University of Sheffield

Developing a Virtual Reality Exposure Therapy System for Self-Treatment of Common Phobias

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A report submitted in fulfilment of the requirements
for the degree of BEng in Computer Science

in the

Department of Computer Science

May 12, 2020

Declaration

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Abstract

Virtual Reality - a technology that allows users to transport themselves into entirely simulated, digital worlds of their choosing, has finally arrived on the consumer market. This technology presents a number of opportunities, particularly in therapy.

Exposure therapy is a psychological treatment to aid the patient in combating phobias and anxiety disorders. While often effective, it suffers from many limitations that can be removed by adapting existing treatments to be delivered through a virtual reality system in the patient's own home. The aim of the project is to develop a virtual reality exposure therapy system for a modern day, commercially available head mounted display. The system will act as a "virtual therapist" that will guide patients through their treatment, introducing stimuli, and tracking their progress.

Acknowledgements

First and foremost, I'd like to thank Dr. Heidi Christensen for agreeing to supervise my project, and for suffering through all the spider-related creepiness I could come up with. Without the constant guidance and feedback, this project simply would not have been possible. I'd also like to thank Professor Glenn Waller for his invaluable insight into exposure therapy principles and applications, this proved really useful in showing me where to focus my research early on. Finally, I'd like to say a big thank you to all my testing participants for facing their fears and giving me some great data and feedback.

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Glossary

Below is a list of terms defined in the context in which they are used throughout this report.

- **VR / Virtual Reality:** The field of applying motion sensing technology to immerse the user in a virtual environment.
- **Virtual Environment:** A digitally created space simulated by a computer, similar to environments employed in video games. Designed for use with VR hardware, these can contain any number of objects and behaviours for the user to interact with.
- **HMD / Head Mounted Display / VR Headset:** A virtual reality device that fits over the user's head and provides a dynamic view of the virtual environment.
- **FPS / Frames per Second:** The number of times the image on a screen is updated to give the impression of motion. Higher framerates result in a smoother video.
- **Imaginal Exposure:** The discussion or imagination of a stimulus.
- **In vivo Exposure** Physically confronting a stimulus. This report uses the term when referring to the realistic confrontation of the stimulus in a virtual environment.
- **SUDS / Subjective Unit of Distress:** A quantitative measurement of distress from a patient.
- **Oculus Rift CV1:** The first consumer version of the VR headsets manufactured by Oculus.
- **Haptic Feedback:** Tactile output from a system, typically in the form of vibrations. Provides the user with some physical feedback during appropriate times.

Chapter 1

Introduction

1.1 Background

The core principle of exposure therapy is to have the patient confront their fear, either by simply talking about a particular stimulus, or by physically confronting the stimulus the patient is afraid of. This treatment is often used to treat disorders such as PTSD, but also for more common phobias, such as fear of spiders, fear of flying, and so on. While these phobias may seem less significant than a disorder such as PTSD, many people find the symptoms extremely debilitating, and thus turn to exposure therapy. The problems with this treatment arise when one starts to consider the practicality of the stimuli themselves, how does a patient confront a fear of flying without physically boarding a plane? How does a patient confront a fear of open spaces without leaving the safety of their home to go their appointment with a therapist? Even without considering these problems, the very nature of appointments themselves introduce limitations. They are often expensive, inconvenient for the patient, and cannot be booked as regularly as may be effective. What many of these patients may not be aware of, is that they may already own a device that can allow them to circumvent all these limitations while still obtaining effective treatment - a virtual reality headset.

While virtual reality devices have existed is some form or another for over 50 years, it has only been very recently that this technology has successfully reached the consumer market. While virtual reality itself is a rather broad term, this report will be referring to virtual reality head mounted displays, rather than other variations of this technology. While these devices are far from being present in the majority of households, they are more common than many may think. A significant proportion of VR headset owners purchased their devices for the purpose of playing video games, and consuming other digital media. It therefore seems sensible to look to Steam, the world's largest distribution platform of digital media, for an idea of just how many people are in possession of this technology. Looking at the most recent hardware survey at the time of writing [1], approximately 1 percent of users responding to the survey own a VR headset. While this may sound insignificant, there are approximately 14 million users actively logged on to the platform at the exact time of writing, as per Steam's own statistics [2]. This equates to at least hundreds of thousands of VR headsets within everyday households, and thus there is a significant demographic of people who could potentially benefit from a virtual reality exposure therapy treatment system.

1.2 Aims and Objectives

The goal of this dissertation project is to analyse conventional methods of exposure therapy, as well as implementations of virtual environments, to design and develop a virtual reality exposure therapy system for the treatment of a variety of common phobias. In order to make use of the rising adoption of VR hardware within the home, this system will be designed to function independent of an actual therapist. Instead, the system itself will act as a virtual therapist, guiding the user through the treatment through text and vocal cues.

A number of user testing sessions will be run, to help determine the effectiveness of the system, as well as assess ways in which the system can be improved. Rather than tackling disorders such as PTSD, this project aims to address more common, every day fears. This will also simplify user testing, as test subjects with uncommon or volatile disorders will not be required.

1.3 Overview of the Report

Continuing with a literature survey in Chapter Two, this report will investigate common phobias and their effects on patients. The chapter will go on to discuss previous virtual reality exposure therapy systems, and what approach should be taken in the development of a new system, with consideration to common design principles of virtual environments. In Chapter Three, the information gathered in the literature survey will be analysed to determine the best approach when integrating exposure therapy treatment within a virtual environment, allowing the definition of the system's requirements. Once the requirements are in place, the chapter will go on to determine how best to analyse the effectiveness of the system through user testing. Chapter Four will outline the design of both the user testing process, and of the system itself, from a user-oriented perspective, and from an architectural perspective. Chapter Five will detail the work completed for each iteration of the system and discuss key components from a more technical standpoint. Chapter Six will present and analyse the results of the system evaluation, as well as discuss further possible improvements, before the report in concluded in Chapter Seven.

Chapter 2

Literature Survey

This chapter will draw from a multitude of sources to outline the effect that even the most common, everyday phobias can have on the lives of those suffering from them, before investigating the fields of exposure therapy and virtual reality, in order to gain an understanding of how these domains may be combined for the treatment of these phobias. This information will be crucial in the following chapter when devising the overall approach of this project when developing and testing such a system.

2.1 Common Phobias

As the aim of the system is to treat everyday phobias, it is important to first establish which phobias are the most common, and what effect they may have. The most common phobias as detailed in an American study [3] (America being the country with the greatest number of VR headset owners, and thus the largest potential userbase) are listed below in descending order of commonality.

1. **Insects** [4]: More than a simple dislike of insects, entomophobia stems from an irrational fear, and can induce severe physical symptoms, such as hyperventilation, high heart rate, and even panic attacks. For some individuals, the thought of encountering an insect can trigger enough anxiety to make them avoid places or activities where they may be present, placing a considerable limitation on the individual's daily routine.

2. **Heights** [5]: While the symptoms of acrophobia are often only triggered by extreme heights, some individuals experience symptoms even when presented with heights that many would consider mundane, such as footstools and stepladders. These symptoms typically include nausea, disorientation, high heart rate and chest pains. Some individuals will attempt to avoid common situations that trigger their fear of heights, such as climbing stairs, driving along bridges, and even looking out windows.

3. **Storms, thunder or lightning** [6]: During a storm, astraphobia can induce symptoms of nausea, shaking, chest pain and panic attacks. While some individuals suffering from this phobia feel the need to hide themselves from an ongoing storm in a safe place, such as a bathroom or closet, others feel a compulsion to stop what they are doing and monitor the storm until it passes.

4. **Being in or on water** [7]: When presented with even small amounts of water, individuals suffering from aquaphobia can experience symptoms of nausea, difficulty breathing, and intense fear. This can lead to the overall avoidance of even small bodies of water.

5. **Flying** [8]: With symptoms similar to the previous phobias, aviophobia can induce panic even when planning a flight. This can lead many people to avoid air travel completely, significantly restricting leisure and business trips.

6. **Being in closed spaces** [9]: Claustrophobia typically induces symptoms of intense panic, disorientation, and nausea. This can lead people to avoid triggering environments as much as possible, such as elevators, air travel, subways and other public transport, as well as crowded rooms, or rooms without windows.

While many people suffering from these phobias are able to manage them to have a minimal impact, others who experience the symptoms with more severity can find the phobia is of extreme detriment to their everyday lives. These phobias each have a range of treatments, but each of the previously referenced sources for the above phobias highlight **exposure therapy** as a particularly effective avenue of treatment. It is this approach that the project aims to investigate.

2.2 Exposure Therapy Principles and Best Practises

Towards the start of the project, a discussion was held with Professor Glenn Waller, the head of the Psychology Department at the University of Sheffield. This section references that discussion [10] throughout, in addition to other sources.

While exposure therapy often involves the presentation of the physical stimulus the patient is distressed by, the purpose of this is to induce the *thoughts* of the stimulus for the patient to confront. Because of this, many treatments involve a simple discussion of the stimulus, or instructing the patient to hold an image of the stimulus in their head. This is known as imaginal exposure, whereas confronting the physical stimulus itself is known as in vivo exposure, many treatments combine both. To measure the effectiveness of exposure therapy, Subjective Units of Distress (SUDS) are used. This is the self-reported distress the patient is feeling at the time of measurement. There are four main approaches towards exposure therapy, as detailed below.

1. **Graded Exposure** [11]: The stimulus is approached in increments, from the least intense version of the stimulus to the most. Once the user feels comfortable enough, they move on to the next increment on the scale. For example, imaginal exposure may be employed at first, the stimulus may be discussed or images or video may be shown. Then in vivo exposure is introduced, the stimulus may be placed on the far side of the room from the patient, before being moved gradually closer until in physical contact with the patient

2. **Systematic Desensitization** [12]: A variation of graded exposure, the patient is taught a number of relaxation techniques, such as breathing and muscle exercises, before being instructed to define *their own* scale for the stimulus. Once this scale is devised, the patient is exposed to the stimulus at the lowest stage of the scale, and progresses through each stage while exercising their relaxation techniques.

3. **Flooding** [13]: In contrast to systematic desensitization, the patient is subjected to the highest level of the stimulus immediately, rather than gradually progressing through a scale. Usually taking the form of in vivo exposure, the patient will be forced to confront their stimulus in a safe, controlled environment until they stop feeling distressed. For example, the patient may be given a spider to hold in their hands straight away, and instructed to continue until they no longer feel anxious.

4. **Inhibitory Learning** [14]: This technique takes the concept of graded exposure, and attempts to remove the predictability. Rather than progressing gradually from the bottom of the scale to the top, the treatment may start from the middle, and aim to reach the end of the scale as fast as possible, while introducing random variations at each step. For example, if the stimulus was a spider, a different looking spider may be used for each step, or it may be placed in a random part of the room.

Although each method has its own advantages, they are all subject to a number of logistical limitations. Appointments are typically no more regular than weekly, as therapists may have other patients to see, and the patients may not have the time to make regular trips to see their therapist. Were this constraint to be removed, appointments could be as frequently as daily. A further limitation is the logistics of the stimulus itself, it may often be inconvenient or infeasible to provide a physical form of the stimulus to confront in the way in vivo exposure requires. For example, treating a patient for a fear of spiders introduces the need to acquire suitable live specimens, and treating a fear of flying may require the patient to physically board a plane, which is highly impractical in the modern day without intending to make an actual journey. Effectively, these limitations are imposed by the requirement of the treatment taking place in the real world. Through the use of virtual reality technology, it is now possible to conduct the treatment in a *virtual* world, allowing these limitations to be removed.

2.3 Introduction to Virtual Reality

While virtual reality systems can take a multitude of different forms, consumer grade VR systems in the modern day typically take the form of head mounted displays (HMDs); lightweight devices that fit over the user's head and face, which this project will focus on.

As shown if Figure 2.1, HMDs consist of two flat-screen images behind specialized lenses. Each image is projected into a single eye, and shows the same view at a slightly different angle, giving the impression of depth. This provides the user with a three dimensional view of the virtual environment, in the same way they view the physical world. The headset includes on-board motion sensing equipment, allowing the system to track its orientation and lateral movement throughout the room. This effectively allows the system to track the position of the user's head, and translate this into the position of the "camera" within the virtual environment, resulting in an appropriately adjusted view displayed through the headset in real time as the user looks around and moves throughout the space.

Figure 2.1: A typical modern day VR head-mounted display

Many headsets can also be purchased with optional motion controllers, providing the user with "hands" within the virtual environment. As the user's real world view is almost entirely restricted while wearing a VR headset, these controllers can make for an intuitive input device, in place of the user blindly reaching for their keyboard or mouse.

2.4 Previous Virtual Reality Exposure Therapy Systems

Through the use of virtual reality technology, users can be immersed in environments and situations that may be entirely impractical in the real world. When applied to exposure therapy, this effectively allows the patient to confront a wide range of stimuli that they may not be able to through conventional treatment, while remaining in a perfectly safe, controlled environment. Investigating the advantages and limitations of previous implementations of virtual reality exposure therapy will be useful in the design and development of a new system.

2.4.1 Virtual Iraq

Virtual Iraq [15] is one of the most notable examples of virtual reality exposure therapy before the introduction of VR hardware to the consumer market. The system was used to treat soldiers returning from Operation Iraqi Freedom in the mid to late 2000's. During the treatment, the patient was instructed to wear a VR headset with a 3D display, motion tracking capability and integrated directional audio, similar to modern HMDs. This placed the patient within a virtual environment designed to closely resemble Iraq, including representations of cities, roads, and active warzones. The treatment consisted of 90-minute sessions, once a week, for four weeks. The initial session did not use any VR equipment, and instead was focused on eliciting memories and details about traumatic events from the patient. While this served as initial, imaginal exposure for the patient, it also allowed the therapist to use this information to add new aspects to the virtual environment, such as helicopters flying overhead, or gunshots triggering on certain cues to match the patient's memories, tailoring the system to the individual's experiences. The remaining sessions involved the patient using the VR hardware to repeatedly progress through a number of environments. With time, the therapist would add more dramatic cues, such as explosions or fellow soldiers suffering injuries. This could be likened to a graded exposure system, with more distressing stimuli introduced in later stages.

The anxiety levels of the patient were measured using a SUDS scale, and these measurements were taken from the patient every 5 minutes during exposure. Data gathered shows a general decrease in SUDS ratings as the sessions progress. This could easily be integrated with the planned system by simply prompting the user for this input at regular intervals.

In addition to visual stimuli, the system also included tactile stimulation (known as haptic feedback), in the form of a vibrating platform situated beneath the patient's feet. Due to hardware constraints, it would be difficult to implement this into the planned system, although, if motion tracking controllers are to be supported, the haptic feedback of the *controllers* could be utilised to provide vibration limited to the user's hands, rather than their whole body.

2.4.2 Fearless VR

While Virtual Iraq focused on user specific stimuli to treat PTSD, the introduction of modern VR hardware to the consumer market has prompted the development of more generalised VR exposure therapy applications, for common fears and phobias. Released in 2016, "Fearless" [16] is an example of such a system. Developed for the Oculus Rift CV1, the system features interaction with three stimuli: cockroaches, spiders and bees/wasps.

The user is placed within a single virtual environment, representing a home office / study. The flow of the system begins with a prerecorded voice-over giving a brief description of how the application works. The user is prompted with a questionnaire, asking them to check a number of stimuli they are afraid of; however, this information does not seem to feed back into the user's treatment later in the flow of the system, instead, this information is likely sent back to the developer for their own analysis. A graded exposure approach is taken, with the user first being presented with a 2D cartoon image of their chosen stimulus, accompanied by a voice-over detailing various educational facts on the stimulus. This is effectively the lowest level of the scale previously mentioned. The system progresses through levels of increasing "difficulty". For example, the spider stimulus uses spiders of increasing size, before adding more spiders, and finally a large spider descending from the ceiling. A notable limitation of the system is that the behaviour of each stimulus appears to be entirely predefined, with no dynamic interaction between the stimulus and user, for example, the pathing of the spider is not affected by the user's position or actions. After each stage, the system prompts the user to enter a SUDS rating, although, this data once again does not appear to be used for the benefit of the user's treatment.

The system retains no memory of previous treatment sessions. Each time the application is launched, the user must begin from the lowest level of their stimulus. While there is functionality allowing the user to skip sections of the voice-over, effectively hastening their progression through the scale, it still takes a few minutes to reach the final stages. Were the user only wanting to experience the most difficult stages (perhaps because they have already become comfortable with the lower ones), they would have to progress through every previous step first. While the voice-over does provide encouragement for the user to proceed to the next stage, there is no other incentive for the user to push themselves to more difficult stages.

2.5 Virtual Environment Principles and Best Practises

When developing a new VR exposure therapy system, it will be important to pay careful attention to virtual environment design principles. While adhering to these practices may not necessarily impact the *content* of the treatment, it will have a significant effect on the comfort and usability of the system overall.

2.5.1 Simulator Sickness

Simulator sickness [17] is best explained by likening it to motion sickness. An individual may be a passenger in a car, reading a book as the car goes round a turn. The individual's vestibular system (the sensory system in the inner ear that measures balance and spatial orientation) is experiencing motion, and relaying this information to the brain. The individual's eyes, however, are not sensing any change in viewpoint to account for this motion, and so the information they send to the brain does not correlate to that of the vestibular system. This discrepancy in sensory data causes nausea in the individual. Simulator sickness is the opposite of this. The user of a VR headset may be stationary in the real world, but instead experiencing a roller coaster ride through the headset. Once again, the user's senses are telling their brain different things, and the user becomes nauseous as a result.

Some users are less susceptible to simulator sickness than others, and users commonly build up a resistance through use of VR systems, although there are certain principles that can be followed to further mitigate simulator sickness. Many virtual environments are designed so that no movement is required at all, by ensuring everything the user will interact with is in reach of the user's start position within the environment, allowing the user to remain seated throughout. Alternatively, developers may chose to adopt a "room scale" design, in which the virtual environment is no larger in area than the size of a typical room, so that the user may physically move around their real room, and have their motion translated into the *virtual* room. As the movement throughout the virtual environment exactly matches the user's movement through the *real* one, there is no conflicting sensory data to induce nausea. This introduces problems when the user's physical room is smaller than the virtual space, as the user will be unable to reach certain areas of the virtual environment, as they may be blocked by physical walls or furniture. If movement beyond the bounds of the user's physical room is required, many virtual environments allow the user to "teleport" around the scene, circumventing the impression of strict movement, and thus avoiding nausea.

Another crucial consideration is the application's performance. Even with a fraction of a second of latency, the user can easily notice a delay between the movements of their real head, and their *virtual* one (the camera within the environment). While conventional video games on computers and games consoles typically run at a frame rate of 30 or 60fps, Oculus recommends VR applications should remain above 90fps [18], for the sake of the user's comfort.

2.5.2 User Interface Design

Although modern day VR headsets have higher resolution displays than most modern monitors, the physical screen is placed only centimeters away from the user's eyes, so the perceived resolution is rather low. Because of this, large chunks of text can often be hard to read, concise text with large font is often preferred. Where possible, many virtual environments instead use a voice-over to convey information. Where visual UI elements *are* used, they should be placed far enough from the user so as to not strain their eyes, but also close enough to not interfere with the environment, a distance of around 3 metres is usually sufficient [19].

When interacting with the system's user interface, one obvious consideration is that the user's vision of the physical world is extremely limited by the headset, so the use of a keyboard and mouse is generally avoided in the design of VR systems. Instead, a "gaze based" approach is often taken, in which the program is constantly analysing the centre point of the user's view, so that the user may select interface elements simply by looking at them.

Alternatively, many systems make use of motion tracking controllers, allowing the user to navigate the UI with what is essentially a laser pointer. The user will point their controller towards whatever element they wish to activate, directing a beam within the environment, from the user's hand to the interface element. A button can then be pushed on this controller to activate the element. This is considered a much more intuitive interaction with the UI, though it does require the user to own compatible controllers to be used.

2.6 Hardware Considerations

There are a number of commercially available VR headsets on the market today. As each of these use different SDKs, it is important to chose one to focus development on. An important aspect of this decision is the popularity of each headset. Looking again at the Steam hardware survey [1], it can be seen that the Oculus Rift CV1 is most widely used, followed closely by the HTC Vive. These two headsets have a significant lead over third-place, the Windows Mixed Reality headset. According to documentation provided by the manufacturers of the Oculus Rift [20] and the HTC Vive [21], both headsets can be adjusted to allow the user to wear glasses inside the headset.

2.7 Software Considerations

In order to facilitate the development of virtual environments, a game engine shall be used that can integrate with an SDK for the chosen VR system. These game engines provide some form of editor for the development of environments, and a way to integrate program code into each environment. Two popular game engines with VR support are Unity [22], and Unreal Engine [23].

Both engines have thorough documentation and active communities, both of which will be invaluable during development. Unity is generally accepted to be the easier of the two to use, and supports the integration of JavaScript and C# code, while Unreal Engine supports the integration of C++ code, and is more often used for high budget projects.

2.8 Summary

This chapter has investigated the effects of common phobias, and the various exposure therapy techniques that can be used to treat them, most of which implement some form of difficulty scale for their stimulus. To address the limitations of conventional exposure therapy, virtual reality was introduced, and previous virtual reality exposure therapy systems were investigated, before discussing design principles of virtual environments, which will be important when ensuring the UI is intuitive, and the environment is comfortable for the user to experience. It was found that the most popular VR HMD is the Oculus Rift CV1, and that VR SDKs could be integrated with either Unity of Unreal Engine for development of the system.

Chapter 3

Analysis and Requirements

The aim of the project is to gain an understanding of the fields of exposure therapy and virtual reality to develop a user-directed VR exposure therapy system for the treatment of suitable phobias, before testing it with a number of users to identify potential improvements. As these fields have been investigated in the previous chapter, this chapter will draw on the information gathered for analysis against the overall goal in order to reach a set of requirements for the system, and the project as a whole. Once the requirements are set, a methodology for user testing will be developed, and potential risks to the project will be assessed, as well as any ethical, professional or legal issues that may arise.

3.1 Analysis

The reasoning for the treatment being self-administered within the user's own home is for the sake of accessibility, allowing a wide range of people to conveniently treat themselves with no monetary cost to each session. It therefore seems reasonable to begin by considering design decisions that will affect the system's accessibility the most, and continuing to develop the design from there.

3.1.1 Accessibility

As learned in the previous chapter, the VR headset owned by the most people is the Oculus Rift CV1, it is therefore this device that the system should be developed to support. Both Unity and Unreal Engine support integration with the Oculus SDK. As either engine could be used to develop the system, Unity will be used, due to its simpler nature. While the Oculus Rift CV1 does support optional motion controllers, not all owners of the headset have these, and so the system should be developed to allow input via the Oculus Remote (a small, wireless remote with basic navigation and selection buttons, included with every Oculus Rift CV1). The integration of the motion tracking "Oculus Touch Controllers" could allow the user a more dynamic range of interaction with their chosen stimulus, so this could be implemented if there is enough time.

As the system is to be developed for the use of a multitude of users, each with varying amounts of space in their homes for traversal of virtual environments, the most accessible design would be to develop a virtual environment in which no lateral movement is necessary, instead allowing the user to progress through the full flow of the system while remaining seated or standing in a fixed position. This approach also conveniently solves the problem of simulator sickness. As no locomotion will be required, there will be no movement to induce nausea in the user, assuming the camera is working correctly, and no bugs are causing unintended camera movement. When switching between environments (for example, when changing stimulus) the virtual world should simply disappear and reappear, giving the impression that the user has teleported to a completely new area.

The performance of the application should also be a priority. To prevent any nausea, the system should maintain an average of 90 frames per second, on machines that meet the Oculus Rift CV1 minimum specifications.

3.1.2 Implementing Exposure Therapy Within the Virtual Environment

The absence of a professional therapist is an important consideration that will define a number of design decisions. It essentially precludes the use of flooding exposure. While flooding can be effective, it can also be a highly volatile form of therapy, and exposing the user to this without a professional present is ill-advised, not only would the system be unable to help the user through a panic attack, the user would most likely remove the headset immediately, and disengage with the system.

Conversely, graded exposure could be implemented rather intuitively in a virtual environment, with each step on the scale similar to a level in a video game. Each step could be predefined, and progressed through linearly, much as video games increase with difficulty as the player progresses. It would *not* be feasible to allow the user to define their own scale for their stimulus, as in systematic desensitization, as this would require the system to interpret the user's input to programmatically generate a fitting environment and stimulus behaviour. For example, if the first step on the scale defined by the user was a spider in a glass box sealed with a padlock, and the second step was for that padlock to be removed, the system would have to understand this, and automatically generate a padlock, with an appropriate 3D model, texture, and collision mesh. This is likely far out of the scope of this particular project. Despite this, elements of systematic desensitization can still be integrated with the inclusion of relaxation techniques. These could be taught to the user via a prerecorded voice-over, or even visual animations showing breathing and muscle relaxation techniques.

Virtual reality lends itself well to inhibitory learning, as variations that may not be practical in the real world can be introduced easily. For example, when confronting a spider, the type of spider could be instantly changed every minute by changing the 3D model, or the entire environment surrounding the user could be changed with every step in the scale. The main difficulty in this approach would be time constraints. While the full implementation of inhibitory learning is possible, it likely involves too much work to develop suitable variations for every stimulus while still ensuring the system is robust and free of bugs. Instead, elements of inhibitory learning can be combined with graded exposure and systemic desensitization.

The treatment will involve progression through a predefined scale of incrementally increasing difficulty, starting from simple imaginal exposure, such as the presentation of two dimensional figures, and ending with more direct interaction with a virtual form of the stimulus itself, such as playing with a spider. This will be similar to the design of Fearless VR, with a number of adjustments to compensate for that particular system's limitations: The user will be presented with the difficulty scale before starting each session, allowing them to start at any level they wish, provided that level has been previously unlocked. While the user can still skip through each level to quickly reach their desired difficulty, they should not be allowed to jump *immediately* to the final level, as this would effectively be flooding. A voice-over will also be integrated which could teach the user various relaxation techniques such as muscle and breathing exercises. A key element of inhibitory learning is the unpredictability of each session, therefore the nature of each level should not be revealed before the user reaches that particular level.

3.1.3 Phobias for Treatment

Now that the method of exposure therapy has been determined, it can be established what phobias the system will be developed to treat. As previously discussed, the following list details the phobias in descending order of commonality [3]. While each of these phobias have significant symptoms, not all of them are suitable to integrate into the virtual environment that will be developed.

1. **Insects**: Insects in particular lend themselves well to implementation in a virtual environment. Due to their small size, they can be modelled to a lesser detail when compared to larger animals. There is also the potential for significant variation in behaviour, for example, a spider may traverse a table slowly, in a straight line, or quickly, in an erratic pattern. If motion tracking controllers are to be supported in the system, insects could also be held in the user's virtual hands.

2. **Heights**: Height can be communicated very effectively in VR through the headset's dual screens allowing for depth perception. In addition to this, the motion tracking capabilities of the headset allow the user to peer over the edge they are standing on, closely mimicking the real life situation. Heights can be presented in a number of ways, such as a rooftop of a tall building, or the side of a bridge, allowing for variation in the environment. Height can also be incrementally increased easily, allowing this stimulus to easily fit into a scale.

3. **Storms, thunder or lightning**: While this is plausible in VR, implementations of realistic weather systems can be challenging, involving complex animation and particle systems. It would also be infeasible to replicate the sensation of rain on the user, severely affecting the user's sense of presence. This phobia will not be included within the system.

4. **Being in or on water**: Similar to storms, the fear of being in water likely has a strong physical component which could not be replicated with current VR hardware. This phobia will also not be included within the system.

5. **Flying**: Although the physical sensation of turbulence, or inertia during takeoff and landing could not be replicated, a significant aspect of the fear of flying is being enclosed within the aircraft itself. This could easily be replicated in VR by simply modelling the aircraft interior as the virtual environment. Variation could easily be introduced by positioning the user within different locations in the aircraft, or using different aircraft altogether. A difficulty with this stimulus would be implementing the UI. As passenger planes typically do not have large empty spaces, it may be challenging to integrate UI elements into the environment, without placing them so close to the user that they are hard to read.

6. **Being in closed spaces: e.g. a cave, tunnel or elevator**: This particular stimulus is harder to immediately judge. A significant factor of claustrophobia may be the physical restriction on the individual's movement, which would not be feasible to implement in VR. For example, the user may see a wall in front of them, but would be able to reach forward in the real world and feel that there is no wall really there. This stimulus also introduces the same UI concerns as the fear of flying. On the other hand, this stimulus would integrate easily with a scale system much in the same way the fear of heights would, the distance of the walls of the virtual environment could be incrementally decreased with each level. There is also good potential for variation, as the stimulus could be presented as a small room, an elevator, or even a cupboard. This stimulus should be included within the system, so that it can be seen how easily it will integrate with this style of treatment.

3.1.4 Expandability

As it is difficult to predict how much development time each stimulus will take, there should be a focus on designing the system to be easily expandable. This way, one stimulus can be developed for testing with the first round of participants, and other stimuli can be added later, if time allows. As each stimulus will have common functionality, much of this can be abstracted, so that additional stimuli can be implemented with minimal development.

3.1.5 Gamification

There is another problem introduced by the lack of a physical therapist that is not addressed by Fearless VR - motivating the user to progress through the difficulty levels of each stimulus. An effective way to motivate users to complete an activity has shown to be gamification [24]. This is the integration of elements typically found in games, such as competition, and point scoring. This seems to be a particularly natural addition to the system; The user is already interacting with a computerized environment, and this project's implementation of exposure therapy even includes "levels" for each stimulus, that could easily correspond to levels in a video game. Therefore, a scoring system will be integrated into the flow of each treatment session, with the user accumulating points as they interact with their stimulus, and losing points for failing to engage with the treatment. For example, were the treatment to involve a spider, the user could gain or lose points depending on whether the user is actually looking in the spider's direction.

Through this system, a further limitation of Fearless VR can be addressed, and gamified, dynamic behaviour for each stimulus can be integrated, for example, a "catch the spider" game, in which the spider runs from the user's hands (perhaps trying to catch the spider in a cup) could be implemented, if the Oculus Touch Controllers are to be supported. The user should always be allowed to progress through to the next level if they feel ready, regardless of their score. The system also could award a medal based off their performance for each level, although the boundary for each medal will be difficult to define, so this should be optional. These scores should be saved and the highest should be presented to the user during each level, this effectively allows the user to compete with themselves to beat their previous high scores. As a secondary requirement, these scores could also be presented as a graph, allowing the user to track their progress.

The system will also require a mechanism for the user to enter their SUDS rating, much like Fearless VR, this should take the form of a 1-10 input presented to the user throughout the flow of each stimulus. This data should be saved so that SUDS ratings from the test subjects can later be viewed for analysis. If possible, this data should also be made available for the user to view in a results tracker so that they may track their progress through their treatment. No scoring should be associated with the user's SUDS rating, as this will likely influence their input and taint the data.

3.2 System Requirements

3.2.1 Primary Requirements

1. Operate on the Oculus Rift CV1, with a performance of at least 90fps on Oculus-compatible machines.
   (a) It is common for the framerate to occasionally fall below this, so 90fps should be the target *average* framerate throughout use of the program.
2. Allow interaction with interface elements through the Oculus Remote.
   (a) The directional buttons on the Oculus Remote will be used for navigating the UI.
   (b) Pressing 'select' on the Oculus Remote will select the highlighted UI element.
3. On starting the program, present the user with a 'level selection' area.
   (a) This allows the user to select any unlocked level for any implemented stimulus, as well as view the results tracker, and scoreboard, if implemented.
   (b) The user should be able to return to this area at any time.
   (c) This area should be free of any stimulus.
4. At minimum, the spider stimulus should be implemented.
5. So that further stimuli can implemented with minimal development time, the following subsystems used by the spider stimulus should be abstracted and generalised:
   (a) Scoring and level progression.
   (b) Loading and saving user data for each level.
   (c) User interface and SUDS input.
   (d) Voice-over instructions for each level.
6. Each stimulus should consist of a number of levels of incrementally increasing difficulty.
   (a) Upon selecting the stimulus, the user should be presented with a list of levels, and allowed to select any level previously unlocked at which to enter their treatment.
   (b) No title or description of levels that have not been unlocked should be provided.
   (c) Level Zero will be an introduction, explaining to the user how the treatment works, and giving relaxation techniques via a voice-over.
   (d) Level One will be the first level of difficulty, and will be unlocked by default, so that the user does not have to progress through the introduction each time.
   (e) The user can only unlock a level from the interface of the previous level.
   (f) The user should be able to repeat the current level, or return to previous levels.

7. The overall flow of the treatment should be gamified.
    (a) The user should gain or lose points depending on their engagement with the stimulus at each level.
    (b) Within each level, the system should display the user's current score against their highest score previously achieved.
8. The system should allow the user to enter their SUDS rating.
    (a) This should be presented as a 1-10 selection.
    (b) This input should be prompted between each level.
    (c) This data should be saved, and viewable for later analysis.

3.2.2 Secondary Requirements

1. Further stimuli should be added.
    (a) Spheksophobia - Fear of wasps.
    (b) Acrophobia - Fear of heights.
    (c) Aviophobia - Fear of flying.
    (d) Claustrophobia - Fear of enclosed spaces.
2. Support of Touch Controller.
    (a) The user should see a virtual copy of the touch controllers in their hands within the virtual environment.
    (b) These should emit a virtual laser, which highlights interface elements when pointed at them, these elements can be selected using the controller's trigger.
    (c) Levels of higher difficulty should in some way involve interaction with the stimulus through the user's hands.
    (d) The Touch Controllers should provide haptic feedback at appropriate moments. For example, vibrating when touching a spider.
3. Gamification Enhancements.
    (a) The system should award a medal based off the user's score at each level, and display this on the level selection menu.
    (b) Rather than only storing the highest score for each level, the scores achieved for every attempt should be stored so that these can be output as a graph.

4. An appointment tracker should be implemented with the system.
   (a) The system should analyse patterns in the user's SUDS ratings, as well as their scores achieved at each level, to schedule an appointment for the user at an optimal time.
   (b) The user will be in some way awarded points or medals for using the system before, or during the day of their scheduled appointment.
   (c) The user should be allowed to set up appointment notifications, sent to their phone number, email, or some other messaging platform.
   (d) The user should be allowed to change their notification settings at any time while using the system.
5. The system should be published to the Oculus Store for easy distribution and maximum accessibility.

3.3 System Evaluation

3.3.1 User Testing

In order to properly evaluate the system, it will need to be tested against users who suffer from the phobias it is designed to treat. As the treatment is designed to be user-led, each testing session should involve as little as possible interaction with the test supervisor. Each session should begin with a pre-treatment discussion and briefing, before allowing the user to progress through the flow of the system as independently as possible. The testing session should conclude with a post-treatment discussion and questionnaire, in which the supervisor will obtain feedback from the test subject. This data will be used to assess the effectiveness of the system, and make improvements when developing the next iteration. The details of the design of the user testing sessions will be developed in the next chapter.

3.3.2 System Testing

In order to ensure the system's functionality is working as intended, it shall also be tested throughout development. In order to measure whether the system is achieving its target average frame rate, a performance analysis algorithm should be integrated that will output the average framerate achieved by the end of the testing session. Details on the implementation of this algorithm can be found in the next chapter. For more complex aspects of the system, such as the behaviours of the stimuli and usability of the interface within the virtual environment, manual testing will be required.

3.4 Risk Assessment

As with the development of any system, A number of risks exist that could potentially hinder development, disrupt the user testing process, or cause general disruption to the project. Table 3.1 aims to identify potential risks, and provide methods to prevent these appropriate to severity and likelihood. The following terms are used throughout.

- Likelihood
  1. Highly unlikely - Almost guaranteed not to occur
  2. Unlikely
  3. Moderately likely
  4. Likely
  5. Highly likely - Almost guaranteed to occur
- Severity
  1. Inconsequential - No tangible effect of project
  2. Minor - A noticeable effect on the project, but does not affect primary requirements
  3. Moderate - A noticeable delay to the project, may affect primary requirements
  4. Major - A large delay on the project, will likely affect primary requirements
  5. Critical - Almost certain to prevent fulfilment of primary requirements

Risk	**Likelihood**	**Severity**	**Prevention**
Loss of system code	3	5	Ensure all system code is backed up in online source control, such as GitHub
Addition of new requirements	3	3	Pay careful attention to requirements analysis before implementation
Unforeseen difficulty integrating VR with game engine	3	4	Develop a prototype using chosen hardware and software to confirm feasibility
Physical injury of test subject	2	4	Ensure VR play space is free of tripping hazards Configure Oculus Guardian system before each session
Insufficient test subjects are found	3	4	Plan for user testing as soon as possible in project timeline
Approval for user testing denied by Ethics Committee	3	3	Careful consideration should be given to ensure the design of the user testing sessions is compliant with the university's ethics policies

Table 3.1: Project Risk Assessment

3.5 Ethical, Professional and Legal Issues

As the system involves deliberately subjecting users to distressing stimuli, careful attention will have to be given to the user's well-being, both in the design of each level, and in the user testing process. While the user should be encouraged to challenge themselves with their treatment, they should also be encouraged to use the system safely, and not push themselves into excessive distress. For similar reasons, proper virtual environment design practises should be employed to prevent any nausea being induced in the user during their use of the system.

A key legal consideration in software development is data security and privacy. Any data regarding the user's treatment, such as SUDS ratings and scores achieved should be encrypted if stored on the cloud, and only stored with the user's express permission. The same consideration applies to user contact details, if optional requirement 4C is to be implemented. The relevant ethics documents are attached in Appendix A.

As each virtual environment will consist of a large range of graphical assets (3D models, textures, animations, etc), it will be out of the project's scope to create all of these from scratch. Instead, downloadable assets will be used and integrated with each environment. Due consideration must be given to copyright, and no assets should be used without permission. Similarly, this report should not infringe on copyright in any of the figures used.

3.6 Summary

In this chapter, it was determined that the system should be developed to support the Oculus Rift CV1, using the Unity game engine. The system will allow the user to treat their phobia of spiders, by progressing them through a scale of increasing difficulty for each one. The system will be gamified, and award the user points throughout each treatment session. The system will provide a means for the user to enter their SUDS rating throughout their treatment, and this will be separated from any gamified elements. A number of secondary requirements were also defined, such as further stimuli, integration with motion controllers, and development of an appointment scheduler. System evaluation was discussed, and potential risks and other issues were investigated, with consideration of how to address these.

Chapter 4

Design

This chapter will outline the key design decisions made before development can begin. As the aim of the project is to develop an effective virtual reality exposure therapy treatment system, user testing sessions should be conducted to analyse its effectiveness, obtain feedback, and generally inform the development of the system. The development of the system should be split into a number of iterations.

A lightweight prototype will serve to prove the feasibility of implementing stimuli into virtual environments with the given software development tools, before starting work on Iteration One. Iteration One will fulfill the primary requirements outlined in the previous chapter. Once this is complete, a round of user testing will be conducted, and the resultant data will be used to inform the development of Iteration Two, which will implement any secondary requirements that are feasible, and improve upon existing components of the system. A second round of testing will commence to prove the effectiveness of Iteration Two's improvements, and inform any possible further work.

4.1 Iteration One User Flows

4.1.1 Level Selection Area

This is the first environment that will presented to the user. It will primarily consist of interface panels, allowing the user to select the phobia they wish to treat themselves for. Each phobia will list their levels, those that have been unlocked will display a title and the highest achieved score at that level. The user will be allowed to select any unlocked level, and the UI elements for locked levels should be greyed out. On selection, the level selection area will be replaced with the environment corresponding to the chosen stimulus, and the treatment will begin at the selected level.

4.1.2 Spider Levels

Table 4.1 details the design of each level for the spider stimulus. Further levels and additional stimuli could be added, as per the secondary requirements.

Level	Design	Scoring System
Zero	A 2D voice-over explaining to the user how the system works	Max score awarded by default
One	A 2D cartoon image of a spider, basic facts on spiders	Answering basic comprehension questions
Two	A 2D realistic image of a spider, further facts on spiders	Answering more advanced comprehension questions
Three	A small 3D spider in a glass box on the table	Getting as close as possible to the box
Four	The glass box is removed, the spider sits on the table and does not move	Getting as close as possible to the spider
Five	The spider begins to slowly walk in a predefined pattern	Answering questions on the sequence of the spider's walking path
Six	The spider walks faster in an erratic pattern	Looking at the given markers within the environment
Seven	The spider model is enlarged, and continues its previous behaviour	Increasing the size of the spider model towards a maximum
Eight	Multiple spiders of varying sizes walking erratically on the table	Sitting with the spider for a predefined length of time
Nine	A single large spider descending from the ceiling towards a position directly in front of the user's face	Sitting with the spider for a predefined length of time

Table 4.1: Spider Stimulus Level Design

4.1.3 Virtual Therapist

Each level should include a voice-over to serve as a virtual therapist. This will guide the user through the treatment, and instruct them on how to obtain a high score. In order to make the system as expandable as possible, a voice synthesis service should be used, so that this dialogue does not have to be manually recorded for each new stimulus and level. This will be achieved through the use of AWS Polly [25], as this will allow text to quickly be converted to an audio file for easy integration with the system. The free tier allowance will likely far exceed the amount of dialogue needed.

4.2 System Architecture

4.2.1 Unity Engine

As the system is being developed with the Unity game engine, the technical design decisions must be made in the context of this domain. Development is split between C# scripts, and the Unity Editor, which is used to build the virtual environment, and combine any number of components to produce "GameObjects".

Unity Component System

In order to give each GameObject its required functionality, individual components will be assigned to GameObjects within the editor [26]. For example, the spider itself may have a renderer, an animator, and a collider (to test collisions with other GameObjects). Control code will be written in C# scripts which are also attached as components, these will give GameObjects bespoke behaviours and properties. An example of what this may look like in practise is seen in Figure 4.1.

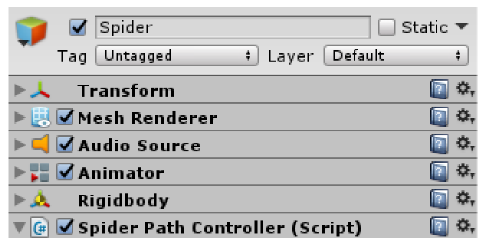

Figure 4.1: A possible composition of a spider GameObject, seen through the Unity Editor

MonoBehaviour

By default, every class in Unity derives from MonoBehaviour [27], this allows the engine to call methods with certain names based on certain conditions. For example, the "Start" method is called once on each script, when that script is initialized (which usually occurs as soon as the scene is loaded), this will be used to establish communication between scripts, and set the environment running with its original behaviours. The "Update" method is called once every frame, and will be used to check for and handle user input, as well as calculate and update the positions of any moving GameObjects, and track the user's score.

4.2.2 Persistent Storage

In order to save the user's scores and SUDS ratings between sessions with the system, data must be stored in a persistent file. While in theory a database could be used, the simplicity of the data does not require this. Instead, Unity's script serialization system [28] will be used, allowing all user data to be stored in a single class, which is then serialized into a single save file, and deserialized back into a class when data is retrieved.

4.2.3 Generalization of Stimulus Environment

So that further stimuli can be added with minimal development time, all the core system functionality that is not specific to the spider should be abstracted so that they may be implemented by other stimuli. In order to achieve this, this functionality should be accessible through an abstract class, with each stimulus split into its own environment (known in Unity as a "scene") being controlled by a class that derives from this.

4.2.4 System Architecture Diagram

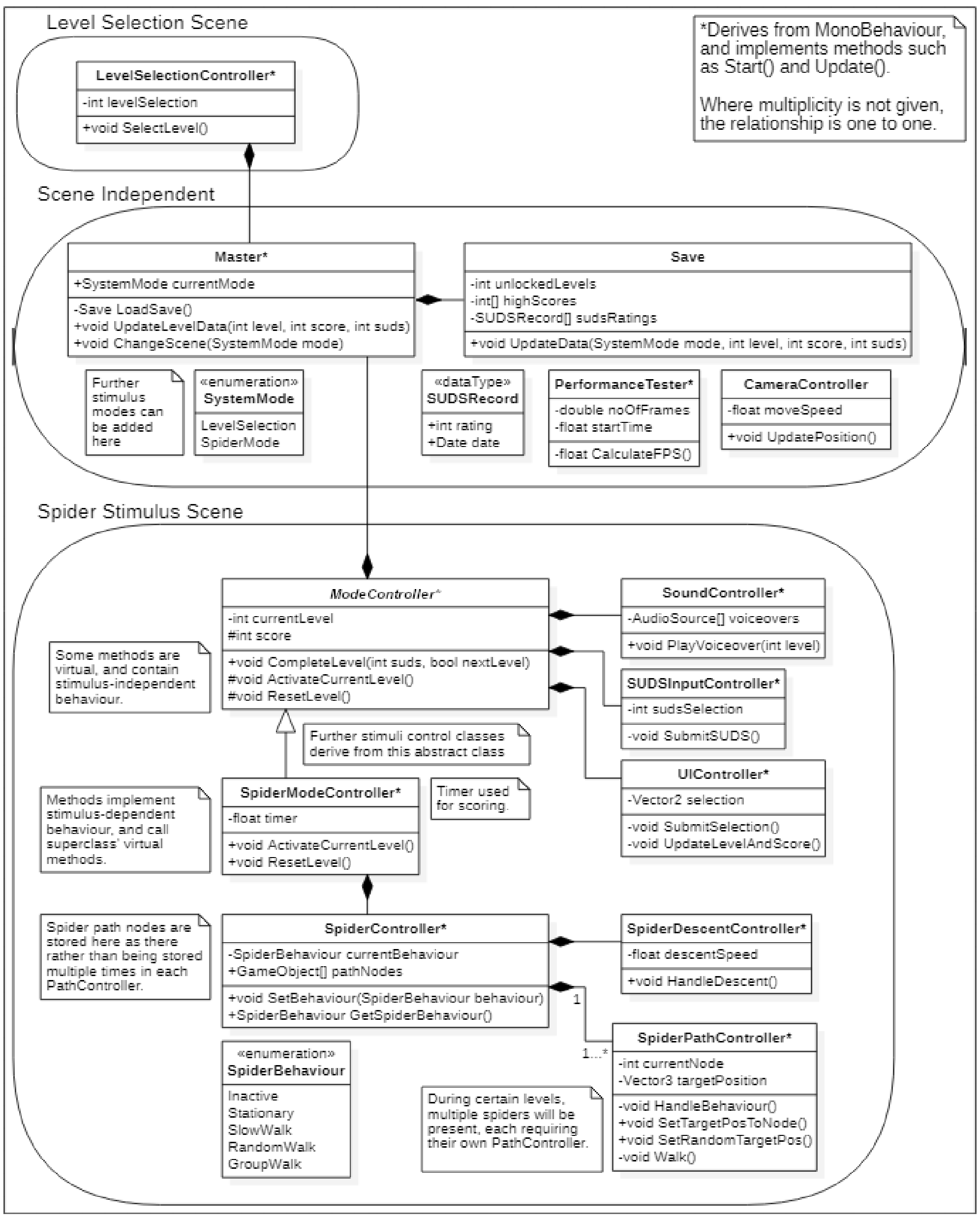

Figure 4.2: System architecture diagram

Architecture Clarifications

The diagram shown in Figure 4.2 is meant to serve as a general explanation of how the core components of the system fit together. Many of the finer details have been abstracted away for the sake of simplicity and readability. For example, the ModeController class will contain a SUDSInputController, although the latter class will also contain a reference to the former, so that it can trigger the ModeController's "CompleteLevel" method, once the user enters a SUDS value. Although this link goes both ways, only the most meaningful aggregation is shown on the diagram. This is a common caveat across the system's architecture, due to a lack of any singular flow of execution, as the Unity scripts will nearly all be running in parallel. In addition to this, many of the access modifiers may be different to how they appear in the diagram. For example, although only the CameraController class will need access to its "moveSpeed" property, this may in practise become a public variable, so that it is exposed through the editor for ease of development.

4.3 User Testing

4.3.1 Testing Methodology

In order to properly evaluate the effectiveness of the system, a number of user testing sessions will be conducted, using test subjects that self report as having arachnophobia. Each testing session should begin with a pre-treatment briefing, in which a brief explanation of the system will be given, along with basic instructions on how to use the VR equipment.

The test subject will progress through each level, giving a SUDS rating for how anxious each one made them feel. The treatment will end once the test subject has either progressed through each difficulty level, or they choose to end the treatment of their own accord. While users are encouraged to progress as far as they are able, it is not necessary for users to complete the final level in their initial session.

In the same way that the first appointment in the Virtual Iraq system was used to gain insight into the patient's specific previous experiences so that these could be built in to the system later, the test subject should be asked to recount scenarios in which their chosen stimulus made them feel anxious. As arachnophobia is common, these may show commonalities between test subjects, and therefore should be added into the next iteration of the system, if possible. As this constitutes imaginal exposure, these questions should be left until the end of treatment, so as to not interfere with the difficulty scales.

Test subjects will be booked for multiple sessions, in which they will repeat the treatment with their chosen stimulus, allowing SUDS ratings to be charted across sessions.

4.3.2 Control Conditions

Baseline Anxiety

Before the user starts their treatment, some initial data should be gathered, such as how anxious the user has been feeling on the particular day of testing. Should a user report a higher baseline anxiety on the day of their second session, this can be factored in when interpreting their data. In order to mitigate any external factors that may cause anxiety, the treatment should take place in a private room, with no unnecessary observers or other stimuli.

Previous VR Experience

Unlike those within the demographic the system is being developed for (Oculus Rift CV1 owners), the test subjects used may have little to no prior experience with the use of virtual reality hardware, or interaction with virtual environments. The subjects' experience with VR systems should be noted, as this may affect how easy they find the environment to understand, and how much nausea is induced, if any.

Independent Use

To reflect the self-treatment style of the system, the user should be left to progress through their treatment as independently as possible, although a supervisor should remain on hand to ensure the well-being of the test subject, assess their interaction with the system, and provide assistance if any problems are to arise. This will provide insight as to how users may interact with the system in their own home, and assess whether it is intuitive enough to use without external guidance. The test subject will be able to enter their SUDS ratings via the system UI during their treatment, rather than having to communicate this verbally to the test supervisor.

4.3.3 Questionnaire

Before each session, test subjects will complete a short questionnaire to determine their baseline anxiety, and previous experience with VR systems. Upon conclusion of the treatment, the test subject will be given a longer questionnaire to complete, and feedback will be obtained. These questionnaires are attached in Appendix B.

Chapter 5

Implementation and Testing

5.1 System Iterations

5.1.1 Prototype

As discussed in the previous chapter, development started with a prototype that would prove the feasibility of integrating the Oculus SDK with the Unity Engine to produce a compelling virtual environment. This prototype serves as a proof of concept, and is not intended to fulfill the primary requirements. Rather than including a number of stimuli each in their separate scenes, the prototype features basic interaction with three stimuli: spiders, heights, and enclosed spaces, within one virtual environment, as seen in Figure 5.1, which roughly resembles a home study / therapist's office. There is no level progression system, and the UI only serves to switch between stimuli.

Figure 5.1: The prototype virtual environment

5.1.2 Iteration One

Iteration One focused on fulfilling the primary requirements, and providing a system that would easily be testable by future test subjects. As seen in Figures 5.2 and 5.3, various details have been added to the environment, and the lighting has been improved. The user has been moved closer to the UI, and the UI elements have been enlarged. Both the SUDS input system, and general UI are shown.

Figure 5.2: The virtual environment, after completing the "Spider in a Box" level

Figure 5.3: The virtual environment, during the "Spider Walks in a Pattern" level

Figure 5.4 shows the level selection area. Each of the ten levels are shown, but those that have not been unlocked are greyed out, and cannot be selected by the user. Where the level has been completed, the highest achieved score is presented next to the level title. The selected level is highlighted in yellow, and navigation is achieved through the Oculus Remote.

On making a selection, the spider scene will load, preconfigured for the chosen level. Typically, all GameObjects and their data are isolated between scenes, therefore the GameObject storing the user's selection was assigned a specific flag, allowing it to persist between scenes. This allows the "SpiderModeController" script to begin the spider scene at the level specified.

Figure 5.4: The level selection virtual environment

5.1.3 Final Version

Based on the feedback detailed in the next chapter, the model used for the spider was replaced with one of higher detail, as seen in figure 5.5. This model is also more visible against its background, and features more detailed animations.

Figure 5.5: The final version's environment, during the "Spider Walks in a Pattern" level

As seen in Figure 5.6, the level selection area has been updated to feature a graphical guide to the buttons used to control the system. These show the Oculus Touch controllers, which are now supported. The Oculus Touch Controllers provide more buttons than the Oculus Remote, allowing the user additional control over the environment, without having to reach for the keyboard, or struggle with awkward combinations of buttons.

Figure 5.6: The final version's level selection environment

A number of further improvements have been made since Iteration One that cannot be represented in a still image. The script of the voice-over has been changed in an attempt to provide clearer instructions to the user, and the overall audio has been rebalanced to make these instructions more audible. Additionally, the scoring system has been tweaked to make attaining the maximum score more challenging.

Furthermore, there have been a number of improvements to the user interface. Problems were encountered in Iteration One where the system would read a single input multiple times. For example, when the user pressed the "select" button, the system would select the highlighted option, transition into the next menu, and immediately select the default option. To prevent this, time-based checks have been added, forcing a short interval between reading each input.

As many of the final system's components are difficult to convey in a report alone, a demonstration is available at **https://www.youtube.com/watch?v=OWpEEU95sqI**. This shows the serves to demonstrate the overall flow of the system, interaction with the user interface, the spider behaviours, and the virtual therapist voice-over.

5.2 Expandability

5.2.1 Multi-Choice Question System

As seen in Figure 5.3, some levels require the user to answer a number of questions. For the spider stimulus, this applies to three levels (therefore three "question rounds"), with each round consisting of three questions. For other stimuli, it may be more appropriate to have more or fewer rounds of questions. The system has been developed so that the abstract ModeController class can programmatically find all the question GameObjects present in the current environment, and store these appropriately, so that each question can be handled as the user progresses through the treatment.

```
//ModeController class
//Each question round holds its own array of GameObjects, one for each question
protected QuestionRound[] questionRounds;

//Each mode has its own num of question objects, these need to be found/stored
protected void loadMultiChoiceQuestions(int numOfQuestionRounds){
  questionRounds = new QuestionRound[numOfQuestionRounds];

  //Find all the question round GameObjects in the scene, sort the array
  GameObject[] questionRoundGOs = GameObject.FindGameObjectsWithTag("QuestionRound");
  Array.Sort(questionRoundGOs, compareObjNames); //Sort in ascending order

  //Create each question round, filling it with questions
  for (int questionRndNum = 0; questionRndNum < numOfQuestionRounds; questionRndNum++){
    questionRounds[questionRndNum] = new QuestionRound(NUM_OF_QUESTIONS_PER_ROUND);

    //Load each question round with its questions
    for (int questionNum = 0; questionNum < NUM_OF_QUESTIONS_PER_ROUND; questionNum++){
      try{
        //Determine the name of the question GameObject
        String questionObjectName = getGameObjectPath(questionRoundGOs[questionRndNum]);
        questionObjectName += "/Question " + (questionNum + 1);

        //Now we have the name, find the GameObject and put it in the array
        GameObject question = transform.Find(questionObjectName).gameObject;
        questionRounds[questionRndNum].questions[questionNumber] = question;
      } catch (Exception e) {
        Debug.Log("Couldn't find Question " + (questionRndNum + 1) + ":" +
            (questionNumber + 1) + " - " + e);
      }
    }
  }
}
```

Now references to each question GameObject are stored in ModeController, this class is able to handle the management of the questions, without any bespoke control code for each stimulus.

```
//ModeController
public virtual void selectMultiChoiceAnswer(int selection) {
  int questionRoundNum = getQuestionRoundForLevel(currentLevel);
  Debug.Log("Answered Q "+questionRoundNum+":"+questionNum+" with "+selection);
  //If the answer was correct, increase the score
  if (selection == correctAnswers[questionRoundNum, questionNum]) {
    score += 100f / (float)NUM_OF_QUESTIONS_PER_ROUND;
  }
  //Deactivate the question just answered
  questionRounds[questionRoundNum].questions[questionNum].SetActive(false);
  //If we're not at the last question
  if (questionNum < NUM_OF_QUESTIONS_PER_ROUND - 1) {
    //Activate the next question
    questionNum++;
    questionRounds[questionRoundNum].questions[questionNum].SetActive(true);
  }
  else {
    //Activate the question summary
    uiController.setQuestionSummary(score, NUM_OF_QUESTIONS_PER_ROUND);
  }
}
```

This allows minimal development in the stimulus-specific controller. All that is needed is a call to the methods in the superclass, a mapping of correct answers for each question, and control code for any special cases. For example, the ”Spider Walking in a Pattern” level, changes the spider's walking pattern with each level.

```
//SpiderModeController, derives from ModeController
//Similar to Start(), but before, used for initialisation
public override void Awake() {
  loadMultiChoiceQuestions(NUMBER_OF_QUESTION_ROUNDS);
  correctAnswers = new int[,] { { 2, 2, 1 }, //lvl 1+
                                { 1, 2, 0 }, //lvl 2
                                { 2, 2, 2 }}; //lvl 5
  base.Awake(); //For stimulus independent code
}

public override void selectMultiChoiceAnswer(int selection) {
    base.selectMultiChoiceAnswer(selection);
    //On this level, the spider switches it's walking path
    if (getCurrentLevel() == 5) {
        spiderController.changeWalkingMode();
    }
}
```

5.2.2 Prefabbed User Interface

The user interface will essentially be the same for each stimulus environment. Work has been done on the scripting side so that the control code for this UI is abstracted away and doesn't need to be rewritten for each stimulus, but this code relies on each scene having the same interface elements, and that GameObjects follow a naming convention.

Rather than build this hierarchy of GameObjects within the editor with each new stimulus, one overall UI has been built as a prefab, so that this may be placed in any scene. This prefab contains all the necessary UI elements with appropriate naming and tags, and their control scripts. This prefab can simply be pasted into any future environment and will be immediately functional, although the content of each level's instructive text or questions will need to be changed to fit the stimulus.

5.2.3 Additional Spider Behaviours

While the focus of expandability has been to easily facilitate new stimuli, work has also been done to allow the existing spider stimulus to be built upon. For example, for the "Spider Walks in a Pattern" level, rather than hard-coding set shapes for the spider's path to follow, a "path node" system was used, as seen in Figure 5.7. This allows the definition of any shape or route for the spider, by simply dragging and dropping the path node GameObjects within the scene. This allows for more complex pathing behaviours, and could be even be used to move the spider along the floor, walls or ceiling, rather than simply across the table.

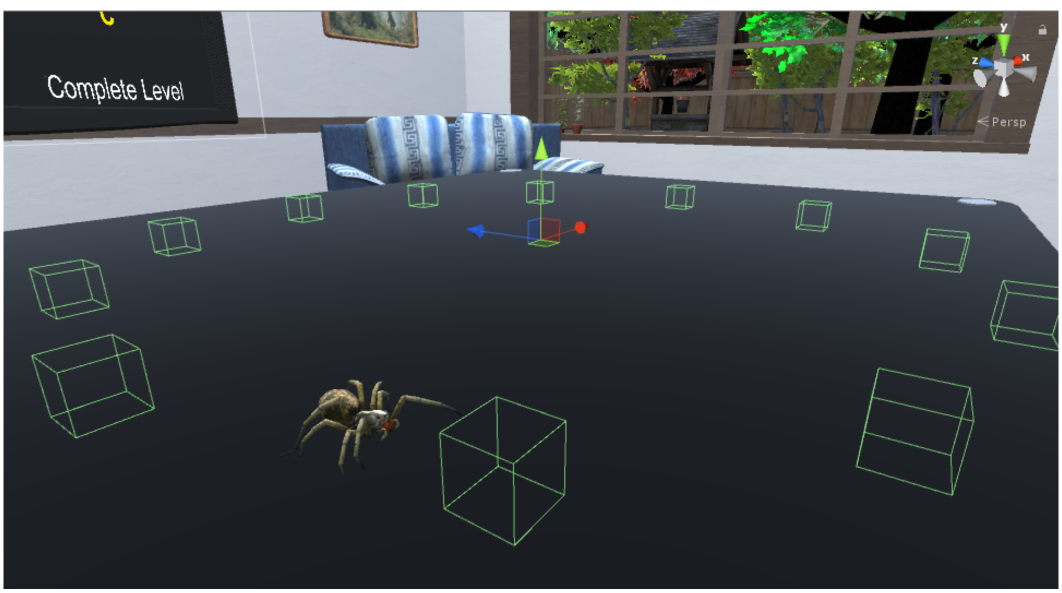

Figure 5.7: The "Spider Walks in a Pattern" level, with path nodes highlighted in the Unity Editor

5.3 User Testing Execution

5.3.1 Testing Logistics

User testing took place according to the methodology outlined in the previous chapter. A private room was booked on university campus, and participants with a fear of spiders were tested with the system one at a time. While the ongoing testing during development is done through the Unity development environment, the testing sessions used a full, exported build of the system, running off an executable file. Before each session, each participant was asked how anxious they had been feeling on that particular day, this will serve as baseline data. Each participant was left to progress through the treatment independently during both of their sessions, submitting their SUDS values through the UI after each level. The system automatically saved these SUDS values along with achieved scores to a file, and this data will be discussed with the participants' answers to the questionnaires in the next chapter.

5.3.2 Impact of COVID-19

As a result of the worldwide COVID-19 outbreak, only one round of user testing was possible, with three participants, before the nationwide lockdown was imposed, closing university campus. The third participant's second session was conducted online, a number of weeks after their first, once they had access to the necessary VR equipment. The decision was made to end user testing as it was felt that the testing supervisor should be on hand during the treatment in the event that the participant becomes overly distressed, however, an exception was made in this case as the participant has already progressed through the treatment during their first session, and felt comfortable enough to complete a second session without any further support in the room, as they already knew what to expect from each level.

As only Iteration One could be tested with users, the focus of Iteration Two was to polish and improve the existing systems, such as the UI and the spider's model, movement, and animation, rather than add entirely new functionality that could not be properly tested.

5.4 Performance Testing Execution

In order to assess whether the system is meeting the minimum average framerate specified in the requirements, the time taken to render each frame is calculated, and used to compute an average framerate. This value is output to the debug console, and is simply read off the screen at the conclusion of the session. In order to account for any particular events that may affect the framerate, the system was tested by manually progressing through the entire flow, from the level selection area to the final level, before measuring that session's average framerate.

Chapter 6

Results and Discussion

This chapter discusses the data gathered during the user testing sessions, both through the questionnaires and the system itself, collecting SUDS values and scores for each level. Most data points are gathered on a 1-10 scale, with a score of 10 meaning ”I was extremely anxious”, ”I felt the system really hard to use”, etc. This data will be used to analyse the success of the system, and discuss potential further work. The full results can be found in Appendix C.

6.1 User Testing Results

6.1.1 Anxiety During Treatment

Table 6.1 shows each participant's SUDS values entered after each level of treatment within the virtual environment. As previously discussed, the third participant had a large interval between their sessions, which may explain why their scores tended to *increase* during their second session. Overall, it can be seen that anxiety has tended to decrease between sessions.

		SUBJECTIVE UNITS OF DISTRESS - SPIDER LEVELS										
		L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	Av'
Subject 1	Session 1	1	1	2	2	3	4	3	5	6	4	3.1
	Session 2	1	1	1	1	1	2	3	3	3	3	1.9
	Difference	0	0	-1	-1	-2	-2	0	-2	-3	-1	-1.2
Subject 2	Session 1	1	1	2	2	3	3	4	4	5	5	3
	Session 2	1	1	2	2	2	2	3	3	3	4	2.3
	Difference	0	0	0	0	-1	-1	-1	-1	-2	-1	-0.7
Subject 3	Session 1	1	1	2	2	2	2	3	3	3	4	2.3
	Session 2	1	1	3	2	3	4	4	6	5	6	3.5
	Difference	0	0	1	0	1	2	1	3	2	2	1.2
Average	Session 1	1	1	2	2	2.7	3	3.3	4	4.7	4.3	2.8
	Session 2	1	1	2	1.7	2	2.7	3.3	4	3.7	4.3	2.6
	Difference	0	0	0	-0.3	-0.7	-0.3	0	0	-1	0	-0.2

Table 6.1: SUDS Values across Spider Levels

As seen above, the average decrease in SUDS values between levels was 0.2, although the small size of the dataset means the potentially anomalous data from Subject Three is significantly skewing this average towards zero. This data has also been analysed against each participant's baseline anxiety, as seen in the appendix, and while this leads to slight variations in each participant's SUDS values, the end result is the same.

When designing the levels, the focus was to follow the graded exposure technique, so that each level was slightly more difficult than the last. When asked "Do the levels seem to be in the correct order of difficulty", all participants reported that they were, with one participant suggesting that perhaps the final two levels should be switched. This is confirmed by Figure 6.1 below. This graph also shows average anxiety was **lower** during the second session.

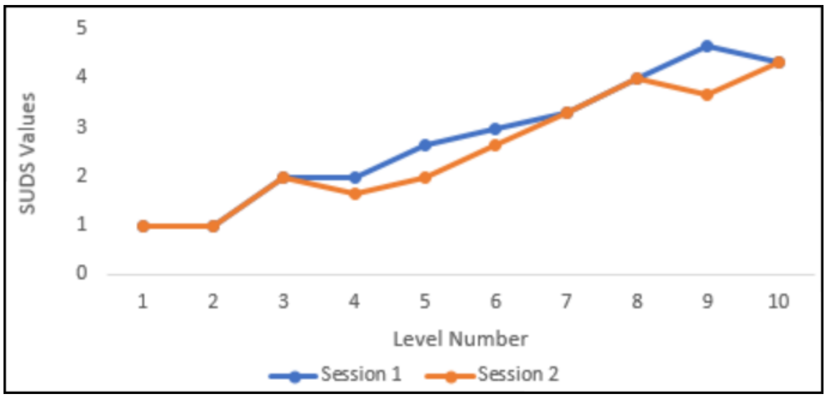

Figure 6.1: Average SUDS Values Across Spider Levels

6.1.2 Anxiety Towards Spiders Overall

Before the first session, participants were asked how anxious they imagine they would feel directly confronting a spider. This question was asked again after the second session. The difference in each participant's answers has been taken to represent their change in anxiety response towards spiders in general. As seen in Table 6.2, the average change in this value was two points, representing a decrease of 20%. Interestingly, Subject Three reported the greatest reduction in anxiety towards spiders, despite reporting higher anxiety during each of the second session's levels. Again, this is likely due to the large time interval between sessions.

SUBJECTIVE UNITS OF DISTRESS - IMAGINED SPIDER			
	Pre-Treatment	Post-Treatment	Difference
Subject 1	7	5	-2
Subject 2	5	5	0
Subject 3	7	3	-4
Average	6.3	4.3	-2

Table 6.2: SUDS Values for an Imagined Spider

When factoring in baseline anxiety, this average reduced to a 17% change. Given the primary purpose of the system is to reduce users' anxiety in their chosen stimulus, even a 17% reduction over two short sessions is a promising initial result for the first iteration, although, needless to say, further testing should be conducted with a much larger sample group.

6.1.3 Achieved Scores

Table 6.3 shows the average scores achieved for each level between the two sessions. When asked "How much did the scoring system motivate you to progress and engage with each level", the average response was 6.7, although, as seen below, the average score achieved each level is very close to 100. This may mean the gamification elements act on a less noticeable, subconscious level, with users being drawn towards high scores without noticing. The final two levels are scored based on how long the user sits with the stimulus, each user scored 100% for both of these levels across each session, which may be unlikely had the score only been a moderately motivating factor. Alternatively, it is possible users were accumulating scores incidentally as they progress through treatment, without making a deliberate effort to. If it is the case that users are scoring 100% without deliberate effort, it seems likely the scoring system is too generous.

		ACHIEVED SCORES - SPIDER LEVELS										
		L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	Av'
Average	Session 1	100	100	77.7	100	100	100	100	100	100	100	97.8
	Session 2	100	100	89	91	89.7	100	100	100	100	100	97.0
	Difference	0	0	11.3	-9	-10.3	0	0	0	0	0	-0.8

Table 6.3: Average Achieved Scores across Spider Levels

It can also be seen that the average score achieved tends to decrease between sessions, due to a lower average score achieved on the third and fourth levels in the second session. These are the only two levels that involve physical movement, by getting close to the cage, or the spider, whereas the other levels are scored based off time, answers to multi-choice questions, or enlarging the spider model. It is possible that, while the scoring system provides a good incentive to mentally engage with the treatment, it fails to engage users *physically*. The only case in which the second session has seen a higher score for a particular level, was where a participant failed to score maximum during their attempt in the first session. This allowed the participant to later "beat" their previous score. This may also explain the general downward trend; After achieving the maximum score, the user has less incentive to engage with the scoring system, as it is impossible to overwrite a maximum score. The scoring system will be revisited later in the chapter.

6.1.4 Interaction with the System and Environment

When asked "how hard was the system to use", the average score given by participants was 2.3, meaning users generally found the interface intuitive, and were not confused during the flow of treatment. When asked "How nauseous did the virtual environment make you feel", each participant gave a score of 1, meaning no nausea was induced. These are promising results, although all three participants did respond as having at least some degree of previous experience with VR systems. While this is the system's target user base (VR headset owners), users with no previous experience are more likely to experience nausea, or be unsure how to interact with the virtual environment, ideally, further testing should be conducted to verify these problems do not arise for potential users that are new owners are VR equipment.

6.2 Performance Testing Results

The average framerate has been recorded as well above the minimum 90 frames per second outlined in the requirements. This has been tested on a number of machines that meet the minimum hardware requirements to support the Oculus software, including machines available on university campus, as well as home computers.

6.3 Improvements Within Hardware Constraints

While each of the system's primary requirements as outlined in Chapter Three have been met, the majority of the secondary requirements have not, largely owing to time constraints, and the complications of the COVID-19 outbreak. Given more time, each of the secondary requirements could be met, and further functionality could be added, while remaining within the project's current hardware constraints.

6.3.1 Further Stimuli

As specified in secondary requirement 1, the remaining four stimuli, wasps, heights, air travel, and enclosed spaces could be added into the system. Each of these would sit within their own scene, and tie into the existing functionality that has been abstracted into the "ModeController" class. Each scene would require its own bespoke virtual environment, for example, an airplane cabin for the fear of flying scene, audio voice lines, and its own design of levels. The levels of the wasp could take a similar form to that of the spider, with the wasp's pathing behaviour using an adapted version of the spider's, employing the same node based system. Other stimuli would likely require further adaptation. User testing for this stimuli would take the same form as the spider stimulus, with the only change being the use of test subjects with different phobias.

6.3.2 Enhancements to Stimulus Interaction

When test subjects were asked to recount previous distressing experiences with spiders, each response involved an encounter within the subject's own home, usually at night, or in bed. It may prove effective to add interactions with the stimuli that reflect these accounts. For example, a level could be added in which the user is sitting in bed, in a dark bedroom, with spiders crawling over the duvet.

Support for the Oculus Touch Controllers has been added into the system, although the only advantage that has so far been exploited of this input method is the additional buttons, rather than the motion tracking capabilities. Allowing the user to use their hands within the virtual environment gives way to more sophisticated interactions with both the environment and the stimulus. For example, the user could use their hands to open the spider's cage, and then pick it up and place it on the table. This would also allow the spider to react to the user's movement. For example, were the user to move their hands too quickly, the spider may dash in the opposite direction.

6.3.3 Gamification Enhancements

As mentioned previously in the chapter, it is possible the current scoring system is too forgiving. Rather than artificially increasing the difficulty by increasing the number of questions or increasing the length of time the user has to sit with the stimulus, more advanced scoring systems could be implemented. Were the user able to interact with the environment with their hands, they could be scored based off of direct physical interaction with the stimulus. For example, a level could be added where the user has to catch spiders in a cup, and tip them out the window, which would score the user on how many spiders they free in a set amount of time.

To further gamify the system, the element of competition could be added, using online scoreboards, or even real-time multiplayer, in which two users could sit opposite a table from each other, both completing objectives related to their stimulus. Rather than only awarding a score, further incentives could be added, such as customization options for the environment, or for the virtual therapist's voice.

6.3.4 Appointment Tracker

As the user is not attending any physical appointments, they will have no treatment schedule to follow, and may therefore put off using the system. To mitigate this, the system could schedule the user appointments based off their previous progression through each stimulus, and their recorded SUDS ratings. For example, if the user has repeatedly attained a high score at a certain level, and has simultaneously been inputting low SUDS ratings, the system could recommend a virtual appointment within a few days at a higher difficulty level. As appointments should be as regular as possible, the system could also send reminders to the user's email or social media, as discussed in the requirements.

6.4 Improvements Outside Hardware Constraints

Beyond the potential enhancements mentioned above, a wide variety of improvements could be made if the hardware constraints were removed. The following possibilities are feasible with hardware that is commercially available in the present day.

6.4.1 Haptic Feedback

A major limitation of the system is that the simulation is constrained to only the audiovisual. Through the use of a haptic suit, the user could physically *feel* their stimulus, and environment. This gives way to a number of enhancements for the spider stimulus alone, such as simulating the sensations of a spider walking across the user's body, and picking the spider up with their hands. This also makes the effective simulation of other stimuli feasible where they were not before, for example, a fear of storms could be treated by simulating the sensation of water drops on the user's body, and the vibrations caused by thunder.

6.4.2 Augmented Reality

When asked if they had any further feedback, responses from test subjects involved the limited size of the "play area" (as they had to remain within the bounds of the tracking sensors' visibility), and the suggestion that the spider should appear in more places, rather than only on the table. As the test subjects recounted typically seeing spiders in cupboards, or in the corners of rooms, they felt this is where they should appear in the virtual environment. Rather than simply adding these behaviours into a completely simulated environment, the use of *augmented* reality could be employed. This would allow the user to navigate around their own real house, but confront *virtual* stimuli, which would be projected into the real world through the use of augmented reality glasses. This would also solve the problem of the limited play area, as there are no external sensors tracking the user, the user would be allowed to explore any physical space that is available, and confront stimuli in their real life environment.

An augmented reality system could also project a user interface into the user's real world environment, allowing them to enter SUDS ratings and view their scores in a similar way than the in the existing system.

Chapter 7

Conclusions

Exposure therapy is a technique employed to help patients overcome their phobias. It involves exposing the patient to their fear in a safe environment so that they can begin to overcome their anxiety. Conventional exposure therapy faces a number of limitations, a physical appointment usually has to be booked with a potentially expensive therapist, and the stimulus typically needs to be on hand, which may be logistically difficult, depending on the patient's particular phobia.

During this project, a virtual reality exposure therapy system has been developed using the Unity game engine for the independent treatment of arachnophobia using the Oculus Rift Consumer Version One within the user's own home. Research showed fears of insects to be among the very most common phobias, the system has been developed in such a way to be easily expandable to include more sophisticated stimulus behaviours and interactions, and to include other common phobias, such as fear of heights, fear of flying, fear of wasps, and claustrophobia.

A variety of exposure therapy techniques were analysed, and a "graded exposure" technique was employed, in which the user confronts the stimulus in a number of levels, each one slightly more intense than the last. To incentivise the user to engage with the treatment, the overall flow of the system has been gamified, so that the user is awarded a score based on their interaction and attentiveness during each level. Each level features a voice-over that explains to the user what they should be doing in that level, and how to achieve a high score.

Once the primary requirements of the system were met, it was evaluated with a number of participants. Data was collected through questionnaires, and through the system itself. As is standard in exposure therapy, "Subjective Units of Distress" were used to measure each subject's anxiety response during each level, and to the stimulus in general. Each participant progressed through the entire treatment, on two separate sessions, giving a SUDS score for each level. The results show that, in general, the test subject's anxiety response during each level has decreased, as has their reported anxiety response to spiders in general. While this is a promising initial result, the COVID-19 outbreak meant only a small sample size was possible, and ideally further testing would be conducted. User feedback was generally positive, with subject's reporting that they found the system easy to use, and that the gamification elements were effective. The system performed acceptably, and participants did not encounter any bugs or crashes during testing.

Based off feedback from the test subjects, a number of improvements were made, such as replacing the spider model with one that had a more detailed model and animations. The scoring system was tweaked, the user interface was refined, and more detail was added to the voice-over dialogue to better explain to the user what they should be doing, although these improvements could not be tested with users during the lockdown.

Given more time, a number of other stimuli could be added, as well as entirely new subsystems, such as online scoreboards and an appointment tracker. Were the hardware constraints removed, a vast number of opportunities are introduced. Further virtual reality hardware could be used to create a more detailed and compelling virtual environment, or augmented reality hardware could be used to bring virtual stimuli into the real world, allowing the user to face their fears in the environments in which they typically present themselves in real life.

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Appendix A

Ethics Documents

Developing a VR Exposure Therapy System for Self-Treatment of Common Phobia - Consent Form

Please tick the appropriate boxes	**Yes**	**No**
Taking Part in the Project		
I have read and understood the project information sheet dated 14/02/2020 or the project has been fully explained to me. (If you will answer No to this question please do not proceed with this consent form until you are fully aware of what your participation in the project will mean.)		
I have been given the opportunity to ask questions about the project.		
I agree to take part in the project. I understand that taking part in the project will include attending two separate sessions, each one involving a pre-treatment questionnaire, a post-treatment questionnaire and the treatment itself, which will require the use of a virtual reality headset, in which the chosen stimulus (spiders, wasps, heights, air travel, or enclosed spaces) will be presented through a number of levels, with incrementally increasing realism / interactivity. Each level may require a certain degree of interaction with the stimulus to progress. Each level will require a 1-10 rating of distress in order to progress.		
I understand that my taking part is voluntary and that I can withdraw from the study at any time; I do not have to give any reasons for why I no longer want to take part and there will be no adverse consequences if I choose to withdraw.		
How my information will be used during and after the project		
I understand my personal details such as name, phone number and email address will not be revealed to people outside the project.		
I understand and agree that my words may be quoted in publications, reports, web pages, and other research outputs. I understand that I will not be named in these outputs unless I specifically request this.		
I understand and agree that other authorised researchers will have access to this data only if they agree to preserve the confidentiality of the information as requested in this form.		
So that the information you provide can be used legally by the researchers		
I agree to assign the copyright I hold in any materials generated as part of this project to The University of Sheffield.	☐	☐

Name of participant [printed] Signature Date

Name of Researcher [printed] Signature Date
Fred Tovey-Ansell

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Ethics application

Section B: Basic information

1. **Supervisor**
   Dr Heidi Christensen (heidi.christensen@sheffield.ac.uk)

2. **Proposed project duration**
   Start date (of data collection) and Anticipated end date (of project)
   24/02/2020

3. **Project code (where applicable)**
   N/A

4. **Suitability**

   Is taking place outside the UK
   No

   Involves the NHS
   No

   Is healthcare research
   No

   Is a human-interventional study
   Yes

   Is Economic and Social Research Council funded
   No

   Is likely to lead to publication in a peer-reviewed journal
   No

   Is being led by another UK institution
   No

   Involves human tissue
   No

   Is a clinical trial of an Investigative Medicinal Product
   No

   Is social care research
   No

   Involves adults (over 16s) who lack the capacity to consent
   No

5. **Indicators of risk**

Involves potentially vulnerable participants

Yes – In order for the research to be effective, participants must have a self-reported phobia of at least one of the stimuli included in the system. While the user will likely face some degree of distress during the session, they will be free to take a break or end the session at any time. The system has been designed to ease the user into the treatment as gradually as possible, and the participant will be monitored by the researcher at all times, providing assistance if needed. The participant will also be allowed to bring someone to the session with them for additional support.

Involves potentially highly sensitive topics

No

Section C: Summary of research

1. **Aims and Objectives**

Summarise the project's aims and objectives

The purpose of this project is to evaluate the quality, usability and effectiveness of a virtual reality exposure therapy system. The system is designed to allow users to treat their phobias of five different stimuli: Spiders, wasps, heights, enclosed spaces and air travel. The system uses an Oculus Rift Consumer Version One to interact with various 3D models representing your chosen stimulus. The results from the study will be used to improve the design of the system, and assess its effectiveness.

2. **Methodology**

Summarise the project's methodology

The subject will first choose one of the five stimuli that they are not afraid of, and one of the five stimuli that they *are* afraid of. They will confront virtual forms of both of these stimuli during the study, through the virtual reality headset which they will be wearing. The device restricts nearly all vision of the real world, and allows interaction with the virtual environments developed for the system.

Before wearing the headset, we will first brief the subject on how to use the system, and answer any questions they may have. We will also ask a number of control questions (see attached questionnaire), such as how the subject is feeling at the time, their previous experience with virtual reality (if any), and how distressing they find their chosen stimulus.

The treatment for each stimulus is comprised of a number of levels of increasing intensity. The levels will start as easy as possible, with initial levels showing the subject simple images with a voice-over. In following levels, the subject will confront the stimulus more directly. For example, for the spider stimulus, the first level will show the subject a 2D cartoon spider, and the voice-over will talk through a number of spider related facts. The next levels will place a small, virtual spider on the table in front of the subject within the virtual environment, which will start to move around. Later levels will use more spiders, some of which will be much larger. Each level will involve a scoring system, and will allow the subject to earn points by engaging with the treatment, and interacting with the stimulus. The subject will not be required to walk around while wearing the headset, and will instead be allowed to remain seated or standing in a fixed position, depending on the level they are on.

These levels are designed to make the subject feel slightly anxious (this means the treatment is working). While the subject will be encouraged to challenge themselves to complete as many levels as they can, it will be made clear that they are not expected to complete them all, and that they are free to remove the headset and stop the treatment at any time. Throughout the study, there will be someone on hand at all times to support the subject if they become too distressed, or are unsure what to do. Each level prompts the subject to give a 1 to 10 rating of how anxious they feel at that moment, and they will be encouraged to answer this as honestly as possible.

To familiarise the subject with the equipment (and to gather some baseline data), they will first progress through the levels corresponding to a stimulus they are *not* afraid of. After they finish with this stimulus, they will then progress through the levels for the stimulus they *are* afraid of.

Once the subject decides they are finished with the treatment, or they have finished all levels, they will remove the headset and complete the attached questionnaire. This will ask the subject a number of questions on their experience with the system, how easy and comfortable they found it to use, and how effective they feel it was at treating their phobia, if at all. We will also ask the subject to recount some past experiences with their stimulus in the real world, so that we can integrate these into the system for future users, if appropriate.

3. Personal safety

Does your research raise any issues of personal safety for you or other researchers involved in the project?

No

Explain the issues of personal safety raised and how these issues will be managed

N/A

Section D: About the participants

1. Potential Participants

How will you identify the potential participants?

Potential participants will report a phobia of at least one of the five following stimuli: Spiders, wasps, heights, enclosed spaces or air travel, as long as they do not have a history of these stimuli inducing panic attacks, or they for any reason should have a medical professional on hand while confronting these stimuli. They will also report to have *no* phobia of at least one of these stimuli.

2. **Recruiting Participants**

How will the potential participants be approached and recruited?

Participants will be personally contacted by the researcher, or contacted through the University's email announce system / social media. They will be given a verbal description of the experiment along with an information sheet. They will indicate their interest in becoming involved by signing a consent form.

3. **Consent**

Will informed consent be obtained from the participants?

yes

How do you plan to obtain informed consent? (i.e. the proposed process)

Consent will be obtained by asking the participants to sign a consent form, after they have read an information sheet detailing their involvement in the research.

4. **Payment**

Will financial/in kind payments be offered to participants?
no

5. **Potential Harm to Participants**

What is the potential for physical and/or psychological harm/distress to the participants?

The headset blocks all view of the real world, and so there is the potential for the user to collide with real world objects, or trip over obstacles. The system has been designed in such a way so that physical movement around the room will not be necessary, and test subjects will be instructed to remain seated or standing in a fixed position.

While using the headset, there is a small chance the test subject may experience some nausea, known as simulator sickness, as a result of interacting with the virtual environment.

The study will almost certainly place the subject in a certain degree of psychological distress.

How will this be managed to ensure appropriate protection and well-being of the participants?

The system has been designed so the user should not have to move around the space while wearing the headset. As a further precaution, unnecessary obstacles such as chairs and trailing wires will be removed from the space.

The system has been designed in such a way as to reduce simulator sickness as much as possible, and to introduce each stimulus as gradually as possible, allowing the user to slow down or stop whenever they feel too distressed or nauseous. It will be made clear (both by the researchers and the system itself) that the subject will be free to remove the headset at any time, or end the testing session entirely should they feel too nauseous, or too distressed. There will always be someone on hand to support the subject in this event.

Section E: About the data

1. **Data Confidentiality**

   What measures will be put in place to ensure confidentiality of personal data, where appropriate?

   Data collected will be anonymous and no other personal details will be recorded. The user's input to the system will be recorded, as well as their responses to the questionnaire, although there will be no way to identify the individual from this data.

2. **Data Storage**

   The researcher will act as the custodian for the data generated.
   The data will be analysed by the researcher in their password-protected personal computer.
   The data will be anonymously stored.
   The data will be only accessible by the researcher.
   Any personal data will be destroyed after the successful completion of this project.
   The research is not externally funded.
   No audio or video media of the subject will be recorded.
   The data will be stored in the researcher's personal, password protected computer, or securely on the cloud.

Participant Information Sheet 14/02/2020

1. Research Project Title

"Developing a Virtual Reality Exposure Therapy System for Self-Treatment of Common Phobia"

2. Invitation

You are being invited to take part in a research project. We describe the reasons the research is done and what it will involve. We ask you read the following information carefully and ask any questions that may arise.

3. What is the project's purpose?

The purpose of this project is to evaluate the quality, usability and effectiveness of a virtual reality exposure therapy system. The system is designed to allow users to treat their phobias of five different stimuli: Spiders, wasps, heights, enclosed spaces and air travel. The system uses a virtual reality headset (the Oculus Rift) to interact with various 3D models representing your chosen stimulus. The results from your testing session will be used to improve the design of the system.

4. Why have I been chosen?

You have been chosen as you report to have a phobia of at least one of the previously mentioned stimuli, and are thus a candidate for treatment by the system being developed.

5. Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part you will be able to keep a copy of this information sheet and you should indicate your agreement to the online consent form. You can still withdraw at any time. You do not have to give a reason.

6. What will happen to me if I take part?

You will be asked to attend two sessions. Each session will be composed of a pre-treatment questionnaire, treatment using the system, and a post-treatment questionnaire. You will be free to progress through the treatment at your own pace, but sessions are not expected to last longer than 45 minutes.

7. What do I have to do?

Attend two sessions, each time answering a series of questions before and after the treatment. During the treatment, you will be required to wear an Oculus Rift virtual reality headset, in which you will be placed within a virtual environment, where you will be unable to see or interact with the real world. You may remove the headset or end the session at any time. There will be 10 levels, each one presenting you with an incrementally more realistic representation of your stimulus. Some levels may require you to simply sit and observe the stimulus, later levels may require more direct interaction. Between each level, the system will require you to give a 1-10 rating of how anxious you feel. Similar questions will appear in the questionnaires. The system may monitor your performance at each level and use this to calculate a score, you will not be required to achieve any particular score, this is simply an incentive for you to engage with the treatment. You will be asked to progress through as many levels as you feel able, once you have either finished all the levels, or decide to end the treatment, you will remove the headset and you will be asked to complete the post-treatment questionnaire.

8. What are the possible disadvantages and risks of taking part?

The headset is designed to block all view of the real world, and so there is potentially a risk for you to collide with real world objects or trip over obstacles, however the system has been designed so that you shouldn't need to move much around while wearing the headset, and there will always be someone on hand watching you to make sure you don't bump into anything.

A common reaction to virtual reality is a nausea similar to motion sickness. The system has been designed in such a way as to mitigate this, and you will be free to remove the headset and take a break any time you wish.

The treatment is designed to cause a certain degree of anxiety, this means the treatment is working. You will be free to progress through the treatment at your own place, and end the session if you feel too distressed. You will however be encouraged to progress as far through the treatment as you feel able, although there is no expectation for which level you should reach. You are welcome to bring someone along to the session with you for support, although you will be encouraged to progress through the treatment as independently as possible.

9. What are the possible benefits of taking part?

If the treatment is effective, you should experience some degree of reduction in your fear of the stimulus, although this may not be long lasting after only two sessions. Through experience with the virtual environment, it is possible you will accumulate a tolerance to the nausea that may be caused, and you may find that next time you use a virtual reality system, you experience these symptoms less than you would have done otherwise. (it is entirely possible you do not experience any nausea during these sessions)

10. What happens if the research study stops earlier than expected?

Should the research stop earlier than planned and you are affected in any way we will tell you and explain why.

11. What if something goes wrong?

If you have any complaints about the project in the first instance you can contact any member of the research team.

12. Will my taking part in this project be kept confidential?

All the information that we collect about you during the course of the research will be kept strictly confidential. You will not be able to be identified or identifiable in any reports or publications. Your institution will also not be identified or identifiable. Any data collected about you in the questionnaire will be stored securely online, or on the researcher's personal, password protected computer. Data collected may be shared in an anonymised form to allow reuse by the research team and other third parties. These anonymised data will not allow any individuals or their institutions to be identified or identifiable.

13. Will I be recorded, and how will the recorded media be used?

You will not be recorded in any way other than your input to the questionnaire and the virtual reality system without separate permission being gained from you. Your movements within the virtual environment may be recorded by capturing what you see on the screen throughout the session, though this will not capture your face, body, or any information about you.

14. What type of information will be sought from me and why is the collection of this information relevant for achieving the research project's objectives?

The questionnaire will ask you about your phobia of the stimulus, how anxious it makes you feel, and what experiences you may have had with the stimulus in the past. The questionnaire will also ask various questions on your experience with the system, such as how easy / comfortable you found it to use, how realistic you felt the environment was, etc. This information is relevant in assessing the effectiveness of the system, and its ease of use, and will be used to make improvements.

15. What will happen to the results of the research project?

Results of the research will be published. You will not be identified in any report or publication. Your institution will not be identified in any report or publication. If you wish to be given a copy of any reports resulting from the research, please ask us to put you on our circulation list.

16. Who is organising and funding the research?

The project researcher is Fred Tovey-Ansell (Computer Science undergraduate, University of Sheffield), and is supervised by Dr Heidi Christensen (Department of Computer Science, University of Sheffield)

17. Who has ethically reviewed the project?

The University of Sheffield's Research Ethics Committee monitors the application and delivery of the University's Ethics Review Procedure across the University.

18. Contacts for further information

Researcher: Fred Tovey-Ansell, University of Sheffield, ftovey-ansell1@sheffield.ac.uk

Supervisor: Dr Heidi Christensen, Department of Computer Science, University of Sheffield.
Heidi.christensen@sheffield.ac.uk

Thank you for taking part in this research.

Appendix B

User Questionnaire

Pre-Treatment

1. Do you have previous experience with VR systems?
2. On a scale of 1 to 10, how anxious have you felt today?
3. On a scale of 1 to 10, how anxious do you think you would feel if directly confronting your stimulus in real life? (10 being a severe panic attack)
4. Susceptibility to simulator sickness
   (a) Have you had experience using VR systems in the past?
   (b) If so, on scale of one to ten, how nauseous did use of these systems make you feel?

Post-Treatment

1. Treatment effectiveness - On a scale of 1 to 10, how anxious do you *now* think you would feel if directly confronting your stimulus in real life?
2. User Comfort
   (a) On a scale of 1 to 10, how nauseous did the virtual environment make you feel?
   (b) What particular parts of the system made you feel nauseous, if any?
3. Ease of use
   (a) On a scale of 1 to 10, how difficult did you find it to interact with the system?
   (b) Were there any moments where you were unsure what you were supposed to be doing?
4. Presence
   (a) On a scale of 1 to 10, how believable did the virtual environment feel?

   (b) On a scale of 1 to 10, how believable did your stimulus feel?

5. Gamification - Do you feel the points system incentivises you to progress?
   (a) On a scale of 1 to 10, how much did the scoring system motivate you to progress and engage with each level?
   (b) Do the levels seem to be in the correct order of difficulty?
6. Robustness - Did the system appear to work as intended?
7. Previous experiences - Please give an account of previous experiences you may have had with your chosen stimuli in the real world.
8. Do you have any further feedback regarding the system, or the user testing session?

Appendix C

User Testing Results

		SUBJECTIVE UNITS OF DISTRESS - SPIDER LEVELS										
		L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	Av'
Subject 1	Session 1	1	1	2	2	3	4	3	5	6	4	3.1
	Session 2	1	1	1	1	1	2	3	3	3	3	1.9
	Difference	0	0	-1	-1	-2	-2	0	-2	-3	-1	-1.2
Subject 2	Session 1	1	1	2	2	3	3	4	4	5	5	3
	Session 2	1	1	2	2	2	2	3	3	3	4	2.3
	Difference	0	0	0	0	-1	-1	-1	-1	-2	-1	-0.7
Subject 3	Session 1	1	1	2	2	2	2	3	3	3	4	2.3
	Session 2	1	1	3	2	3	4	4	6	5	6	3.5
	Difference	0	0	1	0	1	2	1	3	2	2	1.2
Average	Session 1	1	1	2	2	2.7	3	3.3	4	4.7	4.3	2.8
	Session 2	1	1	2	1.7	2	2.7	3.3	4	3.7	4.3	2.6
	Difference	0	0	0	-0.3	-0.7	-0.3	0	0	-1	0	-0.2

			SUDS - SUBTRACTING BASELINE ANXIETY - SPIDER LEVELS										
		Baseline	L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	Av'
Subject 1	Session 1	3	-2	-2	-1	-1	0	1	0	2	3	1	0.1
	Session 2	3	-2	-2	-2	-2	-2	-1	0	0	0	0	-1.1
	Difference	0	0	0	-1	-1	-2	-2	0	-2	-3	-1	-1.2
Subject 2	Session 1	2	-1	-1	0	0	1	1	2	2	3	3	1
	Session 2	3	-2	-2	-1	-1	-1	-1	0	0	0	1	-0.7
	Difference	1	-1	-1	-1	-1	-2	-2	-2	-2	-3	-2	-1.7
Subject 3	Session 1	2	-1	-1	0	0	0	0	1	1	1	2	0.3
	Session 2	1	0	0	2	1	2	3	3	5	4	5	2.5
	Difference	-1	1	1	2	1	2	3	2	4	3	3	2.2
Average	Session 1		-1.3	-1.3	-0.3	-0.3	0.3	0.7	1	1.7	2.3	2	0
	Session 2		-1.3	-1.3	-0.3	-0.7	-0.3	0.3	1	1.7	1.3	2	0
	Difference		0	0	0	-0.3	-0.7	-0.3	0	0	-1	0	-0.2

SUBJECTIVE UNITS OF DISTRESS - IMAGINED SPIDER			
	Pre-Treatment	Post-Treatment	Difference
Subject 1	7	5	-2
Subject 2	5	5	0
Subject 3	7	3	-4
Average	6.3	4.3	-2

SUDS - IMAGINED SPIDER - SUBTRACTING BASELINE			
	Pre-Treatment	Post-Treatment	Difference
Subject 1	4	2	-2
Subject 2	2	2	0
Subject 3	5	2	-3
Average	3.7	2	-1.7

		ACHIEVED SCORES - SPIDER LEVELS										
		L0	L1	L2	L3	L4	L5	L6	L7	L8	L9	Av'
Subject 1	Session 1	100	100	100	100	100	100	100	100	100	100	100
	Session 2	100	100	100	73	69	100	100	100	100	100	94.2
	Difference	0	0	0	-27	-31	0	0	0	0	0	-5.8
Subject 2	Session 1	100	100	33	100	100	100	100	100	100	100	93.3
	Session 2	100	100	67	100	100	100	100	100	100	100	96.7
	Difference	0	0	34	0	0	0	0	0	0	0	3.4
Subject 3	Session 1	100	100	100	100	100	100	100	100	100	100	100
	Session 2	100	100	100	100	100	100	100	100	100	100	100
	Difference	0	0	0	0	0	0	0	0	0	0	0
Average	Session 1	100	100	77.7	100	100	100	100	100	100	100	97.8
	Session 2	100	100	89	91	89.7	100	100	100	100	100	97.0
	Difference	0	0	11.3	-9	-10.3	0	0	0	0	0	-0.8

User Questionnaire, Participants 1, 2, 3 → Average/Comment

Baseline - Do you have previous experience with VR systems?

Yes - all participants had VR experience, as would be expected from the target user.

Susceptibility to simulator sickness - On a scale of one to ten, how nauseous did the use of these systems make you feel?

2, 1, 1 → 1.33, very limited nausea induced when using other systems.

User Comfort

(a) On a scale of 1 to 10, how nauseous did the virtual environment make you feel?

1, 1, 1 → 1, On average less than other systems (very slightly)

(b) What particular parts of the system made you feel nauseous, if any?

No nausea from any participants

Ease of use

(a) On a scale of 1 to 10, how difficult did you find it to interact with the system?

3, 2, 2 → 2.33, subject 1 only had very brief confusion when first using the system

(b) Were there any moments where you were unsure what you were supposed to be doing?

Only some uncertainty around what to do during voiceover

Presence

(a) On a scale of 1 to 10, how believable did the virtual environment feel?

7, 3, 8 → 6, Moderately believable

(b) On a scale of 1 to 10, how believable did your stimulus feel?

7, 6, 7 → 6.67 - Interesting subject two found the stimulus real, but not the environment

Gamification - Do you feel the points system incentivises you to progress?

(a) On a scale of 1 to 10, how much did the scoring system motivate you to progress and engage with each level?

7, 7, 6 → 6.67, Interesting that the average score across each level was 97.37%, perhaps the scoring incentive acts more unconsciously, or maybe the accumulation of score is more incidental - would be interesting to test with harder scoring systems

(b) Do the levels seem to be in the correct order of difficulty?

Yes, although Subject One felt the final two levels could be switched

Robustness - Did the system appear to work as intended?

No bugs *noticed* by participants, there was a bug in the backend where SUDS scores were being saves at a value 1 lower than they should be, which has since been fixed

Previous experiences - Please give an account of previous experiences you may have had with your chosen stimuli in the real world.

Always encounters in the home, especially in bed or at night. Would be interesting to add a bed level, although laying down in VR is problematic due to sensor tracking.

Do you have any further feedback regarding the system, or the user testing session?

General consensus was to use a higher detail 3D model. Spiders could also be added in other parts of the room (floor, walls, etc) rather than just the table, to introduce more unpredictability