Implicit Fear-based Virtual Reality Exposure Therapy Paradigm for Use in Low Income Environments

by
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Thesis presented in partial fulfilment of the requirements for the degree of Master of Engineering (Mechatronic) in the Faculty of Engineering at Stellenbosch University

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April 2022

Declaration

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Date: April 2022

Abstract

The presence of Post-Traumatic Stress Disorder (PTSD) in South Africa is an issue that only continues to grow in both severity and prevalence. The disorder affects people of all demographics and all income brackets. Often, the trauma goes untreated and develops into PTSD, causing rapid deterioration of both the victim's mental health and those that care for them. The presence of PTSD can give rise to other anxiety related disorders, often exacerbating the situation. Each case is different to the next, with unique symptoms complicating treatment. In the South African context, the prevalence of PTSD is extremely high, with the history and social context providing a unique environment for this disorder. The frequency and severity of traumatic experiences is significantly higher in low-income areas and post-migration communities than those in safer, higher-income areas. The underlying issue stems from the disparity between the presence of trauma and the accessibility of treatment.

This project focuses on the validation of a potential form of treatment for PTSD, utilizing virtual reality (VR) and the methodology of Exposure Therapy. The VR paradigm to be validated was tested on a sample population of 22 healthy participants. The paradigm itself was designed and created to be compatible with current VR technologies and meet all the necessary criteria to be used as a facilitation tool for Virtual Reality Exposure Therapy (VRET). Each participant was put through a VR simulation that was designed to consistently induce stress/anxiety while monitoring the physiological feedback of the participants. Additionally, each participant was asked a number of questions pertaining to their experience – both in the context of their sense of presence and how they were feeling at certain points in the simulation. The design of the simulation focused heavily on optimization and efficiency, hoping to reduce the risk of motion sickness and improve the overall efficacy of the paradigm. The simulation showed encouraging performance results, with the average frame time kept below 11 ms (ensuring the device maintains a refresh rate of 90 Hz). Nausea (a measurement for the onset of motion sickness) was well-controlled and almost entirely mitigated – with the largest mean for self-reported nausea being only 0.65 out of 10. Additionally, dizziness (another measurement for onset of motion sickness) had a peak mean of 1.45 out of 10. The value representative of physiological stress (the Continuous Decomposition Analysis (CDA) scores) supported the success of the paradigm. The CDA means across all participants consistently peaked at the same points in the simulation and showed meaningful significance when compared to the stimuli and their corresponding events. Furthermore, the self-reported stress and anxiety levels of all the participants support the findings from the physiological data. Unfortunately, there was no significant correlation between the Presence Score metric and any of the other variables. This study supports the efficacy and validity of the simulation as a VRET paradigm for use in the treatment of PTSD.

Opsomming

Die teenwoordigheid van Post-traumatiese stresversteuring (PTSV) in Suid-Afrika groei tans in beide erns en voorkoms. Die versteuring raak mense van alle demografiese herkoms en inkomstegroepe. Trauma word dikwels onbehandeld en ontwikkel in PTSV, wat vinnige agteruitgang van beide die slagoffer se geestesgesondheid en dié van versorgers veroorsaak. Die teenwoordigheid van PTSV kan aanleiding gee tot ander angsverwante versteurings, wat dikwels die situasie vererger. Elke geval is anders as die volgende, met unieke simptome wat behandeling bemoeilik. In die Suid-Afrikaanse konteks is die voorkoms van PTSV uiters hoog, met die geskiedenis en sosiale konteks wat 'n unieke omgewing vir hierdie versteuring bied. Die frekwensie en erns van traumatiese ervarings is aansienlik hoër in lae-inkomstegebiede en postmigrasie gemeenskappe as dié in veiliger, hoër-inkomste gebiede. Die onderliggende kwessie spruit uit die verskil tussen die teenwoordigheid van trauma en die toeganklikheid van behandeling. Hierdie projek fokus op die validering van 'n potensiële vorm van behandeling vir PTSV, deur gebruik te maak van virtuele realiteit (VR) en die metodologie van blootstellingsterapie. Die VR-paradigma word ondersoek in 'nsteekproefpopulasie van 22 gesonde deelnemers. Die paradigma self is ontwerp en geskep om versoenbaar te wees met huidige VR-tegnologieë en voldoen aan al die nodige kriteria om as 'n fasiliteringsinstrument vir Virtual Reality Exposure Therapy (VRET) gebruik te word. Elke deelnemer is deur 'n VRsimulasie gesit wat ontwerp is om konsekwent stres/angs te veroorsaak terwyl die fisiologiese terugvoer van die deelnemers gemonitor word. Daarbenewens is elke deelnemer 'n aantal vrae gevra oor hul ervaring – beide in die konteks van hul gevoel van teenwoordigheid en hoe hulle op sekere punte in die simulasie voel. Die ontwerp van die simulasie het sterk gefokus op optimalisering en doeltreffendheid, met die hoop om die risiko van simulasie siekte te verminder en die algehele doeltreffendheid van die paradigma te verbeter. Die optimaliseringspogings was suksesvol in terme van beide die ervaring en die prestasie van die simulasie. Naarheid ('n meting vir die aanvang van simulasie-siekte) was goed beheer – met die grootste gemiddelde vir selfgerapporteerde naarheid slegs 0,65 uit 10. Boonop het duiseligheid (nog 'n meting vir die aanvang van bewegingsiekte) 'n piekgemiddelde van 1,45 uit 10. Die waarde verteenwoordigend van fisiologiese stres (die CDAtellings) het die sukses van die paradigma ondersteun. Die CDA-betekenis oor alle deelnemers bereik konsekwent op dieselfde punte in die simulasie en toon betekenisvolle betekenis in vergelyking met die stimuli en hul ooreenstemmende gebeure. Verder ondersteun die selfgerapporteerde stres- en angsvlakke van al die deelnemers die bevindinge van die fisiologiese data. Daar was geen beduidende korrelasie tussen die *Presence* telling en enige van die ander veranderlikes nie. Hierdie studie ondersteun die doeltreffendheid en geldigheid van die simulasie as 'n VRET-paradigma vir gebruik in die behandeling van PTSV.

Acknowledgements

A very large thank you to both my supervisors and my co-supervisor, for their support, assistance, and wisdom throughout the process. Without whom I would neither have been able to complete the task nor ever had the opportunity to attempt it.

A sincere thank you to all behind the scenes who made this possible, from those handling the necessary communications to those facilitating the testing and ethical approval process.

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Nomenclature

Abbreviations

API	Application Programming Interface
CBT	Cognitive Behavioural Therapy
CPT	Cognitive Processing Therapy
CPU	Central Processing Unit
DSM-V	Diagnostic and Statistical Manual of Mental Disorders (5th Edition)
EDA	Electrodermal Activity
ET	Exposure Therapy
FPS	Frames per second
GAD	Generalized Anxiety Disorder
GPU	Graphics Processing Unit
HMD	Head-Mounted Display
HR	Heart Rate
OCD	Obsessive Compulsive Disorder
PE	Prolonged Exposure
PI	Place Illusion
PSI	Plausibility Illusion
PTSD	Post-Traumatic Stress Disorder
SC	Skin Conductance
SR	Skin Resistance
VRET	Virtual Reality Exposure Therapy

Symbols

k	Number of levels of a variable

$\sum$ ‘Sum of’ operator

x Used to represent general variable

Greek letters

$\hat{\varepsilon}$ Greenhouse-Geisser estimate

$\tilde{\varepsilon}$ Huynh-Feldt estimate

Subscripts

SS_M Model sum of squares

SS_R Residual sum of squares

Dimensionless numbers

df Degrees of freedom

Glossary

The following terminology is defined with reference to Unreal Engine's extensive documentation and accompanying glossary [1]:

Actor An *Actor* is any object that can be placed into a level. This is a generic *Class* that supports transformations in 3-Dimensional space.

Blueprint Also known as the Blueprint Visual Scripting system. It is a node-based interface that is used to define object-oriented classes or objects within the engine.

Character A *Character* is a subclass of a *Pawn* Actor that is intended to be used as a player or AI character – complete with collision setup, input bindings and additional code for player-controlled movement.

Class A *Class* defines the behaviours and properties of an *Actor* or *Object*. They inherit information from parent *Classes* (referring to *Classes* it was 'sub-classed' from) and pass information to children *Classes*.

Component A *Component* is a piece of functionality that can be given to an *Actor*.

Event In *Blueprints*, an event is the first-executed *Node* within a flow of logic/code. Similar to the role of a function in traditional Object-Oriented Programming (OOP).

Node A single block of visual scripting code.

Object The base of much of Unreal Engine, containing essential functionality. Nearly everything within Unreal Engine 4 inherits information from *Objects*.

Pawn A subclass of *Actors*, *Pawns* often serve as in-game avatars or persona. They can be controlled by a player or by the games Artifical Intelligence (AI).

Project An Unreal Engine 4 *Project* holds all the content of the game.

Viewport This is the visual representation of the level within Unreal Engine 4 *Project*. They contain a variety of tools to help one see the data needed.

1 Introduction

The presence of Post-Traumatic Stress Disorder (PTSD) in South Africa is an issue that only continues to grow in both severity and prevalence. It is a poorly diagnosed [2] and poorly treated condition [3] that effects large portions of the population, regardless of demographic. This project focuses on the validation of a potential form of treatment for PTSD, utilizing virtual reality (VR) and the methodology of Exposure Therapy.

1.1 Background

There are several kinds of anxiety disorders that exist, with the most notable being generalized anxiety disorder (GAD), obsessive-compulsive disorder (OCD) panic disorder, post-traumatic stress disorder (PTSD) and the various phobia-related disorders [4].

The focus of this study, and the paradigm at its core, is PTSD. Defined by the American Psychiatric Association as “a psychiatric disorder that may occur in people who have experienced or witnessed a traumatic event such as a natural disaster, a serious accident, a terrorist act, war/combat, or rape or who have been threatened with death, sexual violence or serious injury.”[5]

This disorder is rife amongst the South African population, and combatting it requires novel approaches [6]. The need for a more accessible and effective solution is clear, with many experts proposing the use of emerging technologies such as virtual reality [7]–[9]. There are several well-documented forms of treatment for PTSD. Amongst them, Exposure Therapy offers encouraging results [10], [11], especially when paired with the advent of advancing technologies [12].

This is where the motivation for virtual reality as the focus of this projects originates. Although still a relatively new technology, especially in the medical research fields, its integration has already shown promising results [13]. These results are expected to only improve as the technology advances and the understanding of its potential within the medical industry improves.

1.2 Motivation

PTSD is an increasingly common problem, faced by up to 20% of all people exposed to lifetime traumas [14]. In 2013, the American Psychiatric Association revised the definition criteria of PTSD, this was published in the 5th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V). The disorder has since been labelled as a Trauma and Stressor-Related Disorder, rather than a simple Anxiety Disorder [15].

The disorder affects people of all demographics and all income brackets, given that traumatic events can and do happen to anyone at any time. Often, the trauma goes untreated and develops into PTSD, causing rapid deterioration of both the victim's mental health and those that care for them [1]. The presence of PTSD can give rise to other anxiety related disorders, often exacerbating the situation [4]. Each case is different to the next, with unique symptoms complicating treatment.

In the South African context, the prevalence of PTSD is extremely high [16], with the history and social context providing a unique environment for this disorder. The frequency and severity of traumatic experiences is significantly higher in low-income areas and post-migration communities than those in safer, higher-income areas [6]. The underlying issue stems from the disparity between the presence of trauma and the accessibility of treatment.

Studies have been done with a specific focus on adolescent populations and the prevalence of both trauma and the lasting effects that may follow. One such study [16] highlights the role trauma has in a group of low-socioeconomic communities within KwaZulu Natal. 10% of the population showed clinically significant traumatic stress symptomology, this is compared to the 2.3% of the general population in South Africa. Furthermore, another study focusing on the efficacy of treatment of PTSD in countries around the world dedicated two chapters to the situation in South Africa alone, emphasizing the concerning amount of trauma exposure experienced by the general population (estimated at 78.3% as of 2007 [17]). Studies like those cited highlight not only the prevalence of PTSD, but the lack of access to diagnosis and treatment.

With the rapid advancement of technology, it has become possible to improve the treatment of several disorders [18]. With this, virtual reality has emerged as a potentially ground-breaking medium for diagnosis and treatment. This new medium can facilitate forms of psychotherapy that previously required considerable time and expertise from medical professionals [19]. The most successful of these new methods focuses on combat-related traumas, by successfully providing exposure therapy without the risk of harm to the patient or the medical professional [20].

The opportunities afforded by the advancement of virtual reality, and the associated form of treatment dubbed 'Virtual Reality Exposure Therapy' (VRET), have not yet been utilised in the South African context and the method – in the context of anxiety disorders - is still in its infancy worldwide. This project serves to explore this gap and aims to provide and validate a feasible paradigm for the diagnosis and treatment of PTSD.

VRET, however, still has many limitations. One of these limitations is its lack of versatility – the difficulty with which a paradigm would be tailored to a specific individual. Additionally, specialised training is required to be undertaken by the medical practitioner administering the treatment. The criteria involved with creating a successful paradigm for use in VRET include facilitating prolonged, controlled exposure in an environment that is believable without the risk of motion sickness – or other such consequences. The interactivity of the paradigm will have to be adaptive in nature and allow some control on the part of the practitioner.

1.3 Objectives

Aim: The primary aim of this project is to validate a paradigm for the inducement of anxiety in healthy controls – so that it can help develop future treatment strategies for Post-Traumatic Stress Disorder in the given context.

Objective: The primary objective of this project is to design, create and validate a paradigm that is compatible with current virtual reality technology and meet all criteria necessary for use in Virtual Reality Exposure Therapy.

Hypothesis: It is hypothesized that the paradigm will elicit a clear anxiety response in the participants proportional to the increase in implemented threat level. Furthermore, an improvement in graphical fidelity and optimization of the paradigm will result in fewer participants experiencing nausea/motion sickness etc.

2 Literature review

The following section covers the research done for all the aspects of the project that require understanding and context before a final method of approach can be decided on and implemented. The literature covered begins with the disorder that the paradigm is intended to treat, followed by the methods of treatment currently available and those that are emerging. The most promising of these emerging methods of treatment is then discussed in more detail as well as the more nuanced aspects of successful implementation. This section ultimately serves as both foundation and support for the chosen methodology to follow.

2.1 Post-Traumatic Stress Disorder

Post-traumatic stress disorder (PTSD) has been known by several names in the past, such as ‘shell shock’ and ‘combat fatigue’ [5]. Although it was primarily attributed to war veterans originally, PTSD is a psychiatric disorder that can affect anyone who has experienced a traumatic event. Even witnessing such events can be a catalyst for this disorder. Given that the events that cause this disorder are not exclusive to any one demographic, it is a concern for people from all walks of life.

Trauma is generally defined as either the emotional response to a terrible event or used to refer to the event itself, including injury, attack against oneself etc. According to a 2017 study of trauma and PTSD in the WHO World Mental Health surveys [21], trauma exposure is common across the world with 70.4% (n = 68 894) of respondents having experienced lifetime traumas (averaging 3.2 traumas per capita). It was found that the types of trauma had a significant effect on the risk and the persistence of the disorder. The types with the greatest effect were rape, other sexual assault, being stalked and the unexpected death of a loved one. Although the frequency of the first three are low, they carry a high risk of PTSD while the fourth type is common with lower risk.

With the recent outbreak of and response to the COVID-19 virus, a significant portion of the population has been exposed to an increased frequency of traumatic events.[22] Health care workers have been victim to this more so than any other professional demographic. Over and above the intrinsic concern for them as people, there is the added emphasis of their responsibilities as health care workers – causing a greater degree of alarm to the potential of their inability to operate competently. A meta-analysis of 55 2020 COVID-19 related studies, aiming to identify the prevalence of depression, anxiety and PTSD in health care workers during the pandemic was recently published [22]. Within the 97 333 health care workers across 21 countries, a pooled prevalence of 21.5% (95% CI, 10.5%-34.9%) was found for PTSD.

According to the statistics collected during the course of 2021 [23], South Africa is ranked 3rd for the country with the highest crime rate per 100 000 people. Furthermore, when filtering the statistics for violent crime, South Africa then ranks 5th for murder and 1st for rape. South Africa has reportedly had 35.9 murders and a staggering 132.4 rapes per 100 000 people. With the WHO World Mental Health survey [21] finding that rape and other sexual assault are the two trauma types with the greatest effect towards the onset of PTSD, this puts South Africa in an alarming light in the context of PTSD prevalence. A nationally representative survey done in 2013 goes on to conclude that; “The occurrence of trauma and PTSD in South Africa is not distributed according to socio-demographic factors or trauma types observed in other countries” [24]. The authors believe that this likely has more to do with the public setting of trauma exposure and thus highlights the political and social context of the country. Additionally, it is believed that many of the crimes and events that are strongly associated with the prevalence of PTSD are significantly under-reported – effectively skewing many of the results and further emphasizing the need for intervention.

A disorder like PTSD typically has a significant effect on the individual’s life, as well as the lives of the people around them. If not correctly diagnosed and treated, the quality of life of someone with PTSD is severely reduced, often resulting in co-occurring conditions. Referred to as ‘comorbidities’, a 2003 paper investigated the frequency of association with several co-occurring conditions [11]. The study found that major depressive disorder had the greatest percentage presence when averaging between male (n=139) and female (n=320) participants (47.9% and 48.5% respectively). However, alcohol abuse or dependence was more prevalent amongst the male population (51.9%). Other comorbidities studied were (in descending order) drug abuse or dependence, simple phobias, social phobia and dysthymia. Even the lowest of these still occur in 21.4% of the male population and 23.3% of the female population.

2.1.1 Diagnostic Definitions and Criteria

According to the DSM-V [25], diagnosing PTSD is a multi-tiered process defined by criteria and specifications. It is further stated that, along with the stipulated criteria, the diagnosis cannot be considered complete without the specifications. These specifications serve as additional criteria that must be present for the standard criteria to be applied. This is to ensure that overlapping criteria (with other disorders) do not cause a misdiagnosis should they appear in isolation from the relevant specifications. There are only two specifications described in the DSM-V[11]:

1. Dissociative symptoms – This is where an individual experiences at least one of either depersonalization and/or derealization. The former is categorised by one feeling disconnected from oneself, while the latter doubts the realism of their surroundings.

2. Delayed expression – Acting as an incubation test-timer following a traumatic event, ensuring that diagnosis is not met prior to a minimum six-month period. There do exist exceptions to this rule, with rare cases showing an immediate onset of symptoms.

An important characteristic of PTSD is that its occurrence is not distributed according to sociodemographic factors [24] – emphasizing the need for an accessible and reliable form of treatment.

2.1.2 Treatment

There are three primary forms of psychotherapy treatment used today for PTSD. They are Prolonged Exposure (PE), Cognitive Processing Therapy (CPT) and Cognitive Behavioural Therapy (CBT). A recent review done on these evidence-based psychotherapy methods [26] goes into considerable detail for each method, while attempting to analyse the efficacy of each.

Prolonged Exposure is a psychotherapy intervention based on the emotional processing theory originally presented by Foa and Kozak in 1985 and updated in 1986 [27]. The theory suggests that a person's fear is represented in their memory as a cognitive structure, to be addressed through psychoeducation. Typically estimated to take between 8 and 15 sessions [28] that include in vivo exposure as well as imaginal exposure. In these sessions patients are asked to recount the traumatic event in the present tense, repeating this exercise while recording it, and to practice imaginal exposure outside of the sessions. This form of therapy has been shown to be effective for treating the trauma of survivors from various cultures and nationalities, independent of time since the traumatic event [29].

Cognitive Procession Therapy is more trauma focused, drawing instead on the social cognitive theory and informed emotional processing theory of Resick and Schnicke [30]. This method of intervention allows for the cognitive activation of the traumatic event, while identifying any maladaptive cognitions – such as assimilated and over-accommodated beliefs. According to the foundational theories, the primary aim is to shift the patient's beliefs toward accommodation. Although not as much a focus as it is for PE, psychoeducation also plays a large role in CPT. According to the manual, 12 weekly sessions are usually required – in either individual or group format. These sessions are typically made up of Cognitive Therapy and exposure components [31]. Although somewhat antiquated, some versions of the treatment include making a written account the patient's thoughts, feelings and sensory information experienced during the traumatic event. CPT was originally developed to treat survivors of rape [30] however, has found to be effective across trauma types and populations. Furthermore, it has been found to be most effective for sexual assault survivors, war veterans and adult males with PTSD [32].

Cognitive Behavioural Therapy has both trauma focused and non-trauma focused version of the intervention – with a mix of the two typically being recommended. The trauma focused version is based on cognitive and behavioural models that draw from PE and CPT. This intervention includes exposure techniques [33] as well as cognitive techniques [34], [35], allowing effective treatment of a wider range of traumas. The exposure techniques used for trauma related stimuli typically utilizes in vivo exposure and teaching patients to identify the triggers. With its combined techniques and versatile approach, CBT has been found to be effective in treating a variety of trauma types [36]. Given this versatility, CBT has been more commonly applied as the intervention technique facilitated by newer technologies, such as Virtual Reality. As such, this study chose to focus on CBT for the application of virtual reality facilitated psychotherapy.

2.2 Cognitive Behavioural Therapy

Cognitive Behavioural Therapy (CBT) is a form of psychotherapy that focuses on the effect a person's thoughts, beliefs and attitudes has on their behaviours [37]. CBT is based on the premise that certain beliefs/ideologies are held by the practitioner. The primary of these beliefs is that negative thought patterns can lead to psychological issues. Additionally, they hold the belief that negative behaviours can lead to negative psychological traits. Therefore, by improving these behaviours toward a more positive direction, one can overcome many of the emergent psychological issues associated with the aforementioned negative behaviours.

This method of psychotherapy has been thoroughly reviewed and concluded to be effective for disorders such as depression, panic disorder, anxiety disorder and PTSD [38], [39]. A paper from 2012 [39] did a review of meta-analyses exploring the efficacy of CBT. Reviewing a sample of 106 meta-analyses, they found that CBT used to treat PTSD was superior to all other treatments except eye movement desensitization – to which its efficacy was equal.

Within the umbrella of CBT, there exist several types of therapeutic approaches. These include Cognitive Therapy, Dialectical Behaviour Therapy (DBT), Multimodal Therapy and Rational Emotive Behaviour Therapy (REBT) [40]. Among these, Exposure Therapy (ET) is considered to be the most effective in treating PTSD although under-utilized, as stated by a 2004 paper surveying psychologist's attitudes towards the utilization of ET for PTSD [41]. The authors state that this hesitancy appears to be due to a significant number of barriers to implementing the exposure necessary for the therapy. The typical barriers expressed are anger, emotional dissociation (or 'numbing') and overwhelming anxiety. More relevant to the project goals, however, are the limitations involving the ability to communicate effectively and efficiently with the patients. One of the first papers to explore the use of virtual reality in exposure therapy for treating PTSD [42] used Vietnam War veterans as their sample population, hypothesizing that the ability to recreate believable and immersive environments would greatly improve the results of the treatment. They used two virtual environments: a virtual Huey helicopter flying over a virtual Vietnam, and a clearing surrounded by Vietnamese jungle. Their results showed that the 6-month follow-up reported reductions of PTSD symptoms ranged from 15-67% - a significant decrease shown in all three symptom clusters. A more recent review of the maturity of virtual reality therapy for anxiety and related disorders was done for the Journal of Anxiety Disorders [13], citing several meta-analyses done to assess the deterioration rates [43]–[45], retention rates [46], [47] and efficacy [19], [20], [48]–[50] of virtual reality in context. They concluded that VR therapy significantly outperforms waitlists and psychological placebo conditions. Additionally, the article states that the dropout rates are not significantly different relative to in vivo treatment, but deterioration rates are significantly lower than waitlist conditions. Most importantly, they conclude that VR therapy alone is effective for PTSD, depression, and anger.

This review of the current state of VR in the context of psychotherapy provides a very encouraging picture for both the current ability of the methods and their rapidly growing potential.

2.3 Virtual Reality Exposure Therapy

Defined by its use of virtual reality technology, Virtual Reality Exposure Therapy (VRET) simply applies the traditional concepts of exposure therapy with the presence and immersion afforded by this emerging technology.

The most unique, and subsequently important, factor that this new method brings to the table is that of the immersion achievable through it. Immersion is achieved by synchronising all sensory inputs of the virtual environment with that of one's own – creating a believable experience for the user both consciously and unconsciously. [51]

Although still an emerging field, virtual reality exposure therapy has already proven to be a promising method of treatment in a variety of areas. Several meta-analyses have been done, such as in [45] and [52], both finding that VRET is potentially equivalent to in vivo exposure – the primary format for traditional psychotherapy interventions. This suggests that VRET could serve as a suitable replacement for the traditional ET in cases where it is not feasible – such as where required training is lacking, or real exposure is expensive and impractical.

As with any emerging technology (and the adjacent software), developers and users are always limited by the technology itself – often having to rely on advances in the field to solve limiting issues. VR is no different, with much of the limitations around its efficacy in the psychotherapy industry due to the hardware limitations in comparison to existing methods (like the use of computers). Additionally, without a deeper understanding of the technology behind the methods, one is bound to an even smaller percentage of the performance. While it is true that a VR program can be optimized to achieve astounding results (both visually and functionally), the knowledge required to do so tends to sit in other industries – as such the growing integration between technical and medical fields catalyses the growth of methods such as VRET. Within this growing niche is the theory that as more technically trained people integrate with the relevant industries, the major risk associated with VR – motion sickness – will be exponentially reduced [53]. This follows on from research showing that motion sickness in VR is largely driven by poor performance and low framerate (the speed at which the screen refreshes) [54].

In addition to the research of virtual reality as a treatment tool, there has been research done into the role virtual reality has and can play in diagnosing psychiatric disorders. A literature review done by Bennekom et al [55] concludes that virtual reality affords the ability to objectify the diagnosis of psychiatric disorders, thus contributing to the reliability of these diagnoses. With similar limitations discussed (as per aforementioned), the promise of virtual reality seems to be in that it is already able to show profound progress and continues to improve rapidly.

With VRET being a developing field there are many limitations that still inhibit its progress. The most obvious of these is the lack of variety within the body of research, with the majority of studies focusing on combat-related trauma and phobias [56]. Additionally, despite the prevalence of these studies, there is still very little in the way of standardization for the simulations themselves. This is likely due to a lack of skills with the relevant technologies, adding to the risk of these simulations unwittingly falling victim to the 'uncanny valley' phenomenon [57] – where the simulation is real enough to create a sense of immersion but lacking in realism enough to make the user feel uncomfortable and subsequently break immersion. Furthermore, although there have been attempts to create a set of experimental guidelines [58], even the most comprehensive of these give but a general outline – with the focus remaining on the psychotherapeutic aspects of the experiment.

Physiological feedback is a vital part of the use and validation of VRET. There are several forms of this that exist for anxiety detection and measurement. These include (but are not limited to) EEG, cardiac changes, ocular events, changes in skin response, muscular activity, and respiratory patterns [59].

Physiological measurements are considered to be more reliable and accurate than the often-used subjective stress appraisals of the past [60]. As such, subjective appraisals are recommended to be included only as an auxiliary result, while the physiological data serves as the primary result set.

2.4 Physiological Feedback

In the pursuit of proving an empirical correlation between any input stimuli and the participant's reaction physiological feedback is a vital part. This method is more objective than self-reported measurements and has the additional benefit of not requiring communication with the subject [61], [62]. In the context of measuring anxiety, the two primary forms of physiological measurements are Electrodermal Activity (EDA) and Heartrate (HR) due to their considerably researched correlation to various sympathetic and parasympathetic nervous system responses [59], [63]–[66]. Although Electromyographic (EMG) feedback is also used it has not been as extensively researched and tends to be a more complex method of feedback [59].

Skin conductance (SC) and skin resistance (SR) are electrodermal parameters. These are often also referred to as Electrodermal Activity (EDA), which in turn refers to the variations in electrical activity of the skin – measured through the corresponding conductance [67]. This is due to natural sweat secretion. Changes in the skin conductance usually occur within a few seconds of the onset of the stimulus, making this a very useful measurement for stress-response paradigms. Although EDA is linked to other factors (such as internal temperature regulation), there is considerable research showing a strong correlation to emotional arousal [67]–[69]. The sweat gland activity corresponds with the arousal of the sympathetic branch of the autonomic nervous system, subsequently increasing the skin conductance [70]. Therefore, increases in electrodermal activity (specifically SC) have been found to strongly, positively correlate with anxiety [71]. Although EDA has a relatively slow response delay when compared to heart rate response (with a delay of 1-3 seconds), it has been found to more strongly correlate with anxiety and more consistently predict the relevant arousal [72].

Measuring a person's heartrate has long been a method for measuring their response to various forms of stimuli, typically using variables drawn from the original cardiography measurement. These variables include the baseline (mean heartrate over time), variability and accelerations of the heartrate [63], [64]. Research suggests that the sympathetic nervous system contributes significantly to the physiological reactivity of treatment exercises [64]. This system is responsible for the body's stress response, while the parasympathetic nervous system is responsible for homeostasis (psychological equilibrium). Both these systems contribute towards the HR measurements, while only the sympathetic nervous system contributes to the EDA responses. Interestingly, HR variables are more effective in predicting dimensions of PTSD in certain cases (such as sustained increase of HR predicting increase of numbing symptoms [63]), while some cases show little significance with HR as primary predictor. Similar to skin conductance, HR has been found to strongly correlate with emotional arousal, including anxiety [63], [66].

However, when it comes to physiological feedback for treatment paradigms facilitated in VR, there have been studies done using healthy or subclinical samples that did not find significant HR responses to VR stressors [73], [74]. A paper by Diemer et al proposes that the threshold for HR responses is higher than that of SC level changes [75]. Their study also mentions several studies [73], [76]–[78] that reported a significant increase in SC levels but with an effect on HR only being observed by one of these studies [78]. Based on evidence presented in these studies, EDA measurements are the most consistent form of physiological feedback for studies using VR. This is an important consideration given the nature of this study.

2.5 Role of Implicit Fear

An insightful aspect in the treatment of PTSD is the individual's reaction to implicit fear-based stimuli, gauging their reactions for things that don't necessarily require conscious introspection. Guiding the design of elements within any virtual reality fear-based simulation is Slater's theory of place illusion (PI) versus plausibility illusion (PSI) [79] – essentially separating stimuli in terms of which form of presence it relies on to be effective.

Examples of PI elements – as presented in a more recent study involving coping reactions toward a survival horror VR game [80] – are things like darkness, sounds in the environment, uncertainty related to the course of the simulation etc. These elements are defined by their abstract and implicit nature. Contrasting these are the PSI elements, which included loss of control of virtual weapons, hostile characters or elements attacking the player, the approach of a clearly hostile creature/monster, etc.

Furthermore, according to a study focusing on automatic processing of arachnophobia [81], implicit associations with phobias are sensitive to treatment. Which lends credence to the same techniques being effective for the treatment of the implicit aspects of PTSD. Another study focusing on the return of fear following exposure therapy [82] proposed that their results suggest that a change in the patient's sub-conscious attitude toward the phobic stimulus (e.g. heights for one with acrophobia) is an important milestone of exposure therapy. Furthermore, an implicit measure (such as the Personalized Implicit Association Test) can provide meaningful feedback regarding such a change and subsequently be used to assess the efficacy of the exposure treatment – both short and long term.

A 2013 study with a specific focus toward CBT's role in resolving implicit fear associations in generalized anxiety disorder states that "…the normalization of this bias might be a crucial factor in the therapeutic action of CBT." [83] This aspect of the treatment of generalized anxiety disorder, and its psychological proximity to

PTSD, are shown to be vital factors in validating the efficacy of the application of CBT.

2.6 Optimization & Motion Sickness

To effectively put into use the theory laid out above, the participant needs to believe the virtual environment they are put into. In order for this immersion to be achieved, the simulation must be optimized for performance, and the risk of motion sickness must be reduced. The most pressing question initially is when does this need for optimization become a perceivable threat, and what is necessary to mitigate it?

A study done by the University of Amsterdam explored the roles of both immersion and presence in the treatment of acrophobia using virtual reality [84]. Although no clear relationship was found between presence and anxiety, indicators were found as early as the pre-test phase for participants who experienced less presence and thus less anxiety in the virtual paradigm. It is important to point out the significant advances in virtual reality technology since the study was published (revised in 2003).

It has been more recently found that there are three categories that influence the satisfaction of a user's experience in VR [85], namely immersion, interaction with virtual environment and social interaction. Furthermore, the study states that it has shown that immersion mediates the person-environment interaction effects on satisfaction and loyalty. Although the emotions discussed have more positive connotations than the ones this study aims to elicit, it is reasonable to posture that the effects of immersion are pivotal for the user's commitment and belief in the virtual world – and thus the effectiveness of the elements of that world.

Regarding the risk of motion sickness, an exploratory study from the Institute of Systems and Robotics, University of Coimbra [54] revealed some of the most effective ways of inducing motion sickness – thus allowing others to reverse-engineer their simulations to avoid these elements. The most effective ways to induce motion sickness were stated to be:

- Changing head orientation without user input
- Modifying field of view or zooming in/out
- Variations in acceleration

From these results, it could then be stated that in order to reduce motion sickness the user input must be responsive and consistent throughout the simulation, the user must have a constant frame of reference and the camera must not be altered (no lens effects/distortions etc.). Notably, a common cause of many of these potential issues is lag in framerate or dips in performance – causing the simulation to become unresponsive or the camera to behave in unexpected ways. This ultimately drives the necessity for optimization of the simulation to mitigate motion sickness and achieve greater immersion. Unfortunately, there is little research to link specific values of metrics to the success or failure of the implementation of VR in psychotherapy.

For the optimization of the simulation, the standard procedures in the game development industry were referred to and used as a foundation. Documentation detailing the procedures and guidelines for creating Virtual Reality simulations with the overarching goal of optimization were used in conjunction with the industry standard pipeline [86]. General tips, such as limiting the number of elements per object, were added to a checklist that would be continuously referred to throughout the design process.

Forum articles and blog posts were referred to for information regarding the industry standard pipeline for similar projects. One such article, from the 80.lv website [87], breaks the entire process down into 8 distinct steps with a focus on environment creation. Although not identical to the goals of this project, articles like this provide a solid foundation for defining the steps of the simulation design process. More uniquely, an journal article published back in 2011 (updated 2015) by the Institute of Computer Graphics and Algorithms from Vienna University of Technology [88] explores the process of content creation for 3D games in a more structured manner. This paper further defines the process for creating a simulation similar to the one required for this study. An obstacle experienced throughout the process, however, is whether one is efficiently utilizing the latest technology and software. Although the general pipeline does not change much, tweaks and adjustments are made monthly with each new software patch and hardware upgrade. In an attempt to mitigate the potential deficit, the process should be defined only after choosing the software to be used in the design and creation of the simulation. This limits both the time spent keeping up to date and the variability in the process.

2.7 Closing Thoughts

Having discussed the available literature a few things have become clear: PTSD is a considerable issue both globally and locally, with a clear need for more versatile and effective treatment options. The research supports the use of the traditional exposure therapy and encourages the integration of virtual reality in facilitating treatment. Despite the limitations mentioned, the research suggests that with more focus spent on developing and applying the skills required to optimize the use of the technology (for performance) the majority of these limitations can be significantly mitigated. In so doing, the efficacy of the paradigm should be increased by improving the user's sense of presence and reducing the risk of motion sickness. However, there is a considerable absence of guiding values for metrics within the context of psychotherapy. Careful scrutiny of the research suggests that the guiding metrics are based on the specific VR device used. As such, the technical documentation, and guidelines (for VR in gaming and general development) discussed in Section 3 and 4 must serve as a foundation for the design of a successful simulation. Following this, the simulation design and philosophy will be introduced and discussed. The conclusion from the literature is that a virtual, generalised local environment, with clear associations to the prevalence of violent crime, is a worthwhile foundation for an exposure therapy paradigm making use of implicit fear association. The design of this environment, with a particular focus on maintaining the highlighted suggestions for creating an effective virtual reality paradigm for the treatment of PTSD, will be discussed in the following section.

3 Simulation Design

The core element of the project, the simulation, had to be designed from the ground up with very specific criteria governing the process. The process involved with designing and implementing an environment to facilitate the paradigm and the mechanisms therein is outlined below. The section begins with how the simulation was initially approached and continues with how these ideas were then implemented and iterated upon. Both theory and application are discussed in this section, with an overarching focus on performance optimization of the program itself – with the intention of creating a compelling and immersive experience.

3.1 Previous Work

It is important to note that this was not the first iteration of the paradigm designed and tested as a potential form of treatment for PTSD [89]. The previous version was also designed and tested by the same research team but with less knowledge on the subject and software. It was from the results of the preliminary testing done during my undergraduate project [89] (which was a new attempt at an older project - also supervised by Dr D van den Heever and Dr S du Plessis.) that the decision to redesign the simulation from the ground up was concluded. Key issues and shortcomings – such as motion sickness prevalence and inconsistent experiences - were highlighted and analysed to ensure a smoother design process and a more effective simulation.

The primary limitations of the previous study were the effect of motion sickness on the participants' experiences, the hardware and software limitations and the small sample size. It was concluded that the prevalence of motion sickness was due to the simulation's poor performance (evident in visual glitches and framerate spikes/lags) and the limitations of the hardware in mitigating these risks. Fortunately, the advent of newer VR hardware has already reduced the effects of the limitations on the user experience. This effect has only been compounded by the rapid improvement of the software in the same time period, allowing for far more freedom with the design of the new environment. Learning from the previous study, however, the performance of the simulation (regardless of the improved technology) needed to be the primary focus of the design process.

The new environment was designed from scratch, with everything from the buildings to the mechanics newly implemented into this project. An early focus of this project was the recreation of an environment that would be familiar enough to a participant to elicit the implicit fear-based responses required [79], but not so similar that mistakes could be identified with the recreation – ultimately distracting from the intended experience. Within this goal, the believability [90] of the environment had to be an early focus – as after-thought modifications would likely only cheapen the effect and presence achievable by the simulation.

The overall goal of the simulation was to induce a measurable anxiety response, reliably and consistently, in the participant(s) – validating its potential for exposure therapy facilitation. Given the nature of PTSD and the governing criteria of Exposure Therapy it was vital that the stimuli used to induce anxiety were based on implicit fears [82], [83], with no explicit stimuli present.

3.2 Threat Level Overview

In order to create a simulation that could reliably and consistently induce anxiety an ordered layout of events had to be decided on. This would ensure that the simulation could be used as a controlled environment for the facilitation of exposure therapy. The simulation was initially designed to increase the anxiety response of a participant with time, allowing a basic general model to be used in the analysis of the paradigm's success. Later, however, the design was modified to suit a more complex model that included two peaks – one to happen within the second quarter of the simulation and another one around the end of the third quarter. This decision was driven by the fact that the previous study showed that a consistent increase was very difficult to achieve and not directly indicative of a successful paradigm. Designing for expected peaks also better demonstrates the paradigm's ability to consistently induce anxiety, with more specific event-based responses being shown.

These events were organised into threat levels and implemented in groups based on their threat level allocation, as shown in Table 1. Some aspects would be incremental and others binary (on or off). The goal with this structure is to gradually increase the severity of some stress events while using others to create peaks in the physiological response graph. This was done by intentionally increasing implicit-based anxiety-inducing stimuli.

The current threat level would increment each time the participant passes through a marker, allowing consistent control in the presence of fear-based stimuli. Each marker representing a specific (and unchanging) threat level per run of the simulation. This mechanism ensures each iteration of the paradigm follows the same structure and controls the same variables. As can be seen in the tables below (Tables 1-3), the layout of the overall threat level system was a complex procedure. The tables attempt to summarise the threat level system with the use of categories (audio, visual and miscellaneous environment aspects) and colour coded blocks (with the values of the relevant variables represented in the necessary blocks). In general, green blocks denote the introduction of a stimulus or aspect, yellow blocks indicate a change in a variable for these aspects and red blocks indicate the absence of that aspect. In addition, grey blocks are used to indicate the presence of an aspect or stimulus but without any changes.

Table 1 – Summary of the threat level layout for the audio components.

	Time of Day	Audio					
		Day/Night Sounds	Heavy Breathing	Heartbeat	Aggressive Man	Gunshots & Screams	Follower
Baseline	10H00	1/0					
1	12H40	0.75/0					
2	15H20	0.5/0					
3	18H00	0.25/0					
4	20H40	0/0.25	0.1				
5	23H20	0/0.5	0.15				
6	23H20	0/0.75	0.15				
7	23H20	0/0.75	0.15				
8	23H20	0/0.75	0.15				
9	23H20	0/0.75	0.15				
10	23H20	0/0.75	0.15				

Table 2 - Summary of the threat level layout for the miscellaneous environment components.

	Time of Day	Environment - Misc				
		Subjective Appraisal	Passive Characters Talking	Aggressive Character	Follower - Active	Cramped route
Baseline	10H00					
1	12H40					
2	15H20					
3	18H00					
4	20H40					
5	23H20					
6	23H20					
7	23H20					
8	23H20					
9	23H20					
10	23H20					

Table 3 – Summary of the threat level layout for the visual environment components.

		Environment - Visual

	Time of Day	Mist/Fog	Stars	Unfriendly signage	Crash Scene
Baseline	10H00	0.05			
1	12H40	0.075			
2	15H20	0.075			
3	18H00	0.075			
4	20H40	0.1			
5	23H20	0.25			
6	23H20	0.4			
7	23H20	0.6			
8	23H20	0.8			
9	23H20	0.8			
10	23H20	0.8			

Based on the previous study [89] and the studies done by Lin [80] and Lynch [91] (both discussed in further detail later in the section), the primary stress events that are expected to be the most effective are: the heavy breathing, the thickening fog and the active follower. Although these events are expected to vary in effectiveness based on several factors and variables that might arise in any particular run-through. The goal is to ensure that even if they vary in their effectiveness, the results are consistent relative to the overall simulation for that participant.

3.3 Environment

3.3.1 Theory and Philosophy

Designing the environment began with extensive research and reference collection. For this, Google Earth was utilised for satellite images of relevant areas and layouts, with Google Maps used for architectural reference and scaling. Figure 1 shows some examples of reference images used. These were then cross-referenced and used with Unreal Engine to block out a preliminary environment to ensure layout and scale were correct.

Figure 1 - Examples of reference used to generate environment layout. Google Earth was used to source and select the images.

The environment was chosen to fit several criteria. The environment had to be from a low-income, high-crime rate area that was still central enough to be recognizable by the majority of the local populace. Utilizing ISS Africa's crime statistics map, categorizing the statistics by the municipality/district [92] and filtering the results by sexual crimes only a list of possible locations were recorded. Amongst the locations with the highest sexual crime statistics and fitting the aforementioned criteria, Mitchell's Plain was chosen as the reference site with several sections analysed and amalgamated to create the simulation environment. The design had to be one that was clearly associated (in the local context) with potential for crime and/or harm.

In order to achieve an environment that was believable it was important that the buildings be created and placed in a more realistic way. For this, the procedural generation approach was explored. Procedural generation being the method of creating data algorithmically rather than having to do it manually – in this case the data was the geometry, textures, and layout of the buildings in the environment. After finding that this approach also improved the efficiency of designing the layout and allowed rapid iteration, it was implemented in the environment design process.

Finally, the route the participants were to travel had to be mapped out. Here, the main focuses were length, complexity, and the orientation of the route. Given that the participants might be unfamiliar with the format of the simulation (virtual reality and the interface devices), manoeuvring through the environment had to be accessible and straight-forward enough that it would not impact the simulation as a whole. This is discussed in more detail in the User Experience section. Below, in Figure 2, a comparison between the old environment [89] and the new environment is shown – with their respective routes super-imposed.

Figure 2 - Route comparison between the old environment (top) and the new version (bottom). Note the complexity of the first version, in contrast to the simplified second version.

3.3.2 Performance and Optimization

A procedural approach was taken for the design and generation of the buildings. This allowed for rapid concept generation when laying out the buildings and designing the environment. The goal was to create high-fidelity buildings, within certain architectural and design parameters, without having to spend time on individual buildings. This needed to be achieved without severely impacting performance – as such the optimization of the process maintained priority throughout.

The greatest challenge with using procedural generation to generate geometry in a high-fidelity environment is limiting the impact on performance. Each building was randomly generated using a specified set of assets. These assets were made up of sections of walls, roof, and doors. This process is explained in more detail below, with 'the user' referring to the developer making use of the methods described. The flowchart shown in Figure 3 serves as a summary for the general logic and more detailed explanation that follows.

3.3.3 Building Generation

The individual house generation relied on the use of Data Tables – defining the assets to be considered in the randomization process. When generating the new asset, the program replaces each existing component with a randomly selected one (via a seed) from the chosen Data Table. This allows one to control which assets are in consideration for each component type – defined by the use of Component Tags (descriptor variables attached to each component).

The Blueprint for this method took a set of exposed variables and applied them to the pre-generated list of components upon starting the program. This could easily be adjusted to correspond with a user-defined event.

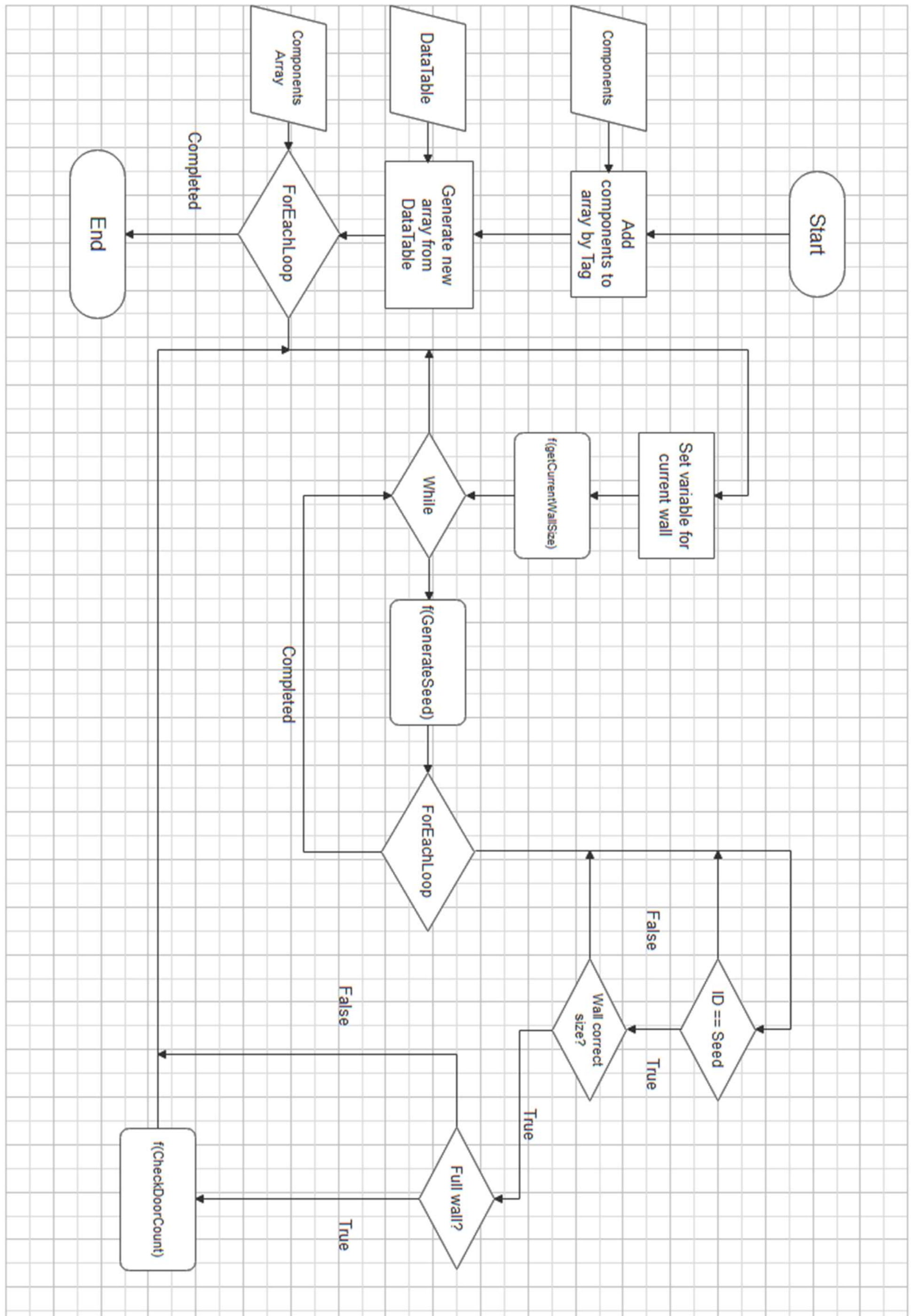

Figure 3 - Simplified flowchart showing the logic for the generic procedural generation per building.

Fundamentally, this works by the user creating a house/building inside the Blueprint from the assets available and attaching the relevant Component Tags to each component used. These Tags are then used to define which components are randomized and whether the component is part of the material assignment process.

Additionally, one may choose their desired number of doors (within the randomization process) to be present in the final version of the asset. This could be very useful when creating several instances where the user might want to randomize where the doors are placed but still ensure that there are only a certain number of doors present. The door used could be set inside the Blueprint or be promoted to a variable and exposed to allow the user to decide per Blueprint. However, if one wished to have a dedicated door (like the 'front door'), then removing the relevant Component Tag would ensure the component was not randomized. Subsequently, this component would then not be included in the door count.

The materials to be used could be defined by the user by use of the exposed variables for the Actor. There was also a variable that could be selected for generating materials, this would cause the Blueprint to run the material assignment process as well as the randomization process.

This parameterized asset selection allowed control over variables such as architectural style of the building, geometric complexity of the models used and how many variations are possible. The same was then done for the textures applied to each asset, ensuring the variables of each were consistent and well-optimized.

3.3.4 Material Assignment

Each Preset exists as a Blueprint with a set of static mesh components that makes up the 'house' it represents. Since different wall/roof components have differing numbers of material slots, the material assignment for each is handled within the Event Graph of the Preset Blueprint. The material assignment event loops through each element of an array that has been compiled by searching for components with a specified Tag. The set of materials is then determined and is applied to the current component. The variable (integer) used to drive this is the number of materials possessed by the current component. Following this, a secondary switch is used to cycle through the materials of the current component. The Material Index (integer) drives this switch node. Each static mesh component uses a specific order of materials to ensure that the material assignment event described above handles each component correctly.

In Figure 4 an example building that has been generated procedurally can be seen, with textures applied. These textures were also generated procedurally, however the main focus of this figure is to demonstrate the geometric complexity of the asset. The asset shown has a total of 17228 triangles and 18993 vertices. With the colour key provided (displaying the complexity of the assets geometry ascending from dark blue to white) in the screenshot, it can be seen that the asset is not complex at all – ensuring minimum impact of performance. The majority of the edges of the polygons that make up the asset's geometry are dark blue to light green in colour – comfortably below a 5 out of 10 on the complexity colour scale. Despite this geometric simplicity, high-quality textures read very well on the asset and produce an adequately realistic final product.

Similarly, in Figure 5, different materials are applied to the same asset to show that the asset is able to use various textures while maintaining a high-quality result. Often materials are tailored to a specific asset or model, but this can be incredibly time-consuming. As such, being able to apply a variety of materials to any single object is a very valuable mechanic in the pursuit of efficiency and optimization. The geometric complexity is also shown in the figure, demonstrating the asset's ability to use high-quality materials with a very low geometric complexity – ensuring minimum impact on performance. Furthermore, the complexity of the materials (shader complexity) applied is also shown in this figure, clearly achieving a computationally inexpensive result. This complexity is usually measure in terms of the number of instructions required per shader.

An important milestone in this process was packaging the procedural generation code and submitting it to the Unreal Engine Marketplace. This platform provides an opportunity for review and careful analysis of the methods implemented. The Unreal Engine Marketplace has a strict set of guidelines [93] and reputably high standards. Passing the review process and having the packaged code accepted to their platform provides official validation of the quality and efficacy of the approach taken. After several amendments, the packaged code and assets were accepted and published to the Unreal Engine Marketplace as of March 2021 [94].

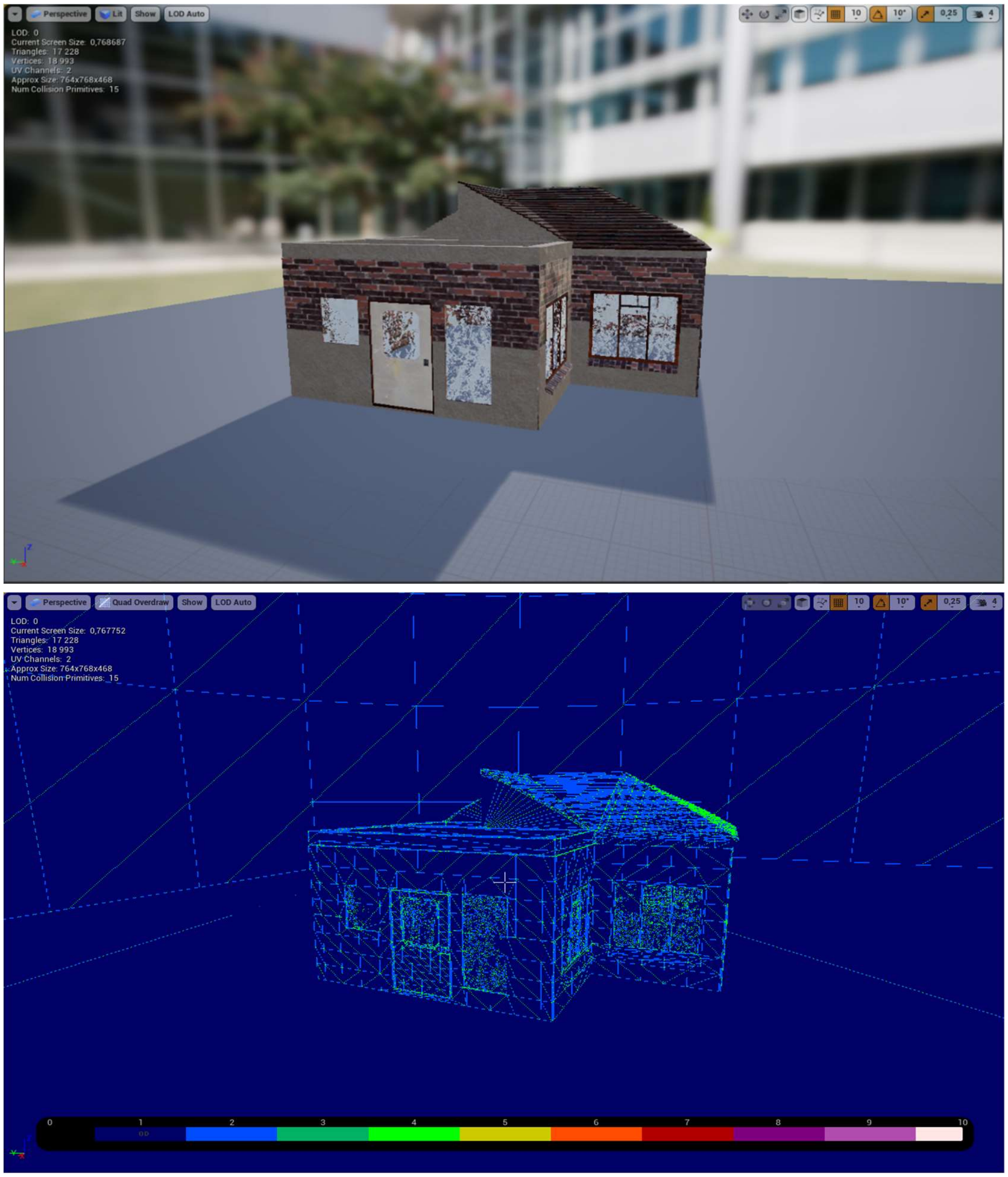

Figure 4 - Example of a procedurally generated building, showing both its in-game rendered version (top) and its geometric complexity in the context of a colour key.

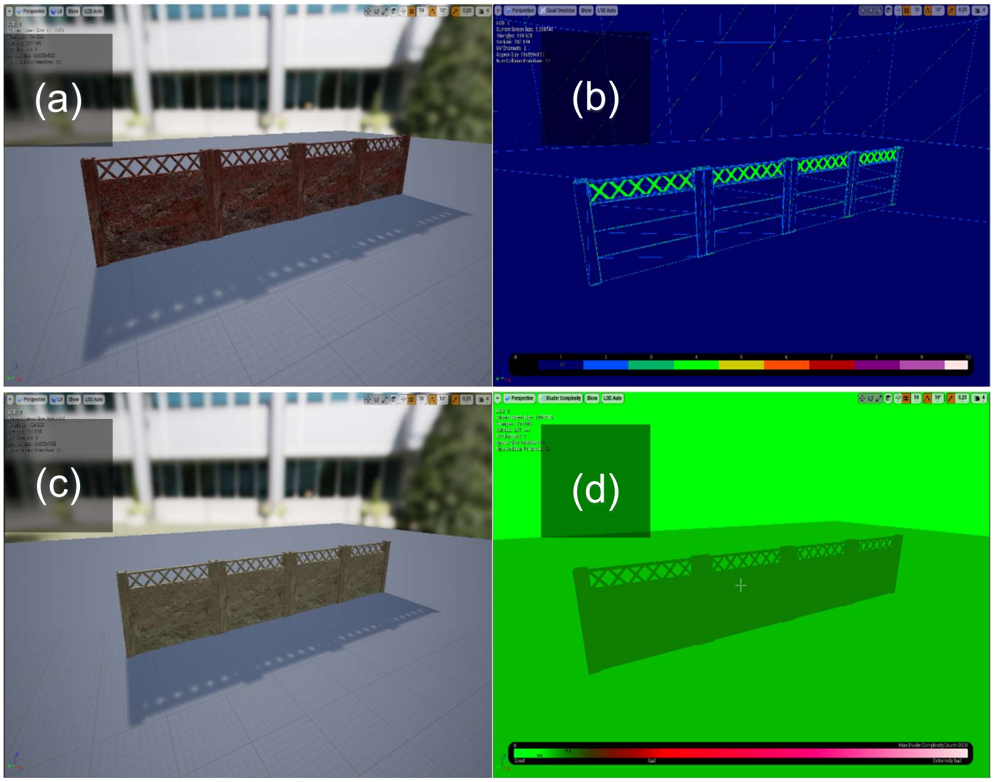

Figure 5 - Comparisons of different textures on the same asset (a & c), while also showing the geometric complexity (b) and shader complexity (d).

3.4 User Experience

A vital aspect of the simulation is the user experience – how the user interacts with and perceives the virtual world. In a study done on undergraduate students with the aim of analysing fear experiences with video games [91], it was found that the interactivity of the games strongly predicted the fear experienced by the player. The most frequently reported cause for fear amongst the 'open ended' stimuli (as opposed to 'forced choice' stimuli) was interactivity. Furthermore, the study states that a more involved perspective (first-person perspective vs third-person perspective, see Figure 6) improves the overall immersion – and thus fear response. This is consistent with Slater's [79] findings regarding the Place and Plausibility Illusion(s) – further emphasizing the importance of a well-tailored user experience in the pursuit of an impactful and effective virtual experience.

Figure 6 - (Top) An example of a first-person perspective game, taken from Eidoes-Montreal's Thief. (Bottom) In comparison, a screenshot from the third-person perspective game Umbrella Corps, released by Capcom.

To maintain the immersion of the participant the illusion of virtual agency needed to be consistent and fluid. The first step was to ensure that interaction is simple and intuitive, allowing very little distraction from the virtual environment. The standard Oculus Touch controllers were used for this purpose, keeping all movement to a single joystick for one handed use. The second controller was to remain in the participant’s grasp to maintain immersive consistency (having two hands in the virtual environment rather than just one). Movement in the paradigm itself was purposefully made to be slow and consistent (with no scaling to speed), with the ability to rotate the player's view in a windowed fashion – 45 degrees at a time. The rotation mechanic was a calculated trade-off between immersion and motion sickness. Consistent with the findings of Patrao et al [54], the previous tests showed that using a rotation mechanic that turned incrementally (per degree of rotation) caused many participants significant levels of motion sickness.

Given the importance of the controller in the user experience facet of the simulation it was vital that the control mapping and sensitivity settings were intuitive and easy to use. Initial versions of the controls for the Oculus Touch motion controllers proved to be too sensitive for the participants, so several iterations were done before settling on the final version.

The decision to use the motion controllers instead of the previously used game controller was largely due to the fact that the motion controllers emulated hand control (an example of the participant's virtual hands are shown in Figure 7) and movement within the virtual environment. This allowed an additional dimension of immersion to be incorporated without adding complexity to the user interface. The only controls needed in the final version were the joystick of the right controller, and the trigger (as shown in Figure 8). The joystick would handle virtual locomotion – forwards/backwards to move in the respective direction and left/right to rotate in a windowed-fashion (45 degrees at a time). The virtual rotation was necessary due to the participants having wires attached to them for both physiological measurements and the connection of the Head-mounted Display (HMD) to the computer. The controller in the left hand had no part in the control of the player character but provided a more rounded sense of immersion by having both hands visible in the simulation.

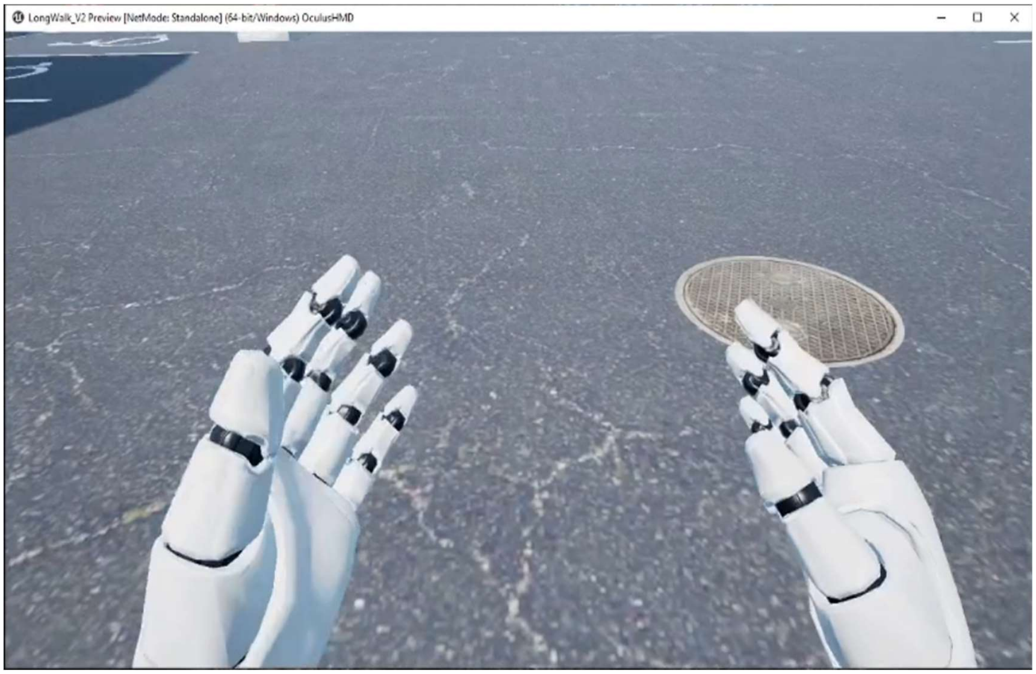

Figure 7 - Screenshot taken from the simulation showing the participant's virtual hands.

Figure 8 - Controller layout for the Oculus Touch motion controllers, showing labels for only the relevant controls.

3.5 Guidance System

To ensure the ability of the participant to navigate the simulation environment, without the need for verbal assistance, a guidance system is used. This system also serves as an implicit fear stimulus, allowing the embodiment of the 'fear of the unknown' whenever it is out of sight. Since verbal communication with the participant would very likely break their immersion - requiring them to be aware of the 'real world' and thus contrasting it to the virtual world – the guidance system needed to be robust enough to ensure any participant is able to complete the entire simulation without assistance within a reasonable time.

Previously, a more complex and computationally expensive system was implemented, making use of multiple instances of the original marker and using Unreal Engine's particle system (aka Niagara [95]) to generate each. For the new guidance system, a simplified approach was taken by replacing the particle systems used in previous versions with semi-transparent, solid, glowing green cylinders. This would serve as the new marker asset. This decision was based primarily on the impact the system had on the simulation's performance, with the goal of reducing any unnecessary load on the device that might reduce framerate. As can be seen in Figure 9 the old version had considerably more complex shading. This, coupled with the fact that there were multiple instances of the marker, creates a significant load on the computer running the paradigm.

The new marker was just a single asset that simply disappeared and reappeared (at a new, designated location) as the participant passed through it - moving further along the route with each reappearance. This contrasts greatly with the particle system(s) used previously, with multiple instances used – being activated and deactivated as necessary. Additionally, it was important that the next position the cylinder appeared was visible from each previous point. To assist in this, the cylinder was given a bright-green glow that was visible above the roofs of the houses in the environment. Shown in Figure 10, the new cylinder presented as a cleaner and simpler visual asset, standing out against the background without the need for a complex particle system or lighting setup.

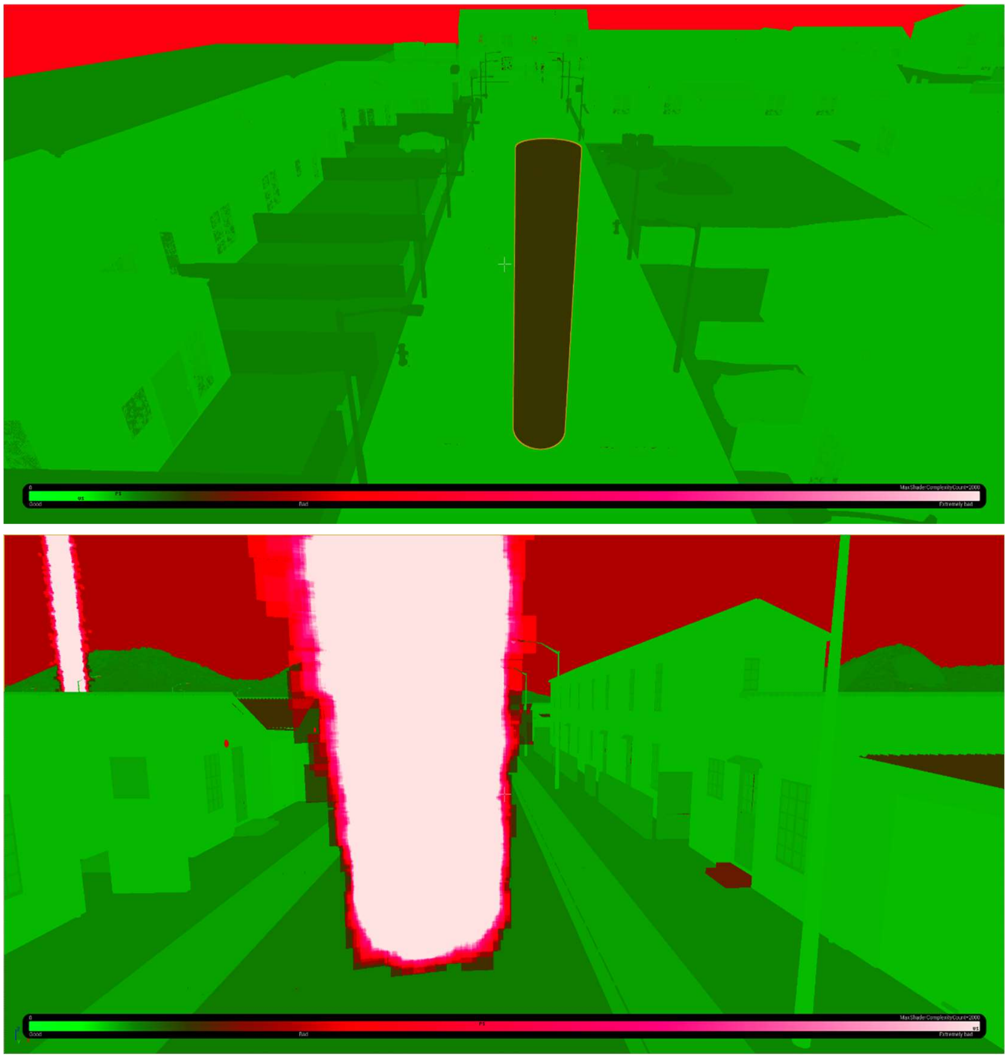

Figure 9 - (Top) The new marker shown in the environment on a colour spectrum denoting the shader complexity of each asset. (Bottom) Below that is the original marker design shown using the same colour spectrum view.

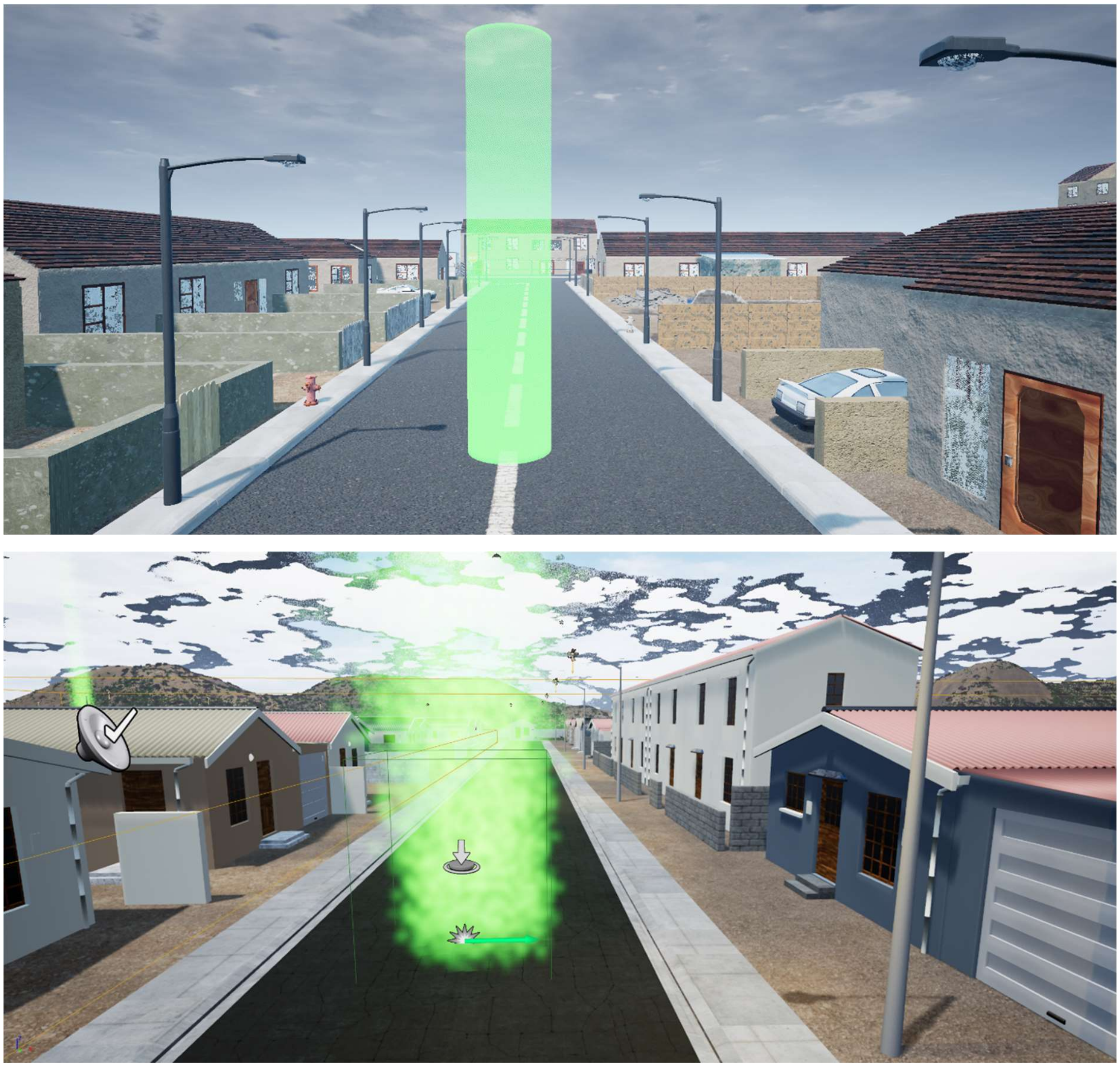

Figure 10 - (Top) The new, simpler, and cleaner marker design shown in the environment using the standard view. (Bottom) The old marker asset (seen from the developer's viewport), with hundreds of particles and a visually complex aesthetic.

3.6 Sound Design

Taking much of the inspiration from successful horror/thriller game franchises, the sound design was integral in creating and maintaining the immersion required to make the simulation believable. According the studies done by Lin [96] and Lynch & Martins [91], audio components are a pivotal aspect to the experience of video games, particularly horror-themed ones. In the former study – which builds on the latter done in 2015 – the aspect of sound was reported as one of the most effective fear elements in a VR survival horror game. This is further supported by similar results found in Lynch & Martins' analysis, with audio being reported as the 3rd most frequent cause for fear amongst the open-ended stimuli (interactivity and surprise taking 1st and 2nd place, respectively). Importantly, both these studies based their original hypotheses on the early work of Slater [79] and her definitions of the PI and PSI.

Everything from footsteps to heavy breathing was implemented to sell the participant's existence in the virtual space, with careful attention paid to when these sounds were implemented, their relative volumes and their spatial orientation. In addition to the quality of the audio used, measures were taken to include aspects such as attenuation for external sounds. As such, placement of the audio components became very important to ensure the realism of the environment. Audio assets that were intended to sound as if they were far away, were placed the necessary relative distance from the participant's virtual character and given the attenuation properties consistent to the environment and intended sound. Whereas audio components that were intended to sound as if they belonged to the participant themselves were implemented as two-dimensional sounds – not taking placement or distance from player into account. Much of the technical aspects of the audio components themselves were handled by the Unreal Engine, further detail can be found in the relevant documentation [97].

With the importance of good sound design highlighted above, the application of the audio mechanics became a vital step in the optimization pipeline. Second to the visual stimuli, errors with the audio can cause an abrupt disruption of immersion. There is a fine line between sound integration that compliments the paradigm and something that will detract from the intended experience. The human ear can detect a time difference as slight as 30 microseconds without any training [98]. Another article states that when it comes to audio latency even the milliseconds matter [99]. This article, reporting on a study done on the audibility of group-delay equalization [100], discusses the importance of mitigating latency of audio. Furthermore, the original study reports that the smallest mean threshold for negative group delay was 0.56 ms and 0.64 ms for the positive group delay. These results effectively leave very little room for error when designing compelling audio mechanics. However, even the best sound design will fall apart if the system cannot handle the processing costs of the paradigm. Thus, the focus on the optimization of the process from beginning to end.

3.7 Visual Design

Another important step in the design process was to decide on several visual aspects of the environment. The immersion potential of the simulation as whole would depend heavily on the visual believability of the objects and actors present. However, this had to be achieved without severely impacting the performance of the paradigm – since any visual lag would detract from the participant's immersion.

According to Oculus's developer documentation [101] there are several things to look out for when designing a VR application. The primary issues (that are relevant to this paradigm) to consider are high triangle counts (the complexity of the geometry), complex facial animations, dynamic shadows and dense foliage. Furthermore, the Unreal Engine documentation for developing a VR application [102] puts emphasis on maintaining a platform-specific target frame rate – to mitigate simulation sickness. Additional suggestions for managing this include keeping users in control of the camera, maintaining constant movement speed (with no ramping up or down) and avoiding any post-process effects that greatly affect what the user sees. Further on in the guide, the design and resolution of textures and lighting is brought into focus. The main points of consideration would be the resolution of the textures, the number of textures used per material and the types of rendering utilized for the materials and simulation.

The obvious and present visual element is the lighting – more specifically the virtual sky. As the simulation is designed to go from a mid-morning scene to a late-night scene (a comparative example is shown in Figure 11) the virtual sky would be taking on the largest role in lighting the environment. The sky has to incorporate a primary light source (i.e. the sun/moon), diffusion elements (i.e. clouds/atmospheric fog) and a background (preferably one that makes use of complex gradients). When shifting to a night-scene, a sunset-like event needs to take place – including colour variation in the primary light source and background. The addition of stars adds realism and believability to the scene. All this is done in the hopes of capturing the realism of the scene through peripheral visual elements. However, at this level of complexity, optimization needs to be prioritized in order to maintain the required levels of performance.

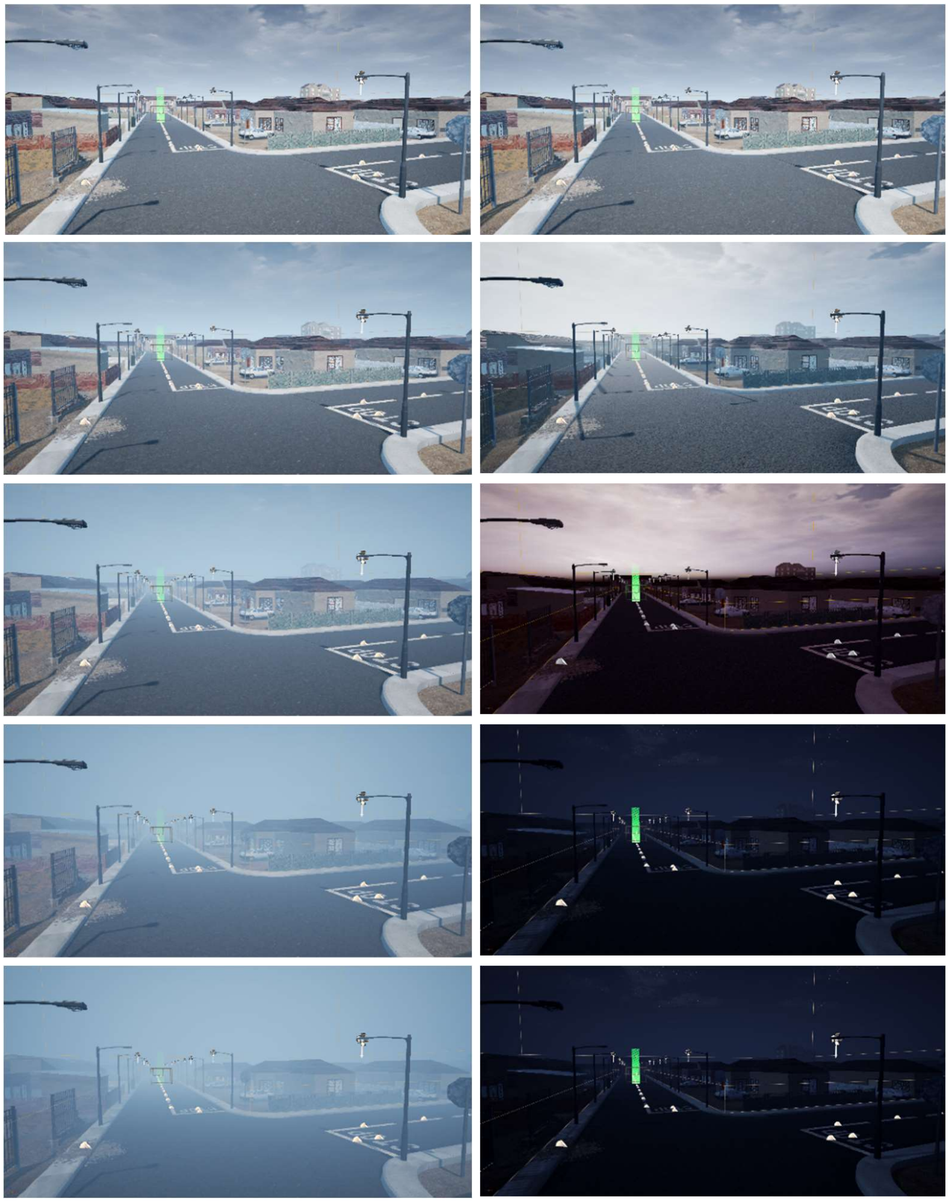

Figure 11 – Screenshots taken from the simulation environment, showing (left) a change in the fog density only and (right) a change in time of day only.

Auxiliary visual elements that tie the environment together include streetlights, debris and dirt/grunge, and people dotted about the environment in believable situations and contexts. The textures and materials for each of these elements had to be carefully considered, designed and chosen to maintain the believability of the scene without impacting the performance. An example comparing the visual results of different texture resolutions is shown in Figure 12, note how little of a difference the upscaled (4K) resolution texture makes to the visual result.

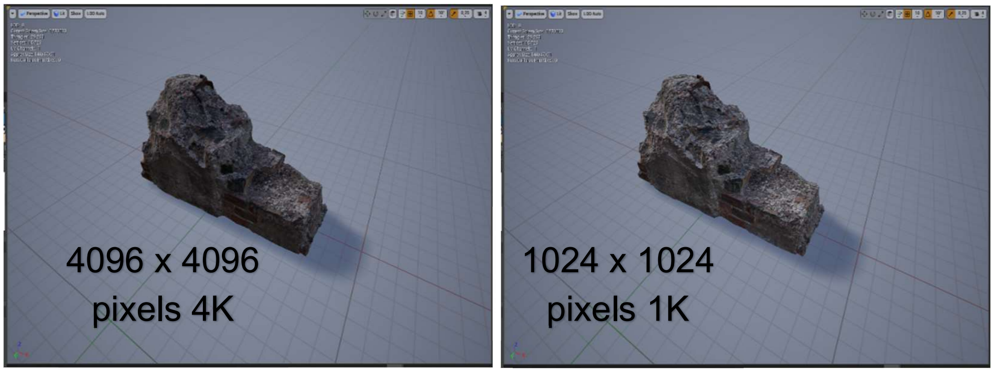

Figure 12 – Comparison between two different texture resolutions (4K and 1K) and the visual results when applied to the same model.

To achieve realistic visuals for the objects and the environment each asset needs to be textured. This involves applying a 2D image (or set of images) to the geometry of a 3D object. However, in order to make this believable, several layers of textures are applied – with each representing a different visual aspect of the object. With an example shown in Figure 13, comparing the material and the textures that make it up, the cost of performance versus the visual results must often be carefully weighed. The visual aspects the textures represent include (but are not limited to) the colour, the roughness (how shiny or rough the surface is) and the normal map (2D representation of 3D geometry such as bumps and crevices). A technique known as Physics Based Rendering (PBR) is used to achieve a realistic look for all these textures and is the main proponent for the current generation of real-time rendering. This is done through the estimation of derivatives of radiometric measures with respect to arbitrary scene parameters [103]. In short, PBR is a texture-focused workflow that simulates how light interacts with a model, and with the advancement of the technology used to calculate these simulations the accuracy of the workflow has improved dramatically - now able to achieve more realistic results.

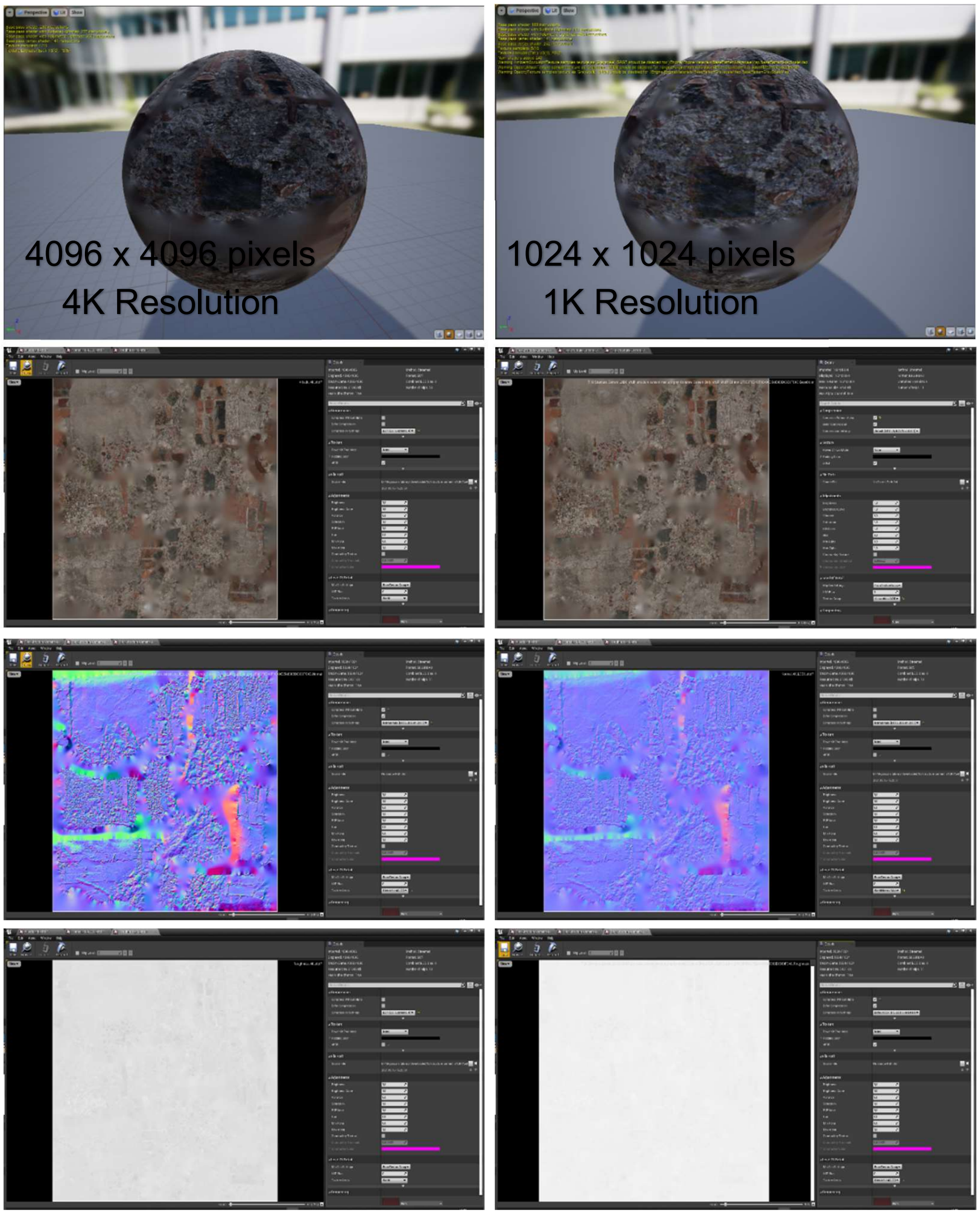

Figure 13 – Comparison between the same materials as in Figure 12, broken down into their separate textures and compared side-by-side. The shape on which the material is applied at the top of the figure is known as a Shader Ball.

However, when applying textures to objects to be used for VR, there are several limitations to navigate. PBR textures can be quite taxing on a system, especially when dynamic lighting is used, forcing the software to recalculate the shaders every tick. As such, it is recommended by most developers [104] to use as few texture maps per material as possible. Additionally, the resolution of each texture map needs to be considered. Due to these limitations, any software designed for use in VR has an upper limit in terms of the realism achievable. An example of a performance load comparison is shown in Figure 14, showing the same two materials from Figures 12 & 13 applied to the same model and viewed using a shader complexity colour scale (going from green to white). The darker of the two (the model with the 4K material applied) is the model that has a greater shader complexity and thus a greater impact on performance.

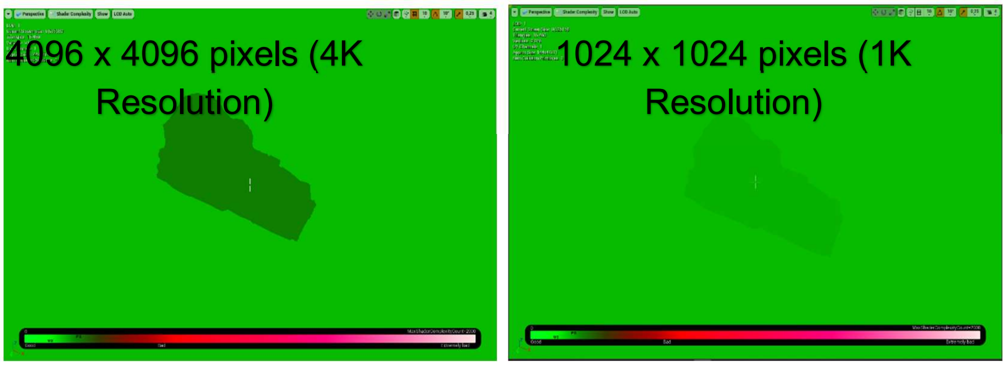

Figure 14 – Comparison of the same asset from Figure 12, viewed using a colour spectrum that denotes the complexity of the material applied to the asset. The darker of the two is the asset that has the greater impact on performance.

3.8 Passive Characters

Passive characters, in the context of this simulation, are virtual people that exist in the environment but do not interact with the player character. They exist solely to give the environment, and in turn the simulation as a whole, a more believable and populated atmosphere. These characters should blend in well-enough to the surrounding environment that they do not distract the player from the simulation itself but register in their subconscious as inhabiting the same virtual world.

Figure 15 - Screenshots showing passive characters in the environment. A daytime lighting scene was chosen to better display the characters for the screenshots. However, the characters in the bottom image are typically encountered after nightfall. The white mannequin in the top screenshot was included in the first few tests due to an error, and then kept on to maintain consistency of variables.

The passive characters designed and chosen for this simulation, as shown in Figure 15, were given attire and appearances that fit into the environment - with the exception of the white mannequin, which (existing due to an error appearing early in the testing process) was kept in the simulation to maintain experimental consistency. They were given animations that were dynamic enough to be noticeable but not distracting or alarming. These animations were kept relatively short to reduce system load and put on loop should they remain in the player's view for long enough. In both examples in Figure 15, variants of a generic conversation were chosen as the context in which to animate the characters. These were chosen due to their non-engaging nature, allowing the player to feel as if the interactions did not involve them and could be entirely avoided (both in engagement and being noticed by the characters). The second set of passive characters were given slightly more animated gestures and mannerisms, intended to imply their intoxication. This was an attempt to add an additional layer of implicit fear stimuli to the later passive characters – in line with the rapidly advancing time of day.

3.9 Active Characters

In contrast to their passive versions, active characters are virtual people that interact with, and even affect, the player character. These characters exist to create urgency and discomfort for the player but must be very carefully designed and implemented – as believability tends to break once virtual characters begin to interact with the player character. The roles of these characters were philosophically compared to that of the zombies in the previous fear-based studies done by Lin [96] and Lynch & Martins [91] – the presence of which played a significant role in both studies. The goal was to implement active characters that clearly intend to interact with the player character but only do so through auditory and visual stimuli. Reason being that these two are the only senses that are effectively stimulated through VR technology.

Screenshots of both characters are shown in Figure 16. The first active character that the player interacts with is an unfriendly male, initially standing with arms crossed, just off the road. As the player character passes him on the road he will begin to animate and shout something generic but clearly unfriendly toward the player character. Volume spatialization and attenuation were crucial in the implementation of the character. Once the player character is far enough away, the unfriendly man will cease shouting and return to his idle stance. The second active character, and by far the most complex, was dubbed 'the follower' – since this character's main role is to follow the player character while begging for money. This character was programmed to include its own collision detection, path-finding and auditory cues. Additionally, it was programmed to begin following the player character at a certain point in the simulation and stop a certain distance away. Should the player character attempt to approach the follower, it should then back away. This character had sounds for its footsteps as it approached the player character, implemented with the aim of causing the player to turn around as they become aware of the additional footsteps. Both these characters are designed to remain in the realm of implicit fear-based stimuli, with neither character presenting as a clear threat or even explicitly threatening the player.

Figure 16 - Set of screenshots showing the active characters in both their idle and active states. (a) The first of the active characters in its idle stance, (b) the active following character approaching the player character and (c) the character from (a) shown during its shouting animation.

For the design of the character that would actively follow the player, an industry-standard character creation software was used – Reallusion's Character Creator 3. This was chosen to ensure a realistic character could be designed and produced, while still maintaining an optimized pipeline – something that is required in the game design/animation industry. Unlike many of the other characters in the paradigm, the believability of this character relies heavily on how it moves. Thus, no shortcuts could be taken when creating the character model, the skeleton (or 'rig') or the animation applied to the skeleton. Shown below, in Figure 17, are several views that tell the design and optimization story of the virtual character. In the top left screenshot, the character's skeleton (for the purposes of animation) is shown, super-imposed over the fully rendered model. There are balls that exist between the 'bones' (and at the end of some 'bones') serving as joint indicators, showing where each of the 'bones' are constrained – very similar to the joints in a human body. The lines connecting the feet, hips and hands are indicating the implementation of an Inverse Kinematics (IK) animation system. This system essentially allows the character rig to operate around a joint, inversely to the orientation of the skeleton. For example, with traditional kinematics (often referred to as Forward Kinematics or FK), the leg will operate around the hip joint while the subsections of the leg will operate around joints within the leg (knee, ankle etc.). However, IK will calculate the movement of the leg (including the subsections and joints) around both the hip and the foot, ensuring the leg bends correctly based on the orientation of the foot and the hips. Thus, the screenshot of the skeleton (Figure 17(a)) shows that this model operates around the hips, a point midway between the ankles and around the wrists. Next to this screenshot (Figure 17(b)), is a wireframe view of the character model. This screenshot shows the geometric complexity of the model and its layers of clothing in a way that the developer can use to check the quality of the geometric layout. The screenshots in the bottom left and right of the collage just show the model with and without the textures applied, allowing another level of quality control when checking the final model.

This model, once placed in the environment, can be viewed through several types of colour spectrums each denoting a different aspect of its impact on performance. In Figure 18, two of these spectrums are shown, one for the geometric complexity and one for the complexity of the shaders used. As can be seen, the geometric complexity of the character falls within a comfortable range – with nearly all of the model remaining below the 4^{th} centile. However, the shading complexity of the model is less consistent, with the areas of exposed skin heading into the red portion of the spectrum. The optimization compromise here is that the areas of exposed skin make up a small percentage of the visible character but are vital for believability of the character and its role in the simulation. Additionally, with the low computational load presented by the geometric complexity of the model, a slightly higher shader complexity is achievable without significantly impacting the system.

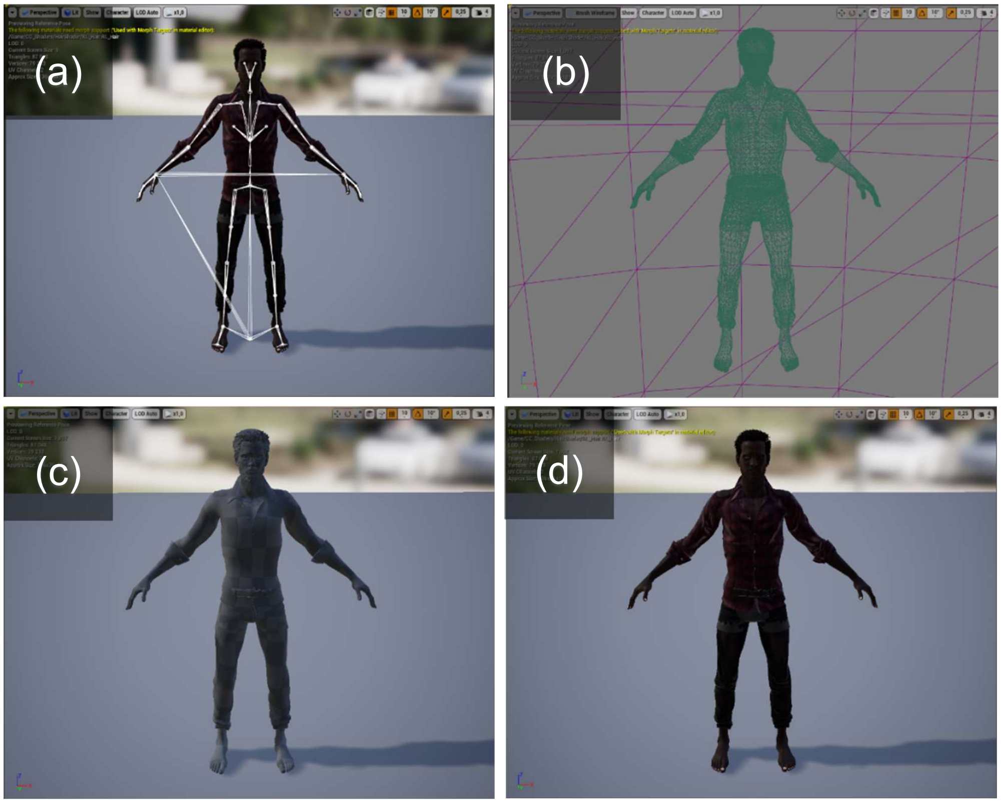

Figure 17 – A collection of screenshots of the active character that follows the player, showing several of the view modes used when checking the quality and design of the character. (a) The animation skeleton of the character can be seen with joints and 'bones' super-imposed over the fully rendered model. (b) The geometry of the model is shown using a wireframe view. Beneath this, the character is shown both textured (d) and untextured (c).

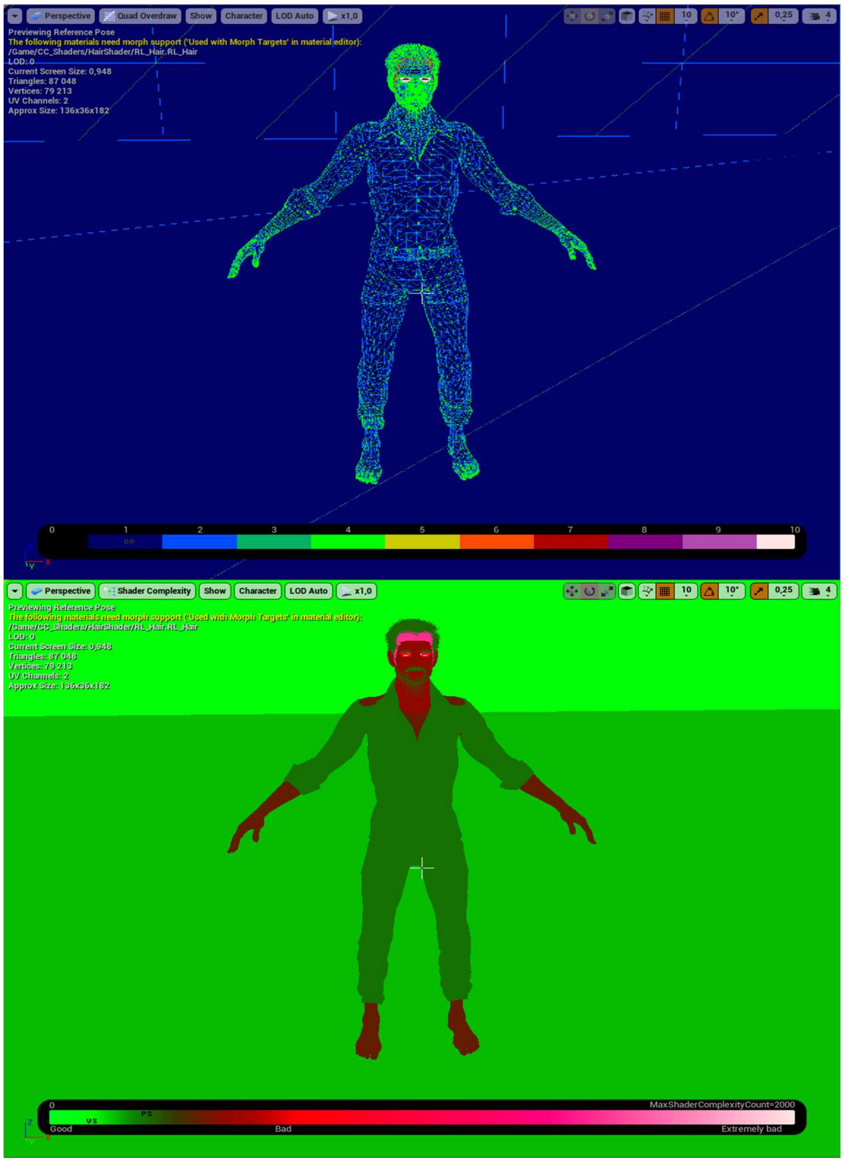

Figure 18 – The same active character that follows the player is shown against two different developer mode colour spectrums, one for geometric complexity (top) and one for shader (texture) complexity (bottom).

3.10 Performance Metrics

In order to verify the steps taken to improve performance and optimize the simulation, performance tests had to be done. These tests took the form of statistic streaming (see example in Figure 19), FPS (frames per second) benchmarking and polycount and memory-load comparisons. Statistic streaming refers to the native mechanic in Unreal Engine to stream the performance statistics of the simulation live (i.e., while playing/running) [105]. This allows the developer to see a simulation's load on the GPU and CPU – more efficiently diagnosing any issues or bottlenecks. These were captured and used to compare the load on the system while running the simulation as well as while interacting with specific sections of the environment.

In order to discuss the statistics necessary for performance profiling, a few terms need to first be defined. A 'draw call' refers to any call from the simulation to the graphics API to draw objects in the program (typically done per object but can be done in batches). Typically, ideal in the hundreds when profiling a mobile or VR application [106]. 'Ticking' or a 'tick' refers to the running of a piece of code at regular intervals (typically once per frame). These can be further categorized by the type of code the tick is responsible for (such as Blueprint ticks, actor ticks, etc.). Finally, a 'pass' is a set of draw calls executed by the GPU. These sets are grouped together by their role in the pipeline (e.g., a rendering pass) and to ensure a specific order of execution. Passes exist primarily to render meshes, including the textures, visual geometry and final render.

For the CPU dependent statistics there are two groups: scene and game. Scene refers to all the statistics that make up the visual aspects while game refers to the statistics that are code-bound. For the scene statistics, the primary values of interest are:

- Dynamic path draw calls – This refers to all draw calls made for continuously updating aspects such as dynamic lighting and shadows.
- Mesh draw calls – All draw calls made for objects in the scene.
- Present time – CPU version of total time for all processes to complete.
- Lights in scene – Represents the number of light assets present in the scene.

While the primary values for the game statistics group are:

- Blueprint time – The total time for all Blueprint ticks to be executed.
- World Tick Time – The total time for all event ticks (in the simulation) to be executed.
- Ticks Queued – The number of ticks that are processed per game tick.

The profiling statistics that are GPU-bound focus more on performance metrics that are pixel based, often providing as much information to the artist as the developer. When profiling the scene's performance against the GPU, the following statistics were considered:

- [TOTAL] – The total time taken for all GPU processes to be executed.
- Basepass – Time taken for the base pass (rendering of materials, vertex/pixel shaders and lighting on objects) to complete.
- Lights – The time taken for all lights in the scene to be processed.
- Translucency – The time taken for materials possessing translucent
- ShadowProjection – The time taken for shadows generated by object obfuscation of light.

The GPU and CPU profiling were primarily used as part of the optimization workflow and not as a set of performance result metrics. This is due to their complex nature and the fact that the measurements are designed to provide developers with immediate feedback regarding the computational load of the scene. The response times of the GPU and CPU are integrated into the FPS Chart section of the performance profiling, and thus presented as part of the FPS benchmarking results.

Figure 19 – A screenshot of the Unreal Engine viewport with Engine Stat Streaming Table visible.

For the FPS benchmarking the simulation was run while the game engine continuously captured the FPS data, after which it output the raw data to a .csv file. The general goal was to keep framerate above 60 fps (as per the Unreal Engine guidelines [102]) with an overall goal of an average refresh rate of 72 Hz on the device itself (Oculus Quest 2). Along with the raw data, the engine also produced a brief summary of the overall performance of the simulation. Two methods were used to capture this data, one where the simulation is run without any background applications running and then one where the simulation is running as per the testing procedure setup. Both of these methods were run multiple times, with the results then averaged across the sample population for each method. The summary values were the primary values compared as it is the overall performance that is most important. These better reflect the computational load of the simulation on the testing system and the respective system's ability to handle it. In contrast, the raw values that make up a graph like the example in Figure 20 will typically show fluctuations in the fps count over the course of the simulation, without providing any context as to what caused these spikes in latency. Due to these inevitable fluctuations without context, this information is not as relevant for the context of the study.

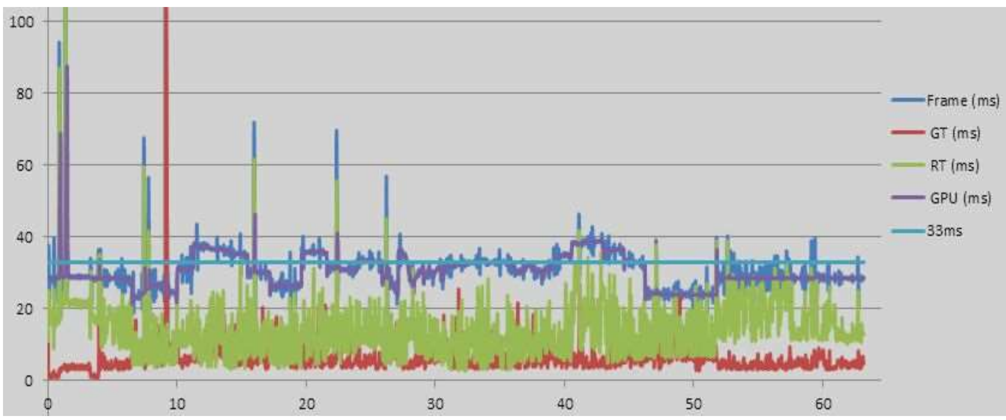

Figure 20 – An example of a graph created with the output from the FPS data gathered in Unreal Engine. The abbreviations refer to Game Thread (GT), Render Thread (RT) and Graphics Processing Unit (GPU).

The polycount (the number of polygons making up a specific model or present in a scene) and memory-load (the amount of memory required for an asset or scene) comparisons comprised of checking the geometry metrics of each version of the simulation. These included values for the number of individual objects present in the scene, the amount of space in memory required for these objects, the memory required to store and render the textures applied to the objects and the overall performance impact they have. Ideally, a well-optimized paradigm will allow for a higher polycount and memory-load without perceivably impacting the performance. Although there is no ideal range for these metrics, the performance of the system (usually measured using fps statistics) is heavily dependent on these statistics. As such, should there be any performance issues the polycount and memory-load metrics will give a good indication of what the cause is. Conversely, should the system perform well under the simulation load, these metrics will serve as a good indication of what is achievable given the current setup and act as a guide for further improvements and modifications.

3.11 Closing Thoughts

The design of the simulation focused heavily on the performance optimization of the paradigm itself, ensuring performance maintenance was included in every step of the pipeline. Visual aspects formed a large part of the design process, vital parts of which were decided on based on the supporting evidence from the literature. Interactivity and user experience were also discussed and emphasized for their profound effect on the success of any paradigm. Both passive and active characters were included in the design pipeline and carefully designed to both compliment the research done and keep performance load at a minimum. The performance profiling methods were also discussed, with specifics of each step and contributing aspect mentioned and elaborated upon. With the implementation stage completed, and the paradigm running as intended, the next step was to test the paradigm with participants and gather the data required for analysis and review.

4 Methodology

The primary goal of the study is to validate the paradigm outlined in the previous section as a tool for facilitating virtual reality exposure therapy - using a combination of physiological data and supporting subjective appraisals. This section covers the ethical and methodological considerations for testing procedures, as well as the steps taken for recruitment, screening, testing and data acquisition. All the below was done with the aim of creating a clinically sound testing environment (within limitations) that was replicable and reliable.

4.1 Ethical Considerations

The study was approved and renewed (10 July 2021) by the Health Research Ethics Committee (HREC) under the Project ID 8044 with the Ethics reference number N18/10/108 (see Appendix A). It is part of a larger study focusing on stress sensitivity in Schizophrenia, known as the Shared Roots study (N13/08/115). Additionally, the testing done for this study was done parallel to a study on biofeedback and the fear of heights [107].

The tests posed the risk of only limited impact on the safety and well-being of a participant. As such, it was considered a low-risk study. There was, however, the risk of dizziness/nausea. Thus, a written consent was obtained from all participants detailing this potential problem. Nausea and dizziness are the most common side-effects of VR use and result from conflicting signals between the vestibular cochlear system and the visual system - typically as a result of the relatively low refresh rate of the screen used in the HMD (90 Hz). The VR paradigm at the core of the study was designed to limit the amount of time spent in the virtual space. If participants felt excessively dizzy or nauseous, the head mounted display was to be removed immediately. If participants were unable to tolerate the virtual environment, they were excluded from the study. Given that the virtual reality headset being used had undergone considerable refinement, as well as our experience using an older HMD, it was expected for nausea to not be a significant problem.

In the case of any participant experiencing significant distress - which could include, but was not limited to, extreme hyper-arousal or re-experiencing trauma (flashbacks) - they were referred for the appropriate care after being screened by a qualified member of the study team. Participants were to be referred to their existing healthcare providers. If these were not available, a referral was to be made by a clinician study team member to a private healthcare provider or their local clinic - whichever was appropriate. Participants were excluded from the study were they unable or unwilling to complete VR tasks due to significant distress. Total sound exposure was minimal and fell well within the Centres for Disease Control and Prevention’s guidelines for noise exposure.[108]

Where possible distance-based methodologies were adhered to. The study did, however, require face-to-face visits for the primary VR and physiological feedback data acquisition. High risk population members for COVID-19 transmission were not examined, as advanced age and physical ailments were exclusion criteria. Mindfulness of participant concerns surrounding the COVID-19 exposure was practiced, and these risks were clearly communicated to participants/researchers as well as how they were mitigated.

All precautions in line with those upheld by the university, as a whole, were taken. Masks were worn by both examiner and participant at all times. Hand sanitizer was provided to all participants at the start of the consultation, after visits to the rest rooms and following the conclusion of the session. Participant visits were carefully spaced so that no more than 2 participants were in the same area. There was a 1.5-meter distance between participant and examiner whenever possible.

In addition to those outlined above, several other risk mitigating procedures were employed. Those applied during the simulation include a tiered threat level system that could compensate for a participant that became distressed and the use of subjective acute stress appraisal to monitor the participants discomfort before, during and immediately after the simulation.

4.2 Recruitment

The primary population for the recruitment process was the student body of Stellenbosch University (Tygerberg Campus included). Given that this study was done to validate the current paradigm, the students served as the healthy control population for the testing procedures. Maintaining COVID protocols, the recruitment process was done through an online booking system, which then allowed the necessary screening before any face-to-face meeting was required. A final total of 22 participants were recruited, tested and their data recorded.

Given the primary goal of this study as being validatory and not to treat any specific disorders as yet, there were few exclusion criteria applied when recruiting. These criteria are listed below:

- Serious or unstable medical condition(s) - determined by screening
- Education level below Grade 7
- Psychosis arising from acute substance intoxication - determined by screening
- Failure to tolerate the virtual environment during acclimatization phase

4.3 Screening

There were several screening tests used during the various stages of the study. During recruitment, the primary screening done was COVID-19 related – ensuring the potential participants were confirmed as negative cases. Once recruited, the student control population (the entire population of this study) were assessed using a MINI plus PTSD screen [109] to ensure the participants did not have any underlying disorders or complexes - administered by the research team's clinical psychologist. In addition to ensuring the potential participants have no serious or unstable medical conditions, a substance use screen was done using the Kreek-McHugh-Schluger-Kellogg scale [110].

4.4 Testing Procedures

Participants were met at the entrance to the building where the testing took place, and provided with a cloth mask, had they been without. All participants and research personnel were provided with Personal Protection Equipment (PPE). This included a surgical mask for staff, a surgical mask for participants and hand sanitizer available to all. Additionally, gloves were provided for research staff working with the research equipment. Participants were screened again when presenting at the testing facility (see Appendix C for questionnaire used at the site). If a participant screened positive (i.e., has COVID-19 symptoms), they were isolated and taken to the assigned faculty office for this purpose. They were then to be referred to an appropriate diagnostic service for formal screening.

Once the participants were screened and cleared for involvement in the study, they were informed of the procedures and methodologies as outlined in the Informed Consent document (see Appendix B). After the participants had agreed to the procedures and signed the relevant documentation, they were screened for any additional exclusion criteria. Provided no exclusion criteria were met, the participants were then given a second briefing regarding the specifics of the paradigm and encouraged to ask any questions should they be confused. Upon acknowledgement of understanding, the participants were prepared for the physiological feedback and the simulation itself (including application of HMD and handing over of motion controllers). Once inside the virtual space, the first stress appraisal questionnaire was done. An acclimatization phase was then implemented to ensure the participant's ability to tolerate the virtual environment and become familiar with the controls required to manoeuvre within the virtual environment. Once this was completed, the paradigm was initiated, and the participant was left to complete the simulation without verbal assistance. Midway through the paradigm, a second stress appraisal questionnaire was implemented within the virtual environment by way of street billboard (shown in Figure 21). Finally, once the simulation was completed but before the HMD was removed, the final stress appraisal questionnaire was done. The data acquisition software was run for the duration of the simulation only, excluding acclimatization and cooldown. After the simulation had been completed and the VR equipment returned, the participant was asked to complete the Presence Questionnaire (IPQ).

The test station setup included the following specifications:

Desktop PC – CPU: Intel Core i9-9900K; GPU: NVIDIA Quadro P6000; RAM: 64 GB.

VR HMD – Oculus Quest 2 (native resolution of 90 Hz) with Oculus Touch Motion Controllers; PC Link cable.

Physiological Data Acquisition - BIOPAC MP160 with EDA100C with analogue signal trigger.

Testing Area – 5 m x 5 m space adjacent to computer setup.

During the course of the simulation, there were several responsibilities that were upheld by the testing team. The facilitator of the test had to ensure that the participant was safe and understood what was required of them. Furthermore, they were to ensure the simulation ran smoothly and without any major technical issues. All data captured had to be monitored from start to end to ensure no data loss occurred (from issues such as electrode contact loss etc.) and that the data was being captured correctly. Additionally, the test environment variables had to be kept as consistent as possible, ensuring nothing would distract the participant from the simulation.

Once the simulation had been completed, the participants were given two post-simulation questionnaires to complete. One questionnaire was intended to assess the participants' experience in the simulation(s) and quantify it as a measurement of presence, while the other simply assessed their familiarity with computers. For the former, a modified Presence Questionnaire (see Appendix E) [111] was used while an updated Computer Familiarity Questionnaire (see Appendix F) [112] was used for the latter.

4.5 Data Acquisition

This section covers the methods used to acquire the data required for the study. A large part of the physiological data acquisition was handled by BIOPAC's MP160 device (as discussed below) and the accompanying AcqKnowledge software. The various forms of data will be briefly introduced and discussed in the context of the acquisition. Following this, the methods of analysis will be introduced and discussed in further detail.

4.5.1 Physiological

The primary physiological measurement for this project, Electrodermal Activity (EDA) refers to the variations in electrical activity of the skin – measured through the corresponding conductance (as described in section 2).The BIOPAC MP160 device [113] with attached EDA100C module [114] was used to acquire and process the raw physiological data. This data was then output and recorded via the AcqKnowledge software [115] on the test computer.

The module responsible for acquisition and processing of the EDA data contained two low pass filters (1 Hz and 10 Hz) and two high pass filters (DC; 0.05 Hz and 0.5 Hz) with a sensitivity rating of between 2 μS/V and 20 μS/V (depending on input).

Each participant was setup with two electrodes, each attached to their index and middle fingers of their non-dominant hand [67]. These electrodes were then connected to the BIOPAC MP160 via 3m BIOPAC cables, specifically designed for physiological data acquisition. The BIOPAC itself was connected to the primary computer via USB – in addition to a custom Arduino setup connected for the purpose of providing an analogue signal from paradigm to BIOPAC system. This signal was used to identify events during the simulation and thus synchronize them with the data recording(s). Both sets of input data (physiological and analogue) were recorded on the same software, ensuring synchronicity.

4.5.2 Subjective

Along with physiological data, it is important to collect subjective data based on participants' self-reported feelings and experiences. This allows insight into the cognitive relationship between the participant and the stimuli and can be used to support the accompanying data collected. [116]–[118]

For the subjective data acquisition, several methods were used. The primary method of acquisition was implemented via a modified Acute Stress Appraisal [119] (see Appendix D) questionnaire, which was used at three timepoints - before the paradigm began, midway through and once it was completed. The modified version of questionnaire was kept very simple to ensure ease of integration, reducing the risk of confusion or a lengthy discussion that may negatively impact the user experience or their immersion. This subjective appraisal questionnaire focused on four distinct emotions that were deemed relevant for the context of the study – these were stress, anxiety, dizziness and nausea. Stress was defined as the feeling of discomfort/fear that was related to the current or immediate environment/experience. Anxiety was then defined as the feeling of discomfort/fear relating to things to come – such as the participant's performance/expectation of the upcoming paradigm. Dizziness was defined as a partial or sever loss of the sense of balance or a 'spinning'/'swaying' sensation, whereas nausea was defined as a current feeling of queasiness or that the participant feels they might 'throw up'. Each emotion was to be rated out of 10. The primary risk associated with VR exposure is motion sickness [54], as such it was broken up into nausea and dizziness to both more reliably measure the participant's experience of these and to monitor them during the paradigm. Stress and anxiety are oft confused emotions, as such there was a risk of a significant correlation affecting the results. This was mitigated by clearly defining the two in context of each other, while using physiological feedback as the primary measure for emotional arousal. These metrics were also used as a mitigating factor for the risk of severe discomfort during the paradigm, allowing constant, measured monitoring of the participants. The subjective appraisal questionnaire was asked in two forms, verbal and digital (within the simulation). The verbal form was used at baseline and post-completion, while the digital version (shown in Figure 21) was used as the midway questionnaire to ensure the participant's immersion remained intact.

Figure 21 - Screenshot of the digital subjective questionnaire, encountered midway through the simulation by the participants.

Another method used for subjective data acquisition was a modified version of the Presence Questionnaire (IPQ) devised by Schwind et al [111]. This modified IPQ was presented to each participant after they had completed both this paradigm (dubbed the 'LongWalk') and a fear of heights biofeedback paradigm designed and implemented by Dr S Du Plessis [107]. This order of events was due to the testing setup including both paradigms, with participants completing each one individually (all other data was collected per paradigm). The questionnaire's context then covered the participant's experience for both paradigms within a single presence score. The goal of including this questionnaire was to have a numerical metric that measures the participant's immersion or sense of presence within the environments and then compare this to the rest of the data collected. These comparisons were expected to show any correlations/patterns between the participant's virtual presence (i.e., the believability of their experience) and various physiological and subjective results. Additionally, this 'Presence Score' could be used to support the hypothesis that an optimized simulation would result in a more immersive experience and subsequently a more effective treatment paradigm.

4.6 Data Analysis

This section covers the methods used to process and analyse the data collected (as described in the previous section). The methods used to collect the physiological data relied heavily on the BIOPAC MP160 device for pre-processing as well as accuracy of the data collected. The custom MATLAB script used to handle the bulk of the processing is discussed, along with the auxiliary module used. Finally, the software used to analyse the results and apply the methods of analysis is discussed briefly.

4.6.1 Electrodermal Activity

All data collected using the Electrodermal Activity (EDA) measurements was processed and stored as AcqKnowledge (.acq) data files. These data files were displayed as straight-forward time vs skin conductance graphs, with each point stored as a decimal value for a corresponding timepoint. In order to process these further and begin formal analysis, this data was exported as both .csv and .mat files. In conjunction with the raw skin conductance values, an analogue channel recorded the triggers corresponding with events in the simulation. This is exported separately to be super-imposed over the data later, giving context to the EDA data.

The data was then run through a custom MATLAB script that included the Ledalab module – the output of which included several important analyses to compare and review.

4.6.2 MATLAB Code

The primary function of the custom MATLAB script was to take all the data acquired (in their various formats), process it, transform all of it into a single format and output it into .csv document that could be used for further analysis. The first step in this process involved importing the original data acquired via the AcqKnowledge software, separating this into various components - one for each type of data format (EDA and analogue). Following this, the subjective data was imported and reformatted. The physiological data was run through the Ledalab module (discussed below) to acquire additional data features that would be important for the analyses to follow. The analogue signal, marking each event in the form of a trigger signal, was stored per timepoint allowing it to be synchronised with the processed physiological data. All of this data was then put into a table and exported to .csv file to be used in IBM's SPSS software.

Ledalab (amalgamated from *Leipzig electrodermal activity laboratory* [120]*)* is a MATLAB-based module designed with the aim of providing the decomposition of skin conductance (SC) data into its tonic and phasic components [121]. As of version 3 (V3.X) it features two EDA analysis strategies [122]:

- Continuous Decomposition Analysis (CDA) extracts the phasic information beneath the EDA signal with the aim of retrieving the signal characteristics of the underlying sudomotor nerve activity (SNA). The skin conductance (SC) data is deconvolved by general response shape, after which it is decomposed into continuous phasic and tonic components [123]. Recommended for the analysis of skin conductance data.
- Trough-to-Peak (TTP) analysis (or 'min-max') is generally used to quantify the amplitude of the skin conductance response (SCR). This allows predefined response windows [124] and amplitude criterion to be applied. Calculated through the Ledalab module, this method provides information regarding the number of significant SCRs within a predefined response window. Which can then be compared to the same value acquired via the CDA method.

For the CDA, the Ledalab module uses the methods outlined in Benedek & Kaernbach's paper [123] beginning with the deconvolution of the skin conductance data. Mathematically, sudomotor nerve activity can be considered a driver which triggers a specific impulse response (represented as SC responses). This process can be represented by convolution of the driver with the impulse response over time (IRF):

$$SC_{phasic} = Driver_{phasic} * IRF \tag{1}$$

The phasic activity of the SC is assumed to exist upon a slowly varying tonic activity of the SC [67]. As such, the SC activity can be represented as follows:

$$SC = SC_{tonic} + SC_{phasic} = SC_{tonic} + Driver_{phasic} * IRF \tag{2}$$

It should be noted that the process of deconvolution is reversible and as such the convoluted tonic activity is used when estimating the phasic activity. Therefore, the SC data can be represented as:

$$SC = \left(Driver_{tonic} + Driver_{phasic}\right) * IRF \tag{3}$$

Regarding the deconvolution as the reverse of the process of convolution, if either the phasic or tonic fraction can be estimated the other can be calculated as follows:

$$\frac{SC}{IRF} = Driver_{SC} = (Driver_{tonic} + Driver_{phasic}) \tag{4}$$

4.6.3 Statistical Package for the Social Sciences Statistics

Statistical Package for the Social Sciences (or SPSS) Statistics [125] is IBM's (as of 2009) statistical software platform. It was designed for interactive statistical analysis, with an original focus on social science. Considered the world standard in this context [126], SPSS's offers a straightforward and high-level command language – along with a thorough manual.

SPSS was chosen as the primary data analysis software for this study due to its already established validity in the world of statistical analysis and research [127], [128], as well as the software's exceptional ability to act as a comprehensive analysis multi-tool. After all the data had been processed by MATLAB and Ledalab, exported into the appropriate formats and organised, it was then brought into the SPSS software as a database (.sav file). This data was then run through several types of analyses, each undergoing multiple iterations.

Repeated measures analysis was the primary method used to analyse the data. The approach and format of which was taken from Andy Field's publication 'Discovering Statistics Using IBM SPSS Statistics' [129]. Several correlation analyses were done as well, when the relationship between two variables was all that was being analysed. When implementing the repeated measures analyses, there were several features that were highlighted and included in the results. The conclusory features used were for the main effect of the variables, as such the F-statistic, the degrees of freedom (DoF) and the significance (p-score) were recorded. In order to give context to these values, several tests and corrections were explored.

The F-statistic is the model mean squares (MS_M) divided by the residual mean squares (MS_R). The former is made up of the model sum of squares (SS_M) and the model degrees of freedom (df_M), while the latter is made up of the residual sum of squares (SS_R) and the residual degrees of freedom (df_R). These steps are calculated as follows, where the subscript 'grand' refers to the grand variance, n denotes sample size, and k represents the number of levels for the variables used:

$$\boldsymbol{SS_M = \sum_{g=1}^{k} n_g\left(\bar{x}_g - \bar{x}_{grand}\right)^2} \tag{5}$$

$$\boldsymbol{SS_R = \sum_{g=1}^{k} \sum_{i=1}^{n} n_g\left(x_{ig} - \bar{x}_g\right)^2} \tag{6}$$

$$\boldsymbol{MS_M = \frac{SS_M}{df_M}} \tag{7}$$

$$\boldsymbol{MS_R = \frac{SS_R}{df_R}} \tag{8}$$

$$\boldsymbol{F = \frac{MS_M}{MS_R}} \tag{9}$$

The first of the tests is Mauchly's Test for Sphericity, a test that determines the relationship between scores in pairs of conditions – a form of compound symmetry similar to the assumption of homogeneity of variance in between-group designs. This test assesses the hypothesis that the variances of the differences between conditions are equal. The hypotheses take the form of various estimates (calculated by SPSS), which are then applied as corrections and assessed again for their significance. The Greenhouse-Geisser estimate ($\hat{\varepsilon}$) [130] and the Huynh-Feldt estimate ($\tilde{\varepsilon}$) [131] are two of the most commonly used estimates when correcting for a design's departure from sphericity. Generally represented as, where k is the number of repeated-measures conditions:

$Without\ correction\ applied$:

$$\boldsymbol{df}_{\boldsymbol{time/condition}} = (\boldsymbol{n}-\mathbf{1}) \tag{10}$$

$$\boldsymbol{df}_{\boldsymbol{error}} = (\boldsymbol{k}-\mathbf{1})(\boldsymbol{n}-\mathbf{1}) \tag{11}$$

$With\ correction\ applied, where\ \varepsilon\ is\ the\ general\ correction$:

$$\boldsymbol{df}_{\boldsymbol{time/condition}} = \boldsymbol{\varepsilon}(\boldsymbol{k}-\mathbf{1}) \tag{12}$$

$$\boldsymbol{df}_{\boldsymbol{error}} = \boldsymbol{\varepsilon}(\boldsymbol{k}-\mathbf{1})(\boldsymbol{n}-\mathbf{1}) \tag{13}$$

The former of the two corrections is considered the stricter correction and as such is often applied with the understanding that should the design still have a significant main effect after correction there is no need to apply any other.

Following these, several post-hoc comparisons were explored and reviewed for insight into the context of the data. The primary post-hoc test was a between-contrast comparison for each level and the significance attached to the comparison. This allows insight into the relationship between certain stages of the simulation and the corresponding variable(s) being analysed. These results were less conclusory and more for gaining insight, as such they are only briefly included in the reporting of the results.

4.7 Data Management

All data was stored on a password-protected cloud-based server, accessible only to the researchers directly involved in the study. Additionally, the data was backed up to a password-protected HDD. The anonymity of the participants was maintained, with all participants being represented by alphanumerical ID's instead of names. All data, once reviewed, was committed to the Shared Roots REDcap Database [132] as part of a larger study on stress sensitivity (N13/08/115).

5 Results

5.1 Performance Comparisons

The render times for the different performance metrics were recorded for several runs of each of the simulations (old and new). Each version of the simulation underwent several performance tests, which were then averaged and compared. In addition to testing the simulations under the load of the VR headset, they were also tested without the VR device connected (referred to as 'unloaded'). There were relatively large fluctuations in length of time spent in the simulation, as such - in order to ensure that the length of the test could be neglected as a factor - its correlation with the average framerate was explored and plotted.

The correlation between the length of time spent in the simulation and the average framerate was plotted (see Figure 22) and can be seen to have no significant correlation. Allowing one to safely exclude the length of the time running the simulation for the performance profiling tests.

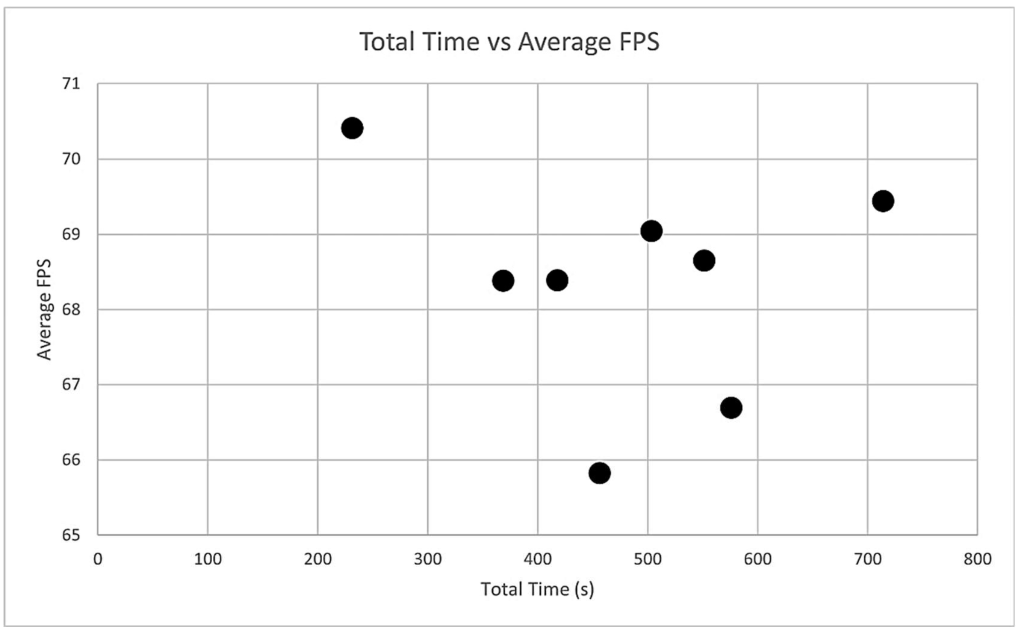

Figure 22 - Graph showing the relationship between the time spent running the simulation and the average frames per second.

For the tests done without any additional load on the system (the VR headset disconnected), the render times for each of the three primary facets of a frame were recorded and plotted. For the application of VR, the goal render time is below 11 ms, ensuring a native framerate of around 90 Hz. Figure 23 shows a comparative bar graph for the two versions, including the render times for the GPU, Render Thread and the Game Time (CPU). Without additional load, both simulations perform very well, with the greatest render time (GPU for both) for the new version just over 10 ms while the old version comes in just below 11 ms.

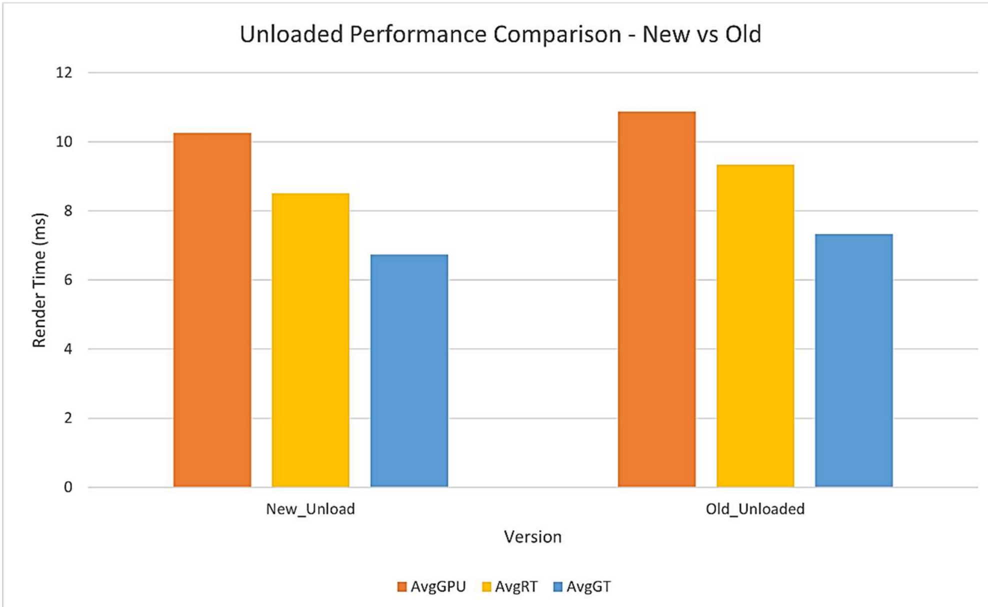

Figure 23 – Comparative bar graph showing the average render times for the GPU, Render Thread and Game Thread. Both versions being compared are unloaded.

However, when placed under the load of the VR device, both versions suffer in terms of performance. As shown in Figure 24, the old version suffers considerably more, with the GPU render time nearly reaching 29 ms per frame. The new version comes in at just under 15 ms, while showing greater consistency between the GPU and the Game Time scores. It is clear that the GPU is causing a bottleneck in the performance of the simulation.

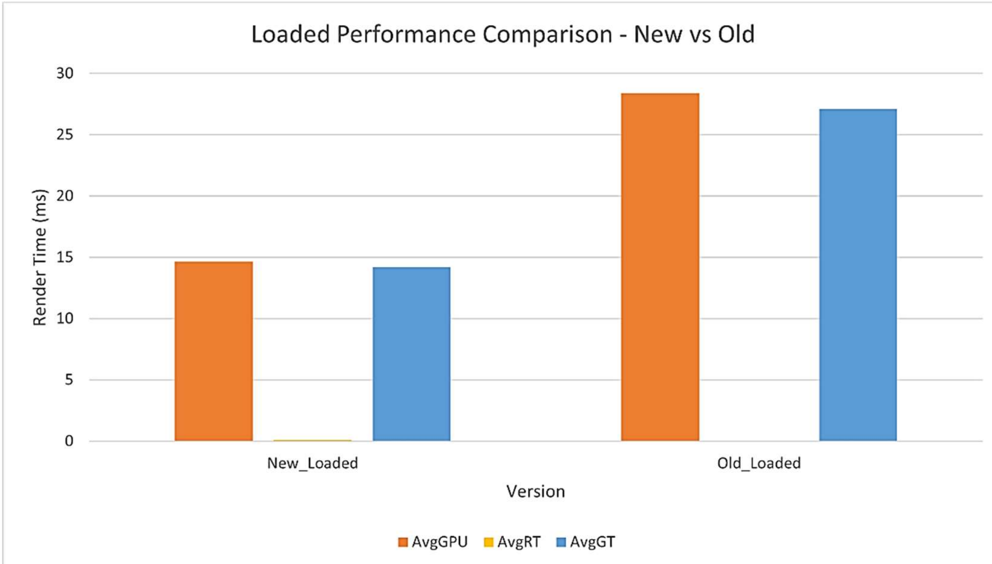

Figure 24 - Comparative bar graph showing the average render times for the GPU, Render Thread and Game Thread. Both versions being compared are loaded.

Finally, the FPS values of each version were compared (shown in Figure 25), including both the loaded and unloaded versions. Here it can be seen that the new version performed considerably better both loaded and unloaded, while showing a smaller difference between the two.

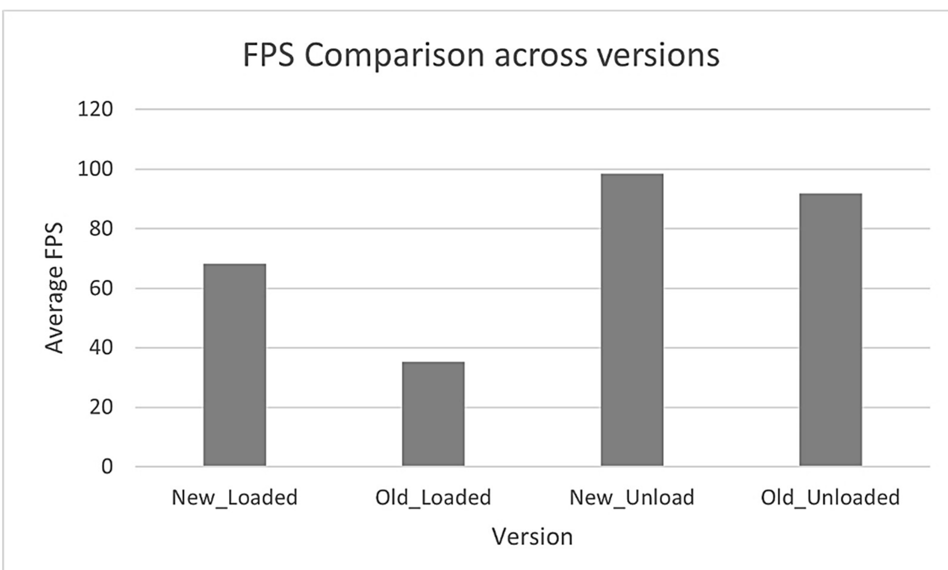

Figure 25 – Bar graph showing the average FPS values for each version (both loaded and unloaded).

5.2 Subjective Appraisals

5.2.1 Acute Appraisals

There was a significant main effect for self-reported nausea, F(1.702, 32.346) = 3.539, p = 0.047. Showing a consistent increase between the baseline and the midpoint of the simulation. Given that the absolute value reported was very low (the maximum mean value being 0.65 out of 10), this increase is considered marginal. Furthermore, there is no reason to suspect any participants under-reported on nausea. There were differences in the standard deviation between the timepoints, with the Mauchly Test of Sphericity showing only minor departure from sphericity ($\varepsilon = 0.851$), but results remained significant after applying the Greenhouse-Geisser correction. The mean values per level are shown in Figure 26 below. Interestingly, the midway (level 2) mean is slightly higher than that of the end period (level 3) mean, suggesting a generalised acclimation to the virtual environment.

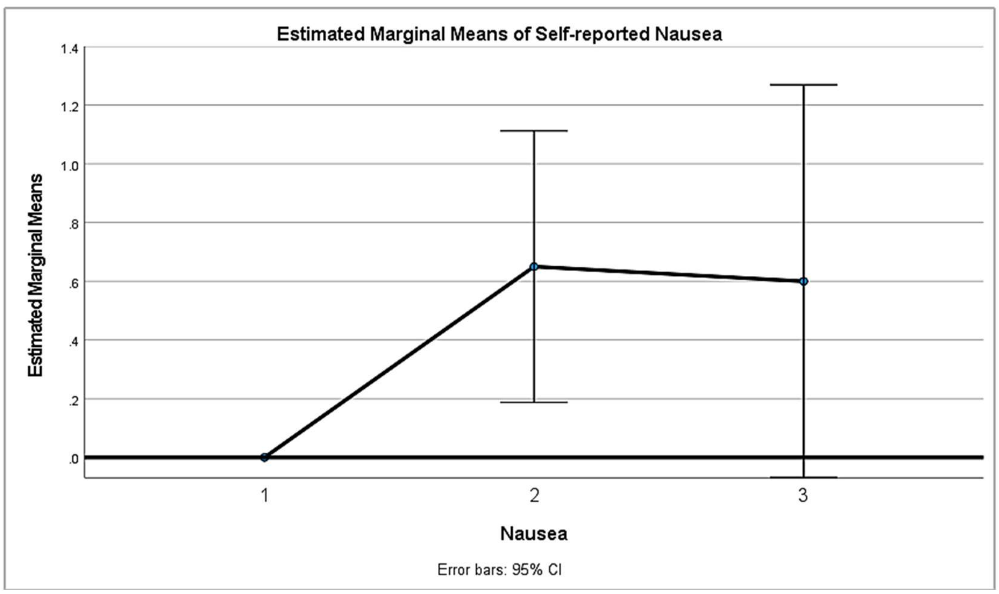

Figure 26 – Graph showing the estimated marginal means of nausea for the Baseline (Level 1), Midway point (Level 2) and the End Period (Level 3).

There was a significant main effect for self-reported dizziness, F(1.355, 25.744) = 5.103, p = 0.023. As for nausea, there was a positive correlation between self-reported dizziness and time spent in the simulation. Similarly, the absolute values reported were very low (the largest mean value was 1.45 out of 10) and thus the increase over time is considered marginal. There were minor differences in the standard deviation between the timepoints, and the Mauchly Test of Sphericity showed only a partial departure from sphericity ($\varepsilon = 0.677$). However, results remained significant after applying the Greenhouse-Geisser correction. The mean values per level are shown in Figure 27.

The correlation between Dizziness and Nausea at the Midway point (Level 2) was not significant, with a correlation coefficient of 0.706 (the largest coefficient between the two variables).

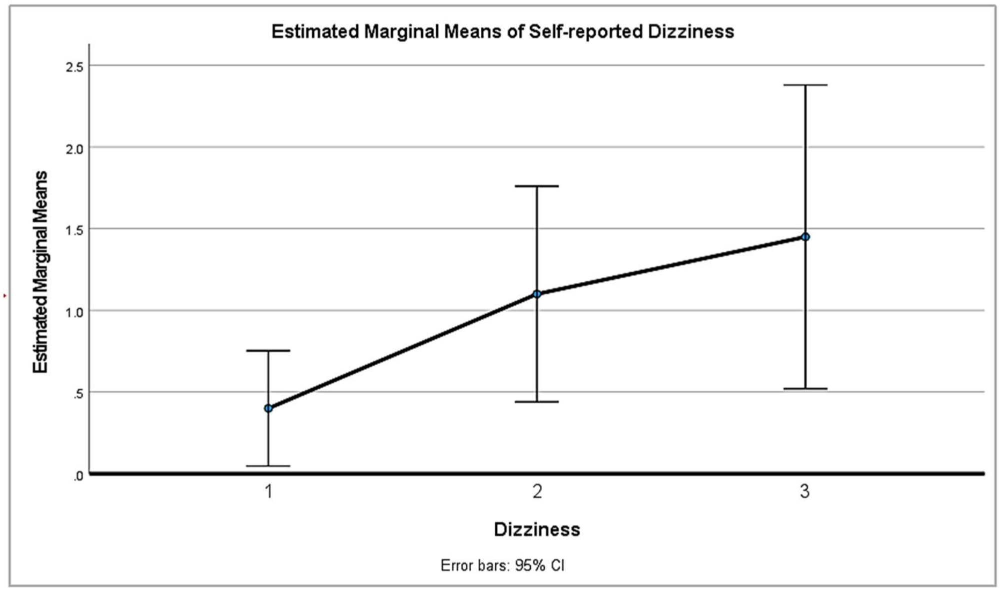

Figure 27 - Graph showing the estimated marginal means of dizziness for the Baseline (Level 1), Midway point (Level 2) and the End Period (Level 3).

There was a significant main effect for self-reported stress levels, F(1.26, 23.94) = 17.962, p < 0.001. As the mean increased, so did the standard deviation of each level – the maximum value of which was 1.777 (mean values shown in Figure 28). Post hoc contrasts between Baseline (Level 1) and Endpoint (Level 3) were significant, F(1, 19) = 24.584, p < 0.001 (Correcting for multiple comparisons using the LSD correction), indicating a significant increase in the subjective levels of stress during the first period of the simulation. Although there existed a partial departure from sphericity ($\varepsilon = 0.63$), the results remained significant after the Greenhouse-Geisser correction was applied.

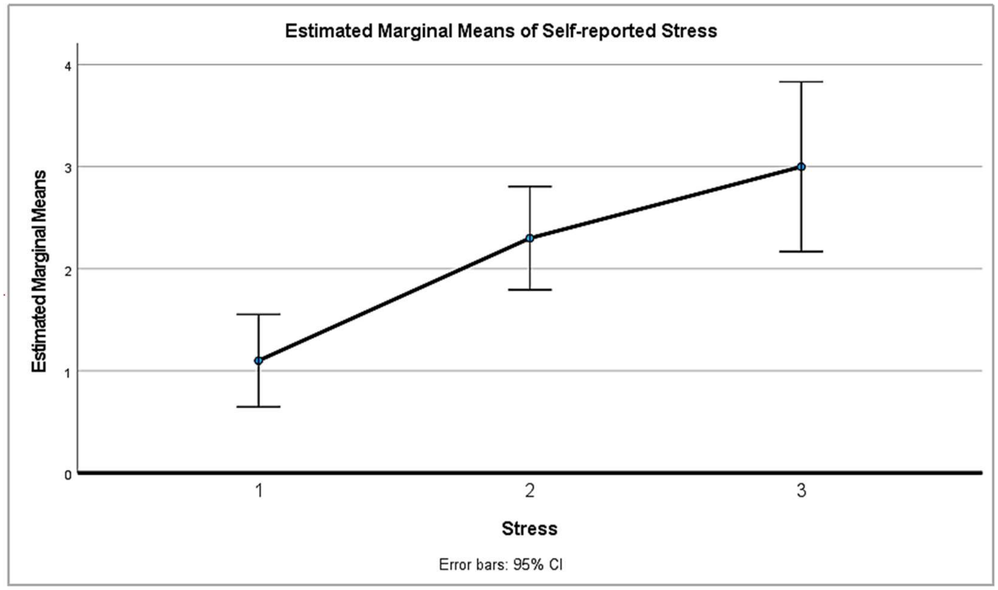

Figure 28 - Graph showing the estimated marginal means of stress for the Baseline (Level 1), Midway point (Level 2) and the End Period (Level 3).

There was a significant main effect for self-reported anxiety, F(1.47, 27.934) = 15.862, p < 0.001, with only minor differences between the standard deviation scores of each level (maximum of 1.877). Post hoc contrasts between the Baseline (Level 1) and the Endpoint (Level 3) were also significant, F(1, 19) = 19.279, p < 0.001 (correcting for multiple comparisons using the LSD correction). The departure from sphericity was minor ($\varepsilon = 0.735$) with the results remaining significant after the Greenhouse-Geisser correction was applied. The mean values per level are shown in Figure 29 below.

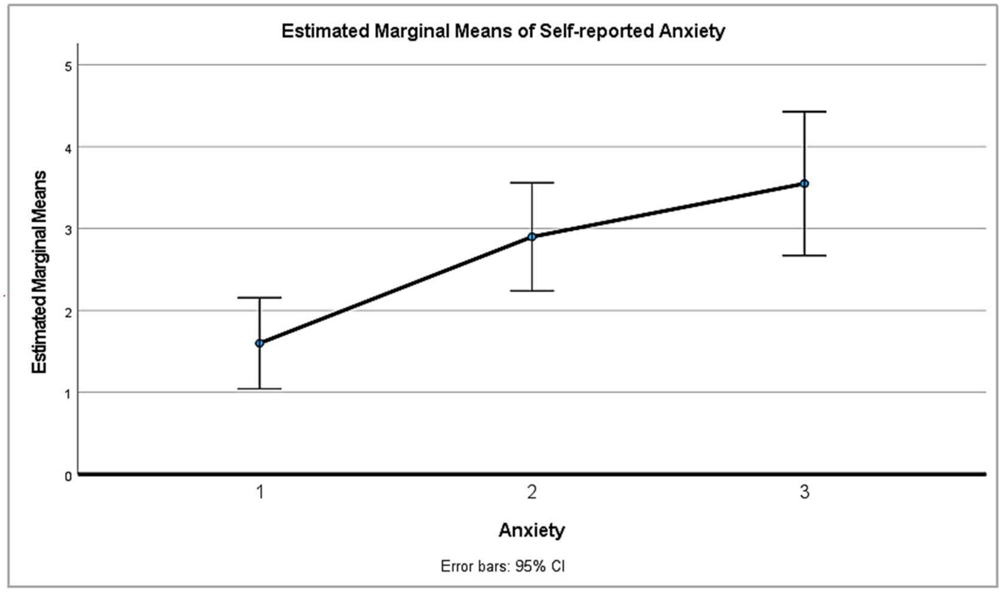

Figure 29 - Graph showing the estimated marginal means of anxiety for the Baseline (Level 1), Midway point (Level 2) and the End Period (Level 3).

The correlation between anxiety and stress was significant, with a correlation coefficient of 0.852 at the End Period timepoint (Level 3). There was no significant correlation between the other two levels.

5.2.2 Presence Score

The Presence Score had no significant correlation to any other variable, subjective or physiological. The greatest correlation was with the self-reported End Period stress levels (with a coefficient of only 0.543), and the CDA score at event 2 (coefficient of 0.527).

As shown in Figure 30, the values of the Presence Score feature varied greatly and erratically. By comparing this to the Figure 31 (Graph for CDA at timepoint 4) it is clear that there are no clear correlations between the troughs and peaks of either feature.

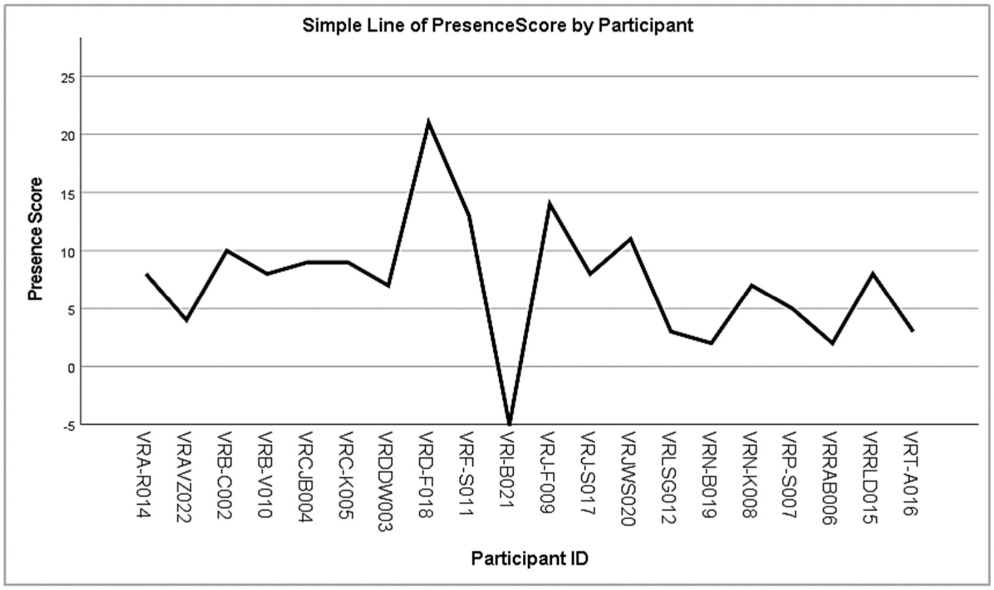

Figure 30 - Line graph showing the presence scores across participants.

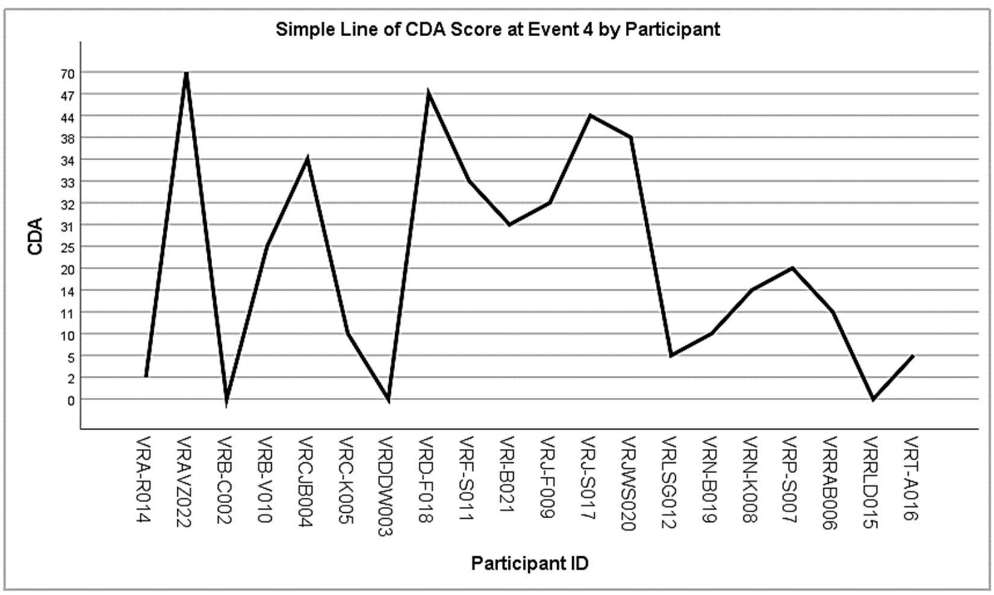

Figure 31 - Line graph showing the CDA count at level 4 (the mean score maximum peak) across participants.

5.3 Physiological Measurements

There was no main effect found for the mean EDA across the timepoints, F(2.31,43.84) = 0.667, p = 0.539. There was variance fluctuation observed between each of the levels with large standard deviation values (as shown in Figure 32). There was considerable departure from sphericity ($\varepsilon = 0.288$) and no main effect was found after applying the Greenhouse-Geisser correction. Post hoc contrasts between levels revealed no significant relationships.

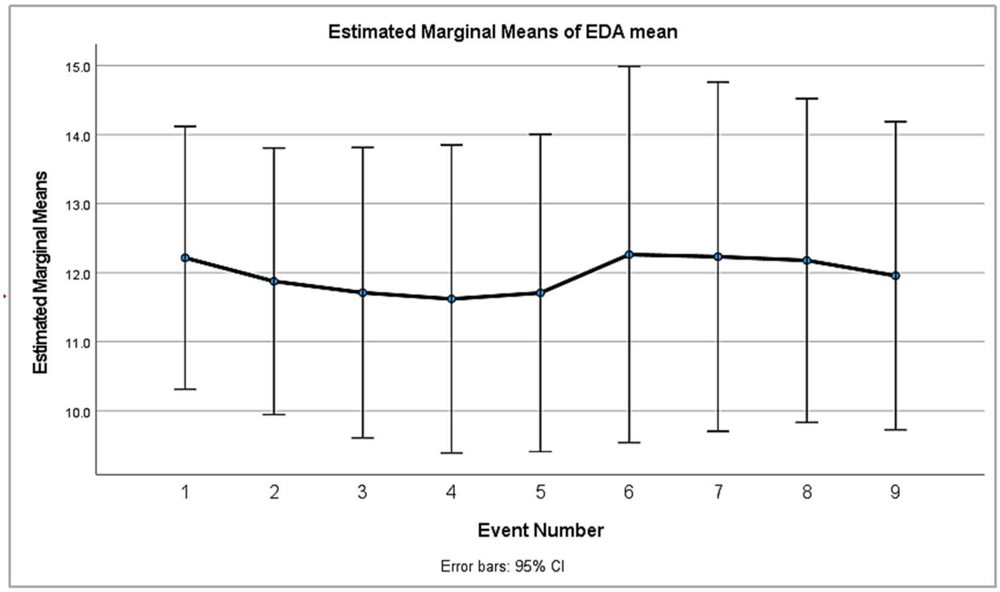

Figure 32 - Graph showing the estimated marginal means of the EDA means for each event (Level 1 to 9).

There was a significant main effect for the CDA values across the timepoints, F(3.902,74.136) = 10.337, p < 0.001. Fluctuations were observed between the standard deviation values of each timepoint, with relatively large values appearing for levels with larger mean values (as shown in Figure 33). Post hoc contrasts (with the Bonferroni correction applied) between Baseline (Level 1) and Midpoint (Level 5) were significant, F(1,19) = 14.084, p = 0.001, indicating a significant increase in the number of stress events during the first half of the simulation. Two clear peaks can be seen in the graph represented by Figure 33, one appearing near the midway point (level 4) and a smaller peak appearing right before the final timepoint (level 8).

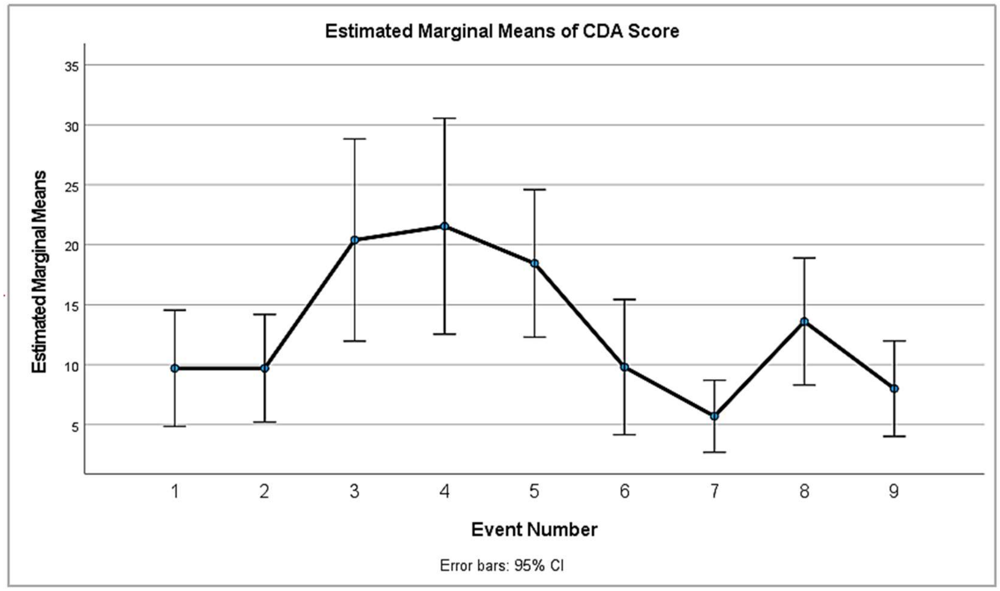

Figure 33 - Graph showing the estimated marginal means of the CDA scores for each event (Level 1 to 9).

There was a significant main effect for TTP values across the timepoints, F(1.784,33.901) = 3.368, p = 0.051. Variance fluctuations were observed between the standard deviation values of each timepoint, with the values appearing in relative sizes for each of the timepoints (as shown in Figure 34). Post hoc contrasts (with the Bonferroni correction applied) between Baseline (Level 1) and Midpoint (Level 5) were not significant, F(1,19) = 3.725, p = 0.069. The significant effect amongst the contrasts instead exists between Baseline (Level 1) and Level 4, F(1,19) = 12.594, p = 0.002. Similar to the CDA means graph (shown in Figure 33), the graph for the TTP values (Figure 34) shows two clear peaks – appearing in the same locations as for the CDA means graph.

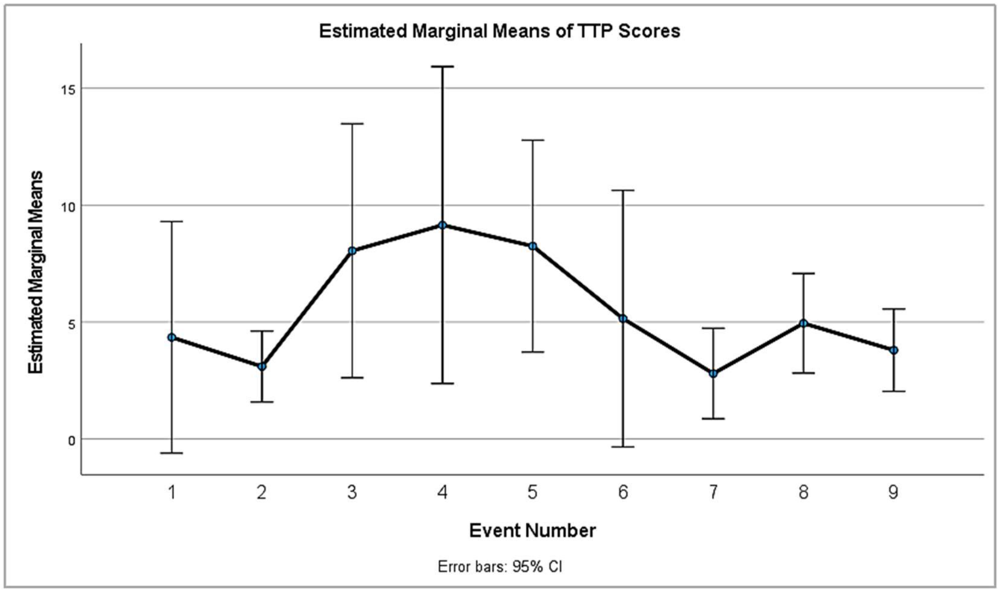

Figure 34 - Graph showing the estimated marginal means of the TTP scores for each event (Level 1 to 9).

5.4 Discussion

The results from the study show a promising summary of several aspects. Premised by successful performance results, showing that the optimization efforts paid off both in terms of the experience and the performance of the simulation, the paradigm operated as intended. Firstly, it is clear that nausea (a measurement for the onset of motion sickness) was well-controlled and almost entirely mitigated – with the largest mean for self-reported nausea being only 0.65 out of 10. Additionally, dizziness (another measurement for onset of motion sickness) showed very similar results – with a peak mean of 1.45 out of 10. In context of the hypothesis, the value representative of physiological stress (the CDA scores) supports the success of the paradigm. The CDA means across all participants consistently peak at the same points in the simulation and show meaningful significance when compared to the stimuli and their corresponding events. Furthermore, the self-reported stress and anxiety levels of all the participants support the findings from the physiological data – with both showing significant main effects and encouraging post hoc test results. Unfortunately, there was no significant correlation between the Presence Score metric and any of the other variables. This is most likely due to the fact that the IPQ used covered the experience of both paradigms done as part of the testing and combined them into a single value. Additionally, anomalies in the testing process (such as one participant experiencing blurry vision and headaches due to problems with their contact lens prescription) seemed to greatly affect the outcome of the Presence Score.

Motion sickness has often been cited as the primary risk associated with exposure to VR and a major limiting factor in the application of VR in psychotherapy. Successfully mitigating and controlling this not only adds to the success of the paradigm in its primary aim, but also provides a set of guidelines for achieving this in future projects. Following this, the consistency with which the paradigm was able to induce feelings of stress and anxiety validates it as a tool for exposure therapy. Further supporting this is the fact that only implicit stressors were used, a key factor in successfully designing a versatile psychotherapy intervention paradigm.

In contrast to the previous studies done, this study focused heavily on the performance of the paradigm itself while maintaining the vital aspects of an effective exposure therapy simulation. Many of the previous studies mixed explicit and implicit stimuli while this study included only implicit stimuli – suggesting encouraging potential for more versatile paradigms. With its focus on the performance of the paradigm, the influence of the stimuli in the environment itself could be more accurately measured, without the presence of uncontrolled variables (such as low framerate causing motion sickness). Another key difference is the local context of which the study builds upon, with strong implications towards the nature of crime and violence within South Africa. The philosophy behind the criteria for choosing the design aspects of the environment suggest that the paradigm's success only further support the complex nature of the relationship between the local populace and violent crime. It is clear that there is a need for more locally contextualised paradigms and studies, given that the success of this paradigm was hinged on the assumption that the average South African is implicitly aware of the potential for violent crime in places like the one designed.

Unsurprisingly, this study faced several limitations. Some of which can be accounted for in future and mitigated, and some of which were beyond control. COVID-19 played a large role in many of the limitations affecting the study – primarily during the data acquisition phase. The lockdown and health restrictions limited the recruitment process, and as such the sample size was smaller than originally desired. Fortunately, a sufficient sample population was still acquired for validation purposes. Due to some technical issues the physiological feedback types were limited to EDA only. Although the research suggests that this is sufficient for measuring emotional arousal during VR psychotherapy paradigms, it was our intention (originally) to include both EDA and ECG feedback in the results. In the context of physiological feedback limitations, it was also found that the wires required for the acquisition of the data negatively impacted some of the participants experiences – being either hyperaware of the attachments or requiring to be relocated to ensure the connection remains intact. Fortunately, the primary limitations of many studies involving VR did not seem to have any significant effect on the success of the paradigm – with both performance and motion sickness being well-controlled.

Regarding the limitations of hardware, the simulation itself evolved quite dramatically throughout the design process. Initially, the high-end desktop used was chosen to ensure as little hardware limitation as possible. However, later during the optimization of the simulation, it was found that it could be run – without issue – on a laptop (albeit a high-end laptop). This knowledge, combined with the knowledge acquired since, provides an encouraging outlook on the success of the optimization process and the accessibility of the simulation.

In the context of the usability of the current framework and the subsequent potential for future work, the most meaningful results were the comments and the feedback from anonymous individuals who acquired a packaged version of the procedural generation script for use in Unreal Engine 4. This, in addition to the feedback from the Unreal Marketplace reviewer(s), provides strong evidence that even the most complex part of the simulation design is user-friendly and re-usable for future work.

Going forward, I look to improving on the design of the simulation further, both in the context of improved technology and my growing skills. Given the chance, there are several skills and concepts that I had only learned near the end of the project itself, that I believe – if implemented – would greatly improve the performance and efficacy of the paradigm. These include (but are not limited to): further improvements on conservative topology, better use of Unreal Engine's LOD (Level of Detail) system, improved environment design and a more concise simulation.

Overall, the success of the paradigm and its validation as a tool for facilitating VRET has been made clear by the results in all sections. This study adds to the growing support for VR in psychotherapy and will potentially have a major impact on the viability of VR in other forms of psychotherapy. Furthermore, the success in the context of the optimization of the simulation could have a significant impact on the accessibility and increased efficacy of custom paradigms, decreasing the reliance on the improvement of the technology. Acting as a rough guideline for the design of VR paradigms for use in psychotherapy, there is great potential for this study to catalyse a greater focus on optimization and efficiency of design. Finally, the local context in which the study draws focus greatly supports and potentially highlights the usefulness and need for a greater focus in this area.

6 Conclusion

The simulation designed as a tool for the facilitation of VRET in the treatment of PTSD showed encouraging results in the context of the aim, objective and hypothesis. The simulation was able to consistently reproduce physiological results that showed effective inducement of stress, while being specifically designed around a structured event (stimuli) layout. The subjective (self-reported) appraisals of the participants strongly supported the physiological data and further supported the hypothesis in the importance of the mitigation of motion sickness. There were no reports from participants of nausea or dizziness that negatively affected their experience, and every participant was able to complete the simulation without any issues. Given the success of the performance profiling results – showing the successful optimization of the simulation compared to previous versions – combined with the reduced motion sickness markers, the primary aims of the study have been met. This study supports the efficacy and validity of the simulation as a VRET paradigm for use in the treatment of PTSD.

With the detailed layout of the simulation design and the guidelines provided throughout, this project also serves as a foundation for further work. Providing recommendations for improvements in design, method and approach, this study shows potential for future work on the subject. Furthermore, the results shown support the hypotheses posited in the context of simulation design, optimization, and their effect on the efficacy of a VRET paradigm. Given the scope of the study, support for further work can be drawn from multiple sections and provide guidance for various topics – both aligned with this study and adjacent topics.

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Appendix A Ethics Approval

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

Approval Letter
Progress Report

12/07/2021

Project ID: 8044

Ethics Reference No: N18/10/108

Project Title: Social stress in a virtual environment and its relationship with childhood trauma in early schizophrenia

Dear Dr S Du Plessis

We refer to your request for an extension/annual renewal of ethics approval dated 21/06/2021.

The Health Research Ethics Committee reviewed and **approved** the annual progress report through an expedited review process.

The approval of this project is extended for a further year.

Approval date: 10 July 2021

Expiry date: 09 July 2022

Kindly be reminded to submit progress reports two (2) months before expiry date.

Where to submit any documentation

Kindly note that the HREC uses an electronic ethics review management system, *Infonetica*, to manage ethics applications and ethics review process. To submit any documentation to HREC, please click on the following link: https://applyethics.sun.ac.za.

Please remember to use your Project Id 8044 and ethics reference number N18/10/108 on any documents or correspondence with the HREC concerning your research protocol.

Please note that for studies involving the use of questionnaires, the final copy should be uploaded on Infonetica.

Yours sincerely,

Melody E Shana
Coordinator: Health Research Ethics Committee 1

National Health Research Ethics Council (NHREC) Registration Number:
REC-130408-012 (HREC1)•REC-230208-010 (HREC2)

Federal Wide Assurance Number: 00001372
Office of Human Research Protections (OHRP) Institutional Review Board (IRB) Number:
IRB0005240 (HREC1)•IRB0005239 (HREC2)

The Health Research Ethics Committee (HREC) complies with the SA National Health Act No. 61 of 2003 as it pertains to health research. The HREC abides by the ethical norms and principles for research, established by the World Medical Association (2013). Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects; the South African Department of Health (2006).Guidelines for Good Practice in the Conduct of Clinical Trials with Human Participants in South Africa (2nd edition); as well as the Department of Health (2015). Ethics in Health Research: Principles, Processes and Structures (2nd edition).

The Health Research Ethics Committee reviews research involving human subjects conducted or supported by the Department of Health and Human Services, or other federal departments or agencies that apply the Federal Policy for the Protection of Human Subjects to such research (United States Code of Federal Regulations Title 45 Part 46); and/or clinical investigations regulated by the Food and Drug Administration (FDA) of the Department of Health and Human Services.

Appendix B Informed Consent Form

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

Measuring physiological responses associated with social stress in a virtual environment and its relationship with childhood trauma in early schizophrenia - A Pilot Study

REFERENCE NUMBER:

PRINCIPAL INVESTIGATOR: Dr S du Plessis

ADDRESS:

Department of Psychiatry

Faculty of Health Sciences

Stellenbosch University

PO Box 19063, Tygerberg 7505

Cape Town

CONTACT NUMBER: (021) 9103605

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

The study will be conducted at the Stellenbosch University. We are recalling a group of around 80 people that took part in the Shared Roots study conducted between 2014 and 2017 to take part in this study. In this study we will be evaluating your response while you perform a few tasks in Virtual reality. Virtual Reality refers to a reality or environment created by a computer. In this study we will have different environments that the computer created and you will be asked to place a helmet on your head which has two small TV screens for each one of your eyes. As you move your head the pictures will change, allowing you to move relatively freely through the different environments created by the computer. We want to measure how your body responds when you do an activity in VR. In the future we hope to treat people suffering from stress in environments such as these.

One of the environments will include a platform which you will be standing on, that will slowly lift to the ceiling. For another, you will be asked to walk through a recreation of a local suburb, following green sign-posts. Finally, you will be asked to give a short speech in front of a virtual audience. To measure how your body responds to these at times stressful situations we will monitor your heart rate, breathing and place a small patch on your hand and beneath your eye, which will measure how your skin responds.

Additionally, a light headband-type device will be placed on your head that will be used to measure brain wave responses, via saturated electrodes that will be pressed against your head. We will also play sudden loud sounds during the course of some of the virtual reality tasks. Although they are loud, they should not hurt your ears. You will also be asked to spit in a cup for us, as we will be measuring the amount of stress hormones your body excretes during the course of the task. Finally, we will ask you at various intervals during the task how stressful you are finding it. Should you at any moment like to discontinue with the study for whatever reason, you are encouraged to do so.

Why have you been invited to participate?

You have been invited to participate as you previously have taken part in our last study, the Shared Roots study. We are looking for volunteers that reached the age of 18 or more, both male or female. We are looking for potential participants that speak fluent English or Afrikaans and that completed grade 7 of the standard education.

What will your responsibilities be?

We will ask you to complete a set of questionnaires and will be asking you some questions regarding your mental health. Besides this, you will only have to follow the path through the virtual environments using a controller you will be guiding with your thumbs. We will ask you to sit down and to tell us if you are feeling dizzy, nauseous or excessively stressed.

Will you benefit from taking part in this research?

There will be no personal benefits should you decide to participate in the research. However, you will have the chance to experience what it is to be in a virtual environment and your involvement in the research will help us as researchers and doctors to have a better understanding of the impact of stress on one’s mind and body. This information could help us to treat people suffering from stress and other mental illnesses in the future.

Are there any risks involved in your taking part in this research?

There will be no serious risks involved should you take part in the study. VR has proven to have little or no long-term side-effects. However, you may experience some nausea and dizziness during the VR activity. You will be seated to avoid potential disorientation during a VR session. You will be informed to slowly move your head to avoid dizziness. You will be given a short break every 15 minutes during a VR session. If you feel dizzy/ nauseous the helmet on your head will be removed immediately. If you do not tolerate the virtual environment well, you will not be expected to complete the task. Some study volunteers might find our VR tasks to be particularly distressing. Like those who have experienced particularly distressful things in their childhood for instance. Should you experience significant distress or start to re-experience particularly intense emotions or experiences from your past, we will refer you for further care to a private healthcare provider or your local clinic.

If you do not agree to take part, what alternatives do you have?

If you do not agree to take part you can simply leave the study without any repercussion.

Who will have access to your medical records?

We will not have access to your medical records and all information collected during the study will be treated as confidential and protected. Should we publish information collected through this study in a journal or part of a thesis, the identity of the participant will remain anonymous. The research team will be the only people to have access to the information collected. The information will only be used for research and development purposes and will remain anonymous. Should data ever be shared with local or international collaborators, your identifying data will be removed. Data will be stored for 5 years in an access-controlled electronic database.

What will happen in the unlikely event of some form of injury occurring as a direct result of your taking part in this research study?

We don't foresee any form of injury occurring during the tests. You will be referred to the appropriate medical services should we pick up anything during the course of the study. In the very unlikely event that you should experience severe psychological distress as a result of your participation in the study, we will refer you to the appropriate psychiatric/psychological services as soon as possible.

Will you be paid to take part in this study and are there any costs involved?

No, you will not be paid to take part in the study, but your transport and meal costs will be covered for each study visit. There will be no costs involved for you, if you do take part.

Is there anything else that you should know or do?

- You can contact Sr Retha Smit at 082 805 8225 for urgent matters. If you would like to discuss something with the doctor, you can use the same telephone number.
- You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your study doctor.
- You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I …………………………………..…………. agree to take part in a research study entitled ***Measuring physiological responses associated with***

social stress in a virtual environment and its relationship with childhood trauma in early schizophrenia *- A Pilot Study*.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ....…........…………….. on (*date*) …………...……….. 2019.

Signature of participant **Signature of witness**

Declaration by investigator

I *(name)* …………………………………………..……… declare that:

- I explained the information in this document to …………………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use a interpreter. (*If a interpreter is used then the interpreter must sign the declaration below.*

Signed at (*place*) ....…........…………….. on (*date*) …………....……….. 2019.

Signature of investigator **Signature of witness**

Declaration by interpreter

I *(name)* …………………………………………..……… declare that:

- I assisted the investigator (*name*) ………………………………………. to explain the information in this document to (*name of participant*) ……………..…………………………….. using the language medium of Afrikaans/Xhosa.

- We encouraged him/her to ask questions and took adequate time to answer them.

- I conveyed a factually correct version of what was related to me.

- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at (*place*) ....…........…………….. on (*date*) …………....………………..

Signature of interpreter **Signature of witness**

Appendix C COVID-19 Questionnaire

Participant ID

* must provide value

Participant ID

Covid19 screening:

	Yes	No	
a. Have you been tested for Covid-19? If so, what were the results?	○	○	reset
b. Have you been in close contact with a COVID-19 case?	○	○	reset
c. Have you been feverish or are you having body chills?	○	○	reset
d. Do you have a cough OR runny nose OR sore throat?	○	○	reset
e. Have you had contact with a person with flu like symptoms?	○	○	reset
f. Do you have new onset of loss of smell or loss of taste?	○	○	reset

Appendix D Modified Stress Appraisal Questionnaire

Please rate how much of each emotion you are currently experiencing, on scale of 1 to 10:	
Emotion	Rating out of 10
Stress	
Anxiety	
Nausea	
Dizziness	

Appendix E Presence Questionnaire

Igroup Presence Questionnaire (IPQ)

	-3	-2	-1	0	1	2	3	
How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)? (extremely aware/ not aware at all)	○	○	○	○	○	○	○	reset
How real did the virtual world seem to you? (completely real/ not real at all)	○	○	○	○	○	○	○	reset
I had a sense of acting in the virtual space, rather than operating something from outside. (fully disagree/ fully agree)	○	○	○	○	○	○	○	reset
How much did your experience in the virtual environment seem consistent with your real world experience ? (not consistent/ very consistent)	○	○	○	○	○	○	○	reset
How real did the virtual world seem to you? (about as real as an imagined world/ indistinguishable from the real world)	○	○	○	○	○	○	○	reset
I did not feel present in the virtual space. (did not feel/ felt present)	○	○	○	○	○	○	○	reset
I was not aware of my real environment. (fully disagree/ fully agree)	○	○	○	○	○	○	○	reset
In the computer generated world I had a sense of "being there". (not at all/ very much)	○	○	○	○	○	○	○	reset
Somehow I felt that the virtual world surrounded me. (fully disagree/ fully agree)	○	○	○	○	○	○	○	reset
I felt present in the virtual space. (fully disagree/ fully agree)	○	○	○	○	○	○	○	reset
I still paid attention to the real environment. (fully disagree/ fully agree)	○	○	○	○	○	○	○	reset
The virtual world seemed more realistic than the real world. (fully disagree/ fully agree)	○	○	○	○	○	○	○	reset
I felt like I was just perceiving pictures. (fully disagree/ fully agree)	○	○	○	○	○	○	○	reset
I was completely captivated by the virtual world. (fully disagree/ fully agree)	○	○	○	○	○	○	○	reset

Appendix F Adapted Computer Familiarity Questionnaire

	Every day	A few times a week	Once a week	Between once a week and once a month	Once a month	Never
How often is there a computer available for you to use at these places?						
At home						
At school						
At work						
In the library that you use						

	Ever y day	A few time s a week	Onc e a week	Betwee n once a week and once a month	Once a mont h	Neve r
How comfortable are you with using a computer?						

How comfortable are you with using a 'mouse'?						
How comfortable are you with using a computer to write a paper?						
How comfortable are you with taking a [~~TOEFL~~] test on a computer?						
How many examinations/test s have you taken on a computer?						
How would you rate your ability to use a computer?						

	Every day	A few times a week	Once a week	Between once a week and once a month	Once a month	Never
How often do you use a mobile phone to get information or buy something?						
[Removed]						
How often do you use an automatic banking machine (ATM)?						
How often do you use an automatic ticket machine to buy a ticket for a bus, train, airplane, or parking garage?						
How often do you use a computer?						
If you answered 'Never' to the previous questions, you do not need to fill out the rest of this section.						

	Every day	A few times a week	Once a week	Between once a week and once a month	Once a month	Never
How often do you use the Internet?						
How often do you use a computer to send or receive electronic mail (e-mail)?						
How often do you use a 'mouse' with a computer?						
How often do you use each of the following kinds of computer software programs?						
Games						
Word processing in your native language						
Word processing in English						
Spreadsheets (e.g. Excel)						
Graphics						

(VR Familiarity Section)				
	Yes	No		I am unsure
Are you familiar with the term Virtual Reality?				
Have you ever worked with Virtual Reality before?				
If you answered 'No' to the previous question, you do not need to fill out the rest of this section.				
	Never	Once	A few times	More often
How many times have you used Virtual Reality hardware/software?				
Which of the following contexts have you used Virtual Reality technology for?				
Gaming				
Software Development				
Multimedia (e.g. Painting, Making a movie etc.)				
Medical Trials/Testing				

Other (Please specify): ……………………….				