Designing VR for Understanding Physiological Effects of Embodiment and Multi-sensory Modalities

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Dedication

I dedicate this to my mother Sri Lakshmi Kothapalli and to all the students who are pursuing their goals to fulfill their dreams. I also want to dedicate this to all the people who are fighting to eradicate Hunger deaths and to all the essential care providers all around the world who are working tirelessly to help the people.

Abstract

Virtual Reality (VR) is becoming more and more recognized in various fields as way to train and educate people. VR has become popular for its spatial audio-visual perception of alternate virtual environments. One other reason it is becoming more accessible is because of larger companies like Google, Microsoft, Facebook and Apple investing a lot of money to do VR research to roll out VR gear that are much more affordable than they used to be five years ago.

In this thesis, we developed software that can be used to conduct VR studies and measure physiological responses related to immersion and presence experienced in VR. The sense of presence in virtual environments may be a key factor in how we perceive and act in VR. Recent studies in VR have also shown that embodiment can improve immersion and engagement. Embodiment is a sense of having a virtual body that a user can relate to as being their own. But giving a virtual avatar for the user is not easy as it requires hardware synchronization with the VR application. Moreover, collecting physiological signal data to understand the effects of embodiment involves sensors that need to be used alongside this other equipment. The main component of this thesis is a software system for research studies that explore the effect of embodiment and multi-sensory modalities on the physiology of a participant.

There has been much growth in how virtual reality technology is being used in various areas like planning and architecture, medical surgeries, education, and research. VR offers real-time immersive experience, interactive simulation. Our thesis is a building block that encourages future researchers to do large scale expansive studies to understand the psychophysiological effects of body ownership and to also increase the number of studies that can be done by a larger array of researchers. By understanding these effects, we can further explore the possibilities of VR in areas

mentioned above. We also discuss how embodiment will affect the sense of presence of a person in a virtual environment. Moreover, we will show how our software can be used to present various stimuli easily and record physiological responses using a wearable sensor. We built a virtual environment for this purpose which integrates hardware together to enable embodiment, multiple-sensory modalities and collect physiological evidence.

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1 Introduction

Virtual Reality has become a major focus of research and has been working on since the '90s. It's capability to create immersive environments and understanding of user perception to an alternate reality and low cost are the main reasons for this enormous leap. These immersive environments are used for various purposes other than just entertainment. Most recent VR research has been on understanding user interaction with virtual interfaces, learning in virtual environments, perception, cognition, performance and also to check if it is possible to recreate natural instincts of a person to VR.

In this thesis, our main focus is on developing a VR software that allows experimenters to do VR studies without the hassle of knowing a lot of computer programming, hardware understanding and also to reduce the experimenter error, which accounts for a significant amount in user studies. It is interesting because it provides a path for studies that can help us in the understanding of how the perception of components like, embodiment, interactivity to stimuli, depth affect the performance of an individual in VR.

1.1 Motivation

Our motivation for this thesis comes from the potential of VR. It's been there since it's conception in 1965 by Ivan Sutherland, but yet we have seen a rise in VR use, just in the last 5 years. This is because, five years ago, commercially available VR hardware was not readily available. In recent times, many bigger companies started developing hardware suitable for Virtual Reality(VR), Augmented Reality(AR) and even Mixed Reality(MR), a simulation where VR and AR are both combined together. Every year, because of some great researches exploring possibilities of use of VR in areas other than entertainment, has led to tremendous improvements in the hardware too, making them more compact, efficient and lighter. The use of sensors for tracking controllers, eyes and even the playing area has improved the development of better applications too. The potential of VR has broadened its domain in Human-Computer Interaction[34], technology in education[49], research and development, 3D modeling, psychological analysis like cognition and emotion studies[20], physiological conditioning to stimuli[56], all of which help researchers and developers to understand both advantages and shortcomings of VR. Hence, our motivation is to provide a software for experimenters that allow them to answer some of the questions existing regarding VR studies and how physiological measures can be used as an evidence to support their claims. This thesis helps in exploring if what can be done in real-world, will be possible in VR, questioning if VR has the same affordances as the actual world using the software developed.

1.2 Virtual Reality

Virtual Reality(VR) is defined as a three dimensional simulation of an environment where a user can interact with the use of a display module and controllers. VR environments can be a known world recreation or an unknown novel environment too. It allows users to interact, navigate and perform tasks.

VR has improved so much since its inception due to the improvements in computer graphics, hardware, visual stimuli, 3D audio and tracking features. The strength of a

VR application is determined by how engaging the environment is, ease of navigation and how realistic it is. To understand the affordances offered, interactivity, and several other factors like physiological reactions, cognitive perception various concepts need to be understood first.

1.2.1 VR and Physiological Responses

Immersion is a factor used to determine how strong a VR application is. It depends upon how engaging the virtual environment is. Immersion is defined as an objective measure of the extent to which the system presents a vivid virtual environment while shutting out physical reality[48]. Engagement can be achieved through performing a task, interacting with objects, perception of self and events happening by getting audio-visual and tactile feedback. Physiological responses are a way to measure engagement. Physiological responses are bodily triggers like heart-rate, skin resistance, eye blinks that occur when a user performs a task, interacts with a stimuli or even move around.

Physiological measures are a good objective measure of understanding user's responses to interaction[26]. So, using physiological measures to determine how engaged the user is, have been vastly researched upon in recent times. One research showed that by observing more of the physiological response of the participant can better interpret the participants' performance[7]. These measures can be used to evaluate level of stress the participant is induced to. Level of stress is an indicator of how engaged the user is. So, physiological responses have become a usable measure to understand VR user experience and engagement. It is important in our thesis because, the software developed collects the physiological measures from users. The experimenters will then be able to conduct more studies to understand the width of

VR research using these response data as evidence.

1.2.2 VR and Multi-sensory Experiences

VR used be more visual around a decade ago but nowadays VR is more complicated and have spatial audio-visual capabilities. Some VR equipment even have tactile feedback through handheld controllers to make the user feel engaged. Multi-sensory experience is gaining popularity to enhance users' experience, interactivity and presence in virtual environments. Presence in VR is defined as a "sense of being there". Sense of being in one place or environment even when a person is physically situated in a different place[19]. Most commonly explored interactions are audio-visual and tactile but there are others like olfactory, vibrotacitle and even sense of taste. An objective of one of the study is, multisensory experience and interaction design, emphasizing the opportunities beyond audio-vision: touch, smell and taste[42]. What this means is that, interaction cannot just be about audio-visual presentations but can be amplified through other modalities. When a stimulus involving these multisensory experiences is presented to the user, the receptors respond and cause changes in the physiology. The change suggests that VR experiences of this kind are more immersive and engaging.

For our thesis, multi-sensory experiences in VR add value by promoting user engagement. But to do this, hardware that enables these sensory experiences, require to be synchronized with virtual stimuli presentation. Our software design enables experimenters to incorporate these features in their user studies. We wanted to build a software that is more than capable in allowing experimenters to integrate hardware easily, with a very low rate of error.

1.3 Research Overview

Our thesis explains why having a software that facilitates researchers to perform experiments on embodiment with multisensory experiences, so that they can answer how these experiences will change physiology of a person and what these responses data (collected using physiological sensors, in this case Biopac) will mean to multi-disciplinary research using VR. The main motives of this software project are to:

- facilitate researchers to do a full VR study, with no programming background
- enable multi-disciplinary VR research
- emphasize the use of physiological responses to interactivity in VR

2 Background

The use of Virtual reality gained popularity in the last decade giving solutions to a wide range of problems in diverse fields. Virtual reality is becoming robust and accessible to everyone. Researchers and developers are trying to make VR experiences more and more realistic and smooth. However, many people still believe that VR is for entertainment purposes. VR is being used in education, training and even in therapies [1, 43]. In one research, the authors explain that training in virtual environments will enhance transferability of information while reducing cost, training time and errors[11]. This is crucial as training is necessary in every industry to reduce errors and improve performance. Particularly this is the case with doctors, designers and emergency responders.

Studies have concluded that there is an association between immersivity and physiological responses. One such study conducted has shown that skin resistance and heart rate variability can be used to show arousal of participants exposed to virtual environments[22]. Our intention from developing this software is to have studies that focus on what role embodiment with multisensory stimuli play in VR experience of a user and how their impact can be understood with the help of physiological measures. This project is important because it serves as a base for researchers to understand the affects of virtual stimuli on user, psychologically and physiologically.

2.1 A Brief History of VR

Virtual Reality was formulated in the 1960s but did not become commercial tools until the 1980s. In 1965, Ivan Sutherland proposed *The Ultimate Display*, talking about artificial world development through graphics and force-feedback[53]. There are two different types of VR: immersive VR and non-immersive VR. Why did VR become so popular? It is likely because, it allows users to immerse into an alternate world and experience the 3D visual environment, interact with the objects within the environment and an endless realm of exploring opportunities. In simple terms, it provides a powerful way of human-computer interaction.

Figure 2.1: The Sword of Damocles: Known to be as the first HMD

While non-immersive VR is mostly simulated environments on the computer likely to be viewed on traditional displays, immersive VR has been evolving ever since as the hardware that is needed are becoming more and more commercially available, becoming compact and user friendly to use. VR is based on three principles, Immersion, Interaction and User involvement. Immersion is defined as the perception of being physically present in an environment though the user knows they are not. Interaction is defined as the way, users react, respond, explore, walk around and touch objects in a virtual environment. User involvement is defined as the perception of the user as a part of the environment and it responding to the user.

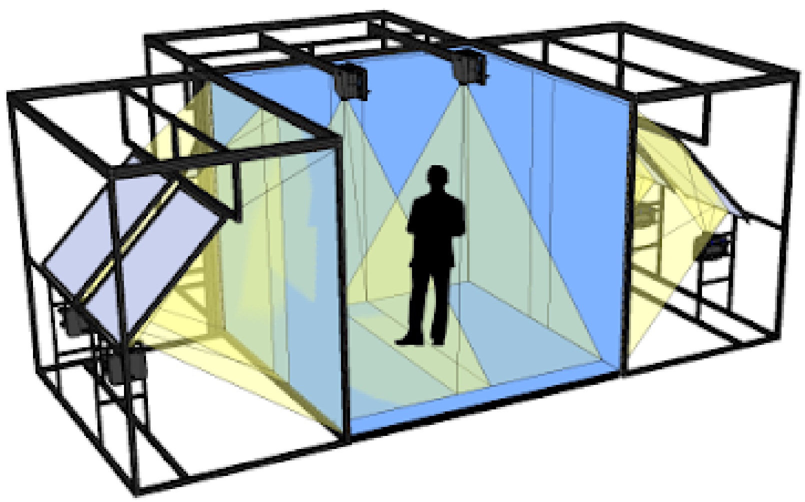


Figure 2.2: CAVE VR System

Non-immersive VR applications do not require complicated hardware. They are generally simple and less expensive when compared to immersive VR applications. Whereas, immersive VR applications require devices to feel immersed in the virtual environment. Head mounted displays(HMDs) are one example of those devices. They provide a stereoscopic view of the virtual scene and the perspective of the scene changes as the head of the user rotates. The first ever HMD was developed by Ivan Sutherland in 1968 called, *The Sword of Damocles*. This headset only showed virtual 3D objects which changed perspective when a user rotated their head. The problem with early HMDs was that they are heavy to use and putting them on for a longer time was not easy. They tended to be heavily corded and connected to the computer. Moving your head around, and distance one can walk with those headsets connected to the computers are drawbacks of them.

Figure 2.3: HTC Vive Pro: Used External Sensors to track the play area

There were systems like Cave Automatic Virtual Environment(CAVE) in Figure 2.2, that have become popular in the early 1990s. CAVE VR system is like a room where all the walls, ground and top are projected to provide an immersive experience. The CAVE system also provides 3D audio to enhance the immersive experience. Over time, HMDs have become compact, powerful, user friendly and easy to carry. In the late 2000s, there were HMDs that were corded but light to carry around. They had separate sensors that defined a play area for the HMD. The HMD and handheld controllers have to be within a predefined range to be able to be used and tracked by the sensors. HTC Vive Pro is an example of it, in Figure 2.3. It used sensors to track

Figure 2.4: Oculus Quest: Cordless and in-built sensors for tracking

the HMD and controllers. Now, we have HMDs that are cordless and have tracking sensors on the headset itself, which enable for tracking a user defined play area, tracking controllers, tracking other objects that can be used in the VR application as well. The Oculus Rift S is an example of one such HMD in which the sensors are in-built but its successor the Oculus Quest (in figure 2.4) is both cordless and has in-built sensors on it.

2.1.1 Other Extended Reality(XR) Technologies

Though immersive, interactive experiences started off with 360-degree images, video and VR, there are other new technologies that have come into play in the last two decades. Some of them are Augmented Reality(AR), Mixed Reality(MR) and Diminished Reality(DR).

While VR is a a complete immersive experience that does not allow the user to see the real world, AR allows superimposing of virtual objects in the real world. In, Augmented Reality, the user puts on glasses that support AR and experiences an immersive virtual experience that is laid out on the real world objects. The main advantage of AR is that, it does not block out the real world from user's view. AR is a parallel experience of both the real world and virtual world. AR is being used in Design & Modelling, Classroom Education and Tourism too. AR allows contextual based immersive experience. In one research, AR is used to present instructions in real time right in the user's field of view allowing users to experience the instructions in actual context in a fun hospital setting[41].

Mixed Reality(MR) is a collective name used for a hybrid reality experience. It can be a combination of VR and AR or any other extended reality technologies. Mixed Reality is described as a virtual continuum which illustrates the relation between AR and VR[37]. Diminished Reality(DR) is another extended reality experience which in simple terms is opposite to AR or MR. In AR/MR, virtual objects are superimposed on real world objects while in DR, the real world objects are concealed, eliminated or diminished from actual reality[39].

2.1.2 Three Illusions of VR

There are three illusions which VR has to achieve to be considered a better VR application: Place Illusion, Plausibility Illusion & Embodiment Illusion [47]

Place Illusion

A Place illusion is the illusion of being in a place even though we know we're not there. The factor that gives a user the illusion that they are in a place which is different from where they really are. An example can be viewing the Eiffel Tower virtually using Google Earth VR but we are not actually there.

Plausibility Illusion

The Plausibility illusion is what's happening is really happening. One example of plausibility illusion is when objects, events happening in the scenario respond to you as if you are a part of the environment.

Embodiment Illusion

Embodiment illusion is the illusion of owning a body which is not really yours but you can relate to the things happening to the avatar. This illusion is very hard to achieve as the brain has to be synchronous with the events happening to the avatar in the virtual environment to that of the actual physical body. One example of the embodiment illusion is the rubber hand illusion [6]. In this rubber hand illusion study, the researchers say that vision, touch and proprioception are related and causes an effect of body ownership illusion. This is because, though there is feedback to the actual hand, rubber hand is visually seen instead of the physical hand itself and user tends to feel rubber hand as their actual hand.

2.1.3 Uses of VR

The uses of VR have vastly increased because of the strong interactivity and realism it offers in a controlled environment. Though there are many different uses of VR, in a poll conducted by us, 42% of the people still believe that VR is for entertainment. Other uses are Education & Training (polled at 28%), Therapies & Fear Conditioning (polled at 28%) and Virtual Collaborations (polled at 3%) though all three of these have great potential.While there are several uses of VR, it is important to show great research studies that have been done to test the usability of VR in areas where it is not quite commonly used[32].

Training and Education

VR is being used in training and education. In disciplines where training is necessary, virtual simulations have offered big benefits. They were used in virtual reality training of astronauts by performing complicated tasks[10]. Other applications include training medicine students in performing microsurgery[21], and virtual sports coaching like baseball coaching[3].

Modeling & Planning

Another area of VR applications are Modeling and Planning. VR has been used to model surfaces, designing and architectural planning[8, 9, 23]. VR allows for real time planning as it allows texture mapping, object placements to see how they look and exist on surfaces.

Teleporting and Telepresence

Teleporting allows for navigation in a vast virtual environment and allows for performing tasks in locations that are hard to physically be in. Telepresence is a technology that allows users to operate in places by means of VR interfaces. VR interfaces allow interaction with distant environment that may be harmful to human life[5, 54].

Collaborative Working

VR also promotes a collaborative working environment. The virtual interface allows the users to have an avatar that can be used to interact with users across the world and work together and perform tasks over computer. Some other significant examples of VR systems are training applications like inspection of hazardous area by multiple soldiers[51], performing complex tasks in open space by astronauts[29].

2.2 Physiological Responses to VR

Physiological responses are bodily triggers in response to a stimulus. Living organisms experience physiological responses to stimuli and they are instinctive. Some people have higher physiological responses to stimuli, called as *flight or fight* response. This means that the person experiencing flight or fight will either try to fight back the stimulus or try to escape from the stimulus. These responses can be measured using various physiological measures. Electrodermal Activity(EDA), Heart Rate Variability(HRV), Electromyography(EMG) and Electroencephalogram(EEG) are some examples.

Our motivation to develop a software that records physiological data for a VR study tracks back to its initial use in physiological computing since the 1980s. Physiological measuring is a good way to understand and explain the cognitive load induced on an individual. Cognitive load is defined as the effort on learning and thinking on working memory when performing a certain task [59]. In a study the researchers used a wide range of psycho-physiological signals in assessing cognitive load, showing that it can be used to determine whether the task performance by the user can be distracted or not[18]. Physiological responses are also used in areas to assess the reflexive reactions to multi-modal interaction and visual perception.

Physiological measures have also been used to compare traditional display devices with HMDs. Several studies have shown what it means to be watching videos, ranging from calming content to scary content, on a HMD and how different it is from viewing them on traditional monitor displays. [57] have compared VR and non-VR driving simulation, [24] have shown the effect of immersion on film viewing in VR where the users reported more intense feelings when compared to a non-VR display. Previous work on using physiological response data by Eudave and Valencia confirmed the increased sense of presence and attentiveness by registering the physiological signals in a virtual driving scenario. There were higher responses in both HR and EDA when using the virtual simulation. They suggest that the increase in HR and EDA, as a stronger response when in virtual simulation when compared to standard monitor display simulation suggesting that physiological signals can be used as a measure of engagement[15].

Due to a big leap in the development of hardware, many developers are trying to build innovative VR applications for various purposes. Applications involving physical activity in a virtual world have become popular. What can be done in real world are being questioned if it can be possible in VR too. Thus activities like VR painting, dancing, signing, exploring places, FPP gaming etc all have become so popular. While there are a huge selection of applications for entertainment purposes, researchers are conducting studies to check the possibility of VR in other areas. The most important evidence any researcher tries to find when using technology as a feedback system is to understand, how the user is responding to that technology interaction. This evidence mostly comes from reported data and observed data from the user. This analysis of both reported and observed measures will enable researchers to understand physical as well as mental states from the participants and correlate them. Many studies have also researched the use of these measures to talk about both psychological and physiological effects of VR. In a thesis submitted, it is shown that physiological responses can be used as an objective measure of presence. They used heart rate, skin conductance and skin temperature to measure the presence factor of the participant. To strengthen their claim, they used both reported presence and observed presence[35]. Reported presence is psychological analysis and observed presence is physiological analysis, both of them combining to give a psychophysiological evidence that presence can be measured using them. So, they are useful for determining the strength of VR interactions both from the user side and also the interface side. Stronger the physiological responses, stronger are the interface, stimuli and interaction.

Apart from determining the interactivity, strength, depth of VR environment using those measures, signals like Electrodermal activity(EDA) are used as an objective tool for VR therapies [22], anxiety detection [25] and also multisensory exposure therapy [31]. These signals provide valuable information about how these VR therapies are conditioning the patients to cope with stress, anxiety, phobias and rehabilitation. Moreover, the advantage of using VR for these purposes is that it can be done in a controlled environment. In this user study [58], the authors provided evidence if fear of flying can be conditioned using VRGET(VR Graded Exposure Therapy) in a controlled environment. From the results of their study, the researchers concluded that VRGET is a viable option to treat fear of flying rather than IET(Imaginal Exposure Therapy) as it has it's limitations. They also discuss that using physiological feedback as a training mechanism may give individuals the control they need to feel ready to perform a task in the real world. From the above studies, we saw that VR is a good tool for Exposure Therapy and also it can be used for virtual training by recreating real life scenarios like fire fighting, combat training, virtual driving, surgeon training etc.

Hence, collecting physiological responses through out software for VR studies may benefit in developing user-based interactive systems or for understanding the implications of interactive systems on users as all the studies mentioned above have shown some form of evidence what they can be useful for.

2.2.1 Sensory Transduction

We want to collect physiological signals to stimuli presentation in VR. What is a stimuli? How does a stimuli call for physiological responses? A stimulus to a receptor generates a series of action potentials via sensory transduction[38]. In general, a higher intensity stimulus will generate a higher frequency of action potentials along the neurone, however differing kinds of receptors will adapt in several ways:

- **Tonic receptors** are slow adapting receptors. They will respond to the stimulus as long as it persists, and produce a continuous high frequency of action potentials.
- **Phasic receptors** are rapidly adapting receptors. They will respond quickly to stimuli but stop responding upon continual stimulation. Therefore action potential frequency decreases during prolonged stimulation. The receptor remains sensitive to a change in stimulus energy or removal of the stimulus.

2.2.2 Startle and Defensive Reflexes

Another use of physiological responses is that it can be used to measure startle and defense reflexes of a user which cannot be clearly seen by a naked eye. Startle reflex is defined to be a response to sudden stimulation or changes in the surrounding environment. The defense reflex is also a sudden response but calls for a fight or flight event. During a defense reflex, an organism usually involuntarily chooses to either fight back or flee from the threatening stimuli. Coming to identifying these response, explained in [27], measurable aspects of startle include but not limited to contraction of facial or neck muscles, arrest of ongoing behaviours, increased physiological arousal and sometimes reports of fear or anger, all of which can be seen through physiological signals.

These measurable aspects of startle can be achieved by the abruptness of the events occurring which the participant is not expecting. If these abrupt events pose as a threat to the participants, they try to protect or fight against these stimuli giving scope for defensive responses.

Though the physiological responses collected can be used to prove that there is higher sense of presence, it is creating these startle and defensive orientations, in VR a major hurdle. One method that is used in startle research involves the presentation of a weak, non-startling stimulus a brief time before the startle-eliciting stimulus. The weaker stimulus is called a prepulse or lead stimulus. Generally, this stimulus does not elicit a startle response. However, it can inhibit the response to a startle-eliciting stimulus, known as the prepulse inhibition of a startle effect (PPI). Hence, Prepulse inhibition is defined as a weak stimulus that can inhibit the response to a startle-eliciting stimulus. A higher level of care must be taken so that the participant does not have any recurring bad reactions to the visual stimuli.

2.2.3 Attention and Orienting

Attention to detail is a competent skill nowadays. It is an observational skill that requires a person to be attentive to all things happening around and to small details. Orienting responses are immediate reflexes to change in surroundings of an organism. They can be used to understand the habituation of a person to a stimuli presentation.

Orienting responses can explain the concept of inhibition in a individual[33]. Usually VR users have to orient themselves constantly to changes in environment, to object interactions, to information processing and exploring.

It is indeed implied that attention is affected by orienting to changes. Various researchers argued that orienting can cause distraction but there are other studies which argue that it can help users to focus on more important things if stimuli are developed in certain fashion. VR in its current stage is an good tool to be used in short sessions to help in conventional delivery of lectures and procedural training [50]. To improve this, we have to understand what form of interactions and to what extent do these interactive affordances have to be integrated in the system.

2.2.4 Novel Stimuli

So far we have talked about what physiological responses, what stimuli are and how they call for these responses. But physiological signals are a great way to measure the novelty of stimuli too. Novel stimuli and their interaction with the user cause significant impact on the user's perception of the environment. It is obvious that there will be better reaction to stimuli as long as there is no habituation to the virtual stimuli and environment. Repeated presentation of the same stimuli will condition the user to it and does not have stronger physiological responses. By using the signal data, an experimenter can determine when a user has no stronger response to these virtual interactions as it doesn't call for any attention from the user. From a study it is shown that users may switch attention allocation when the stimulus is no longer novel or surprising [28]. So it is important to have novel stimuli to have stronger physiological responses and keep the user engaged.

2.2.5 Habituation

One other information that can be seen from physiological responses is to understand how fast users of VR technology get accustomed to it. The strength of a VR applications can be determined by how interactive and engaging it is. At the same time it is also important to understand how users get habituated to training, performance, navigation and interaction with the environment. According to the book[52] habituation is defined as the reduction of responding that occurs to the repeated presentation of the same stimuli. So, by analyzing the physiology of a person, we can see how fast the user is getting used to the stimuli presentation.

2.3 Importance of Physiological Responses

Why is it meaningful to use physiological recordings in any Human-Computer Interaction(HCI) application? As explained in one research, the availability of low cost sensing technologies is one reason and other being the availability of rich data from these recordings to understand the perception and feedback to interactivity with machines and environments. Physiology has been used since the 1980s as a metric to design interactive systems[2]. Physiological computing has a defined role in affective computing and we are trying to leverage that through our software. Affective computing is defined as the study and development of devices, interfaces that can interpret, simulate human affects. It is an interdisciplinary field spanning computer science, psychology, and cognitive science [4]. Any interactive application requires a deep and multidimensional understanding of the user [13]. Psycho-physiological measures are used to understand the mental workload assessment methodologies. Girouard et al. categorized the uses of psychophysiological measures into three groups: 1) evaluation applications, 2) adaptive interface applications and 3) direct input mechanisms [16].

Hence, affective computing through the use of physiological recordings is one of the reasons we wanted to test the usability of VR.

2.3.1 Presence and Embodiment

A higher sense of presence that a person feels, makes them more aware of the surroundings in a virtual environment. Moreover, this presence is supported even more with a sense of the virtual body replicating the participant's real world actions in the virtual world. This is called Embodiment. Embodiment can defined as a visible tangible form that a participant can relate to with respect to their physical form. When a person can relate to this virtual avatar as if it is their own body, there is a tendency to react to audio-visual stimuli that they perceive in the virtual environment. According to a research conducted, it is presented that better the virtual body appearance and the feeling of threatening stimuli to that virtual body, the higher the skin conductance responses[55].

2.3.2 Presence and Modalities

The sense of immersion can also be amplified by involving more modalities in the VR experience. Immersion plays a vital role in determining the learning curve of an individual while engaged in VR. A research study showed that using sensory Audio-Visual-Haptic (AVH) modalities while performing CPR has shown better results when compared to Audio-Haptics(AH) or Visual-Haptics(VH) combinations[14]. It is because audio modality alone cannot be good enough to engage a user. This is often true when we are using a HMD. The user expects to see some form of visual stimuli so it can be more engaging and interactive. Adding sensory modalities like Haptics, Audio, Tactile will result in stronger engagement which will in turn improve the performance. The objects in the virtual environments play a major role in stimulating responses from a user. These responses can be sudden, unforeseen or unanticipated which can cause physiological changes which can be a measure of presence.

2.4 Embodiment

One of the purpose of this software is to see how embodiment affects users' interaction with stimuli and how they perceive ownership of the body. Embodiment has several definitions. In the context of VR, embodiment refers to the illusion of having a substitute virtual body that mimics our own bodily movements and actions. For this reason , we will use *Embodiment* to have a sense of body within the virtual environment with respect to VR. There is evidence suggesting that a virtual body is a contributing factor to the sense of being in the virtual location [30]. Embodiment can be associated with the concept of *sense of agency*[40] and *sense of body ownership*[30]. The sense of body ownership will have a significant affect on physiology of the user. So, body ownership illusion can be measured using physiological data where social anxiety was measured using skin conductance and ECG responses[44].

Embodiment will have psychological effects on the person experiencing it. It is because vision overrides other senses of the body and fixates on the visual avatar as the real body. And once this occurs, this body starts to change our other senses and how one processes that information. So one of the biggest measures of the illusion for embodiment is the feeling of proprioceptive drift [47]. Proprioception is the sense of where our body is in space. In VR using motion tracking, we can really get a better visual motor illusion where the person moves and they can see this virtual body in the virtual world, moving in sync with them and doing what they want it to. Sending those kind of motor signals out there and motor commands, and having the body respond to generally, creates a stronger illusion and a more adaptable one. Embodiment will help in deeper understanding of human behaviour and social interactions [36].

Figure 2.5: A participant experiencing their embodied avatar

Not only does embodiment help in creating a sense of ownership, increasing sense of presence, it also enables participants in perceiving distances, size estimation. Avatar self-embodiment gives a perspective of self awareness in a Immersive Virtual Environment(IVE) along with a tendency to judge distances and sizes accurately. This is with respect to the fact that users will have an avatar to relatively measure distances using that avatar. In a study, the researchers' goal was to see if avatar-self embodiment can have a significant accuracy on measuring in non-photorealistic IVEs. They discuss that providing participants with embodiment enables them to feel more present in the virtual environment, which in turn encourages them to act upon what they see through the HMD in a way that is more similar to how they would act in the real world[46]. Furthermore, in another research, it is found out that, adding a little non-photorealism to the IVE, there was an underestimation of distances[45]. This shows that, just having a fully functional avatar is not enough to be present, also the virtual environment has to be well developed and designed to have a seamless experience.

Further researches on embodiment in recent times have been on a concept called *Enfacement*. Enfacement illusion, as the name suggests is creation of a facial animation that the participant can assimilate to, as if it is their own. Embodiment illusion deals with the body while enfacement illusion is more about the agency of face. Gonzalez-Franco et al. described that increasing enfacement illusion increases self-recognition on avatars that the participants were given [17]. Their research also showed that having enfacement alongside embodiment increased the ownership of the virtual body and that they both are linked with each other. In the study, the researchers used three levels of facial animations, 1) still face, 2) lip sync and 3) animation plus lip sync. They concluded that lip sync and animation plus lip sync conditions were able to create more self identification on the avatar. In another pilot study conducted by Collingwoode-Williams et al., it is proven that giving lip & hand movement sync over non sync of any of those showed higher levels of embodiment [12].

As discussed, creating this embodiment illusion is not easy. It requires expensive technology and hardware to motion capture using infrared cameras and remapping the captured motions to target avatar (or virtual body). Our software makes it easy for experimenters to integrate the hardware together that is necessary to do embodiment studies through motion capturing.

2.5 Summary

Hence, it is very important for any VR study to have user engagement. From the review above, we have seen that it is possible through embodiment and multisensory novel stimuli. We also saw that using physiological responses in these types of user-interactivity studies serves as an objective measure for understanding the psychological effects on users. Emotional engagement is also a way to connect to VR scenario. In a context-free VR environment achieving emotional engagement is difficult as there is no specific task performance or any contextual purpose to the participant in that environment. So having stimulus that adds to the purpose of the study in a way lets experimenters understand the usability of VR technologies in different disciplines. The software implemented in this thesis, integrates the use of hardware to embody participants and see how their interactivity differs from non-avatar VR experiences. It also uses the Biopac sensor synchronously to record physiological data while users are experiencing the virtual environment. In this chapter we explained the use of physiological sensors in doing VR studies. This gives us the background knowledge to include physiological data collection using our software to perform VR studies.

3 Implementation

3.1 Related Studies

We have done a related user study in VR to complement this thesis. The study is to provide evidence that users can habituated to repeated presentation of the same stimuli. In this study, *Richie's Plank Experiment* is used as the VR environment to understand the behavioural effects of repeated presentation of the same task. Participants do the task of walking on the virtual plank a minimum of 5 times. Each time they had to walk from inside the elevator to the edge of the plank, turn around and come back inside the elevator.

To test the effect of repeated performing of the same task, graphs were plotted with Electrodermal activity(EDA) on Y-axis and the iteration number on the X-axis. All the four participants showed decreased EDA as the iteration number increased. This clearly shows that the participants got habituated to performing the intense task of walking on the plank. Initially all the participants had higher EDA values in the first iteration but the EDA values kept on decreasing until their final iteration. This proves our hypothesis that participants get habituated to virtual training.

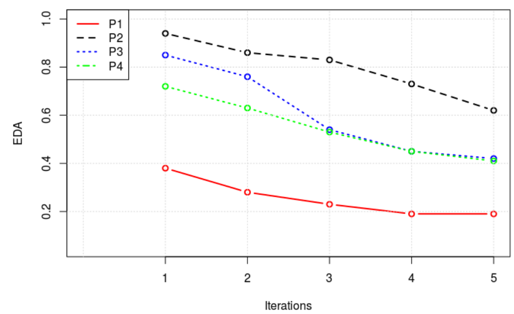


Figure 3.1: Electrodermal Activity Vs Iteration

Given the physiological measure data, we can say that the participants get habituated to repeated presentation of same stimuli or scenarios. Though initially the EDA values are high, there is a drop in it as the time in virtual environment increased indicating that users get habituated. We took insights from this study for the development of our application. The above mentioned study is one of the reasons why wanted to use physiological responses in this VR application.

3.2 Software

The purpose of this thesis is to develop a software to accommodate researchers to understand how embodiment and multiple modalities effect physiological responses of a person in VR. This software can be used to do a user study where subjects can be placed in one of two between-subjects conditions:

- With embodiment
- Without embodiment

Also, within the experiment phase of the software, the participants can undergo three within-subjects conditions:

- Visual stimuli
- Audio-visual stimuli
- Audio-visual-vibrotactile stimuli

The randomization of these conditions is done by the VR application, so it does not allow two same conditions to be presented back to back. This software addresses issues like experimenter error, randomizing conditions and providing flexibility of choosing what stimulus to present.

Node Server

A Node.js server provides a system for connecting to a service for sending & receiving data. This is achieved through TCP or UDP connections. This allows to create own servers using these protocols or protocols like HTTP. It provides a server to which client machines can connect to send and receive data. In this software, we developed a node server to communicate between two machines that allow for tagging of events which can be used to do data analysis.

3.3 Experiment Setup

For experimenters who want to use this software to do VR user studies, they need to use certain hardware for conducting their research. Firstly, a VR head-mounted display like Oculus Quest or Oculus Rift S would work. For embodying the participant, an array of OptiTrack motion capture cameras are required and they need to be placed in a room such that they can track the participant from all four directions. Though there are several different types of physiological sensors available, we chose to use the Biopac sensor to collect physiological signals. To enhance the participants' experience, we used a vibrotactile vest that provides feedback through vibration. A detailed description of the hardware is given in the following subsections.

The virtual environment is developed using the Unity Engine. It is a game development environment that can be used to build interactive applications for computers, mobile phones and even Extended reality(XR) supported games. Unity engine has a complex structure that allows real-life physics, dynamics to the game objects. It can be used to create rigid bodies, objects and even animate them seamlessly using Unity's animator tab. Unity provides Inverse Kinematics(IK) for Oculus headsets to allow avatar dynamics and limb placements. Inverse Kinematics is a mathematical approach through which the system determines the limb positions of the user based on the controllers and headset positions on the participant.

3.3.1 Oculus Quest

The Head-mounted display used for this study is a cordless and sensorless gaming headset. This is a cordless gaming headset which has cameras installed on it, which track the physical space without the use of sensors for hand held controllers. One of the advantages of using this headset is it gives flexibility to the user to define their play area.

3.3.2 OptiTrack

To capture the human subject motion and re-target the same physical movements to the virtual avatar, OptiTrack motion capture system is used. This setup involves 10-infrared motion capture cameras installed in a room space with dimensions 20 feet by 15 feet. These cameras track active markers placed on rigid bodies and re-target the captured motion back to Unity objects.

Figure 3.2: Optitrack Motion Capture Camera

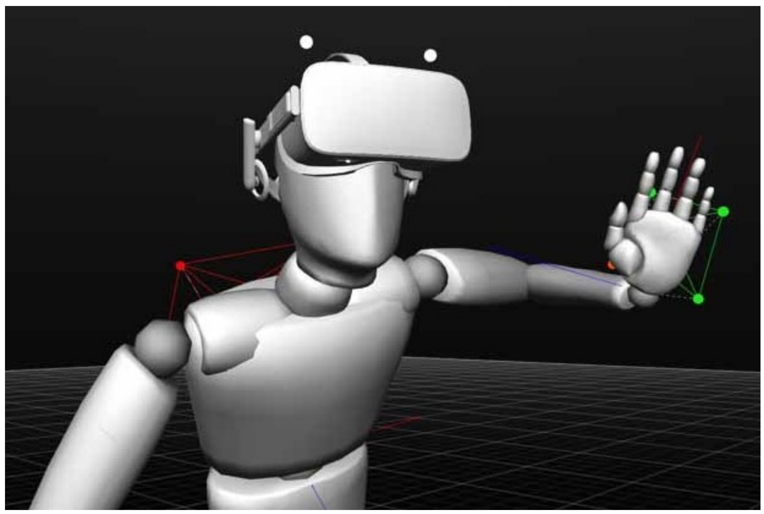


Figure 3.3: Motion Capture and Body Tracking using Motive

3.3.3 Biopac MP160

For the purpose of acquiring physiological response data from the participants, the Biopac MP160 acquisition unit is used. This specific Biopac system uses nomadic transducers that can communicate with the electrodes placed on the participant's body. Biopac is an industry-standard sensor that records physiological signals. It can be used to collect bodily signal data like heart rate, electrodermal activity, polygraph signals, electromyography and electroencephalogram through the use of electrodes connected to the participant. This Biopac unit is a wireless unit. The electrodes do not have to be connected to the main unit through wires. Once they are placed firmly on the participant's body, they start sending out small electric pulses through the electrodes to record the above-mentioned signals. AcqKnowledge software is used for visualizing the data and recording it. AcqKnowledge is proprietary software developed for Biopac to record, visualize, and analyze the signal data.

(a) Main Unit

(b) EDA Unit

Figure 3.4: Biopac MP160 Acquisition Units

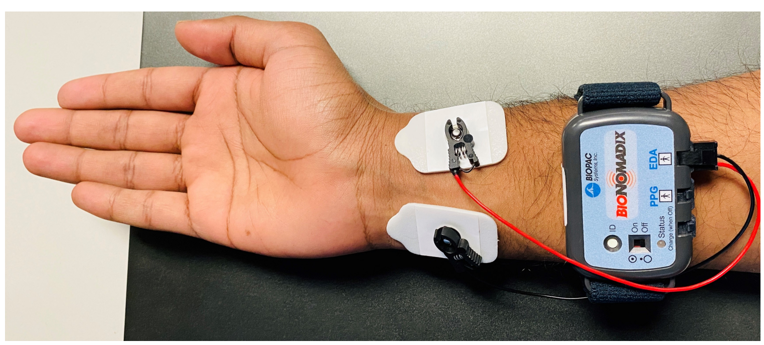


Figure 3.5: Wireless Unit and Electrodes Connected to a Participant's Hand

3.3.4 Subpac M2X

To create a vibro-tactile experience, Subpac M2X backapck (in Figure 3.6), which give out vibration feedback on audio is used. There are several other devices that one can use to give force-feedback, haptic feedback to provide tactile modality. Even handheld controllers have tactile feedback but to have a strong presence, we chose this vest. We used Subpac M2X because, it is like a backpack that can be easily put on carried around that gives out vibration feedback from the padded area at the center.

Figure 3.6: Subpac M2X Vest

3.4 Methodology

3.4.1 System Infrastructure

The system design for this project is shown below in Figure 3.7. It uses two computer systems for achieving the purpose of this VR application. *System 1* runs the Unity VR application on it whereas *System 2* runs the Node server on it along with AcqKnowledge software.

This entire setup is connected to a lot of hardware components to allow experimenters to do complicated, yet very interesting user studies. What we had in mind when we started this project was to develop a user study to understand the physiological effects of VR. We developed a virtual environment to test how physiological responses vary with the presentation of a stimulus. Then we started testing other parameters that involved the use of hardware, which involved complex integration and complex design. We wanted to perform an embodiment study to see how responses changed with and without an avatar. To do this, we had to use OptiTrack motion capture system. Then we wanted to see how multiple sensory modalities affect the presence factor of the participant. We tested using Subpac M2X. As we added layer on layer, we developed interesting questions and the more complicated it became. This gave us the motivation to develop this system design that allows experimenter's like us to question, explore and record evidence that can be meaningful to the research community.

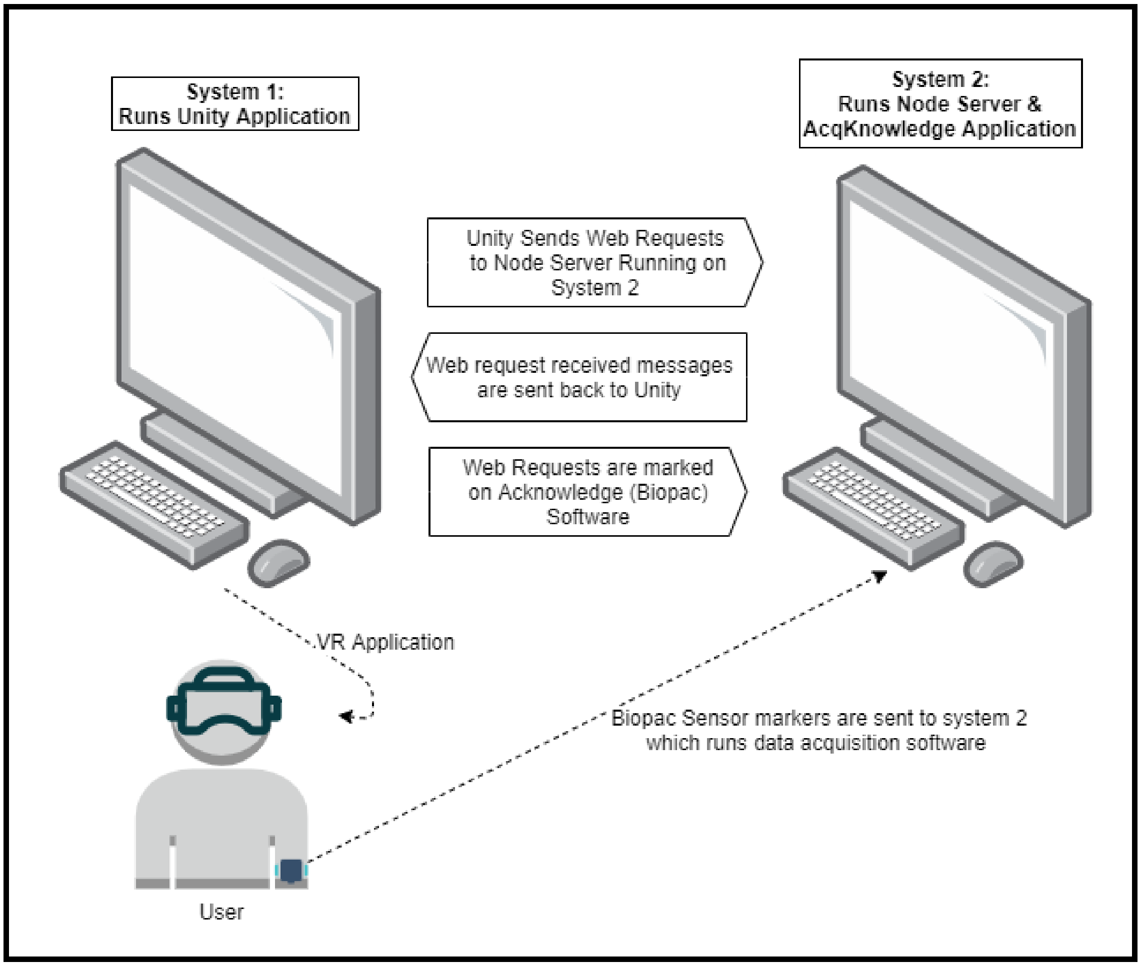


Figure 3.7: System Architecture

- The software working is described, once the VR application starts running on system 1, we start the Node server on system 2 simultaneously.
- Every time the participant is presented a stimulus, the VR application sends out web requests before and after the stimulus presentation to the node server running on system 2.
- These web requests are simulated key press events of the "Escape" key, which AcqKnowledge software listens to and places markers on the data collection file.
- Once the experiment is done the software ends recording data, which can later

be analyzed.

3.4.2 Application Flow

The VR application has several scenes built using the Unity engine and they are loaded according to the Scene Loader script. This is done to reduce experimenter error at the inspector tab of Unity. Previously, we have worked on VR studies and have come across a lot of experimenter errors as not all of them have knowledge about the Unity engine. This software allows the experimenter to communicate with the application at the top level instead of the editor level of Unity (which requires some knowledge).

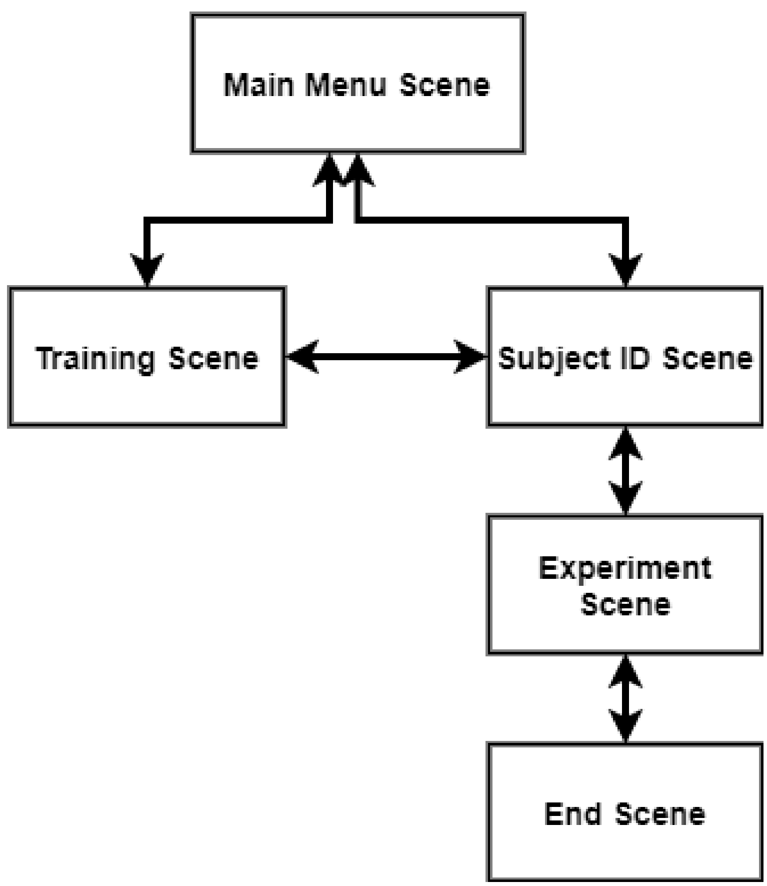


Figure 3.8: Flowchart of the Application

The application loads with a non-VR *Main Menu Scene* where the experimenter can make a choice to navigate to VR *Training Scene* or non-VR *Subject ID Scene*. *Subject ID Scene* is factored in so that the experimenter can enter the subject/participant ID at the application level.

3.4.3 Experiment Flow

Once the participant ID is entered using the input text field, the value entered is used to get a randomized order of within subject conditions, generated before hand. These randomized conditions are generated using python script and basing on the participant's number the conditions array for that number are presented to the participant.

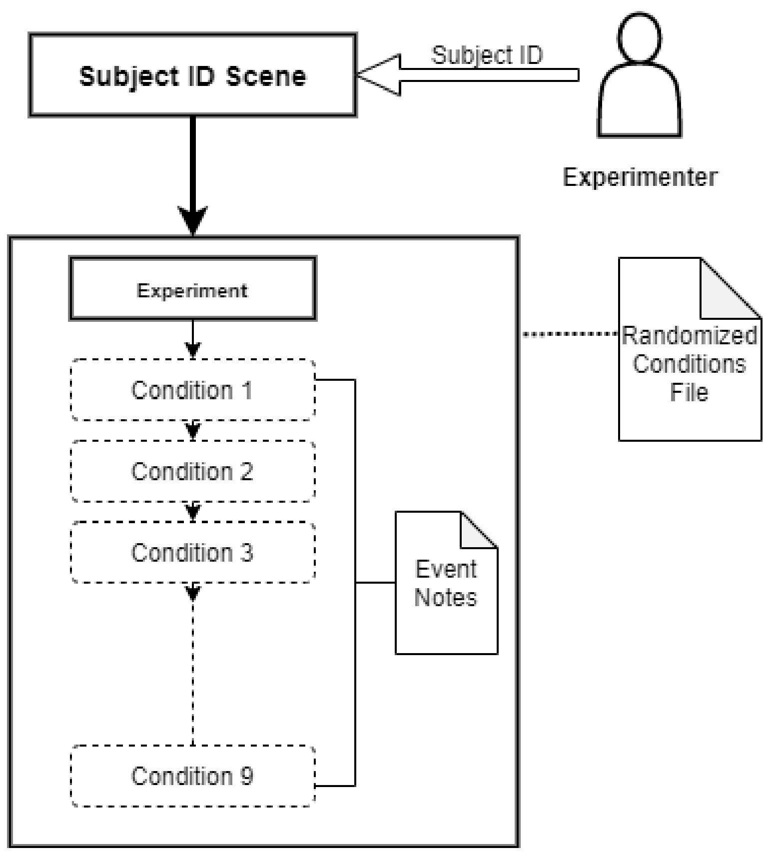


Figure 3.9: Flowchart of the Experiment Scene

The file which determines the random condition order is generated using Python script. Each participant is presented 3 within subject conditions and each of the three conditions is presented three times with no adjacency.

3.5 Condition Presentations

Every participant will undergo three stimulus presentations which involve different different modalities in a random order.

3.5.1 Only Visual

In visual condition a *tree* is displayed momentarily for a while before it disappears. There is no audio of any sort during this prsentation.

```
//Visual Modality Function

        // Stimulus Presentation
        StartCoroutine(GetRequest(request));
        stimulus.StimuliAppear();
        yield return new WaitForSeconds(15);
        StartCoroutine(GetRequest(request));
        yield return new WaitForSeconds(15);
        stimulus.StimuliDisappear();
        StartCoroutine(GetRequest(request));
```

3.5.2 Audio-Visual

In Audio-visual condition, a *tree* appears in front of the participant which is accompanied by a thunder rustling sound which is played through the Oculus Quest's headset audio output.

```
// Audio Visual Modality


        //Stimulus Presentation
        StartCoroutine(GetRequest(request));
        stimulus.StimuliAppear();
        audioData.Play(0);
        yield return new WaitForSeconds(15);
        StartCoroutine(GetRequest(request));
        yield return new WaitForSeconds(15);
        stimulus.StimuliDisappear();
        StartCoroutine(GetRequest(request));
```

3.5.3 Audio-Visual Tactile

In Audio-visual tactile condition, the same *tree* appears along with accompanying audio of the thunder sound. Moreover, the vibrotactile vest donned by the participant vibrates on the participants chest along with the audio. The vibration frequency is matched to that of the audio.

```
// Audio Visual Modality

        //Stimulus Presentation
        StartCoroutine(GetRequest(request));
        stimulus.StimuliAppear();
        audioData.Play(0);
        vestData.Play(0);
        yield return new WaitForSeconds(15);
        StartCoroutine(GetRequest(request));
        yield return new WaitForSeconds(15);
```

```
        stimulus.StimuliDisappear();
        StartCoroutine(GetRequest(request));
```

3.6 Qualitative Measures

In between each condition presentation, there is a predetermined time interval for the participants' physiology to come to baseline before the next stimuli presentation. This predetermined time interval is deduced from running trails on participants in a pilot study. Between each condition, the participants are presented a question about the VR experience. The participants can use their handheld controllers to answer the question.

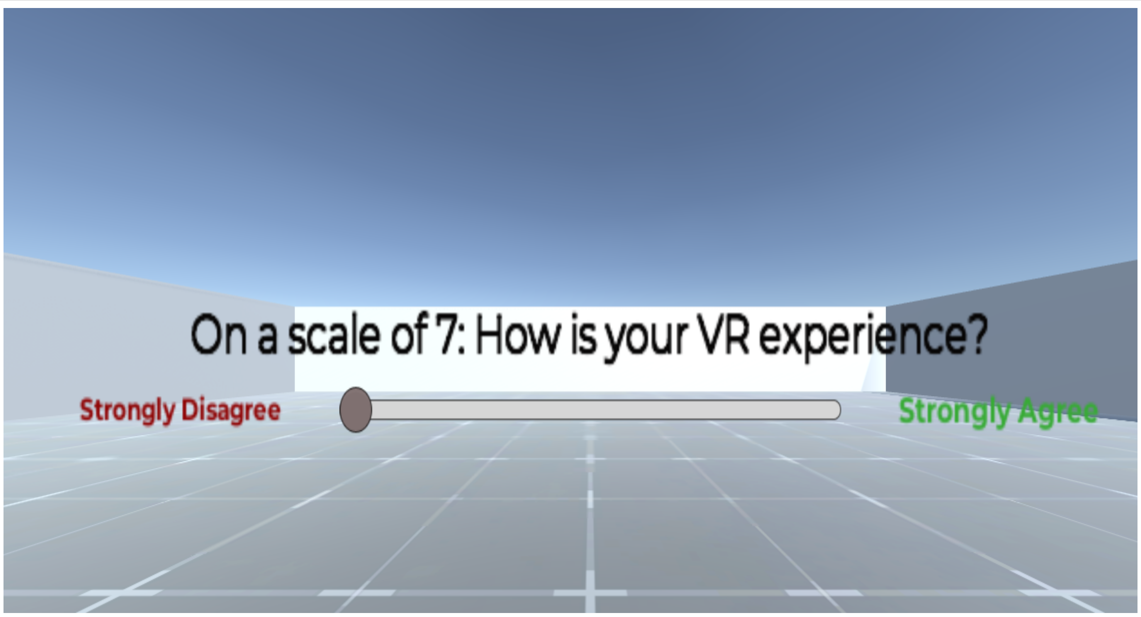


Figure 3.10: An Example of an Experience Question

The answers range on a likert scale from 1 to 7 (strongly disagree to strongly agree) and have to be answered using a UI slider. The questions that can be asked or measured are not limited to what our software is designed to ask. Experimenters can create a text file with questions that can be given as input for the script file for the software to present the participants with those customized questions.

4 Evaluation

4.1 Application Design

Though the previous chapter is complicated with a lot of hardware descriptions and software terms, the Virtual environment design to make it easier for the experimenter to navigate through the application easily. One of our main motivations to work on developing this application is to help experimenters from several disciplines to look at this as a blueprint for making VR based researches. The software developed has better user interface, navigability and documented design.

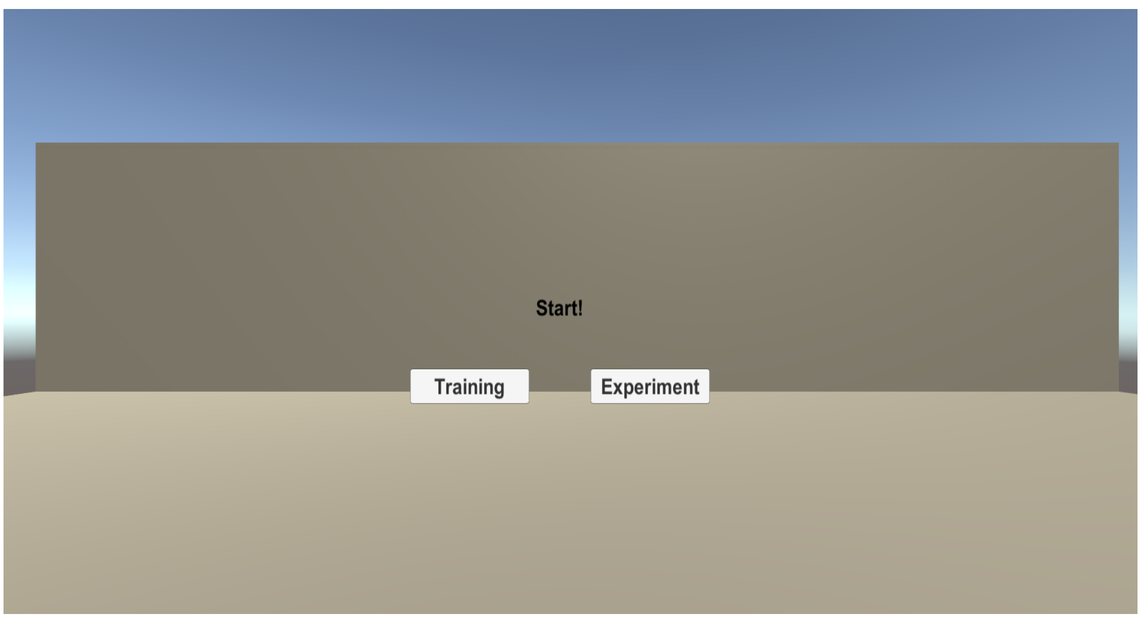


Figure 4.1: Main Menu Scene

The VR application we developed has features incorporated in them after understanding the shortcomings of previous VR studies we have done. Some of the issues we faced in previous studies were, 1) experimenter errors, where the experimenter entered wrong inputs while running the application 2) not being to timestamp/note down unexpected events due to hardware failure 3) unexpected user(participant) errors like participant's phone buzzing, their smart watch notifications and, 4) application errors.

So, we wanted to develop a VR application such that it addresses these shortcomings. The interface is designed for easy navigability for the experimenter. A better interface is one that allows easier understanding of the software and how it runs. We developed navigation using Unity's *SceneManagement* to change between scenes. This enables the experimenter to change between scenes by using User Interface (UI) components like buttons and text fields which were missing from the previous VR applications and studies.

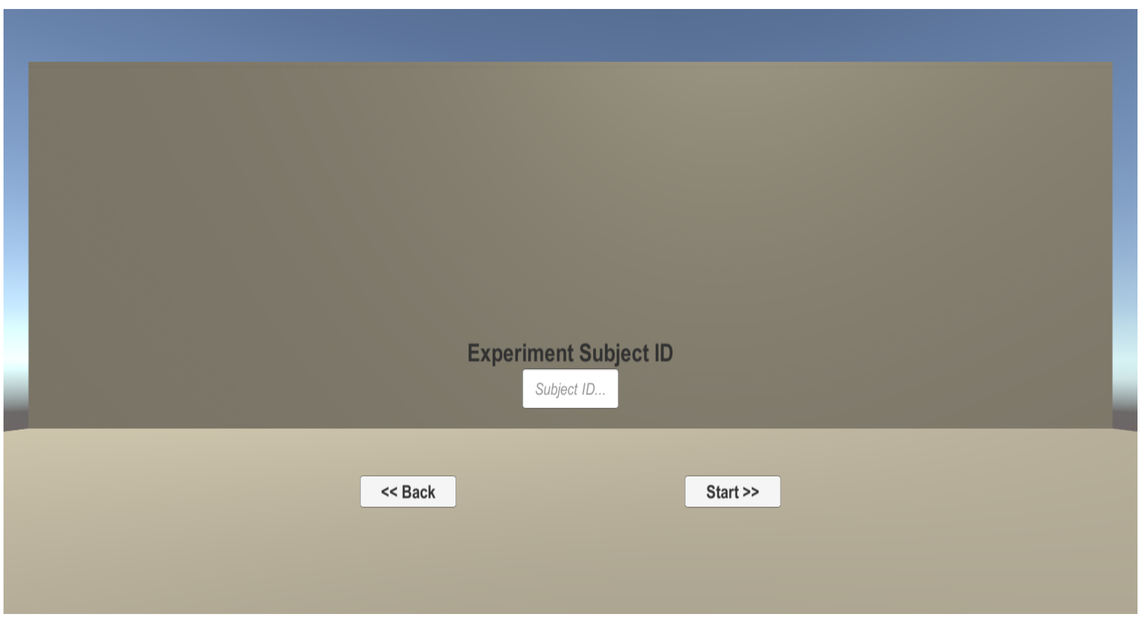


Figure 4.2: Subject ID Scene

4.1.1 Play Area

The play area is a 20 feet by 20 feet space bounded by walls on all sides. This is a simple virtual environment with not many objects interacting with the user. The main object within this environment is a tree which appears and disappears as per the conditions a participant will experience.

Figure 4.3: SIVE Lab Space

4.1.2 Training Environment

In this study, we designed a training environment to get the participants accustomed to VR experience before they take part in the actual experiment. The training scene is designed to resemble the real world Sivelab room though it is not an exact virtual version of it. We have this design for training to make users believe that they are in the actual Sivelab and see their responses and how varied they are after the context is changed. We collect a baseline physiology in this training scenario. We also want the participants to get used to moving around in VR, experience spatial audio, video and interaction. The participant will be presented with an ambient audio to help them relax as VR experience can be overwhelming to few.

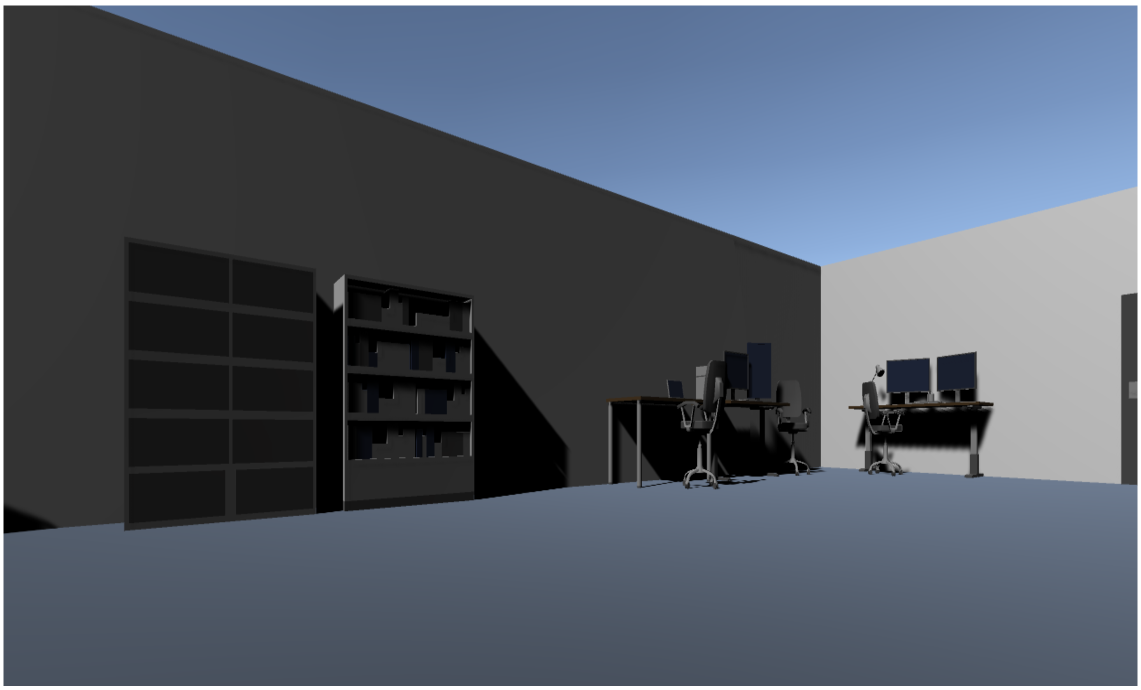


Figure 4.4: A View of the Training Scene

In the training scene the participants are not expected to perform any task as doing one would induce mental workload which will have an impact when they get to the actual experiment environment. The main purpose of the training scene is to calm down the participants and reduce their stress and anxiety levels along with recording and understanding their baseline physiology. Once the participant is done with the training scenario they can be moved to the main menu screen by pressing the "Esc" key on the keyboard.

4.1.3 Experiment Environment

The experiment environment is the virtual interface where the actual studies and data can be collected from. The experimenters will have flexibility to choose what stimuli to present to the participants while the software takes care of the randomization of the presentations.

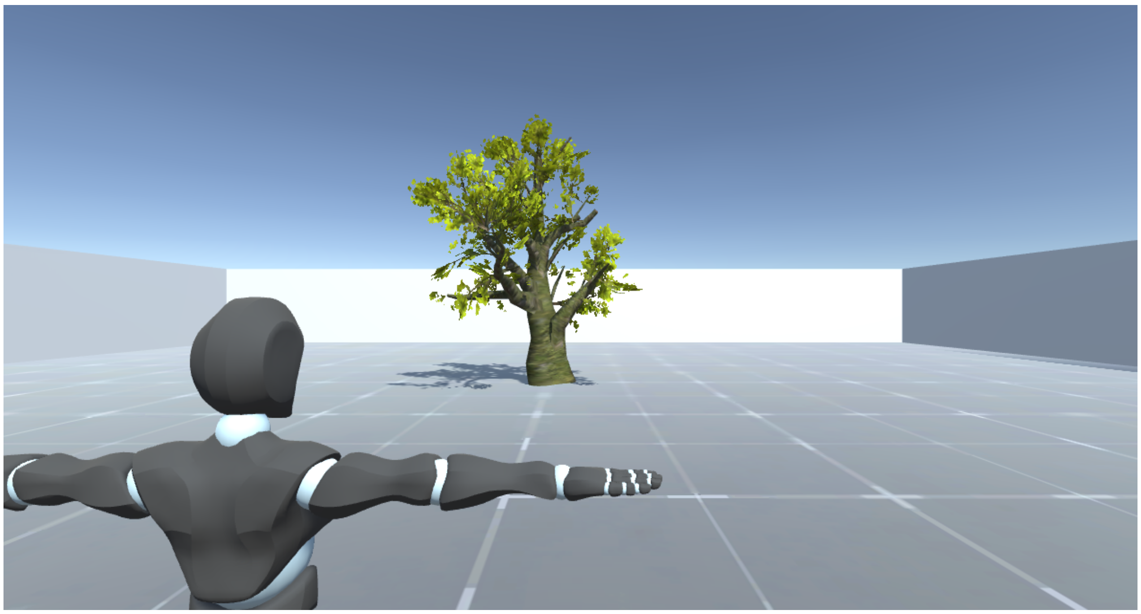


Figure 4.5: Virtual Environment in Player's Perspective

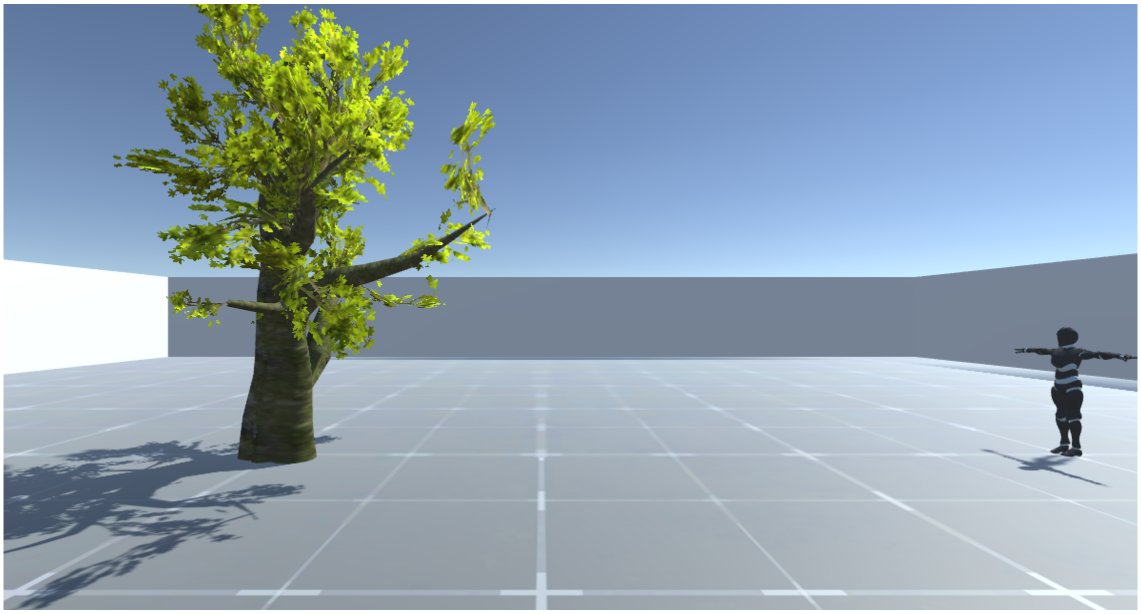


Figure 4.6: Side View of the Experiment Scene

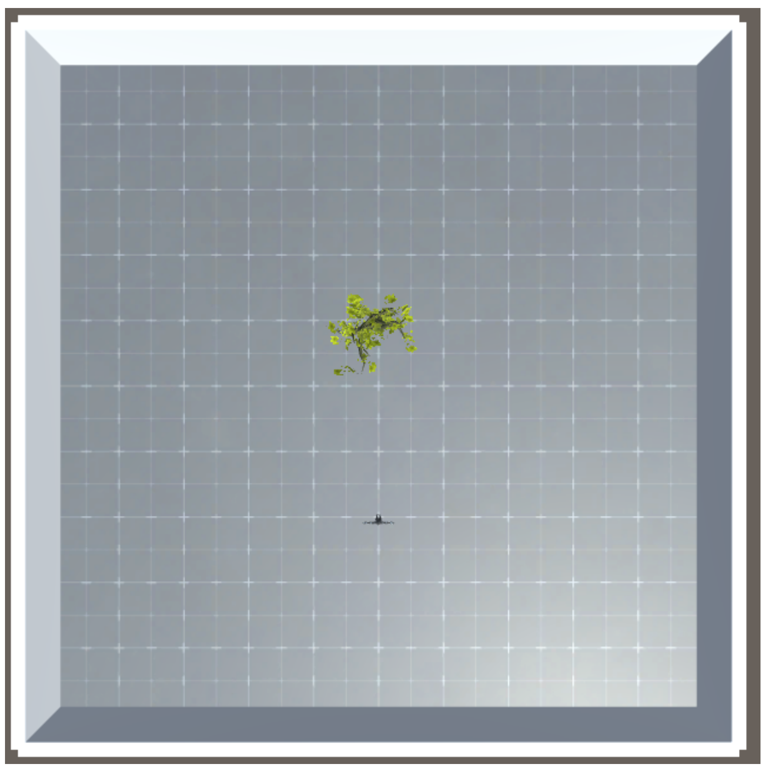
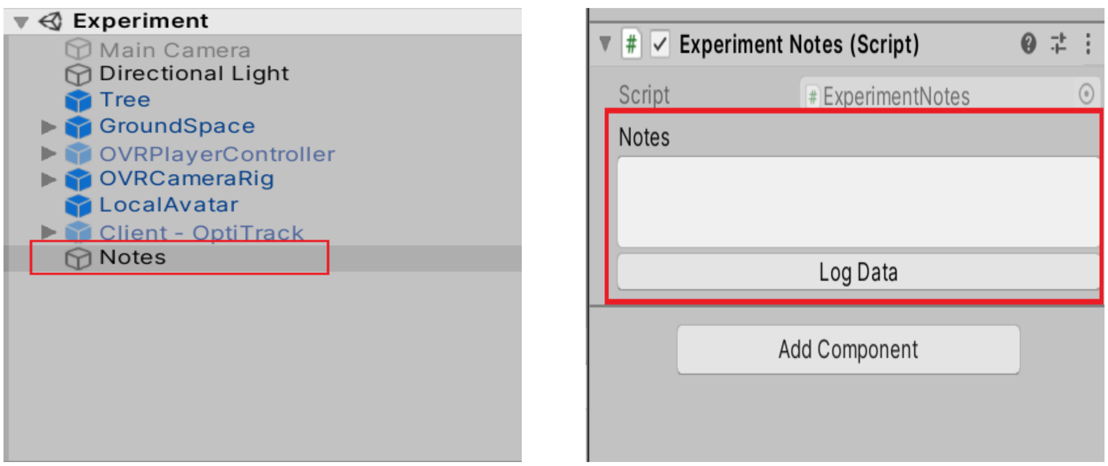


Figure 4.7: Experiment Play Area in Top View

4.1.4 Notes Logger

The notes logger feature is used to record events that are considered erroneous or unexpected during the experiment. Unexpected events in this context are experimenter errors like wrong inputs, participant's electronics notifying, hardware failure if the system freezes. The text area field is included in the experiment scene. The *Log Data* UI button is used to record data into a text file which can be retrieved after the experiment to check if there are any issues with that particular trail.



(a) Hierarchy Tab (b) Inspector Tab

Figure 4.8: Notes Logger in Unity

An example of how the notes are logged is given below:

```
Hardware not working properly @: 21.94946
VR headset issues @: 44.59856
Participant had phone in pocket, buzzed during the experiment @: 77.52681
```

4.1.5 Node Server

To drop event markers in AcqKnowledge software while collecting physiological responses, a node server is developed. This node server runs on the machine to which the Biopac unit is connected and AcqKnowledge software are running. This node server starts listening for connections on the network. The working protocol here is, the machine that runs this unity application will send out "Escape" key sequences to the server, prompting it to tag events on the AcqKnowledge software. Once these key sequences are sent from Unity application to Node server, the server marks these events on the acquisition software and places a live *Event Marker* on the data collection chart.

```
// Node server function that sends "Escape" key
// to mark events on AcqKnowledge Software

app.get('/press', function (req, res) {

    ks.sendKey('esc');
    res.status(200).send('OK');
});
```

4.1.6 Unity Web Requests

As the node server is running in a different machine(which also runs AcqKnowledge Software), it listens for web requests from client machines connected to the same network. When the Unity application starts running, it will send out web requests to place event-markers on AcqKnowledge software allowing experimenters for easier data analysis. Example of how a web request is made is shown below:

```
//http url to make a request to tag AcqKnowledge

private string request = "http://sivelab02.d.umn.edu:18081/press";

//Makes the HTTP request to tag the AcqKnowledge Software running on a
```

```
    different machine
// Function defition below

IEnumerator GetRequest(string uri)
{
    UnityWebRequest uwr = UnityWebRequest.Get(uri);
    yield return uwr.SendWebRequest();
    if (uwr.isNetworkError)
    {
        Debug.Log("Error While Sending: " + uwr.error);
    }
    else
    {
        Debug.Log("Received: " + uwr.downloadHandler.text);
    }
}


//Function call is shown below

StartCoroutine(GetRequest(request));
```

4.2 Sample Data

We collected sample data using the entire hardware apparatus mentioned in the previous chapter through AcqKnowledge software. In the Figure 4.9, the EDA signal data of a participant can be seen. Within the red rectangle are the event markers that the VR application places on AcqKnowledge with the help of Node server. The data is collected for two conditions, *C1* with just visual stimulus presentation where as *C2* with audio-visual stimuli presentation. It can be seen that the combination of audio and visual stimuli created higher responses in the participant.

Figure 4.9: Data Recording on AcqKnowledge Software

4.3 Discussion

The software we developed will enable future researches to perform user studies that will have an impact on virtual training. Providing users an understanding of what it feels like to have an avatar body, to control the body and use it for interactions like socialising, performing procedural tasks, object manipulation will improve VR applications design. Multiple sensory modalities enhance users' engagement keeping them attentive, prompting them to grasp information, and improving their cognitive capabilities in virtual reality. However, there is still a lot to improve technology wise to simplify the embodiment process. It will be a huge success if sensors that measure physiology of the person, can be integrated with VR headsets and can be easily monitored through software extensions designed for this purpose. While it is fascinating to see, hardware upgrading, software also needs to be upgraded to offer better performance & usability. Our research focuses on elements that matter most to the research community in terms of multidisciplinary nature of VR.

Though it is beyond this research, analyzing the data collected from participant will answer a lot of interesting questions. Recorded physiological response data using this software can be used to measure the presence and immersion of the participant in VR. Further analysis can be done to understand the role of stimuli, how different stimuli affects different participants, and how researcher or developers can come to a set of stimuli that work best in VR. Adaptive virtual environments are one series of applications that can be built with real time analysis of these physiological responses. We don't have a firm reason for selecting and presenting the stimuli we presented to the user. We wanted to see if at all, any stimuli can elicit startle reflexes in a participant. We wanted to see if the stimuli presentation causes physiological changes that can be classified as startle or defense responses. Hence, in search of this possibility, this software is developed.

5 Conclusions

The important things we learned from this research are that having a software that enables the fusion of hardware together, will help in performing studies that help the use of VR. Physiological data from the participant to stimulating VR scenarios is very good evidence for understanding how embodiment can create more engagement. The VR Experiment software application developed for the purpose of the study can be used in several other disciplines to understand the potential of VR in those areas. Other conclusions from this research are, it is important to have VR applications easy enough to understand and work with as they can be used in multiple disciplines by experimenters who don't have a lot of technical background. It has been one of our main motivations to see if we can reduce experimenter errors in the process of these VR studies. Experimenter errors can account for a minimum of 3 to 5 percent of unusable data, which is so high for studies consisting of less than 50 participants. We automated as many sub-processes as possible to reduce human error in running studies using this software application.

5.1 Limitations

One of the main limitations of our work is that, though we have a software to run user-studies, there isn't sufficient user data and results to support why embodiment improves immersion. We were set to do an actual user study for this research but unfortunately, we were not able to collect data from participants because of COVID-

19 pandemic. Nevertheless, we did work on building the application and making it more robust and understanding areas where VR physiological user studies can be useful, that can be meaningful and can explain realms that were not explored before.

5.2 Future Work

VR research has a lot of scope and potential as it finds it's use in more and more areas. The question of whether to use or not use novel technology in any area has to be supported by good research studies and experiment trails. The future work of this study will be in understanding several questions like:

- If VR has the capability to elicit orienting responses like the natural world
- If embodying can improve user's cognitive learning and virtual collaboration
- After conditioning to an avatar, understanding the psycho-physiological affects of loss of that avatar

References

[1] M. Algorri. “Interactive virtual environments for behavioral therapy”. In: *Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (IEEE Cat. No.03CH37439)* (). DOI: 10.1109/iembs.2003.1279792 (cit. on p. 6).

[2] J. Allanson and G. M. Wilson. “Physiological Computing”. In: *CHI ’02 Extended Abstracts on Human Factors in Computing Systems*. CHI EA ’02. Minneapolis, Minnesota, USA: Association for Computing Machinery, 2002, pp. 912–913. ISBN: 1581134541. DOI: 10.1145/506443.506655. URL: https://doi-org.libpdb.d.umn.edu:2443/10.1145/506443.506655 (cit. on p. 20).

[3] R. L. Andersson. “A Real Experiment in Virtual Environments: A Virtual Batting Cage”. In: *Presence: Teleoper. Virtual Environ.* 2.1 (Jan. 1993), pp. 16–33. ISSN: 1054-7460. DOI: 10.1162/pres.1993.2.1.16. URL: https://doi.org/10.1162/pres.1993.2.1.16 (cit. on p. 13).

[4] A. Banafa. *What is Affective Computing?* Aug. 2018. URL: https://www.bbvaopenmind.com/en/technology/digital-world/what-is-affective-computing/ (cit. on p. 20).

[5] M. T. Bolas and S. S. Fisher. "Head-coupled remote stereoscopic camera system for telepresence applications". In: *Stereoscopic Displays and Applications* (1990). DOI: 10.1117/12.19896 (cit. on p. 13).

[6] M. Botvinick and J. Cohen. "Rubber hands 'feel' touch that eyes see". In: *Nature* 391.6669 (1998), pp. 756–756. DOI: 10.1038/35784 (cit. on p. 12).

[7] A. Brogni, V. Vinayagamoorthy, A. Steed, and M. Slater. "Variations in physiological responses of participants during different stages of an immersive virtual environment experiment". In: *Proceedings of the ACM symposium on Virtual reality software and technology - VRST 06* (2006). DOI: 10.1145/1180495.1180572 (cit. on p. 3).

[8] S. Bryson. "Paradigms for the shaping of surfaces in a virtual environment". In: *Proceedings of the Twenty-Fifth Hawaii International Conference on System Sciences* (1992). DOI: 10.1109/hicss.1992.183316 (cit. on p. 13).

[9] J. Butterworth, A. Davidson, S. Hench, and M. T. Olano. "3DM: a three dimensional modeler using a head-mounted display". In: *Proceedings of the 1992 symposium on Interactive 3D graphics - SI3D '92* (1992). DOI: 10.1145/147156.147182 (cit. on p. 13).

[10] J. P. Cater and S. D. Huffman. "Use of the Remote Access Virtual Environment Network (RAVEN) for Coordinated IVA—EVA Astronaut Training and Evaluation". In: *Presence: Teleoperators and Virtual Environments* 4.2 (1995), pp. 103–109. DOI: 10.1162/pres.1995.4.2.103 (cit. on p. 13).

[11] J. Chestnut and L. Crumpton. "Virtual reality: a training tool in the 21st century for disabled persons and medical students". In: *Proceedings of the 1997 16 Southern Biomedical Engineering Conference* (). DOI: 10.1109/sbec.1997.583330 (cit. on p. 6).

[12] T. Collingwoode-Williams, M. Gillies, C. McCall, and X. Pan. "The effect of lip and arm synchronization on embodiment: A pilot study". In: *2017 IEEE Virtual Reality (VR)*. 2017, pp. 253–254 (cit. on p. 24).

[13] A. Dirican and M. Gokturk. "Psychophysiological Measures of Human Cognitive States Applied in Human Computer Interaction". In: *Procedia CS* 3 (Dec. 2011), pp. 1361–1367. DOI: 10.1016/j.procs.2011.01.016 (cit. on p. 20).

[14] V. S. I. Durai, R. Arjunan, and M. Manivannan. "The Effect of Audio and Visual Modality Based CPR Skill Training with Haptics Feedback in VR". In: *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 2019, pp. 910–911 (cit. on p. 21).

[15] L. Eudave and M. Valencia. "Physiological response while driving in an immersive virtual environment". In: *2017 IEEE 14th International Conference on Wearable and Implantable Body Sensor Networks (BSN)* (2017). DOI: 10.1109/bsn.2017.7936028 (cit. on p. 15).

[16] A. Girouard, E. T. Solovey, R. Mandryk, D. Tan, L. Nacke, and R. J. Jacob. "Brain, Body and Bytes: Psychophys iological User Interaction". In: *CHI '10 Extended Abstracts on Human Factors in Computing Systems*. CHI EA '10. Atlanta, Georgia, USA: Association for Computing Machinery, 2010, pp. 4433–4436. ISBN: 9781605589305. DOI: 10.1145/1753846.1754167. URL: https://doi-org.libpdb.d.umn.edu:2443/10.1145/1753846.1754167 (cit. on p. 20).

[17] M. Gonzalez-Franco, A. Steed, S. Hoogendyk, and E. Ofek. "Using Facial Animation to Increase the Enfacement Illusion and Avatar Self-Identification". In: *IEEE Transactions on Visualization and Computer Graphics* 26.5 (2020), pp. 2023–2029. DOI: 10.1109/tvcg.2020.2973075 (cit. on p. 24).

[18] E. Haapalainen, S. Kim, J. F. Forlizzi, and A. K. Dey. “Psycho-Physiological Measures for Assessing Cognitive Load”. In: *Proceedings of the 12th ACM International Conference on Ubiquitous Computing*. UbiComp ’10. Copenhagen, Denmark: Association for Computing Machinery, 2010, pp. 301–310. ISBN: 9781605588438. DOI: 10.1145/1864349.1864395. URL: https://doi-org.libpdb.d.umn.edu:2443/10.1145/1864349.1864395 (cit. on p. 14).

[19] C. Heeter. “Being There: The Subjective Experience of Presence”. In: *Presence: Teleoperators and Virtual Environments* 1.2 (1992), pp. 262–271. DOI: 10.1162/pres.1992.1.2.262 (cit. on p. 4).

[20] K. Hiramoto and K. Hamamoto. “Study on the Difference of Reaching Cognition Between the Real and the Virtual Environment Using HMD and its Compensation”. In: *2018 11th Biomedical Engineering International Conference (BMEiCON)*. 2018, pp. 1–5 (cit. on p. 2).

[21] I. W. Hunter, T. D. Doukoglou, S. R. Lafontaine, P. G. Charette, L. A. Jones, M. A. Sagar, G. D. Mallinson, and P. J. Hunter. “A Teleoperated Microsurgical Robot and Associated Virtual Environment for Eye Surgery”. In: *Presence: Teleoperators and Virtual Environments* 2.4 (1993), pp. 265–280. DOI: 10.1162/pres.1993.2.4.265. eprint: https://doi.org/10.1162/pres.1993.2.4.265. URL: https://doi.org/10.1162/pres.1993.2.4.265 (cit. on p. 13).

[22] D. P. Jang, B. K. Wiederhold, S. B. Mcgehee, E. Durso, M. D. Wiederhold, I. Y. Kim, and S. I. Kim. “An investigation of immersiveness in virtual reality exposure using physiological data”. In: *PsycEXTRA Dataset* (2002). DOI: 10.1037/e705452011-010 (cit. on pp. 6, 16).

[23] K.-I. Kameyama and K. Ohtomi. “A Shape Modeling System with a Volume Scanning Display and Multisensory Input Device”. In: *Presence: Teleoperators*

and Virtual Environments 2.2 (1993), pp. 104–111. DOI: 10.1162/pres.1993.2.2.104 (cit. on p. 13).

[24] A. Kim, M. Chang, Y. Choi, S. Jeon, and K. Lee. “The Effect of Immersion on Emotional Responses to Film Viewing in a Virtual Environment”. In: *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 2018, pp. 601–602 (cit. on p. 15).

[25] J. Kritikos, G. Tzannetos, C. Zoitaki, S. Poulopoulou, and D. Koutsouris. “Anxiety detection from Electrodermal Activity Sensor with movement interaction during Virtual Reality Simulation”. In: *2019 9th International IEEE/EMBS Conference on Neural Engineering (NER)* (2019). DOI: 10.1109/ner.2019.8717170 (cit. on p. 16).

[26] D. Kulic and E. Croft. “Anxiety detection during human-robot interaction”. In: *2005 IEEE/RSJ International Conference on Intelligent Robots and Systems*. 2005, pp. 616–621 (cit. on p. 3).

[27] A. Landman, E. L. Groen, M. M. (V. Paassen, A. W. Bronkhorst, and M. Mulder. “Dealing With Unexpected Events on the Flight Deck: A Conceptual Model of Startle and Surprise”. In: *Human Factors: The Journal of the Human Factors and Ergonomics Society* 59.8 (Apr. 2017), pp. 1161–1172. DOI: 10.1177/0018720817723428 (cit. on p. 18).

[28] J. Lee, A. Eden, D. R. Ewoldsen, D. Beyea, and S. Lee. “Seeing possibilities for action: Orienting and exploratory behaviors in VR”. In: *Computers in Human Behavior* 98 (2019), pp. 158–165. DOI: 10.1016/j.chb.2019.03.040 (cit. on p. 19).

[29] R. Loftin and P. Kenney. "Training the Hubble space telescope flight team". In: *IEEE Computer Graphics and Applications* 15.5 (1995), pp. 31–37. DOI: 10.1109/38.403825 (cit. on p. 14).

[30] C. Lopez, P. Halje, and O. Blanke. "Body ownership and embodiment: Vestibular and multisensory mechanisms". In: *Neurophysiologie Clinique/Clinical Neurophysiology* 38.3 (2008), pp. 149–161. DOI: 10.1016/j.neucli.2007.12.006 (cit. on p. 22).

[31] A. Marquardt, C. Trepkowski, J. Maiero, E. Kruijff, and A. Hinkeniann. "Multisensory Virtual Reality Exposure Therapy". In: *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (2018). DOI: 10.1109/vr.2018.8446553 (cit. on p. 16).

[32] T. Mazuryk and M. Gervautz. "Virtual Reality - History, Applications, Technology and Future". In: (Dec. 1999) (cit. on p. 13).

[33] J. McDowd. "Inhibition". In: *Encyclopedia of Gerontology (Second Edition)*. Ed. by J. E. Birren. Second Edition. New York: Elsevier, 2007, pp. 759–763. ISBN: 978-0-12-370870-0. DOI: https://doi.org/10.1016/B0-12-370870-2/00100-1. URL: http://www.sciencedirect.com/science/article/pii/B0123708702001001 (cit. on p. 19).

[34] B. McGuinness and J. F. Meech. "Human factors in virtual worlds. 1. Information structure and representation". In: *IEE Colloquium on Using Virtual Worlds*. 1992, pp. 3/1–3/3 (cit. on p. 2).

[35] M. Meehan. PhD thesis (cit. on p. 16).

[36] C. M. D. Melo, P. Kenny, and J. Gratch. "Influence Of Autonomic Signals On Perception Of Emotions In Embodied Agents". In: *Applied Artificial Intelligence* 24.6 (2010), pp. 494–509. DOI: 10.1080/08839514.2010.492159 (cit. on p. 23).

[37] P. Milgram and F. Kishino. "A Taxonomy of Mixed Reality Visual Displays". In: *IEICE Trans. Information Systems* vol. E77-D, no. 12 (Dec. 1994), pp. 1321–1329 (cit. on p. 11).

[38] *Modalities of Sensation*. URL: https://teachmephysiology.com/nervous-system/sensory-system/modalities-of-sensation/ (cit. on p. 17).

[39] S. Mori, S. Ikeda, and H. Saito. "A survey of diminished reality: Techniques for visually concealing, eliminating, and seeing through real objects". In: *IPSJ Transactions on Computer Vision and Applications* 9.1 (2017). DOI: 10.1186/s41074-017-0028-1 (cit. on p. 11).

[40] R. Newport, R. Pearce, and C. Preston. "Fake hands in action: embodiment and control of supernumerary limbs". In: *Experimental Brain Research* 204.3 (2009), pp. 385–395. DOI: 10.1007/s00221-009-2104-y (cit. on p. 22).

[41] S. Nilsson and B. Johansson. "Fun and Usable: Augmented Reality Instructions in a Hospital Setting". In: *Proceedings of the 19th Australasian Conference on Computer-Human Interaction: Entertaining User Interfaces*. OZCHI '07. Adelaide, Australia: Association for Computing Machinery, 2007, pp. 123–130. ISBN: 9781595938725. DOI: 10.1145/1324892.1324915. URL: https://doi-org.libpdb.d.umn.edu:2443/10.1145/1324892.1324915 (cit. on p. 11).

[42] M. Obrist, G. Boyle, M. V. Brakel, and F. Duerinck. "Multisensory Experiences Spaces". In: *Proceedings of the Interactive Surfaces and Spaces on ZZZ - ISS 17* (2017). DOI: 10.1145/3132272.3135086 (cit. on p. 4).

[43] J. Pair, B. Allen, M. Dautricourt, A. Treskunov, M. Liewer, K. Graap, and G. Reger. "A Virtual Reality Exposure Therapy Application for Iraq War Post Traumatic Stress Disorder". In: *IEEE Virtual Reality Conference (VR 2006)* (). DOI: 10.1109/vr.2006.23 (cit. on p. 6).

[44] X. Pan, M. Gillies, C. Barker, D. M. Clark, and M. Slater. "Socially Anxious and Confident Men Interact with a Forward Virtual Woman: An Experimental Study". In: *PLoS ONE* 7.4 (2012). DOI: 10.1371/journal.pone.0032931 (cit. on p. 22).

[45] L. Phillips and V. Interrante. "A little unreality in a realistic replica environment degrades distance estimation accuracy". In: *2011 IEEE Virtual Reality Conference*. 2011, pp. 235–236 (cit. on p. 24).

[46] L. Phillips, B. Ries, M. Kaeding, and V. Interrante. "Avatar self-embodiment enhances distance perception accuracy in non-photorealistic immersive virtual environments". In: *2010 IEEE Virtual Reality Conference (VR)*. 2010, pp. 115–1148 (cit. on p. 24).

[47] *Psychological Effects of Embodiment Illusion - The Psychology of VR: the Three Illusions*. URL: https://www.coursera.org/learn/introduction-virtual-reality/lecture/zTNw2/psychological-effects-of-embodiment-illusion (cit. on pp. 11, 22).

[48] M. Slater and S. Wilbur. "A Framework for Immersive Virtual Environments (FIVE): Speculations on the Role of Presence in Virtual Environments". In: *Presence: Teleoperators and Virtual Environments* 6.6 (1997), pp. 603–616. DOI: 10.1162/pres.1997.6.6.603 (cit. on p. 3).

[49] Y. Slavova and M. Mu. “A Comparative Study of the Learning Outcomes and Experience of VR in Education”. In: *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. 2018, pp. 685–686 (cit. on p. 2).

[50] Y. Slavova and M. Mu. “A Comparative Study of the Learning Outcomes and Experience of VR in Education”. In: *2018 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)* (2018). DOI: 10.1109/vr.2018.8446486 (cit. on p. 19).

[51] S. A. Stansfield. “A Distributed Virtual Reality Simulation System for Situational Training”. In: *Presence: Teleoperators and Virtual Environments* 3.4 (1994), pp. 360–366. DOI: 10.1162/pres.1994.3.4.360 (cit. on p. 14).

[52] R. M. Stern, W. J. Ray, and K. S. Quigley. *Psychophysiological recording*. Oxford University Press, 2006 (cit. on p. 20).

[53] I. E. Sutherland. “The Ultimate Display”. In: *Proceedings of the IFIP Congress*. 1965, pp. 506–508 (cit. on p. 7).

[54] R. M. Taylor, W. Robinett, V. L. Chi, F. P. Brooks, W. V. Wright, R. S. Williams, and E. J. Snyder. “The nanomanipulator”. In: *Proceedings of the 20th annual conference on Computer graphics and interactive techniques - SIGGRAPH ’93* (1993). DOI: 10.1145/166117.166133 (cit. on p. 13).

[55] G. Tieri, E. Tidoni, E. F. Pavone, and S. M. Aglioti. “Body visual discontinuity affects feeling of ownership and skin conductance responses”. In: *Scientific Reports* 5.1 (2015). DOI: 10.1038/srep17139 (cit. on p. 21).

[56] Q. Wang, H. Wang, and F. Hu. “Combining EEG and VR Technology to Assess Fear of Heights”. In: *2018 9th International Conference on Information Technology in Medicine and Education (ITME)*. 2018, pp. 110–114 (cit. on p. 2).

[57] F. Weidner, A. Hoesch, S. Poeschl, and W. Broll. “Comparing VR and non-VR driving simulations: An experimental user study”. In: *2017 IEEE Virtual Reality (VR)*. 2017, pp. 281–282 (cit. on p. 15).

[58] B. K. Wiederhold, D. P. Jang, R. G. Gevirtz, S. I. Kim, I. Y. Kim, and M. D. Wiederhold. “The treatment of fear of flying: a controlled study of imaginal and virtual reality graded exposure therapy”. In: *IEEE Transactions on Information Technology in Biomedicine* 6.3 (2002), pp. 218–223 (cit. on p. 16).

[59] B. Yin, F. Chen, N. Ruiz, and E. Ambikairajah. “Speech-based cognitive load monitoring system”. In: *2008 IEEE International Conference on Acoustics, Speech and Signal Processing*. 2008, pp. 2041–2044 (cit. on p. 14).

A Appendix A

This appendix includes scripts used to develop the project. These scripts enable and disable VR scenes, Scene management in Unity.

VR Enabler Script

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.VR;
using UnityEngine.XR;

public class VREnabler : MonoBehaviour
{

    void Start()
    {
        StartCoroutine(ActivateVR("Oculus"));
    }

    // This function Activates VR
    // It takes a string argument which is the name of the VR device
    public IEnumerator ActivateVR(string VRD)
    {
        XRSettings.LoadDeviceByName(VRD);
        yield return null;
        XRSettings.enabled = true;
```

```
    }

}
```

VR Disable Script

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.VR;
using UnityEngine.XR;

public class VRDisabler : MonoBehaviour
{

    void Start()
    {
        StartCoroutine(DeactivateVR("none"));
    }

    // This function Deactivates VR
    // It takes a string argument "none" to tell the scenemanager that
    // the scene does not need a VR device.
    public IEnumerator DeactivateVR(string VRD)
    {
        XRSettings.LoadDeviceByName(VRD);
        yield return null;
        XRSettings.enabled = true;
    }

}
```

Scene Loader Script

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;


public class LoadScene : MonoBehaviour
{
    // This method changes scenes based upon the scene order
    // in the build settings of the project.
    // Attach this script to an empty gameobject in your scene for
    // scene management.
    public void SceneLoader(int SceneIndex)
    {
        SceneManager.LoadScene(SceneIndex);
    }
}
```

Notes Logger Script

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEditor;

[CustomEditor(typeof(ExperimentNotes))]
public class NotesLogger : Editor
{

    // This function overrides the button click event to record
    // the notes experiemter wants to be logged.
```

```
    public override void OnInspectorGUI()
    {
        DrawDefaultInspector();

        ExperimentNotes logger = (ExperimentNotes)target;

        if (GUILayout.Button("Log Data"))
        {
            logger.Record();
        }
    }
}
```

Experiment Notes Script

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using System.IO;

public class ExperimentNotes : MonoBehaviour
{

    [TextArea]
    public string Notes;  //Creates a text area on the inspector


    private string filename;
    private string participant = SubIDValue.userName;
    private float TimeT, Elapsed;

    private void Start()
```

```
    {
        TimeT = Time.time;
        filename = "Logger#" + participant + ".txt";

    }

    // When on GUI button click on the inspector, whatever notes written by
    // the experimenter in the TextArea is recorded in a file along with the
    // time at which the event occured during the experiment.
    public void Record()
    {
        Elapsed = Time.time - TimeT;
        File.AppendAllText(Application.dataPath + "/Output/Notes/" + filename, Notes + " @: " + Elapsed + "\r\n");

    }

}
```

The following JavaScript is used to tag event markers on the AcqKnowledge software while data collection from participant is active.

Node Server Script

```
// use the key sender
//   does require that java is installed
var ks = require('node-key-sender');

// use a random number generator
// can safely delete at some point when the keys we need are sent
```

```
const Random = require("random-js").Random;
const random = new Random();

// Express provides a framework that makes handling HTTP
// request/repsonse sequences simpler
var express = require('express');
var http = require('http');

// The main instanced class, called app will be initialized by express
var app = express();
var httpServerRef = http.createServer(app);

// Set the port in the app system
app.set("port", 18081);

// ==============================================
//
// Start the app and let it listen for connections on the
// network
//
// listen opens up a network socket on port "port" and waits for
// HTTP connections
//
// ==============================================
httpServerRef.listen(app.get("port"), function () {
    console.log('SIVE Lab Key Relay for AR/VR Experiments\n\tListening
  on port: ', app.get("port"));
});

// Express ROUTE Section for REST APIs
// This is where you process the GET, POST, PUT, DELETE and other
```

```
// potential routes.

// key press GET ROUTE -- when received, send along a key press
app.get('/press', function (req, res) {

    // Esc key is sent from Unity application to
    // AcqKnowledge Software running on machine
    // where node server is running
    ks.sendKey('esc');

    // Finally, send a status RESPONSE back letting the client know
    // the POST succeeded.
    res.status(200).send('OK');
});

// ERROR Conditions, such as page not foudn or server error
// ------------------------------
app.use(function (req, res, next) {
    res.status(404).send('Page Does Not Exist');
});

// page not found - 500
app.use(function (err, req, res, next) {
    console.error(err.stack);
    res.status(500).send('Internal Server Error.');
});
```