Sense of Embodiment in Virtual Reality

A Project Report

submitted by

BACHALA SRIKANTH

in partial fulfilment of the requirements

for the award of the degree of

BACHELOR OF TECHNOLOGY &

MASTER OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, MADRAS.

May 2020

THESIS CERTIFICATE

This is to certify that the thesis titled **Sense of Embodiment in Virtual Reality**, submitted by **Bachala Srikanth**, to the Indian Institute of Technology, Madras, for the award of the degree of **Bachelor of Technology & Master of Technology**, is a bonafide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Prof.M.Manivannan
Research Guide
Professor
Dept. of AM
IIT Madras, 600036

Place: Chennai
Date: 30th May 2020

ACKNOWLEDGEMENTS

I would like to extend my sincere gratitude to my guide Prof. M.Manivannan, for giving me the opportunity to work with him in the field of Virtual Reality (Sense of Embodiment) and I am very thankful for his outstanding instructive advice and for all the guidance and suggestions he has made during the course of the project. I am deeply grateful of his help in the completion of this thesis. I would like to thank the Department of Applied Mechanics and Department of Electrical Engineering and IIT Madras for providing me with the facilities and the academic wisdom to carry out this project. I would also like to thank the people of Touch Lab for their help and support during the course of the project. Finally, I would like to thank my family, especially my father and mother, for their constant support.

ABSTRACT

Sense of embodiment is how we experience towards our body as being inside it, move it according to our will, and feel to be inside it. This study investigates this relationship towards a virtual body or artificial body. We test how far can we experience the feeling of ownership towards a foreign body, how does the experience of a virtual body feel compared to our biological body and how does this experience of embodying a virtual body can effect our mind.

Now with the help of immersive virtual reality, we are using a virtual body to test our hypothesis on sense of embodiment to experience the same sensations as we experience in our biological body. So, how do we represent users in virtual reality? How do they perceive these virtual representations in virtual reality? And how does these representations influence their virtual reality experience? These questions were answered by using the immersive virtual reality in sense of embodiment.

In this work, we conduct some experiment related to sense of embodiment using traditional approaches (Rubber Hand Illusion) and new approaches (virtual embodiment). From the results of these experiment we try to gain better understanding and try to go a step further in the research of sense of embodiment to find some applications of it.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

SoE	Sense of Embodiment
RHI	Rubber Hand Illusion
VR	Virtual Reality
1PP	First Person Perspective

NOTATION

CHAPTER 1

INTRODUCTION

Since the past few decades, many studies were conducted in the research of embodiment to study how do we experience ourselves being inside a body that interacts continuously with the environment?, How does it feel like to own, to control, and to be inside a body?. With the increasing interest in this subject, many experiments were conducted like the Rubber Hand Illusion (RHI), etc and papers were published. Here, Embodiment usually refers to how the body and its interactive processes, such as perception or cultural acquisition through the senses, aid, enhance or interfere with the development of the human functioning.

1.1 Overview and Problem Statement

Our focus is to study the Sense of Embodiment (SoE) by conducting experiments with an artificial body or virtual body to find the extent of this experience and analyze it to study how does it effect our mind. Traditional approaches to this problem rely on the approach of RHI in various different setups where they study the data of the subjective experience faced by the participants of the experiment and came up with some of the results which are published as papers now. However, there is a limit to the extent to which we can study SoE using RHI.

So, with the growing technology and introduction of immersive Virtual Reality (VR), they started using it to study SoE on a virtual body in the virtual environment.

They no longer faced the constraints of the continuous presence of biological body and came up with some novel approaches to study different aspects of SoE.

As the research in this direction gained traction (Bailey et al. (2016), Slater et al. (2018)), it became clear that immersive VR has become a major tool in the study of SoE. With RHI, researchers were only limited to the feeling of ownership, but with the help of virtual embodiment, they were able to gain a better experience of the feeling of embodiment increasing the aspects which can be studied.

Building upon all these ideas presented by their work, our study starts with the basics in SoE and try to study it in depth. So, first, we start with the RHI experiment and try to understand it, then we move on to virtual embodiment, where we study the subjective experience of virtual embodiment. Lastly, we study how does virtual embodiment changes our mind in an aspect like cognitive task performance.

1.2 Motivation

Human body is remarkable in many ways like how it works in coordination with mind, interacts with the environment, etc. For instance, we feel to be inside the body, can control it and feel it as our own. These kind of feelings even though we experience from the biological body, we are unable study this due to the multidimensional nature of the experience together with the continuous presence of one's biological body. To study how the body and mind's systems interact when we embody a new body, different approaches were introduced. These studies can lead to new ways to treat patients suffering from psychological problems or some other applications. These applications motivates one to conduct research in this field for further improving our understanding towards human mind.

1.3 Contributions of this work

In this study, we conduct three experiments in total:

- Demonstration of Rubber Hand Illusion
- Testing the limits of virtual embodiment
- Studying how virtual embodiment effects our cognitive task performance

In the demonstration of the RHI, we try to study and experience the concepts of proprioceptive drift and feeling of ownership using a simple RHI experimental setup. Here, by stoking both the participant's occluded hand and visible rubbers hand in a synchronous manner, we experience an illusion as if the rubber hand is our real hand, undergo a feeling of ownership over the rubber hand. Then, in the second experiment, the participant will undergo a virtual embodiment of a virtual body, which has features nearer to the participant. Here, we ask the participants to experience the virtual environment and try gain some experience regarding their virtual body.

In the final experiment, we study the effect of virtual embodiment into Ramanujan avatar on the cognitive task performance. In a study conducted by Osimo et al. (2015), people were embodied in a virtual body that represented a famous counselor Dr Sigmund Freud or alternatively a virtual look-alike representation of themselves. This study helped in find a more satisfactory solution to a personal problem of the patients. Similarly, in the study conducted by Slater et al. (2018), people were embodied in a virtual body that represented the famous scientist Albert Einstein or a virtual look-alike representation of themselves. The conclusion was participants embodied as Einstein had an improvement in cognitive task performance. The approach in this study is built on similar ideas with Srinivasa Ramanujan avatar for virtual embodiment which helps in the research on applications of virtual embodiment.

1.4 Organization of thesis

The thesis is organized in a manner as outlined in the index page. Chapter 1 dealt with the introduction and problem statement of the thesis. The 2nd chapter details about the necessary background required for the reader to understand the information presented in this thesis, along with the related previous works performed in this domain. The 3rd chapter deals with our experimental design to study the problem statement. The 4th chapter discusses and analyses the results obtained by the conducted experiments. The 5th chapter presents a conclusion and a future direction for anyone interested to continue this work.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

2.1.1 Sense of Embodiment

Sense of embodiment is the ensemble of sensations that arise in conjunction with being inside, having, and controlling a body. Understanding and defining the SoE towards a body, the following definition is adopted:

"SoE toward a body B is the sense that emerges when B's properties are processed as if they were the properties of one's biological body".

To study SoE, researchers are using immersive VR as a tool to conduct their experiments on a virtual body as in Figure 2.1. These studies are related to body perception like manipulating the identity of a body and to answer questions like 'How and to what extent can we experience a virtual body representation as our own body within a virtual environment?'. Immersive VR is advantageous to use since, it is easy to manipulate the factors to be studied in a controlled way and provides an embodied experience better than RHI.

Everyday experience concerning the biological body can manifest itself in at least three main classes:

- one's self-representation in a body is driven and highly characterized by its spatial attributes

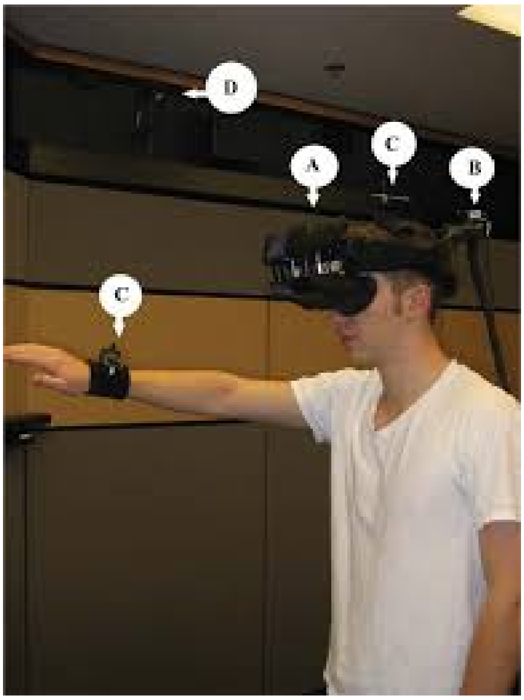

Figure 2.1: A participant experiencing virtual embodiment. The figure depicts: (A) a head-mounted display (HMD); (B) the orientation sensor; (C) the optical tracking sensors; and (D) one of the eight motion capture cameras that track the optical tracking sensors.

- spatial representation is always self-attributed
- body obeys intentions of one's self

The concept of SoE is regarded as having these three underlying sub-components. They are:

1. **Sense of self-location**: It is the feeling of one's self to be located inside the biological body or an avatar's body. It is highly determined by the visuospatial perspective, vestibular signals and tactile input. In VR environment, first person perspective (1PP) is a fundamental requirement to experience the sense of self-location. We can further enhance this by synchronous visuotactile correlation.

2. **Sense of agency**: It is the sense of having "global motor control, including the subjective experience of action, control, intention, motor selection and the conscious experience of will". The feeling of agency results from the comparison between the predicted sensory consequences of one's actions from the the actual sensory consequences. The sense of agency is easily provided in VR when the movements of the user is mapped to the virtual body in real-time or near real-time.

3. **Sense of body ownership**: It is one's self-attribution of a body. This implies that the body is the source of the experienced sensations. To induce ownership in VR, certain structural and morphological constraints are applied on the virtual body to appear human like.

The intensity with which we experience the three sub-components could be considered to vary continuously from none to maximum degree. That is to say, the experience of our biological body is the maximum degree of embodiment. During this experience one feels fully embodied.

2.1.2 Effect of Virtual Embodiment on Minds

Can an avatar's body movements change a person's perception of good and bad? These type of questions were studied in detail by many researchers. In (5), the researchers demonstrated how VR could be used to examine the possible ways that systems of the body may interact to influence cognition (e.g.visual, motor). According to an embodied cognition (EC) approach, cognition is grounded in the body and in the body's relationship to the environment. Embodied cognition defines cognition as an interaction between the mind and the body's systems. People generate mental representations through physical simulations, situated action, and bodily states. Simulation refers to the process in which the brain captures information across the body's modalities (e.g. sight, sound, smell) and integrates all the representations to be stored in a memory. When a person thinks about an experience or an idea, the brain reenacts all the perceptual motor and introspective states that were stored during the time the body and the mind interacted with the physical world. When information is remembered, the body simulates those same systems in the brain as if the body were enacting the experience. A person's virtual body can create different social meaning than the person's physical body suggesting that virtual embodiment can alter personal identity and perception. When an object is reasonably similar to the body or part of the body it is representing, its physical appearance is not the sole factor in creating the illusion of embodiment or body transfer to the physical or virtual objects. Virtual embodiment has psychological and physiological effects.

2.2 Related work

2.2.1 Rubber Hand Illusion

To study SoE, Botvinick and Cohen came up with a new experimental approach to investigate how the human brain integrates sensory and proprioceptive inputs to represent the body in space.This is known as Rubber Hand Illusion.

RHI is a tantalizing illusion, where the feeling that a rubber hand belongs to one's body (feeling of ownership) is brought about by stroking a visible hand synchronously to the participant's occluded hand. A displacement of reaches towards the rubber hand occurred in the case of synchronous stimulation, but not in the case of asynchronous stimulation. This displacement effect has been referred to as proprioceptive drift. This proprioceptive drift is usually thought of as a "three-way interaction between vision, touch and proprioception", in which synchronous stroking (touch) evokes the proprioceptive feeling of the own hand to be displaced towards the seen (visual) rubber hand.

In (2), researchers conducted an experiment related to RHI with the experimental setup as in Figure 2.2 and proposed that the feeling of ownership and proprioceptive drift need not be related. Participants of the experiment rated the subjective experience to own the rubber hand high in a questionnaire if stroking is synchronous but not if stroking was asynchronous. While proprioceptive drift relies on visuoproprioceptive integration alone. Synchronous stroking may not induce any proprioceptive drift additional to the drift resulting from visuoproprioceptive integration. Low drift requires prolonged asynchronous stroking and the feeling of owning the rubber hand requires visuotactile synchronous stroking.

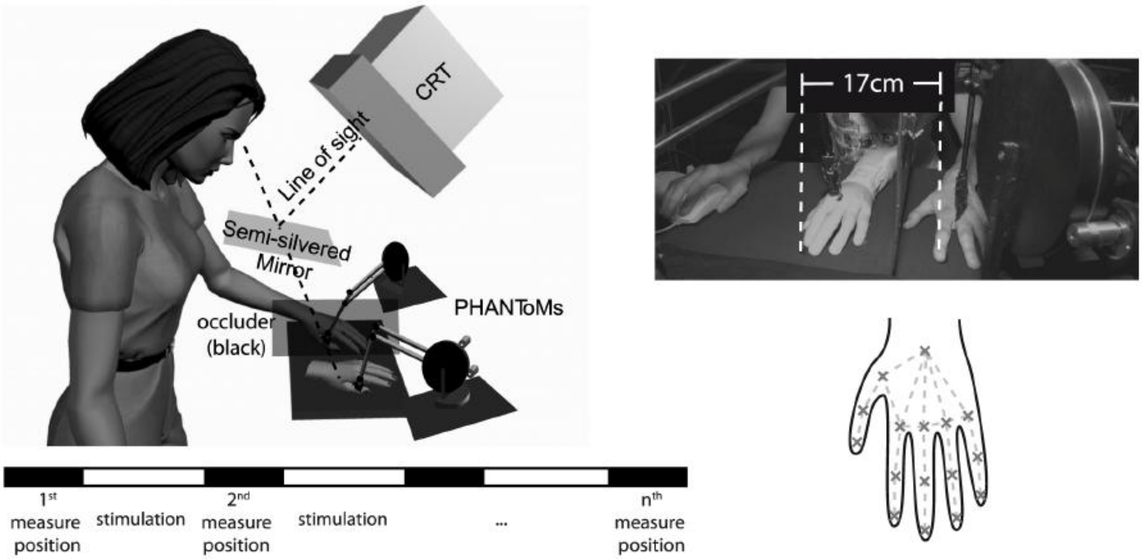

Figure 2.2: The RHI set-up used in the study (2)

So, they concluded that, in the RHI, a drift in the proprioceptively sensed hand position has been reported to correlate with the subjective feeling of ownership. Asynchronous stroking in the control condition has a negative effect on this drift and may indeed be responsible for changes in proprioceptive drift. The results suggested that the practice of using proprioceptive drift to assess feelings of ownership is problematic.

2.2.2 Sense of Embodiemnt in Virtual Reality

In (3), researchers worked on their hypothesis stating 'Being immersed in virtual environment while sharing a common task together with another user will reinforce

Figure 2.3: Setup of the experiment in (3): each user was able to interact in the virtual environment with his own avatar, while the physical setup provided both a reference frame and passive haptic feedback. From left to right: experimental conditions Alone, Mirror and Shared; Physical setup of the experiment.

the SoE'. For this studies, they assumed that 'Seeing another user's avatar will reinforce the user experience and in particular, that it will enable users to experience a higher sense of ownership and agency'. By conducting their experiments as in Figure 2.3, they came to the conclusion that, users were significantly more "efficient" in performing the task when sharing the virtual environment and in competitive level, they felt their presence was higher when sharing the virtual environment.

In (4), the researchers worked on the subject of how does virtual embodiment effect on cognitive task performance and age bias of an individual. So, the volunteers are embodied in a Einstein virtual body and normal virtual body (Figure 2.4) to perform some tasks at separate intervals. Here, the participants were young men, they clearly had overall a strong illusion of body ownership over a much older body as well as over a body representing one of approximately their age. This embodiment induced through 1PP and synchronous visuomotor correlations between the participants movements and those of their virtual bodies lead to equally high ownership and agency rating for both those embodied as Albert Einstein and those embodied in a younger looking virtual body. Embodiment in Einstein leads to changes in implicit attitudes i.e. reduction of implicit bias against age. the 'self' is associated with attributes of the newly transformed body, this allows the participants to ac-

Figure 2.4: The body of the participant was substituted by a gender-matched virtual body, viewed from 1PP, onto which body and head movements were mapped in real time. **left** The Einstein virtual body. **right** The Normal virtual body.

cess mental resources that are normally inaccessible due to their familiar modes of thinking about themselves. Finally, they came to a conclusion that, virtual embodiment can be used to generate an illusion of body ownership of a virtual body that substituted their own body, through 1PP and visuomotor correlations over real and virtual body movements. Embodiment does not only lead to perceptual, attitudinal and behavioural correlates, but can also cause changes in cognitive processing.

CHAPTER 3

Experimental Design

3.1 Demonstration of Rubber Hand Illusion

3.1.1 Experimental Set-Up

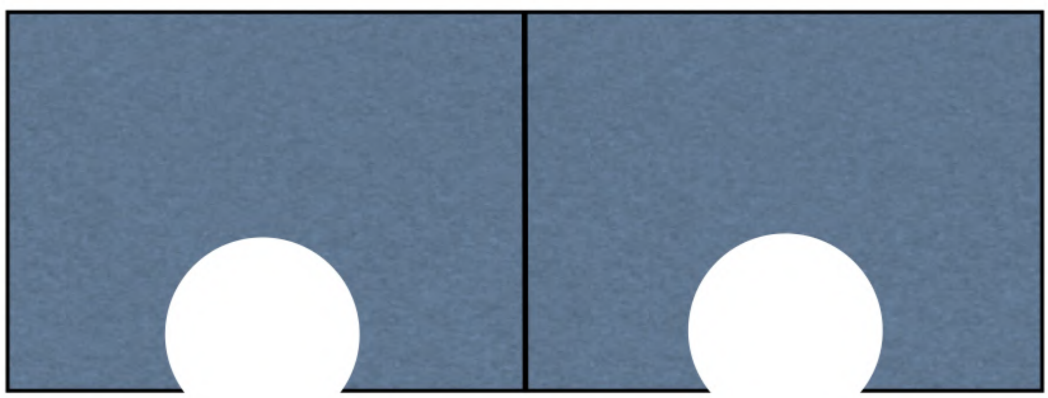

Figure 3.1: Schematic drawing of occluder box seen from the point-of-view of the participant.

This experiment requires three critical pieces of equipment: A rubber hand, two paintbrushes, and an occluder box. To build the occluder box, we will need a piece of cardboard that is about 1 ft high and 2 ft long. Draw a straight line down the middle, and then in the middle of each of the two squares, cut a tunnel large enough for a hand and arm to pass through. Figure 3.1 shows a schematic drawing of this portion of the box, as it would be seen from the point-of-view of the participant in the task. Next, on one side of the cardboard box we attach an opaque top along with an opaque divider between the two halves of the box. The participant's real arm will

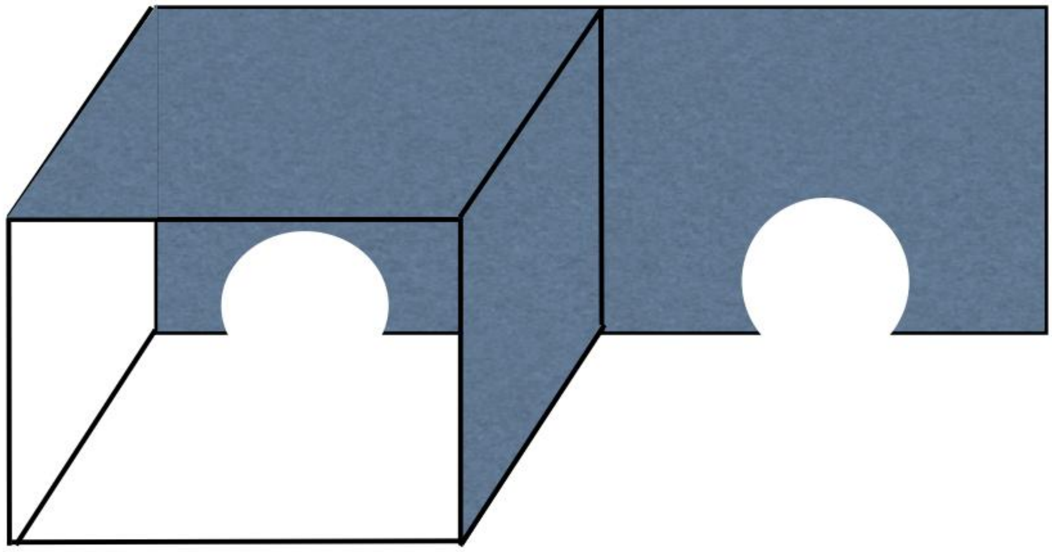

Figure 3.2: Schematic drawing of occluder box seen from the point-of-view of the experimenter.

go into this part of the box, where it will be visually occluded from the participant. Figure 3.2 shows a schematic drawing of the completed box with this attachment on it. Finally, we will need to make survey in order to assess the extent to which your participant experienced the illusion. Figure 3.3 is such a survey, modelled directly on the methods used by Botvinick and Cohen.

3.1.2 Procedure

To induce the illusion in the participant, he/she is seated at a table in front of the flat side of the occluder box.The box should be placed so that he/she can insert his/her left arm comfortably into the hole furthest from his/her left shoulder. Then, the participant is asked to place his/her left hand in the hole furthest from his/her left shoulder. Once the participant is seated comfortably and with his/her arm inserted, we place the rubber arm so that it exits from the hole closer to the participant. The participant is instructed to move his/her left arm and fingers as little as possible.

Instructions: Below, you will find several statements. Please indicate the extent to which you agree or disagree with each statement by making a mark on the line below the statement.

1. It seemed as if I were feeling the touch of the paintbrush in the location where I saw the rubber hand touched.

Strongly Disagree — *Strongly Agree*

2. It seemed as though the touch I felt was caused by the paintbrush touching the rubber hand.

Strongly Disagree — *Strongly Agree*

3. I felt as if the rubber hand were my hand.

Strongly Disagree — *Strongly Agree*

4. It felt as if my (real) hand were drifting towards the right (towards the rubber hand).

Strongly Disagree — *Strongly Agree*

5. It seemed as if I might have more than one left hand or arm.

Strongly Disagree — *Strongly Agree*

6. It seemed as if the touch I was feeling came from somewhere between my own hand and the rubber hand.

Strongly Disagree — *Strongly Agree*

7. It felt as if my (real) hand were turning 'rubbery'.

Strongly Disagree — *Strongly Agree*

8. It appeared (visually) as if the rubber hand were drifting towards the left (towards my hand).

Strongly Disagree — *Strongly Agree*

9. The rubber hand began to resemble my own (real) hand, in terms of shape, skin tone, freckles or some other visual feature.

Strongly Disagree — *Strongly Agree*

Figure 3.3: Survey questions with scales.

Then the participant is asked to look over the wall of the occluder. His/Her own arm will not be visible, as it will be inside of the box portion of the occluder box. But the rubber arm should be fully visible to him/her. Now we sit in front of the participant, and slowly brush both his/her real hand and the rubber hand with the paintbrushes in a synchronous manner for 10 min. The participant may react during the brushing period, exclaiming that he/she feels like the rubber hand is his/her own. We need to inform the participant that such experiences are normal in the context of the experiment. After 10 min, we remove the box and the rubber arm, and ask the participant to complete the survey.

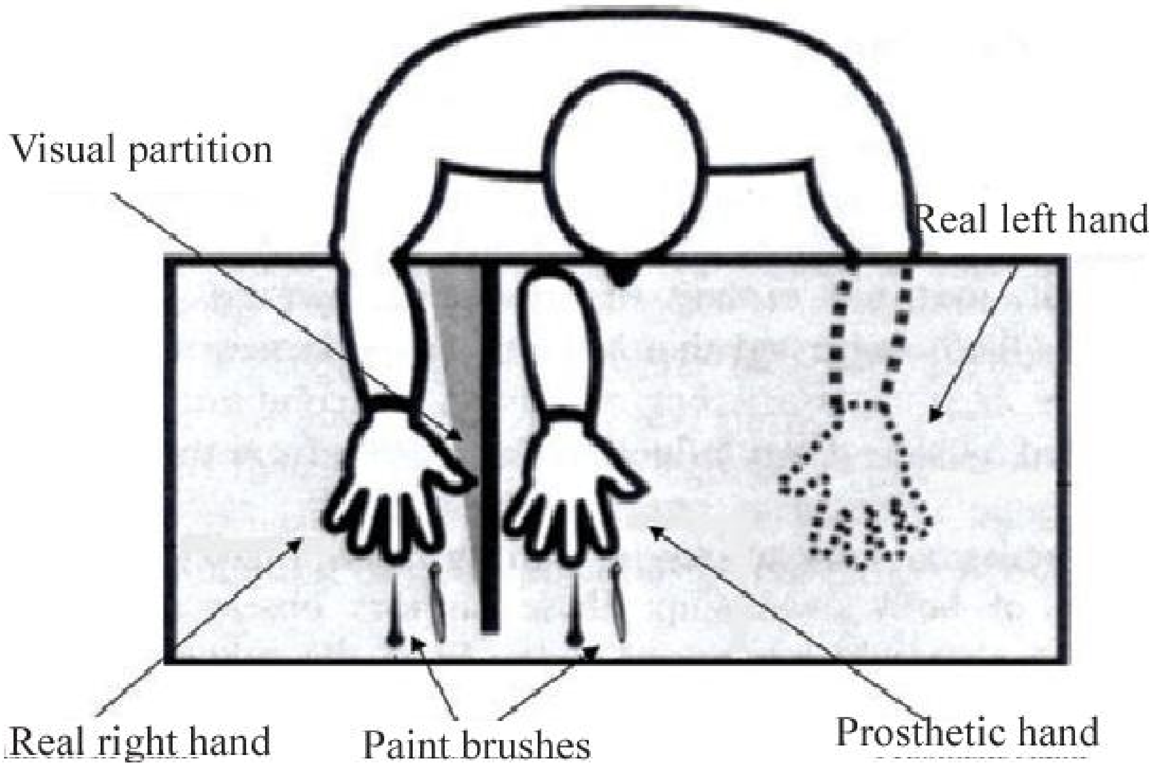

Figure 3.4: RHI Setting

3.2 Testing the limits of Virtual Embodiment

3.2.1 Experimental Set-Up


Figure 3.5: Virtual environment for the experiment.

The experiment is conducted in a VR laboratory. Participants are fitted with a HTC VIVE Head Mounted Display (HMD). To track the body movements of the participant in real time, we use Intel Realsense depth camera with Intel Realsense viewer. Nuitrack SDK is used with the Realsense camera to animate the virtual body by mapping the user's skeleton and virtual body's skeleton. The virtual environment is implemented on the Unity 3D platform as in Figure 3.5. The animation-enabled model of the Normal virtual body (Figure 3.6) is created with makeHuman software. The avatar is adjusted according the features of the participant.

Figure 3.6: Normal virtual body.

3.2.2 Procedure

Participants attended the experiment at pre-arranged times. Upon arriving, they were given an information sheet to read, and after they agreed to continue with the experiment, they were given a consent form to sign, and completed a demographics questionnaire. The VR exposure took place in a laboratory. When ready to start, the participants were fitted with a head-mounted display (HMD). Upon entering the virtual environment, participants found themselves in a virtual room where their body was visually substituted by the life-sized young adult virtual body (Normal)(Figure 3.6), seen from 1PP. Their head and body movements were mapped in real-time to the virtual body. They could see the body both by looking directly toward their real body, and also in a virtual mirror. They were asked to perform a simple set of stretching exercises in order to explore the capabilities and real time motion of the virtual body, including movements of their arms, legs and feet. They were asked to continue performing these exercises by themselves and also look around the virtual room in all directions, where they were asked to state and describe what they saw. The reason for choosing this task was to engage participants for the total time required for them to stay in the virtual environment, and to constantly reinforce visuomotor synchrony, since by turning around and pointing they would continually be aware of their virtual body and that its movements were their own. Finally, the HMD was removed, and all participants completed a post-experience questionnaire (Figure 3.6).

Please use the following scale to rate the statements below:
COMPLETELY DISAGREE 1 2 3 4 5 6 7 8 9 10 COMPLETELY AGREE

Ownership	1. Sometimes I felt as if the virtual body was my body.
Ownership	2. Sometimes I felt as if the virtual abdomen was my abdomen.
Ownership	3. Sometimes I had the feeling that I was looking at myself.
Ownership	4. Sometimes I experienced the abdomen of the virtual abdomen as part of myself.
Ownership	5. Sometimes I was not aware that my physical body was different than the virtual body.
Ownership	6. Sometimes I was not aware that my physical abdomen was different than the virtual abdomen.
Ownership	7. Sometimes it felt as if I had more than one body. *recoded*
Ownership	8. Sometimes it felt as if I had more than one abdomen. *recoded*
Ownership	9. Sometimes I felt myself somehow connected to the virtual body.
Ownership	10. Sometimes it felt like my physical body was changing to take the shape of the virtual body.
Ownership	11. Sometimes it felt like my physical abdomen was changing to take the shape of the virtual abdomen.
Ownership	12. Sometimes I had the feeling that the virtual abdomen belonged to me.
Ownership	13. Sometimes I had the feeling that the virtual body and I were the same.
Location	14. Sometimes I had the sensation as if I was feeling the touch at the location at which the virtual abdomen was stroked.
Location	15. Sometimes it felt as if the touch I was feeling was located somewhere between my physical body and the virtual body. *recoded*
Location	16. Sometimes I had the sensation as though the touch I felt was caused by the hand with the brush touching the virtual abdomen.
Location	17. Sometimes I had the feeling that I was standing in the same location as the virtual body.
Agency	18. Sometimes I felt I could move the virtual body, if I wanted to.
Agency	19. Sometimes I felt I could move the virtual abdomen, if I wanted to.
Agency	20. Sometimes I had the feeling that I had control over the virtual body.

Figure 3.7: Post-experience questionnaire

3.3 Studying how Virtual Embodiment effects our Cognitive Task Performance

The experiment is conducted as a between-groups design with a single factor referred to as "Body," with levels Ramanujan (they had the Ramanujan body) or Normal (they had a young male adult body). The size of the virtual environment and proportions of the content are equivalent to real-life sizes and proportions, and identical in both conditions (Ramanujan, Normal). Participants are randomly allocated to one of the two conditions. Participants visited the laboratory twice, once to complete some baseline measurements, and second a week later for their virtual exposure and the collection of further post-exposure data.

3.3.1 Experimental Set-Up

The experiment is conducted in a VR laboratory. Participants are fitted with a HTC VIVE Head Mounted Display (HMD). To track the body movements of the

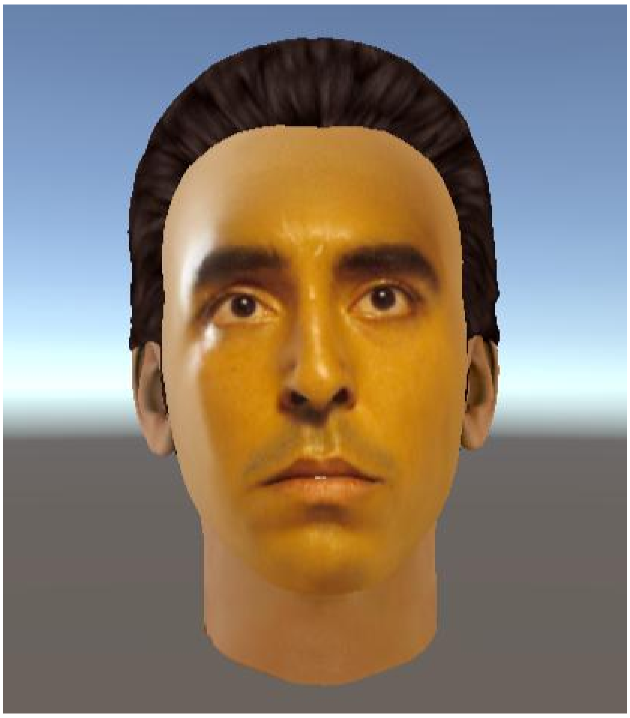

Figure 3.8: Ramanujan avatar.

participant in real time, we use Intel Realsense depth camera with Intel Realsense viewer. Nuitrack SDK is used with the Realsense camera (Figure 3.9) to animate an avatar by mapping the user's skeleton and model skeleton. The virtual environment is implemented on the Unity 3D platform. the animation-enabled model of the Normal virtual body (Figure 3.6) is created with makeHuman software and the Ramanujan model (Figure 3.8) is created using Avatar maker in Unity asset store.

3.3.2 Procedure

Participants attended the experiment at pre-arranged times. Upon arriving, they were given an information sheet to read, and after they agreed to continue with the experiment, they were given a consent form to sign, and completed a demographics questionnaire. Participants were first assessed with the Word Accentuation Test (WAT) (Del Ser et al., 1997), which is used to estimate intelligence. The WAT uti-

Figure 3.9: Intel RealSense Depth camera.

lizes lowfrequency Spanish words with all accents removed to make the pronunciation ambiguous, and it has been shown that it gives a reliable estimate correlated with IQ in healthy adults (Gomar et al., 2011). Participants were also assessed on Rosenberg's self-esteem scale (Rosenberg, 1965). Participants were then seated in front of a desktop computer and completed a Tower of London Task (Figure 3.10) (Shallice, 1982), and the results were recorded (variables: scorepre). After a period of 1 week they returned for the main experiment. The VR exposure took place in a laboratory. When ready to start, the participants were fitted with a head-mounted display (HMD). Upon entering the virtual environment, participants found themselves in a virtual room where their body was visually substituted by the life-sized Ramanujan or a young adult virtual body (Normal), seen from 1PP. Their head and body movements were mapped in real-time to the virtual body. They could see this body both by looking directly toward their real body, and also in a virtual mirror. A series of instructions were then given to them. Participants were instructed that they had to complete a task. They were told that a series of numbers (either positive or negative numbers, fractions, or decimals) would appear around them on the walls or floor and that their task was to locate these numbers and order them in ascending order by selecting them with their hands. The reason for choosing this task was to engage participants for the total time required for them to stay in the virtual environment. Finally, the HMD was removed, and all participants completed the TOL task again (scorepost).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Response Variables

4.1.1 Tower of London Task (TOL)

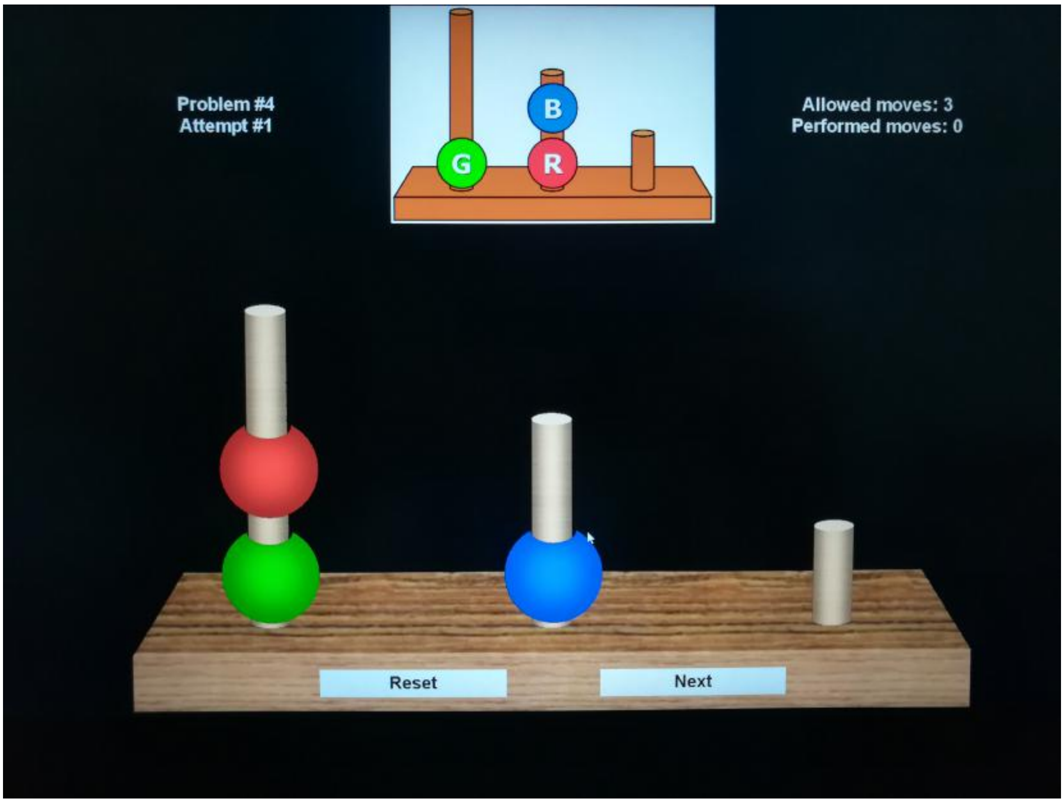

Figure 4.1: Tower of London task.

The TOL task is designed to assess executive functioning and specifically, planning and problem solving skills (Shallice, 1982). In this test, participants are presented with a model where three beads (red, green, blue) are strategically positioned on three rods of descending heights. They are asked to manipulate the beads from a predetermined starting position on a different set of pegs to match the position of beads in the model. There are 12 different problems of graded difficulty, of 2, 3, 4, and 5-move examples, and only 3 moves are allowed per problem. A problem is classified as correct if the end position is achieved in the minimum number of prescribed moves. The algorithm, based on the procedural details adapted from Krikorian et al. (1994), gives 3 points for a successful solution on the first trial, 2 points on the second, 1 on the third, and 0 points if all trials are failed. The total score is the sum of points on all 12 problems, with a maximum possible score of 36. The TOL was administered on a desktop screen a week before participants' virtual exposure (scorepre), and then immediately after their virtual exposure (scorepost). It was completed on the same desktop computer screen both times. The response variable of interest was dscore = scorepostscorepre which showed the degree of improvement (positive values) or decline (negative values) in score after the exposure compared with before. The TOL was downloaded from the Millisecond Test Library and modified with the Inquisit software by Millisecond.

4.2 Discussion

In the first experiment, we study the traditional approaches towards SoE, that is RHI. Here, we try study the feeling of ownership and proprioceptive drift. Participants are to explain their subjective experience and fill the survey according to it.

In the second experiment, we move on to the latest technology, immersive VR to study SoE. Here, the participants are to experience virtual embodiment and fill a questionnaire regarding the sub-components of SoE.

Finally, in the last experiment, we study how this virtual embodiment effect our cognitive task performance. This is conducted by virtual embodiment of Ramanujan's avatar or a normal virtual body. Here, we conduct the WAT and Tower of London test to test the cognitive task performance of the participants.

These experiments help us to get a better understanding of SoE and motivates us to research further.

CHAPTER 5

CONCLUSIONS AND FUTURE WORK

5.1 Conclusion

Recent advancements in the field of VR present a plethora of opportunities to study and research in the field of SoE through the virtual embodiment techniques. In this study, we study SoE again from the RHI to gain better understanding and try to build upon the ideas put-forth by various researchers in this field. Although the findings of this work is not much, but we try to study virtual embodiment and its effects on cognitive task performance to gain new insights.

5.2 Future Work

Although in this study the experiment we tried to conduct experiments based embodiment and its effect on the mind of the participant, the experiments can give us better insights than studying the papers. Thus, we can build up on these experience to take advantage of it take try out some applications of this virtual embodiment. Hence, a future-work could address questions like, 'Is it possible to use SoE to help underachieving students to have a better understanding capabilities during class', 'Is it possible to buff up physical abilities of participant using virtual embodiment', etc.This kind of applications may open up new understanding towards SoE.

REFERENCES

[1] **Konstantina Kilteni, Raphaela Groten, Mel Slater.** *The SoE in VR.* Presence Teleoperators Virtual Environments, (2012).

[2] **Marieke Rohde, Massimiliano Di Luca, Marc O. Ernst.** *The RHI: Feeling of ownership and proprioceptive drift do not go hand in hand.* PLoS One, (2011).

[3] **Rebecca Fribourg, Ferran Argelaguet, Ludovic Hoyet, Anatole Lecuyer.** *Studying the SoE in VR Shared Experiences.* IEEE Conference on VR and 3D User Interfaces (VR), (2018).

[4] **Domna Banakou, Sameer Kishore, Mel Slater.** *Virtually Being Einstein Results in an Improvement in Cognitive Task Performance and a Decrease in Age Bias.* Frontiers in Psychology, (2018).

[5] **Jakki O. Bailey, Jeremy N. Bailenson, Daniel Casasanto.** *When Does Virtual Embodiment Change Our Minds?.* Presence Teleoperators Virtual Environments, (2016).