwards, a T-test comparison between Task 1 and 2, Tasks 1 and 3, and Tasks 2 and 3 for agency and ownership were conducted. ANOVA was also used to determine the variance of agency and ownership with haptics in the virtual environment. Both of these analyses can be found in the appendix.

Risk and Safety

Virtual Reality has developed far enough to the point where practically anyone can use a Head Mount Display (HMD) safely. None of the equipment that the subjects used or tasks that they were asked to do posed a risk to their safety or health. Most researchers conclude that Virtual Reality-Induced Symptoms and Effects (VRISE) are short lived and minor (Cobbs et al., 1999) (Nichols & Patel, 2002). Many researchers believe that that virtual reality can even be beneficial to health in psychological therapy (Schuemie, 2001).

In this research experiment, the risk of any VRISE was minimized. The users were allowed to take a break or stop using the HMD altogether if they felt discomfort in anyway. Before beginning the users, comfort was assured and during the experiment it was verbally reassured. If the user did need a break, it would not affect the collection of data in the experiment because there was no ongoing measurement of agency or ownership nor were the subjects' tasks timed, only a questionnaire was given afterwards. In addition, the Oculus Rift HMD was used, which Chessa et al. in 2016 determined to have a strong effect on immersing a user into a virtual environment while avoiding negative VRISEs, such as simulator sickness, in comparison to other HMDs. The research done by Chessa et al. explicitly suggests that the Oculus rift is a safe and powerful tool to use in research and in clinical applications.

RESULTS

Data

Figure 3: Average Agency for Each Participant

Task	Participants 1-10										Overall Average per task
	1	2	3	4	5	6	7	8	9	10	
1	2.33	4.50	3.67	4.33	3.00	4.33	5.67	4.33	3.33	4.33	3.98
2	3.00	2.33	4.17	4.67	2.67	4.50	5.67	3.67	3.33	4.00	3.80
3	5.50	5.50	3.50	4.33	3.67	5.00	6.67	3.33	3.67	5.17	4.63

Figure 4: Average Ownership for Each Participant

Task	Participants 1-10										Overall Average per task
	1	2	3	4	5	6	7	8	9	10	
1	2.75	4.25	4.75	5.50	3.25	4.25	4.25	4.75	4.75	3.00	4.15
2	2.00	2.75	4.50	6.25	2.75	4.50	4.25	4.00	4.75	3.25	3.90
3	2.00	3.75	4.75	6.25	2.75	4.25	4.25	3.50	4.75	3.50	3.98

The data was collected, sorted, and the mean of the responses was determined as shown in Figure 3-4. The questions were worded so that a higher numbered response would indicate a larger sense of agency, making it easy to compare the mean values for the agency each participant felt in each task. The results show that for each task individually and when averaging the tasks together, Task 1 most strongly caused the illusion of ownership whereas Task 3 most strongly caused the illusion of agency.

Analysis

After a statistical analysis, the results conclusively cannot support the hypothesis. The hypothesis indicates that haptics would be attributed to a decrease in agency and ownership however the T-test done in comparison of agency in Task 1 (without haptic feedback) to Task 2 (with haptic feedback) concluded with a P-value=.578 > σ= .05 that variance between Task 1 and Task 2 is statistically insignificant since it does not meet a 95% confidence interval. When Task 2 was compared to Task 3 for agency, the results showed an insignificant difference with a P-value of 0.0637. All the T-tests with ownership much more inconclusive with P-values always exceeding .6. The failure of ownership to produce results can be seen by the large distribution in Figure 6.

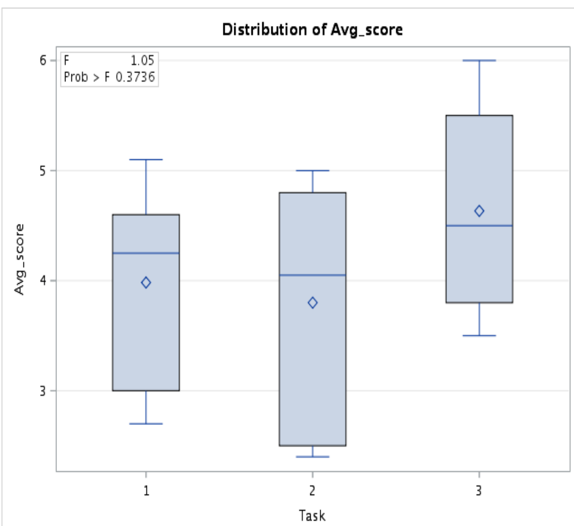

Figure 5: Agency Box and Whiskers Plot. Shows some variance among the tasks that can be analyzed.

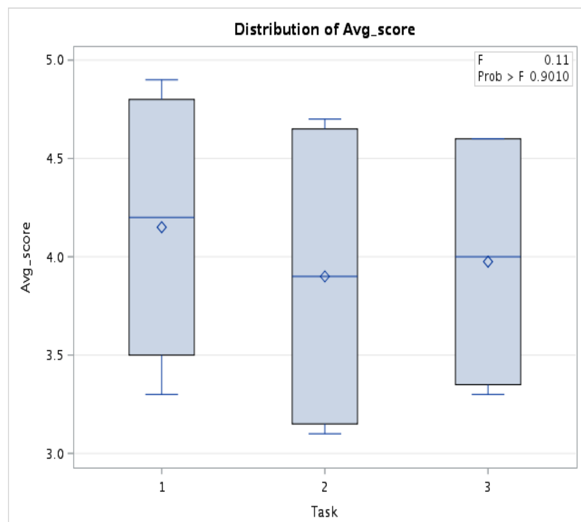

Figure 6: Ownership Box and Whiskers Plot. Shows variance in each task is too similar to draw any conclusions.

However, although this hypothesis was inconclusive, an analysis of Task 2 compared to Task 3 with a P-value of 0.0208, shows a statistically significant variance. The distribution shows that the users generally felt more agency during Task 3 then Task 2. This means they felt like they had more control over their hands using the block when the block and was not virtually present yet they could feel it. This conclusion shows that the initial hypothesis can be supported by proving that haptics plays a larger role than visuals in the agency a user feels over their hands. This means that a user's virtual experience is dependent on haptics instead of visuals. The initial hypothesis is correct in stating that haptics can affect agency, however it does not assume a difference in visual stimulus as well. A modified hypothesis that can be fully supported by this experiment would state that the more one feels with their hands instead of seeing with their eyes, the more agency the will feel over the virtual hands in the virtual environment.

Although the results cannot wholly support the hypothesis an analysis can still be done on the relative differences between the tasks 1 and 2 can be visually compared. The distribution of the box and whiskers plot for agency (Figure 5) visually shows that Task 2 with haptics and visual was associated with the least amount of agency, whereas Task 1 with just the virtual block and no haptic feedback led the users to feel a little more agency. This correlation could be attributed to the idea that proprioception triggered a cognitive response that ascribed the action of lifting a box to the real world instead of virtual reality. Therefore, the illusion of agency a user feels over a virtual hand is lessened when they touch something with their real hands.

DISCUSSION

Comparisons to Past Research

The results of the visual comparison between tasks 1 and 2 for this research compliment and add to past research. Ownership and agency illusions often ignore haptic or even motor conditions. Kilteni et al. (2012) discovered that a user can feel ownership over arms that are longer than normal length, but this research did not account for the fact that if this virtual arm was to be used in a virtual application, the user would be moving their arm and using it complete tasks. The ownership illusion, therefore, may be broken by haptic feedback when completing virtual tasks. In addition, Pusch et al. (2011) describes how a higher fidelity from the hand is desirable over a more realistic hand in creating an effective immersive environment. This implies that lifting a virtual block and real block simultaneously might have a lessened feeling of agency because the hand may have less fidelity, being constrained to holding a block in real life which may have affected the hand tracking.

The results of the T-Test comparison between tasks 2 and 3 however, are not well supported by other experiments, since many experiment don't test the absence of visual feedback with the presence of haptic feedback in a virtual environment. Kokkinara & Slater (2014) experimented with a stimuli in between visual representation and haptic feedback, such as visuotactile and visuomotor stimulation. They correlated a larger ownership illusion to synchronous visuotactile and visuomotor stimulation, indicating that the more virtual interaction is combined with real interaction, the more likely the user will feel ownership over their hands. This may support the idea that more agency occurs with more visual and haptic feedback which would contradict the results. However, it is important to note a distinction between ownership and agency that Argelaguet et al. (2016) makes. Agency describes motor control and awareness of one's actions whereas ownership describes the feeling that one's body is the source where sensations are being felt. This means, even if Kokkinara & Slater determined an increase sense of ownership, that doesn't necessarily contradict this experiments increased sense of agency. Since Kokkinara & Slater didn't explicitly distinguish between agency and ownership their data may also be misleading, for some of what they thought was ownership could have been confused with agency.

Applications

Finding an effective way to immerse and interact with a user in a virtual environment has many futuristic applications. Being able to effectively use hands in virtual reality without losing a sense of agency means that people could expand virtual reality to many more areas. For example, in globalization, people could use virtual reality to play games or communicate with each other across the world. In education, human computer interaction in virtual environments could be used to train doctors to give surgery or train astronauts for foreign environments (Rautaray & Agrawal, 2015). In health, virtual reality could be used to enhance therapy treatments (Schuemie, 2001), like for treating PTSD by creating controllable situations and enhancing emotional engagement (Botella et al., 2015). Overall, more research needs to be conducted with interaction in virtual environments, but once completed the applications are endless.

CONCLUSION

The extent to which haptics play into the illusion of agency over a virtual pair of hands is a specific topic in virtual reality that has not previously been explored. In this study, it was determined that haptics may negatively affect the agency one feels over a virtual pair of hands they use, indicating that more immersive virtual environments should exclude more realistic haptics. Conversely, the results also indicated that if a virtual environment excludes visual display, haptics is likely to increase agency. Since this is a relatively unexplored relationship in virtual reality, more research can be done based of this study to determine whether perspective, location, avatar representation, or other factors may alter the negative effect haptics has on agency. Nevertheless, the discoveries of this research mark a step forwards in creating a fully immersive virtual environment.

APPENDIX

Agency T-Tests

Compare two independant samples - Task1 vs Task2

The TTEST Procedure

Variable: Score

Task	N	Mean	Std Dev	Std Err	Minimum	Maximum
1	60	3.9833	1.7514	0.2261	1	7
2	60	3.8	1.8485	0.2386	1	7
Diff (1-2)		0.1833	1.8006	0.3287		

Task	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
1		3.9833	3.5309	4.4358	1.7514	1.4846	2.1362
2		3.8	3.3225	4.2775	1.8485	1.5669	2.2545
Diff (1-2)	Pooled	0.1833	-0.4677	0.8343	1.8006	1.5973	2.0638
Diff (1-2)	Satterthwaite	0.1833	-0.4677	0.8344			

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	118	0.56	0.5781
Satterthwaite	Unequal	117.66	0.56	0.5781

Equality of Variances				
Method	Num DF	Den DF	F Value	Pr > F
Folded F	59	59	1.11	0.68

Compare two independant samples - Task1 vs Task3

The TTEST Procedure

Variable: Score

Task	N	Mean	Std Dev	Std Err	Minimum	Maximum
1	60	3.9833	1.7514	0.2261	1	7
3	60	4.6333	2.0417	0.2636	1	7
Diff (1-2)		-0.65	1.9021	0.3473		

Task	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
1		3.9833	3.5309	4.4358	1.7514	1.4846	2.1362
3		4.6333	4.1059	5.1607	2.0417	1.7306	2.4901
Diff (1-2)	Pooled	-0.65	-1.3377	0.0377	1.9021	1.6873	2.1801
Diff (1-2)	Satterthwaite	-0.65	-1.3379	0.0379			

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	118	-1.87	0.0637
Satterthwaite	Unequal	115.33	-1.87	0.0638

Equality of Variances

Method	Num DF	Den DF	F Value	Pr > F
Folded F	59	59	1.36	0.2418

Compare two independant samples - Task2 vs Task3

The TTEST Procedure

Variable: Score

Task	N	Mean	Std Dev	Std Err	Minimum	Maximum
2	60	3.8	1.8485	0.2386	1	7
3	60	4.6333	2.0417	0.2636	1	7
Diff (1-2)		-0.8333	1.9475	0.3556		

Task	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
2		3.8	3.3225	4.2775	1.8485	1.5669	2.2545
3		4.6333	4.1059	5.1607	2.0417	1.7306	2.4901
Diff (1-2)	Pooled	-0.8333	-1.5374	-0.1292	1.9475	1.7275	2.2321
Diff (1-2)	Satterthwaite	-0.8333	-1.5375	-0.1292			

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	118	-2.34	0.0208
Satterthwaite	Unequal	116.85	-2.34	0.0208

Equality of Variances				
Method	Num DF	Den DF	F Value	Pr > F
Folded F	59	59	1.22	0.4475

Ownership T-Tests

Compare two independant samples (Ownership) - Task1 vs Task2

The TTEST Procedure

Variable: Score

Task_Owner	N	Mean	Std Dev	Std Err	Minimum	Maximum
1	40	4.15	1.8612	0.2943	1	7
2	40	3.9	1.892	0.2991	1	7
Diff (1-2)		0.25	1.8766	0.4196		

Task_Owner	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
1		4.15	3.5548	4.7452	1.8612	1.5246	2.3899
2		3.9	3.2949	4.5051	1.892	1.5498	2.4293
Diff (1-2)	Pooled	0.25	-0.5854	1.0854	1.8766	1.6228	2.2254
Diff (1-2)	Satterthwaite	0.25	-0.5854	1.0854			

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	78	0.6	0.5531
Satterthwaite	Unequal	77.979	0.6	0.5531

Equality of Variances				
Method	Num DF	Den DF	F Value	Pr > F
Folded F	39	39	1.03	0.919

Compare two independant samples (Ownership) - Task1 vs Task3

The TTEST Procedure

Variable: Score

Task_Owner	N	Mean	Std Dev	Std Err	Minimum	Maximum
2	40	3.9	1.892	0.2991	1	7
3	40	3.975	1.8603	0.2941	1	7
Diff (1-2)		-0.075	1.8762	0.4195		

Task_Owner	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
2		3.9	3.2949	4.5051	1.892	1.5498	2.4293
3		3.975	3.38	4.57	1.8603	1.5239	2.3888
Diff (1-2)	Pooled	-0.075	-0.9102	0.7602	1.8762	1.6224	2.2249
Diff (1-2)	Satterthwaite	-0.075	-0.9102	0.7602			

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	78	-0.18	0.8586
Satterthwaite	Unequal	77.978	-0.18	0.8586

Equality of Variances				
Method	Num DF	Den DF	F Value	Pr > F
Folded F	39	39	1.03	0.9168

Compare two independant samples (Ownership) - Task2 vs Task3

The TTEST Procedure

Variable: Score

Task_Owner	N	Mean	Std Dev	Std Err	Minimum	Maximum
2	40	3.9	1.892	0.2991	1	7
3	40	3.975	1.8603	0.2941	1	7
Diff (1-2)		-0.075	1.8762	0.4195		

Task_Owner	Method	Mean	95% CL Mean		Std Dev	95% CL Std Dev	
2		3.9	3.2949	4.5051	1.892	1.5498	2.4293
3		3.975	3.38	4.57	1.8603	1.5239	2.3888
Diff (1-2)	Pooled	-0.075	-0.9102	0.7602	1.8762	1.6224	2.2249
Diff (1-2)	Satterthwaite	-0.075	-0.9102	0.7602			

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	78	-0.18	0.8586
Satterthwaite	Unequal	77.978	-0.18	0.8586

Equality of Variances				
Method	Num DF	Den DF	F Value	Pr > F
Folded F	39	39	1.03	0.9168

Agency ANOVA

The ANOVA Procedure

Class Level Information		
Class	Levels	Values
Task	3	1 2 3

Number of Observations Rea	18
Number of Observations Use	18

The ANOVA Procedure

Dependent Variable: Avg_score

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	2.30111111	1.15055556	1.05	0.3736
Error	15	16.40166667	1.09344444		
Corrected Total	17	18.70277778			

R-Square	Coeff Var	Root MSE	Avg_score Mean
0.123036	25.26473	1.045679	4.138889

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Task	2	2.30111111	1.15055556	1.05	**0.3736**
					Greater than 0.05

Ownership ANOVA

The ANOVA Procedure

Class Level Information		
Class	Levels	Values
Task	3	1 2 3

Number of Observations Rea	12
Number of Observations Use	12

The ANOVA Procedure

Dependent Variable: Avg_score

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.13166667	0.06583333	0.11	0.901
Error	9	5.6175	0.62416667		
Corrected Total	11	5.74916667			

R-Square	Coeff Var	Root MSE	Avg_score Mean
0.022902	19.70999	0.790042	4.008333

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Task	2	0.13166667	0.06583333	0.11	0.901

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OVERALL REFLECTION

My overall experience researching in a professional lab was beneficial to my educational development in many ways. I learned much about the technology and experimentation surrounding Virtual Reality studies, but more importantly one of the most important skills I learned from working in a lab was how to manage many responsibilities at once and manage my time efficiently.

When researching at the lab, most of my work was independent. I didn't have teachers telling me what to do and when to do it. Instead, I had to figure out what I wanted to do for my project and how to do it. I did have resources and help from other graduate students and my mentor, but all of the project was done independently by me and reviewed by them if had questions about a certain issue. This kind of independent work meant that I had a lot to keep track of on my own, such as maintaining a timeline for my project that would ensure I would meet the science fair and scholars of distinction deadlines.

In addition, unlike most other classes in school, none of my research project was being graded. This means I had to have extrinsic self-motivation for conducting this project and I quickly realized that motivation was just my natural interest and intrigue in STEM. I enjoyed going to lab and using UnrealEngine and the virtual reality head mount display and equipment. I also enjoyed reading about other research projects dealing with virtual reality and drawing conclusions about how my projects should be from them. All this time an energy I spent at lab eventually payed off, for I was very proud of the project I had created in the end.

I discovered how agency was effected by haptic feedback in a virtual environment. To my surprise, I found that absent a virtual block haptics most effectively creates a sense of agency in a virtual environment. This knowledge can be used to further expand how a virtual environment can be interacted with. Future developments could use this information to create more immersive virtual environments either with haptic feedback absent visual display or with visual display and without haptic feedback. However, more research should be conducted and this project should be replicated with more test subjects and maybe different tasks in virtual environment to assure that the results of this experiment are accurate.

Although I have finished this project regarding agency in virtual reality, my time with research has not ended. I intend on continuing researching in this lab helping out with other projects until I leave for college, and then continue researching as an undergraduate in college. Although I may move away from virtual reality research in the future, my goal to positively influence society with advancements in computer technology still stands strong.