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UNIVERSIDADE D
COIMBRA

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ENHANCING AR-BASED EXPOSURE THERAPY APPLICATION

Dissertation submitted to the Department of Electrical and Computer Engineering of the Faculty of Sciences and Technology of the University of Coimbra in partial fulfillment of the requirements for the Degree of Master of Science oriented by Professor Doctor Paulo Jorge Carvalho Menezes

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Supervisor:

Paulo Jorge Carvalho Menezes

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Abstract

In vivo exposure therapy stands as the prevailing treatment for phobias, boasting a remarkable success rate. Nevertheless, this approach does bear certain constraints, including limited control over the phobic elements, impracticality in a conventional office setting, and a notable rate of patient refusal. Technological alternatives like virtual or augmented reality present promising avenues to overcome these drawbacks and enhance the effectiveness of phobia treatment.

This proposal tends to present the enhancement of a previously presented work regarding an Augmented Reality solution that can be employed in a clinical setting as a replacement for *in vivo* exposure therapy. This solution involved the development of an application that allows therapists to bring virtual versions of elements associated with specific phobias of each patient into their office space. The application integrates seamlessly into a typical therapeutic office space, offering patients a realistic and immersive experience of interacting with their phobic elements.

As an extension of a previous development, with the main goal of continuing and enhancing the existing AR solution, the improvements are aimed at addressing limitations identified in the earlier study, including the need for more diverse phobic elements, new stimuli to broaden the patient's experience, and new features to offer a deeper understanding of the patient's reactions, enabling more effective therapeutic interventions. To achieve these objectives, the study introduces the implementation of dynamically loadable elements, support for spatially located sound stimuli, and tracking of the patient eye gaze.

A test was conducted to evaluate the implementation, with a specific focus on the elements' sense of presence and realism. The results from the test were predominantly positive, demonstrating the systems' efficacy in assisting with the treatment of phobias.

Resumo

A terapia de exposição *in vivo* destaca-se como sendo o tratamento predominante para fobias, apresentando uma taxa de sucesso notável. No entanto, esta abordagem possui certas limitações, tal como, um controlo limitado sobre os elementos fóbicos, impraticabilidade num ambiente de consultório convencional e uma taxa notável de recusa por parte dos pacientes. Alternativas tecnológicas como realidade virtual ou aumentada apresentam caminhos promissores para superar estas limitações e aumentar a eficácia do tratamento de fobias.

Esta proposta tem como objetivo apresentar o aprimoramento de um trabalho anterior referente a uma solução de realidade aumentada que pode ser empregada num ambiente clínico como substituto da terapia de exposição *in vivo*. Esta solução envolveu o desenvolvimento de uma aplicação que permite aos terapeutas trazerem versões virtuais de elementos associados a fobias específicas de cada paciente para o espaço do consultório. A aplicação integra-se perfeitamente ao ambiente típico de um consultório terapêutico, oferecendo aos pacientes uma experiência realista e imersiva ao interagirem com os elementos fóbicos.

Como uma extensão do desenvolvimento anterior, o principal objetivo é continuar e aprimorar a solução de Realidade Aumentada existente. As melhorias têm como objetivo abordar as limitações identificadas no estudo anterior, incluindo a necessidade de elementos fóbicos mais diversos, novos estímulos para ampliar a experiência do paciente e novas funcionalidades para oferecer uma compreensão mais profunda das reações do paciente, permitindo intervenções terapêuticas mais eficazes. Para alcançar esses objetivos, o estudo introduz a implementação de elementos carregados dinamicamente, suporte para estímulos sonoros localizados espacialmente e rastreamento do olhar do paciente.

Para avaliar a implementação, foi realizado um teste focado específicamente na sensação de presença e realismo dos elementos. Os resultados do teste foram predominantemente positivos, demonstrando a eficácia do sistema no auxílio ao tratamento de fobias.

List of Figures

Acronyms

AR augmented reality.

HMD Head Mounted Display.

HRTF Head-related transfer function.

ID identification.

IR Infrared.

MRTK Mixed Reality Toolkit.

PC personal computer.

RPC Remote Procedure Call.

TL Therapeutic Lamp.

VR virtual reality.

Contents

1

Introduction

A phobia is defined as an excessive and irrational fear of specific stimuli or situations, leading to personal impairment. This overwhelming apprehension can cause significant distress to individuals when confronted with these triggers, even though the stimuli pose minimal or no real threat [1]. Phobias are widely recognized as one of the most prevalent anxiety disorders [2] and, although symptoms may vary from person to person, certain common signs are frequently observed, such as difficulties in concentrating, excessive worry about future misfortunes, experiencing tension headaches, restlessly fidgeting, an inability to relax, and a tendency to avoid the feared stimuli [3].

Individuals seeking treatment for phobias have access to various intervention options, including cognitive therapy, modeling, imaginal or virtual reality exposure, and direct *in vivo* exposure. Among these options, *in vivo* exposure therapy is widely considered the primary and most effective treatment for specific phobias [2]. This therapeutic approach involves a gradual and controlled exposure to the feared stimuli or situations, allowing individuals to confront and manage their fears in a safe environment. Exposure therapy has proven to be one of the most robust methods for treating phobias. However, it's important to acknowledge that approximately 25% of patients refuse to proceed with this treatment after learning about its nature and requirements [4]. In addition to this, there are various challenges associated with implementing exposure therapy. One significant obstacle is the difficulty of conducting the therapy in a conventional office setting [5]. Also, a major concern lies in the struggle to maintain complete control over the phobic elements during exposure therapy [6]. This lack of control can introduce unpredictability and may potentially cause discomfort for certain individuals during the treatment process. Phobias related to animals pose unique challenges [7], as they often necessitate specialized facilities for effective treatment. Ensuring the safety of both patients and therapists involved in treatment becomes crucial, necessitating expertise in handling and managing animals. Moreover, exposure therapy with animals can be distressing or perceived as cruel by some patients and therapists [8].

To address the drawbacks associated with traditional exposure therapy for phobias, technological alternatives like virtual reality (VR) and augmented reality (AR) have emerged as promising solutions. Virtual Reality (VR) has demonstrated its effectiveness as a viable substitute for *in vivo* exposure, where individuals are transported to a virtual environment to confront their phobic stimuli [5]. VR has been well-received by patients, with a significant percentage preferring it over *in vivo* exposure [2]. It has the potential to provide controlled and immersive experiences, enabling users to face their fears in a safe virtual setting. This controlled exposure provides a gradual and customized approach to phobia treatment, enabling individuals to confront their fears at their own pace while being closely monitored by therapists. Augmented Reality (AR) integrates virtual content into the real world, enabling users to interact with virtual elements in their actual environment [9]. This approach offers a more naturalistic experience, allowing users to interact with virtual objects using their own bodies and making only minor changes to their sensory perception of reality. AR has demonstrated promising outcomes in the treatment of phobias [5] [7] [9], although it is a newer and less explored approach compared to VR.

Both VR and AR offer compelling and convenient immersive qualities that have proven to be particularly effective in the treatment of various phobias. When making the decision between VR and AR for a specific phobia treatment, it's crucial to consider the nature of the phobia and the desired level of exposure. VR, with its ability to transport users to entirely different scenarios, has emerged as a powerful tool in the therapeutic arsenal. In cases of phobias like claustrophobia (fear of enclosed spaces) or acrophobia (fear of heights), where a controlled and fully immersive environment is crucial for exposure therapy, VR shines. On the other hand, Augmented Reality (AR) introduces a different dimension to phobia treatment. By seamlessly blending virtual elements with the real world, AR has the potential to create a more natural and authentic experience. This approach is particularly beneficial when dealing with phobias that can be integrated into the patient's immediate surroundings allowing them to confront their fears in real-life contexts.

1.1 Related Work

In the sphere of therapeutic interventions, a significant trend has arisen, embracing both Virtual Reality (VR) and Augmented Reality (AR) approaches. These innovative solutions capitalize on the strengths of these technologies to create transformative experiences for individuals seeking therapeutic support. In this evolving landscape, various studies have harnessed the potential of VR and AR to address diverse challenges in phobia treatments.

Virtual Reality

In 1995, Rothbaum et al. [10] pioneered an innovative approach to address acrophobia, by introducing virtual reality as an early alternative to conventional *in vivo* exposure techniques. Their pioneering study showcased the potential effectiveness of this novel technology in managing anxiety disorders. Through the utilization of virtual reality, they successfully targeted acrophobia, thereby opening up a promising pathway for therapeutic interventions that extended beyond the limitations of traditional *in vivo* exposure methods.

In 2005, the work of Côté and Bouchard [11] was dedicated to tackling arachnophobia through the integration of spiders within virtual reality environments. Their research showcased notable enhancements in patient symptoms following the implementation of this innovative VR-centered methodology.

Pitti *et al.* [12] (2015) introduced an innovative approach for addressing agoraphobia (fear of leaving known environments considered to be safe), utilizing Virtual Reality alongside polarized glasses and a specialized screen for projection. The study's findings indicated that patients who underwent a combination of treatments (VR exposure and psychoactive drugs) exhibited significantly greater improvements compared to those undergoing alternative treatments. It's important to note, however, that dropout rates between treatments involving VR exposure and traditional *in vivo* exposure were found to be similar.

Augmented Reality

In the year 2005, Juan et al. [13] embarked on one of the initial endeavors to harness augmented reality (AR) for such therapeutic applications, using an HMD and a camera connected to a computer. While their work was primarily exploratory, it served as a cornerstone for subsequent advancements in augmented reality-based interventions. A noteworthy aspect of their study was the introduction of the concept where the therapist observed the exposure process through a computer monitor. This innovative strategy enabled the therapist to closely oversee and direct the patient's exposure encounters within the augmented reality setting.

In 2013, Wrzesien et al. [14] introduced a distinct methodology employing augmented reality (AR) in conjunction with a Therapeutic Lamp (TL) to project images of small animals onto a surface. This innovative approach proved to be successful in addressing specific phobias. Nonetheless, it's crucial to acknowledge that the choice of using projections, as opposed to holograms, within this framework can influence the perception of realism and the level of immersion associated with the phobic elements.

In the year 2020, De Witte et al. [15] carried out a study centered on the management of animal-related phobias through the utilization of an augmented reality (AR) application designed for smartphones. Their objective was to investigate an innovative avenue distinct from conventional *in vivo* exposure therapy. Nonetheless, their approach encountered certain constraints. Although the AR application effectively elicited the intended fear and anxiety linked to the phobic elements, it exhibited limitations in terms of achieving a lifelike realism and fostering interactive engagement with these elements.

Patrão et al. in 2020 [16] presented a shared space AR experiment aimed at addressing arachnophobia. The experiment employed tablets for both the therapist and the patient. While the study revealed favorable results in terms of usability and interaction, it's noteworthy that the utilization of tablets led to a diminished perception of virtual elements, thereby rendering interaction with these elements more intricate and demanding.

Nunes et al. in 2022 [17] presented an innovative augmented reality (AR) solution designed to tackle phobias. This solution empowered patients to engage directly with the phobic elements, all while affording therapists full control over these elements. This pioneering approach marked a substantial stride forward within the field. Nevertheless, the study did encounter certain constraints, such as the flexibility of the phobic elements, challenges associated with therapists accurately perceiving patient reactions, and the absence of certain immersive capabilities.

This dissertation presents solutions for the issues detected in the last mentioned work, bringing in a wave of novel tools that serve to significantly enhance the experiences of both therapists and patients. These innovative additions not only bring a new dimension to the therapeutic process but also contribute to a more immersive and effective journey for the patients. It also achieves a new level of expandability and adaptability previously unexplored within this research domain.

1.2 Main Objectives

Having in mind all that was discussed before, the focus now is on enhancing the previously developed project of an augmented reality (AR) solution, intended to serve as a substitute for traditional *in vivo* exposure therapy in clinical settings. This AR application enables therapists to integrate virtual representations of elements related to each patient's specific phobia directly into their office space. The goal is to create a realistic and immersive experience for patients, allowing them to confront their fears in a controlled and safe manner.

In this approach, the therapist is given full control over the augmented reality (AR) experience through a paired computer. With this control, the therapist can precisely select when each virtual element associated with the patient's specific phobia should be present or absent within the AR scene.

The therapist can also determine the exact location of these virtual elements in the AR space, allowing for a strategic setup to suit the patient's needs. Moreover, the therapist has the capability to manipulate the behavior of each virtual phobic element within the scene. This means that each virtual element behaves in a unique manner, designed specifically based on its characteristics and purpose.

Considering the limitations assessed in the previous solution, including the need for more diverse phobic elements, new stimuli to broaden the patient's experience, and new features to offer a deeper understanding of the patient's reactions, enabling more effective therapeutic interventions. To achieve these objectives, the study introduces the implementation of dynamically loadable elements, along with a framework for their development. This allows for a more flexible and varied selection of phobic elements, offering a richer and more tailored therapeutic experience. Furthermore, the work includes support for spatially located sound stimuli, enhancing the realism and immersion of the patient. This feature provides a complete auditory experience, further contributing to the effectiveness of the therapy. In terms of therapist support, the work implements support to track the patient's eye gaze dynamics during the exposure sessions. This enables the therapist to have a real-time representation of the patient's eye gaze on the paired computer, aiding in understanding reactions and responses during the therapy sessions.

Lastly, it is crucial to validate the developed work by assessing the realism of the phobic elements, the sense of presence they evoke within the shared space, and evaluate the spatial sound capabilities provided in the experience.

1.3 Document structure

The structure of this dissertation is outlined as follows:

- **Chapter 1** delineates the motivation, significance, and contextualization of the work within the contemporary realm of Virtual Reality (VR) and Augmented Reality (AR). It also establishes the study's objectives.
- **Chapter 2** provides a comprehensive breakdown of the proposal, detailing the selection of materials and tools for the work's development.
- **Chapter 3** offers an in-depth account of all the implemented features.
- **Chapter 4** presents a comprehensive analysis of the conducted study used to evaluate the developed work, along with the corresponding outcomes.
- **Chapter 5** concludes this dissertation by summarizing the achievements of the work

and proposing potential avenues for future enhancements to the existing application.

2

Proposal and development materials

2.1 Proposal

The present proposal presents noteworthy new features that have been designed to bolster and broaden the therapeutic possibilities, all the while elevating the experiences of both patients and therapists (figure2.1). These new features focus on the creation and storage of elements, the introduction of sound capabilities, and the incorporation of eye tracking for evaluating patient behavior.

Figure 2.1: Therapy setup.

2.1.1 Dynamically loadable elements

In the majority of VR and AR applications, the included and accessible elements are usually hard-coded into the generated application. Consequently, incorporating new elements requires modifying the original code and then distributing updated versions of the application.

The requirements for exposure therapies often encompass a wide range of elements, which may not be entirely predictable. While certain types of elements may be more common, these trends can change over time. In contrast to the previous approach, where models were fixedly included in the developed applications, this new method introduces a ”load-on-demand” feature. This advancement enables the application to access any model available through an online repository. As a result, therapists and users now have the flexibility to utilize a broader selection of elements, adapting to evolving needs and ensuring a more dynamic and up-to-date experience. This innovative approach addresses the limitations of static model inclusion, offering greater versatility and potential for enhanced therapeutic outcomes.

By incorporating dynamically loading elements, this application reaches a new level of expandability, providing benefits in terms of both the diversity of phobic elements available and the ability to scale for concurrent active devices in multiple locations. By enabling the application to access the online repository at runtime, it can retrieve a comprehensive list of available elements. Therapists now have the flexibility to select and load desired elements on demand, tailoring the experience to each user’s specific needs. This approach significantly simplifies the process of updating available phobic elements or adding new ones. Previously, the only way to add or update an element was to reinstall a new version of the application on each device locally. Now, all that is needed is to include the updated or new elements in the repository, and they automatically become accessible to all devices running the application. This streamlined updating process ensures that the application stays up-to-date and relevant, benefiting both therapists and users with a constantly evolving and diverse set of therapeutic elements. Furthermore, the dynamic loading capability expands the reach of the application, enabling more devices to access and use it simultaneously. This increased scalability enhances the potential impact of the application, as it can now accommodate a larger number of users seeking exposure therapy, regardless of their location. This advancement brings exposure therapy to a broader audience, increasing accessibility and effectiveness for individuals seeking therapeutic support.

Utilizing this method, the application is now equipped to address five distinct phobias:

- Arachnophobia - spider phobia.
- Ophidiophobia - snake phobia.

- Musophobia- rat phobia.
- Ailurophobia - cat phobia.
- Bufonophobia - frog phobia.

The choice of these phobias was made in accordance with the specific criteria outlined by an experienced therapist in this field and can be easily expanded upon.

2.1.2 Spatial sound stimulli

Sound plays a pivotal role in enhancing the immersive experience of Augmented Reality (AR) applications. In the realm of AR, audio serves as a powerful tool to bridge the gap between what users see and what they perceive. The integration of sound, not only adds depth and realism but also contributes significantly to user engagement and interaction.

Incorporating sound effects into elements in the application can significantly enhance the immersive experience and add an extra layer of realism to the virtual environment. While some elements, like spiders, might not produce sound in reality, other elements can be associated with their characteristic sounds to create a more engaging and convincing simulation. For instance, when a user encounters a virtual animal, the application can now include the reproduction of natural and specific animal sounds. By exploring 3D sound-located sources, the sensation of these sounds being produced by the visualized animals is created, thus improving the perceived realism and presence. For example, when encountering a virtual snake, the application can add a hissing sound, which is characteristic of snakes in the wild.

The combination of spatially located sound stimuli with visual elements creates a highly immersive and realistic experience for the patient, evoking stronger emotional responses and better simulating real-life situations. The integration of both visual and auditory cues enhances the sense of presence within the virtual environment. This heightened realism can significantly contribute to a more effective therapeutic process, as the patient feels more engaged and connected to the virtual scenarios. The enhanced immersion and realism foster a deeper emotional response, aiding in the patient's ability to confront and manage their phobias in a controlled and supportive setting.

2.1.2.1 Systematic Desensitization

Sound can also be a powerful tool in the systematic desensitization process. Systematic desensitization plays a pivotal role in therapy, especially in the treatment of phobias and anxiety disorders, offering a well-established and evidence-based method for individuals to gradually confront their fears and alleviate debilitating anxieties. While tools such as adjusting the size of elements have already been implemented to tackle this problem, there remains a gap in the availability of useful methods.

Now, with the addition of sound, there is the opportunity to expose patients to sounds associated with a phobic element (eventually) before introducing visual stimuli. This therapeutic approach can proceed in a more gradual manner, allowing individuals to become accustomed to fear-inducing stimuli in a controlled manner. Initiating the therapy with sound alone can serve as a less overwhelming initial step, preparing the patient for subsequent visual exposure. This step-by-step approach holds the potential to effectively reduce anxiety and enhance the likelihood of successful desensitization.

2.1.3 Eye gaze tracking and avoidance detection mechanism

One significant feature of this application is its ability to maintain a shared space for both patients and therapists, which plays a crucial role in enhancing communication between individuals. Shared Spaces are highly relevant in facilitating effective interaction among two or more people. Moreover, the synergy between Augmented Reality and Shared Spaces enables all participants to engage in face-to-face interactions seamlessly. In the realm of communication, especially when sharing experiences, it is essential to ensure that everyone is within the same context to prevent any potential misunderstandings or misinterpretations of the situation.

This holds particular significance as, during a psychotherapy exposure session aimed at assessing the patient's progress, the therapist naturally relies on observing the patient's behavior, encompassing their facial expressions, body language, and voice tone. Patients may react in various ways to phobic triggers, such as intensely focusing on them, tensing up, or expressing fear through their words and gestures. Conversely, some patients may avoid looking at the triggers altogether by turning away, closing their eyes, or attempting to distract themselves. These cues are essential for the therapist's understanding and

Figure 2.2: Developed applications: Top - Patient view; Bottom - Therapist view.

guidance, but they may be lost when using VR or AR technologies, as the patient's eyes may be hidden by the device, making it challenging to determine if they are looking at the virtual elements or not. Previously, the only input providing information to the therapist about the patient's reactions was the location of their hands in relation to the virtual elements. To improve the therapist's understanding of the patient's response to the virtual elements, the application now includes an eye-tracking functionality. This innovative capability enables real-time tracking of the patient's eye gaze while using the Hololens 2 and simultaneously maps it on the therapist's application (figure 2.2). As a result, the therapist can accurately interpret the patient's reactions to the elements in the virtual space, gaining valuable insights into their emotional responses and engagement with the therapeutic process. To further enhance the therapist's support, the application also includes a mechanism for registering and displaying any avoidance behaviors exhibited by the patient during the exposure therapy session.

2.2 Materials and Development Tools

2.2.1 Materials

As previously mentioned, the developed solution requires two devices: a computer and a Head-Mounted Display (HMD).

Hololens 2

The HMD selected for this project was the Hololens 2 (figure 2.3), due to its wireless functionality, lightweight build, and overall comfortable design. Another significant advantage of this device, especially in a clinical setting where analyzing the patient's expressions is crucial, is that, due to its dimensions and see-through holographic lenses, it does not obstruct the patient's face too much allowing for a comprehensive evaluation of the user's reactions, unlike some other similar solutions that may impede the therapist's ability to observe the patient's expressions accurately.

Figure 2.3: User wearing the Hololens 2.

Image by Microsoft

This headset also fulfills all the necessary technological requirements to successfully implement this project. The glasses integrate see-through holographic lenses with a display resolution of 2k 3:2 light engines, a holographic density exceeding 2.5k light points per radian, and display optimization for 3D eye position. As for sensors, the device is equipped with 4 visible light cameras, 2 infrared (IR) cameras, a Time-of-Flight (TOF) depth sensor, an accelerometer, a gyroscope, a magnetometer, a 1080p30 resolution camera for video, speakers, and a 5-channel microphone array. These sensors enable essential functionalities such as hand tracking, eye tracking, world-scale position tracking, and spatial mapping [18].

This comprehensive array of features empowers the application to provide a highly immersive and effective exposure therapy experience for patients while facilitating detailed data analysis and tracking for therapists. The device's unique calibration to each individual's eye gaze significantly enhances the effectiveness of the eye-tracking capabilities and perceived realism of the virtual elements. The light, infrared (IR), and depth cameras enable the detection and estimation of the position of useful objects, such as markers and the patient's hands. Additionally, several other sensors are used to track the real-time position and orientation of the user's head, such as the gyroscope, accelerometer, among others.

2.2.2 Development Tools

Mixed Reality Toolkit

As seen, the Hololens 2 is a mixed reality device equipped with a diverse range of sensors and capabilities. To leverage these functionalities and create immersive mixed reality experiences, developers can utilize the Mixed Reality Toolkit (MRTK).

The MRKT is a purpose-built toolkit aimed at expediting the development of cross-platform mixed reality applications. It offers a comprehensive set of components and features that developers can utilize to build and craft captivating mixed reality experiences. The primary objective of this toolkit is to streamline the development process, making it more accessible and efficient for creators to construct top-tier mixed reality experiences for the Hololens 2.

Developers have the flexibility to choose between two approaches: using the MRTK directly or integrating it with third-party platforms like Unreal or Unity, allowing them to work within familiar environments.

Unity

The direct use of the toolkit was put aside in favor of development platforms, as they can accelerate the implementation of the application. Among the available options, Unity was selected because it is the platform with which the lab members are most familiar. This choice enables us to leverage the existing expertise and work more efficiently, ensuring a smoother development process and optimizing the utilization of the Hololens 2 capabilities within the Unity environment.

Unity (figure 2.4) is a powerful and versatile cross-platform game development engine and interactive content creation tool that has transformed the world of digital experiences. Originally designed for game development, Unity has grown to become an industry-standard platform for creating a wide range of applications. Unity's multi-platform capabilities enable developers to deploy their creations on various devices, including PC, Mac, mobile devices, game consoles, augmented and virtual reality headsets, and more.

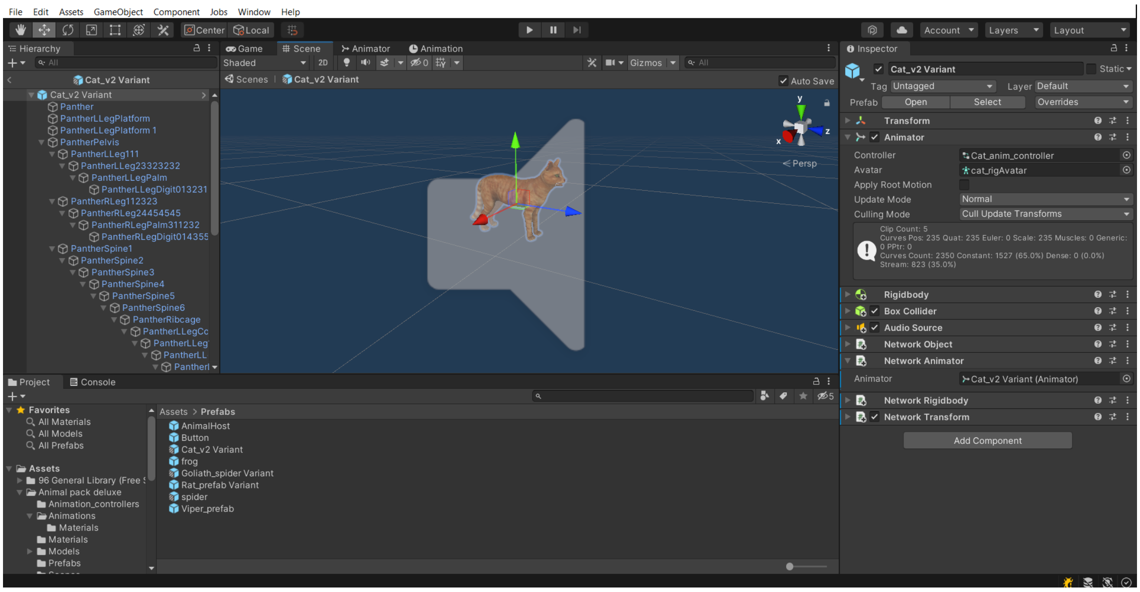

Figure 2.4: Unity environment.

This powerful software also provides access to an online store with a wide array of assets, which can be both closed and proprietary or open source and royalty-free. These assets support diverse technologies, ranging from model importers for seamless integration of 3D models, and communication tools for network functionalities, to various other resources that enhance the development process. Examples of such assets include tools and resources offered by hardware vendors to support the development of applications tailored to their specific platforms. These assets serve as essential interfaces for developers to build upon, allowing them to expand functionality through their own assets and scripts. The decision to adopt this particular platform is driven by the benefits of abstraction, which streamlines tasks like model creation and interface design. The beauty of this abstraction lies in its ability to reduce the time spent on foundational aspects like model creation and interface design, allowing developers to shift their focus toward programming the models and integrating the desired capabilities into their applications. This strategic choice not only accelerates the development process but also empowers developers to create richer and more immersive experiences without being worried by the intricacies of asset creation and interface design.

In this case, the objective is to utilize realistic pre-made models of the phobic elements for constructing a lifelike experience. The platform's adoption simplifies the process of seamlessly incorporating pre-made models into the project and subsequently developing the necessary code to ensure they behave as intended and meet the desired specifications for a successful therapy.

3

Implementation

Having delineated the project proposal and highlighted its contributions to the therapeutic domain, the subsequent chapter will pivot its attention toward a detailed examination of the implementation process pursued throughout this project's development.

3.1 Dynamically loadable elements

Employing runtime loadable elements, rather than preloaded ones, within the application markedly enhances its adaptability and scalability. This approach requires continuous communication between the headset, computer, and the online repository.

The process starts upon launching the therapist application and recognizing the presence of the *Hololens 2*. At this point, a list of all the accessible elements present in the repository becomes visible to the therapist (figure 3.1). Following this, the therapist chooses the desired element for use in therapy and designates its placement within the scene. At this point, both devices seamlessly download the elements from the repository rendering them visible in both the therapist's scene on the computer and the patient's scene on the *Hololens 2*.

3.1.1 Online Repository

The initial step towards implementing this new feature involved establishing the online repository. This repository was set up to house all information regarding the accessible elements, encompassing 3D models, animations, movements, sounds, velocities, and more. By establishing a connection between this repository, the headset, and the computer application, it becomes possible to utilize the stored elements in the therapy sessions ef-

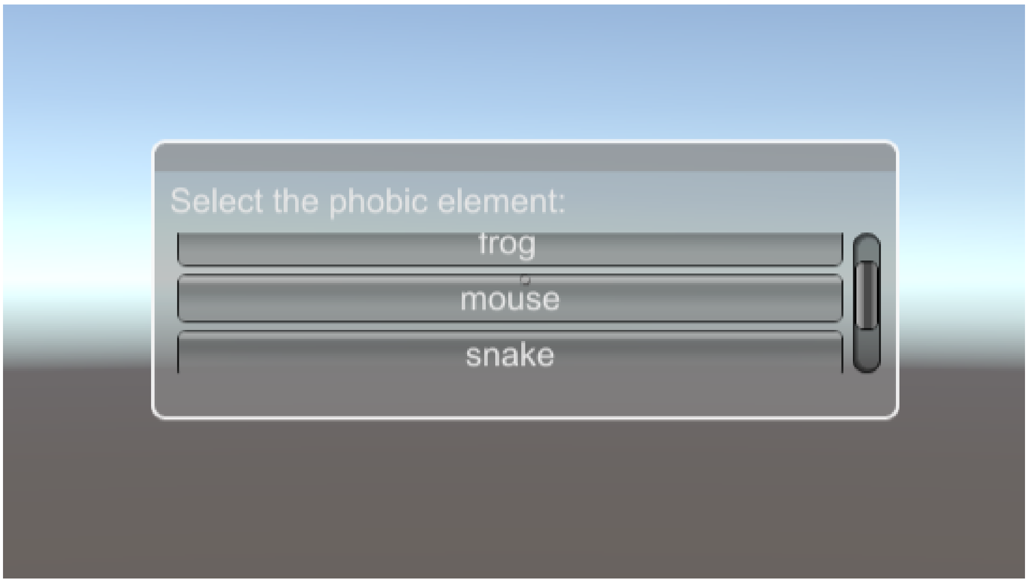

Figure 3.1: Asset list.

fectively.

3.1.2 Communication Architecture

As mentioned above, constant communication between the three elements integrating the project is crucial for it to perform correctly.

Figure 3.2 represents all the communications that happen while the application is running. Upon establishing communication between the computer and the headset, the computer initiates a request for all available elements from the online repository, compiling them into a list that is subsequently presented to the therapist.

Once the therapist gains access to this list, they can select the desired phobic element for use in the therapy. Upon making a selection, the element's ID is transmitted to the Hololens 2. At this stage, the therapist gains control over a representation on the table where the exposure therapy takes place, allowing them to designate the specific location for the elements' appearance. When the decision to add an element is made by pressing the "add" button (figure 3.3), both devices proceed to request and download the chosen element and seamlessly incorporate it into the scene. This process is reiterated each time a new element is added.

The therapist also has the option to change the selected phobic element. When this action

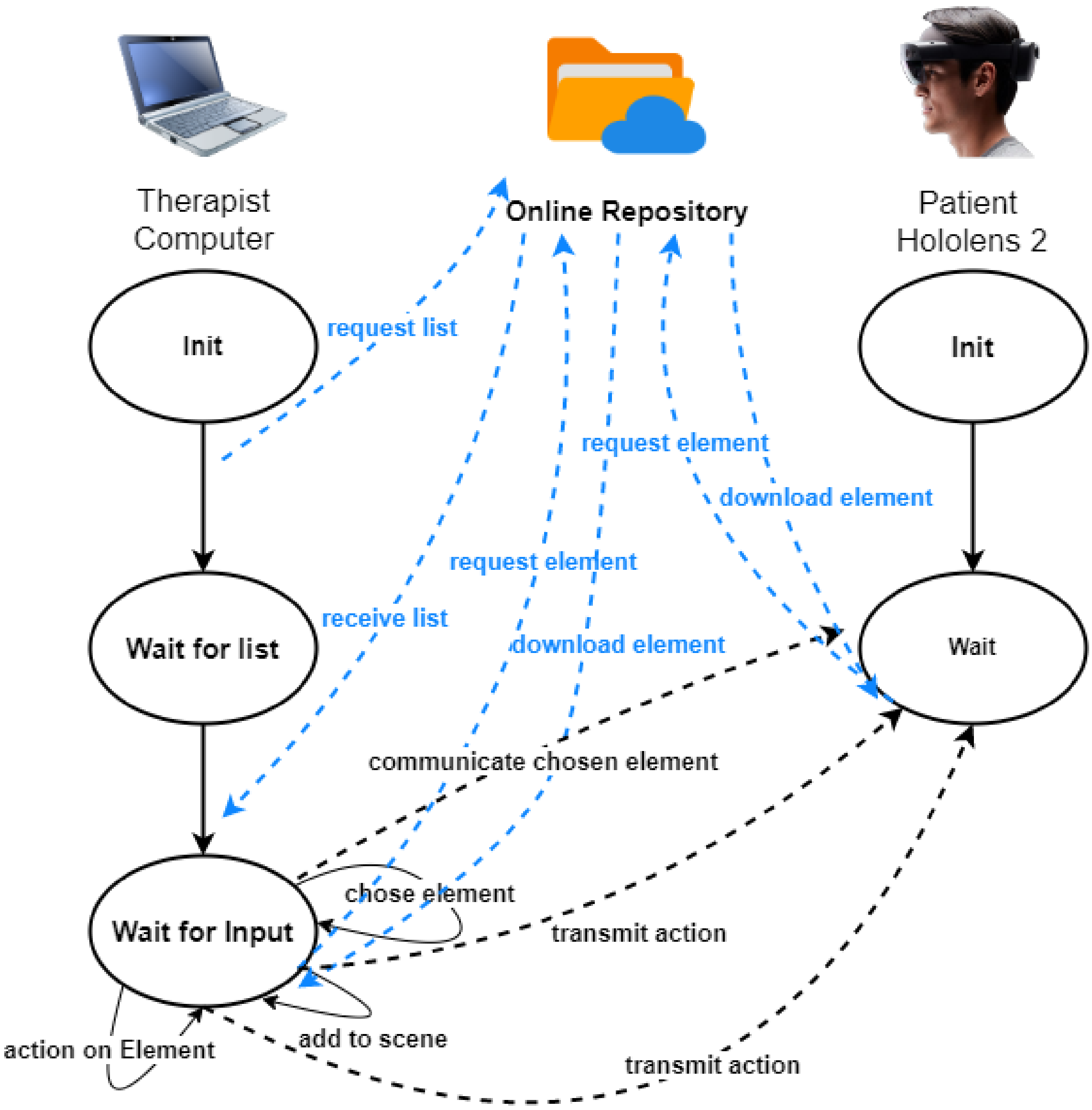

Figure 3.2: Communication architecture.

is selected the described process is repeated, the computer requests the list again, and a new ID is selected and communicated to the headset.

3.1.3 Adapting elements to the application

Since the creation of realistic virtual models to use in therapy is a time-consuming process that requires significant knowledge and practice, the models used in this project were obtained from the Unity Asset Store. After selecting the models from the store, it's important to note that adapting them differs significantly from the previous approach where they were hardcoded in the project. The most notable change involves consolidating all

Figure 3.3: Therapist application.

element functionalities within a single script, as opposed to each element having its own separate script containing all the necessary information and control commands. Given this, it's crucial to consider specific factors when adding new elements to ensure compatibility with the application.

To streamline the development process, a side Unity project was created specifically for managing all aspects related to the elements. This includes tasks like generating asset bundles, editing animations, and fine-tuning velocities.

3.1.3.1 Asset Bundles

The files within the online repository are in the form of Asset Bundles. These bundles are archive files that contain platform-specific non-code Assets (such as Models, Textures, Prefabs, Audio clips, and even entire Scenes) that Unity can load at run time [19]. The asset bundles used in the project are generated from the prefabs of each phobic element. These bundles encompass all the necessary information for each element, such as its animator, audio source, and every component enabling its network behavior. Given that the project involves two distinct platforms (Windows and *Hololens 2*), it becomes necessary to generate two sets of asset bundles, each tailored to its respective platform. Once these bundles are created, the final step in making them accessible within the application is to upload them to the online repository. Upon the completion of this step, the bundles become instantaneously available to any device that runs the application.

3.1.3.2 Animations

To enhance realism, each phobic element is equipped with a series of animations, encompassing an idle stance, walking, turning right, turning left, and a unique action specific to each animal. Since the project uses a uniform control script across all elements, the animator skeleton's configuration and animation triggers must remain consistent for all elements.

Presently, the application accommodates six animals: cat, frog, mouse, snake, spider, and tarantula. The selection of animals was based on the requirements communicated by a practicing therapist in this domain, and the current approach easily allows for the expansion of this selection to encompass newly identified requirements.

In figure 3.4 is possible to analyze the diagram of the animations' transitions used for all elements. The majority of states present in this diagram like, idle, walk, turn left, and turn right are self-explanatory in their functions. However, the state "action" is not as simple; this state is used to accommodate the mentioned animation that is unique to each animal. While in the frog animator, this state prompts the frog to leap, in the case of the snake, it triggers an "attack" animation. This dynamic allows all virtual elements to operate under a single unified script.

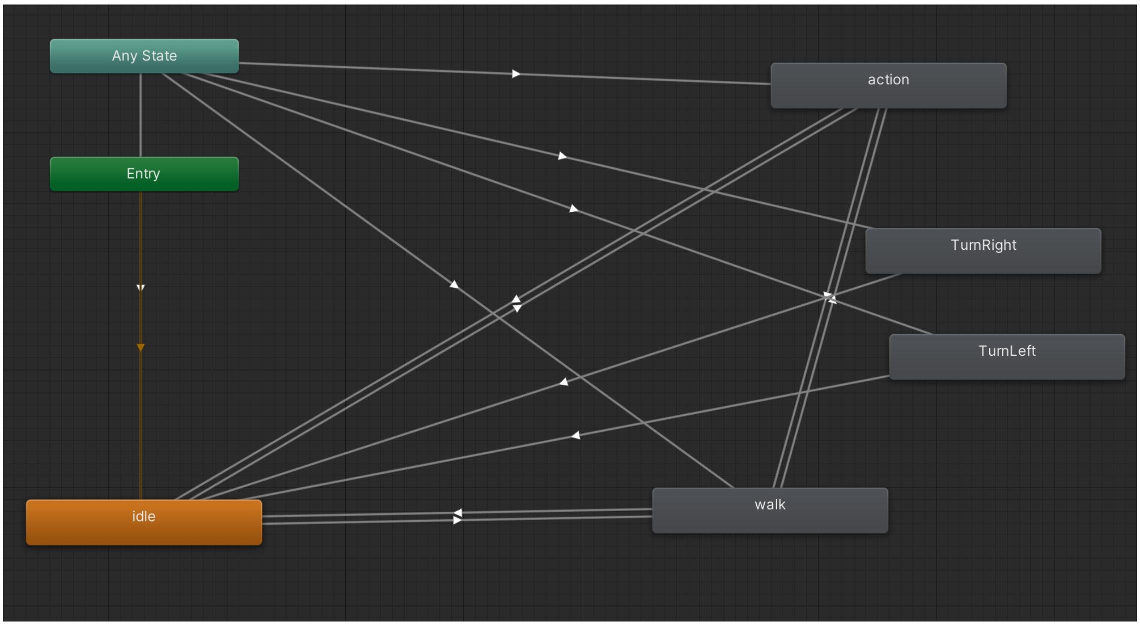

Figure 3.4: Diagram of the animations' transitions.

3.1.3.3 Velocities

Motion is also very important in order to create a realistic and immersive experience. To enable the motion of the elements, they must possess distinct velocities for both forward and rotational movements. These velocities must be tailored individually to each animal, as their unique characteristics dictate.

Typically, these values are inherent within their specific script. However, in this particular scenario, that approach was unfeasible. To address this challenge, a JSON data structure was created, encompassing the names of all fear-inducing elements along with their respective velocity and rotational velocity parameters. This file is stored within the online repository and whenever an element is downloaded, this file is referenced to extract the relevant velocity values. This approach ensures that each animal exhibits a distinct, life-like behavior, guaranteeing a more natural and realistic user experience.

3.2 Spatial sound

For a truly immersive experience, the inclusion of sound is essential. The *Hololens 2* offers HRTF-based spatialization, enhancing the user's perception of sound direction. This technology enables a more immersive audio experience by simulating how sounds would arrive at each ear from different directions, similar to how our ears naturally perceive sound in the real world. This allows users to accurately perceive the direction from which sounds originate in the virtual environment, contributing to a more realistic and engaging experience. As previously noted, most models are equipped with an associated sound source component. This sound source can be activated through the therapist application (figure 3.5), producing audio that the user of the *Hololens 2* perceives with a three-dimensional effect. The user can discern the location and distance of these elements, providing a heightened sense of presence within the virtual environment (figure 3.6).

Figure 3.5: Therapist sound trigger button.

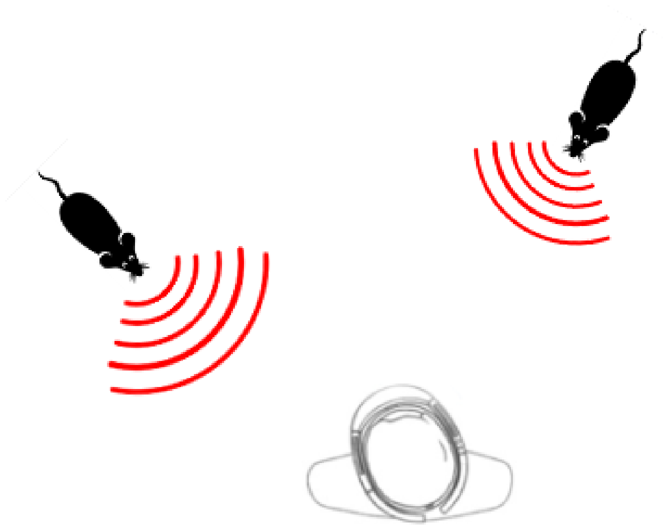

Figure 3.6: Spatial sound representation.

3.3 Eye tracking overview

3.3.1 Calibration

For precise eye tracking functionality, each user is required to undergo an eye tracking user calibration process. During this calibration, users focus on a set of holographic targets (figure 3.7), allowing the device to fine-tune its settings. This ensures a more comfortable and higher-quality viewing experience while maintaining accurate eye tracking.

While eye tracking should work for most users, there are occasional cases where calibration may fail. Several factors can contribute to this, including:

- Users who previously opted out of the calibration process.
- Users who became distracted and didn't follow the calibration targets.
- Users wearing specific types of contact lenses or glasses.
- Users with unique eye physiology, eye conditions, or a history of eye surgery.
- External factors that can disrupt reliable eye tracking, such as smudges on the HoloLens visor or eyeglasses, intense direct sunlight, or occlusions caused by hair in front of the eyes.

3.3.2 Eye gaze tracking

The headset has the capability of tracking the user's eye gaze at all times. This functionality is used to enhance the therapist's comprehension of the patient's reactions to the virtual elements.

It works by having the *Hololens 2* constantly capturing the user's eye gaze coordinates and transmitting them to the therapist's PC through a *ServerRpc*. A ServerRpc is a remote procedure call (RPC) that can be only invoked by a client and will always be received and executed on the server/host. In this case, the client is the headset, and the host is the therapist's computer. Upon receiving the coordinates within the therapist's application, a marker denoting the patient's eye gaze is promptly adjusted to reflect the updated position (figure 3.8). This seamless communication persists throughout the application's runtime, offering an impeccable visualization and a notably essential novel tool for enhancing the

Figure 3.7: Calibration process.

therapist's session assessment.

3.3.3 Response mechanism

A response mechanism was also incorporated, this mechanism allows the application to discern whether the patient is engaged with the phobic elements or deliberately avoiding them. At present, it merely conveys this information to the therapist (figure 3.8), however, in future work, it has the potential for the application to autonomously generate a response based on this data. Such an advancement necessitates a comprehensive evaluation of response alternatives in collaboration with a therapist. This collaborative endeavor is driven by the objective of formulating strategies that authentically enhance the patient's experience while preventing any escalation of user anxiety.

Figure 3.8: Mapping patient's eye gaze on the therapist's view of the shared space object: (top) focus on the snake, (bottom) not focused on any element.

4

Results and Discussion

The tests conducted during the development were specifically designed to assess the realism of the phobic elements incorporated into the system. Moreover, they aimed to measure the degree of presence these elements could elicit within the shared space, essentially assessing how convincingly the virtual elements seamlessly integrate into the real world. Additionally, the evaluation encompassed an examination of the spatial sound capabilities integrated into the overall experience, shedding light on how effectively sound contributed to the overall immersion and sensory engagement of the users.

4.0.1 Procedure

The tests were meticulously executed, ensuring that all volunteers were subjected to uniform environmental conditions. This encompassed standardized lighting levels and surface conditions that were carefully optimized for the evaluation process. Figure 4.1 depicts the assortment of phobic elements employed in this validation procedure.

Before commencing the test, it is crucial to perform a calibration of the *Hololens 2* for the gaze of each subject. This calibration process is quick and simple, and it begins as soon as a new user wears the device. Once the calibration is complete, a sequence of numbers is displayed on the tabletop. Each number corresponds to a specific area where holographic animal representations are slated to materialize. Participants are provided the flexibility to view these numbers in any order they prefer, effectively triggering the appearance of the respective animal at the designated location through their gaze. Once all the animals had been projected onto the table, participants were encouraged to freely observe them from various angles. This phase of the test is meticulously designed to evaluate the authenticity of the rendered elements in terms of their visual representation

Figure 4.1: Animal models used in testing.

and their seamless integration within the room's surrounding environment.

This phase also served to validate the accuracy and precision of the participants' eye gaze. The assessment of this validation was carried out solely by the test conductor, who confirmed with the volunteers whether the animals appeared in the correct locations based on their gaze. The results obtained from this aspect of the experiment were exceedingly satisfactory. The eye gaze tracking of each volunteer consistently demonstrated exceptional precision, underscoring the effectiveness of the calibration process and the reliability of the Hololens 2 device.

The subsequent stage of the test centered around evaluating the lifelikeness and perceived authenticity of the movements. For this purpose, participants were guided to position their hands flat on the table's surface. At this moment, a virtual mouse would commence its motion toward the participants' hands, progressively drawing closer until it reached a point just before contact. Participants were encouraged to assess their perception of the mouse's approximation to their hands, evaluating the realism and accuracy of the interaction. This segment of the test was designed to capture the participants' subjective impressions and input concerning the realism of the virtual mouse's movements and how convincingly it interacted with their actual presence.

The final objective of the test involved evaluating the spatial sound capabilities provided by the system. To achieve this objective, participants were instructed to focus their attention on the animals positioned at the upper left corner of the table. This deliberate arrangement was intended to serve as a distraction for the participants. Concurrently, an additional element that had not been previously observed by the participants was introduced to the far bottom right corner of the table, positioned outside their field of view. The primary purpose of this element was to emit sound, and the intention was to observe whether the participants would shift their attention toward the source of the sound and accurately discern the direction from which the sound originated. This evaluation aimed to assess users' proficiency in localizing and identifying the source of the sound within the virtual environment.

At the end of the experiment, each participant filled out the Presence Questionnaire [20]. This questionnaire aims to evaluate different aspects regarding the shared space between the user and the virtual elements. With a total of 21 items, the questionnaire encompasses seven distinct dimensions: Involvement (5 items), Natural (3 items), Interface Quality (2 items), Resolution (2 items), Auditory (2 items), Haptic (2 items), and Immersion (5 items). Each item within the questionnaire is rated using a 7-point Likert-type scale, ranging from ”not at all” (scored as 1) to ”strongly agree” (scored as 7).

4.0.2 Validation

The analysis of the data was conducted utilizing IBM SPSS Statistics. Descriptive statistics were calculated to assess the dimensions outlined in the Presence Questionnaire [20]. Additionally, Mann-Whitney U tests were executed to determine potential disparities in the overall perception of presence, comparing individuals with and without prior exposure to Augmented Reality (AR) and Virtual Reality (VR). For statistical significance, results were deemed noteworthy if the p-value was less than or equal to 0.05 ($p \leqslant .05$).

4.0.2.1 Participants

The test was executed by 23 non-phobic volunteers, 14 males (60.9%) and 9 females (39.1%) with ages ranging from 20 to 31 years old (mean age of $24.65, SD = 3.20$). The majority of the sample had previous experience with virtual reality ($n = 15, 65.2\%$). Similarly, 14 participants had previous experience with augmented reality (60.9%). Additionally, no gender differences were found regarding previous experience with virtual reality ($\chi^2_{(1)} = 0.014, p = .907$) and augmented reality ($\chi^2_{(1)} = 0.209, p = .648$).

4.0.2.2 Results

As mentioned before the validation is divided into 7 categories:

- **Involvement:** This category is centered on evaluating the degree of user engagement and active involvement during the test. It aims to gauge how enthusiastically users engage and interact with the virtual elements introduced in the experiment. The results revealed notable levels of involvement among the participants ($Min = 5, Max = 7, M = 5.85, SD = 0.59$; Fig. 4.2).

- **Natural:** This category assesses the extent to which the virtual elements, movements, and interactions within the system replicate natural and authentic behaviors. It gauges whether users perceive the virtual environment and its components as natural and believable. The outcomes demonstrate remarkable levels of perceived naturalness and realism about the virtual elements ($Min = 4, Max = 7, M = 5.20, SD = 0.96$; Fig. 4.2).

- **Interface Quality:**This category encompasses the appraisal of the interface quality of the system, encompassing factors such as user-friendliness, intuitiveness, responsiveness, and the general satisfaction of users with the provided interface. The users evaluated this category with a medium score ($Min = 2, Max = 7, M = 4.74, SD = 1.54$; Fig. 4.2).

- **Resolution:** The “Resolution” category concentrates on the sharpness, intricacy, and visual clarity of the virtual elements, as well as their depiction within the system. Its objective is to ascertain whether users perceive the visual components as sharp, clear, and intricately detailed. The overall score for this topic was reported as very high ($Min = 5, Max = 7, M = 6.39, SD = 0.62$; Fig. 4.2).

- **Auditory:** The “Auditory” category assesses the quality and effectiveness of the system’s auditory features, including spatial sound capabilities, sound clarity, realism, and overall user perception of sound within the shared space. Users perceived this dimension as very good ($Min = 5, Max = 7, M = 6.39, SD = 0.77$; Fig. 4.2).

- **Haptic:** The “Haptic” category is not applicable in this system. However, if haptic feedback were to be included in future iterations, this category would evaluate the system's ability to provide realistic tactile sensations and haptic feedback to enhance the overall user experience and sense of presence. As expected, in this dimension the results were low ($Min = 1, Max = 7, M = 4.00, SD = 1.82$: Fig. 4.2).

- **Immersion:** The "Immersion" category encompasses the overall user experience and perception of immersion within the virtual environment. It considers factors such as the level of engagement, the realism of the elements, sensory integration (visual and auditory), and the overall ability of the system to transport virtual elements into the real world. In this category, users reported a high level of immersion ($Min = 4, Max = 7, M = 5.71, SD = 0.80$; Fig. 4.2).

- **Overall Presence:** The "Overall Presence" category provides a comprehensive evaluation of users' overall satisfaction, perception, and impression of the system. It takes into account the assessments made in all the previous categories, allowing for a holistic evaluation of the users' experience, system performance, and the overall sense of presence provided by the application. By considering these categories collectively, a thorough and comprehensive assessment of the system and user experience can be achieved. Results show that the experiment was perceived with a high level of presence ($Min = 5, Max = 7, M = 5.55, SD = 0.54$). Additionally, results showed a similar sense of presence between users with and without previous experience with AR ($U = 53.0, p = .557$). Similarly, there were no significant differences in the sense of presence between users with and without previous experience with VR ($U = 57.0, p = .875$).

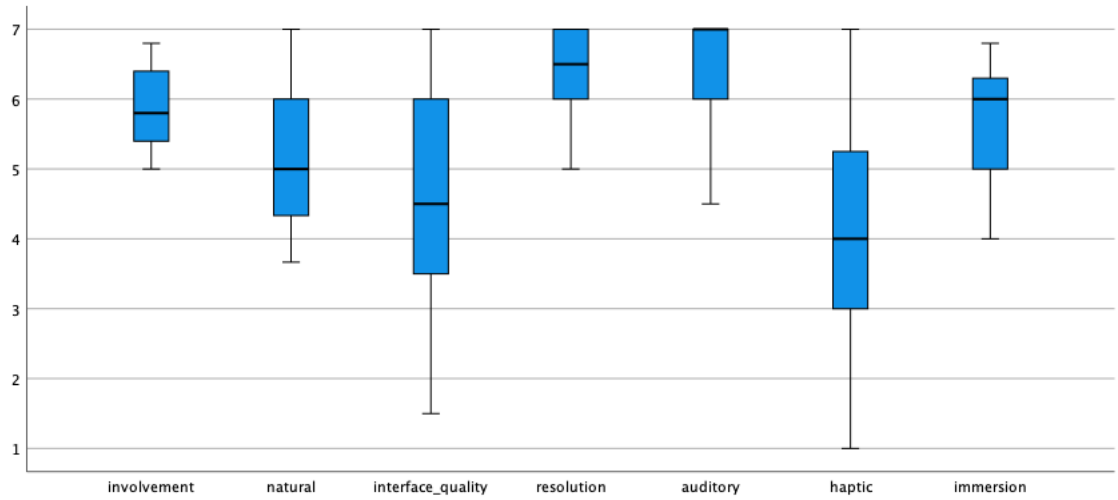

Figure 4.2: Answer distribution for each dimension of the presence questionnaire.

4.0.3 Discussion

The results obtained from the dimensions of the Presence Questionnaire provide valuable insights into the users' experience during the experiment. They collectively suggest a highly positive response to the augmented reality (AR) system:

- Engagement and Involvement: Users exhibited a high degree of engagement and active involvement in the experiment indicating that participants were enthusiastic about the presence of the virtual elements introduced in the test, fostering a sense of immersion and participation in the AR environment.

- Perceived Naturalness: Participants perceived the virtual elements as remarkably natural and believable. This high level of perceived naturalness suggests that the AR system effectively replicates real-world behaviors, enhancing the authenticity of the virtual experience.

- Visual and Auditory Characteristics: The visual and auditory aspects of the virtual elements received the highest scores. Users found the visual elements to be sharp, clear, and intricately detailed, while the auditory features, including spatial sound capabilities, were deemed highly effective and realistic, contributing significantly to the overall sense of immersion.

- Interface Quality: While the interface quality received a medium rating, it's essential to recognize that the interface evaluation considered factors such as interaction. Given that the AR system did not include interaction features, this rating is understandable.

- Haptic Feedback: The low score in the Haptic category was expected since the system did not incorporate haptic capabilities. However, this dimension remains significant for the overall sensation of presence, even though it was not applicable in this context.

- Sense of Immersion: Users reported a high level of overall immersion within the virtual environment suggesting that the AR system successfully engaged users on multiple sensory levels, creating an immersive and convincing experience.

Furthermore, the results consistently indicate that users experience a strong sense of presence when using the AR-developed system, regardless of whether they have any prior experience with augmented reality (AR) or virtual reality (VR) technologies. This conclusion underscores the practicality and effectiveness of the AR-based system for therapeutic applications and lends strong support for future studies in a clinical setting.

Finally, given that this application is designed to provide therapeutic assistance, it is crucial for it to undergo assessment and validation by a qualified professional. This validation process included presenting the concept of the developed application to Dr. Alexandra Pais da Cunha, clinical psychologist and coordinator of the psychology unit at Hospital da Luz Coimbra. The reasoning behind the implementation choices was clarified, and ultimately, the application underwent testing by the doctor. This allowed the therapist to evaluate both the patient's experience and her own viewpoint.

The feedback was overwhelmingly positive, underscoring the application's effectiveness in terms of rendering phobic elements with realism and presence, The introduction of sound to the phobic elements was seen as a significant leap forward in enhancing the patient's experience and the efficacy of treatments. The ability to apply the therapy in a familiar office environment was particularly praised, as it is crucial for the process to take place in a comfortable and recognizable setting.

On the therapist's side of the application, its simplicity and user-friendliness were validated as essential attributes for effective therapy sessions. Also, the newly implemented eye-tracking capabilities were applauded, as it was deemed an immensely valuable tool for facilitating communication and gaining insights into the patient's reactions and emotions.

During the presentation of the implemented solution, discussions arose about possible future improvements. Notably, there were discussions about introducing non-animal phobic elements into the therapy, such as ambulances and syringes. While these ideas were not incorporated into the current project, they were shared with a colleague responsible for future development. This ensures that they will be carefully considered and potentially integrated into upcoming versions of the application.

Additionally, there was a discussion about the potential for future patient trials, where the application could undergo testing in a real-life scenario involving only the therapist and the patient, without any involvement from the developer.

5

Conclusion and future work

This dissertation introduces the enhancements integrated into an Augmented Reality (AR) therapeutic solution, which serves as a substitute for in vivo exposure in phobia treatment. This approach tackles several significant challenges inherent in traditional in vivo exposure therapy techniques, including limited acceptance rates, constraints on therapist control over elements, and spatial limitations within the therapist's office.

The potential to dynamically load meticulously designed exposure elements from an external repository significantly amplifies the scope of this application. This capability facilitates continuous updates to the therapeutic elements at hand and enables the provision of support to users across various locations, thus extending the availability of this solution to a broader patient base.

The incorporation of auditory elements that are intricately linked with the visual components not only enhances the realism of the experience but also opens up novel avenues for therapists to explore and utilize. This fusion of sensory modalities provides a more immersive and multi-dimensional experience.

The tracking of the patient eye gaze culminates in a novel tool that facilitates better comprehension of the patient's responses to the presented virtual elements. This feature allows the therapists to offer enhanced support and guidance throughout therapy sessions.

Additionally, this system underwent validation involving 23 non-phobic adult volunteers, who assessed their sense of presence throughout the experience. The validation outcomes indicate strong user engagement and active participation during the experiment. These results underscore the efficacy of the AR-developed system for therapeutic purposes and advocate for future investigations within clinical environments.

In future work, it would be interesting to explore the possibility, with the help of a therapist's input, of integrating an automated software response based on patient eye tracking, utilizing the existing detection mechanism that has been already established.

Another additional captivating aspect to consider is the incorporation of 3D room mapping, enabling the utilization of the entire expanse of the therapist's office rather than being confined to a table. By doing so, it unlocks the full expanse of the therapist's office, providing a versatile canvas for therapeutic exploration. This expansion of physical space within the therapy setting introduces a diverse array of phobic elements into sessions, thereby broadening the horizons of therapeutic possibilities.

To further expand these possibilities, the concept of virtual portals could be explored. This would allow for new elements to be seamlessly integrated into the existing office architecture, providing a wider selection of phobic elements to be brought into the therapist's office overcoming constraints related to their size or other limitations. These virtual portals are essentially virtual doors and windows that can be strategically placed on physical walls or other suitable surfaces. They serve the purpose of visualizing phobic elements as if they were located outside the room and even allow these elements to enter the space by passing through these virtual openings.

Also, augmenting this system with an array of sensors designed to capture various biosignals from the patient would yield numerous advantages. These sensors could be strategically placed to monitor vital physiological parameters, such as heart rate, respiratory rate, and body temperature. This holistic approach to data collection would enable therapists to gain a more complete and nuanced understanding of the patient's physiological responses to phobic stimuli. By harnessing this wealth of data, therapists would be equipped with invaluable insights into the intricate interplay between a patient's emotional and physiological states during therapy. Such insights could pave the way for more tailored and effective therapeutic interventions, allowing therapists to adapt their strategies in real time based on the patient's physiological feedback. This not only enhances the quality of care but also empowers therapists to optimize their treatment plans for each individual.

Throughout this project's development, two papers were authored, one of which was accepted for publication and recently presented, while the second paper has already been submitted and is currently awaiting acceptance. The initial paper was showcased at The Experiment@ International Conference 2023 (expat'23), and the subsequent paper was submitted to the International Conference on Graphics and Interaction 2023 (ICGI'2023). The author's versions of both papers have been included in the Appendix of this document.

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Appendix

- IBM SPSS Statistics - Portuguese
- Expat 2023 - Full Paper
- ICGI 2023 - Full Paper

Questionário AREsTA

Nome:____

Idade:____

Género:____

Área Profissional:_______________________________________

Alguma vez interagiu com aplicações VR (Realidade Virtual)?

Sim ☐ Não ☐

Alguma vez interagiu com aplicações AR(Realidade Aumentada)?

Sim ☐ Não ☐

Responda às questões de acordo com a seguinte escala:

De maneira nenhuma			De alguma maneira			completamente
1	2	3	4	5	6	7

1. Quão natural te pareceram as tuas interações com o ambiente?

1 2 3 4 5 6 7

2. Em que medida os aspetos visuais do ambiente te envolveram?

1 2 3 4 5 6 7

3. Quão natural era o mecanismo utilizado para controlar os movimentos através do ambiente?

1 2 3 4 5 6 7

4. Quão convincente foi a sensação dos objetos estarem a mover-se pelo espaço?

1 2 3 4 5 6 7

5. Quão consistentes te pareceram ser as experiências no ambiente virtual em comparação com as experiências do mundo real?

1 2 3 4 5 6 7

6. Quão bem conseguiste identificar os sons?

1 2 3 4 5 6 7

7. Quão bem conseguiste localizar os sons?

1 2 3 4 5 6 7

8. Quão bem conseguiste inspecionar ou pesquisar ativamente no ambiente virtual utilizando o tato?

1 2 3 4 5 6 7

9. Quão de perto conseguiste examinar objetos?

1 2 3 4 5 6 7

10. Quão bem conseguiste examinar objetos a partir de múltiplos pontos de vista?

1 2 3 4 5 6 7

11. Quão bem conseguiste mover ou manipular objetos no ambiente virtual?

1 2 3 4 5 6 7

12. Quão envolvido estiveste na experiência do ambiente virtual?

1 2 3 4 5 6 7

13. Quão rapidamente te adaptaste à experiência no ambiente virtual?

1 2 3 4 5 6 7

14. Quão à vontade te sentiste no final de experiência em relação às ações de mover e interagir com o ambiente virtual?

1 2 3 4 5 6 7

15. Em que medida a qualidade da imagem reproduzida interferiu ou distraiu na realização das tarefas atribuídas ou exigidas?

1 2 3 4 5 6 7

16. Em que medida os dispositivos de controlo utilizados interferiram no teu desempenho na realização das tarefas atribuídas ou de quaisquer outras tarefas?

1 2 3 4 5 6 7

17. Quão completamente estavam os teus sentidos envolvidos na experiência?

1 2 3 4 5 6 7

18. Estiveste envolvido na tarefa experimental ao ponto de perderes a noção do tempo?

1 2 3 4 5 6 7

19. Houve momentos durante a experiência no ambiente virtual durante os quais te sentiste completamente concentrado na tarefa ou no ambiente?

1 2 3 4 5 6 7

20. Quão facilmente te adaptaste aos dispositivos de controlo utilizados para interagir com o ambiente virtual?

1 2 3 4 5 6 7

21. A informação fornecida através dos diferentes sentidos no ambiente virtual (p. ex., a visão, toque ou audição) foi consistente?

1 2 3 4 5 6 7

AREsTA - An Augmented Reality Exposure Therapy Application

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Abstract

One of the most common treatments for phobias is *in vivo* exposure therapy. This method is considered a very robust solution with a great success rate but presents some drawbacks that can be solved by recurring to technological alternatives like virtual or augmented reality. The goal is to present the development of an augmented reality application that allows the loading of several phobic elements and the creation of distinct scenarios in a flexible and interactive way. This approach should allow the patient to observe and interact with their phobic elements using the *Hololens 2* while the therapist has full control over all these elements, creating a unique and personalized experience based on the patient's needs.

Augmented Reality; Phobias; Exposure Therapy

1 Introduction

A phobia is an excessive and non-rational fear of specific stimuli or circumstances that cause significant discomfort to the individual who comes in contact with them [1]. These may be triggered by factors such as objects, animals, and situations, that pose little or no actual danger. According to the literature these conditions are among the most common anxiety disorders [2] and even though the symptoms can be specific to each particular case, symptoms like concentration problems, worries about future misfortunes, tension headaches, restless fidgeting, inability to relax, and avoidance are frequently observed in most of the cases [3].

People who seek treatment for these kinds of disorders can find a number of different interventions like cognitive therapy, modelling, imagery or virtual reality exposure, and direct *in vivo* exposure. From all available solutions, exposure therapy is often considered the first-line treatment for specific phobias [2]. *In vivo* exposure, which involves having the patients in direct contact with the feared stimulus [2], is considered one of the most robust methods available for treatments but presents a refusal rate of around 25% after the patients learn what it entails [4]. Adding to this, other problems exist such as the impossibility of performing in the usual office environment [5], the inability to fully control the phobic elements [6], and, in the case of animals, the associated logistics [7], and the fact that some patients and therapists find this method cruel [8].

In order to attenuate these drawbacks, technological alternatives such as virtual and augmented reality have been proposed for this kind of therapy. Virtual Reality (VR) has proved to be a solid substitute to *in vivo* exposure [5], since it enables the transportation of users to a virtual environment where they can confront their phobic stimuli. Its use has shown a good acceptance level, having a substantial percentage of subjects preferring it to *in vivo* exposure [2]. Augmented reality (AR), being related to VR, enables a different type of solution allowing the insertion of virtual content in the real world. One clear advantage of the latter is the possibility of a naturalistic integration of virtual elements and provoking only minor changes to the user's sensory perception of reality [9], without the cognitive burden associated with immersion in a totally new and synthetic environment. In spite of being a newer and less explored method, AR shows positive results in this type of treatment [5] [7] [9]. Comparing the two methods in terms of immersion and self-perception, we may say that, while VR only allows the user to interact using a virtual representation of bodies, AR allows the users to use their own body to interact with the virtual objects [8] creating a more natural and realistic way. In the context of phobia treatments, the immersion characteristics of both methods are very convenient, VR enabling virtual transportation to different scenarios and AR bringing the virtual elements to the user's space. Choosing between them depends on the type of phobia and exposure needed, e.g. VR is typically a better option for cases of claustrophobia and acrophobia, while AR is preferable for cases where the phobic element can be seamlessly added to the patient's surroundings.

2 Related Work

One of the first alternatives to *in vivo* exposure emerged in 1995 with the work of Rothbaum et al. [10] that included an augmented reality experiment to targeting acrophobia. This initial study successfully showed that this technology could be used in cases of anxiety disorders.

In 2005 Côté and Bouchard's [11] focused their work on treating arachnophobia with VR environments containing phobic elements. This study showed improvement in patient's symptoms after using it.

One of the first attempts using AR in this type of treatment was by Juan at al. [12] in 2005. This work, despite of exploratory, already included the idea of having the therapist observe the exposure process through a computer monitor.

De Witte et al. [13] in 2020 worked on using an AR application for smartphones instead of *in vivo* exposure in the treatment of animal-related phobias. This approach while inciting the desired fear and anxiety lack in terms of realism and interaction with the phobic elements.

Wrzesien et al. [14] in 2013 showed an AR alternative using a Therapeutic Lamp (TL), to project small animals on a surface. This method has been shown to be effective but the use of projections instead of holograms can affect the perception of the realism of the elements.

Patrão, et al. in 2020 [15] presented a shared space AR experiment with spiders. The application uses tablets, one for the therapist and another for the patient. The study reveals good usability and interaction, yet, the use of tablets reduces the perception of the virtual elements and makes it difficult the interaction with them.

Based on previous studies and their limitations, the present study aims to overcome some of the problems identified above, such as the lack of therapist control and poor realism while introducing a new level of expandability and adaptability not found this far in this field of research.

3 Objectives

The goal of the present work is to create an augmented reality solution that can be employed in a clinical setting as a replacement for *in vivo* exposure therapy. This solution involves developing an application that allows therapists to bring virtual versions of elements associated with specific phobias of each patient into their office space. The application integrates seamlessly into a typical therapeutic office space, offering patients a realistic and immersive experience of interacting with their phobic elements.

In this approach, the therapist can control the whole experience through a paired computer. That additional computer supports the therapist in the selection of which elements should appear or disappear, determine their location, and fully manipulate their behaviour within the scene. These behaviours are unique for each of the available phobic elements and related to their characteristics and purpose.

Being an extension of a previous development [16], this work aims to continue, enhance and increase its flexibility. The aimed improvements address a previously identified limitation in terms of the variety of phobic elements that were available and the inclusion of new stimuli that may unlock a broader use of this therapeutic tool. To this end it introduces the implementation of dynamically loadable elements, as well as the establishment of a framework for their development. Another added feature is the support for spacially located sound stimuli, that will provide a more complete and realistic experience for the patient. In addition, the project aims to integrate new *portal* elements into the existing office architecture, allowing the incorporation of elements that otherwise would not be logistically possible to bring to the patient-therapist shared space.

4 Proposal

The current proposal brings in three important new features to support and expand not only the therapeutic possibilities but also to improve the patient and therapist experiences.

4.1 Dynamically loadable models

It is common to most VR and game-based applications, the elements included and available are hard-coded in the generated application. In these, the addition of new elements, and in particular active characters, require the modification of the original code and generation and distribution of new versions of the application. Beyond the development effort, new versions may require changes to the interface and available interaction, which will create some undesirable difficulties for the typical user.

The span of elements that can be required for exposure therapies can be quite broad and not fully predictable. It is true that there are some types that are more common, but even these tendencies may vary over time. Similarly to most cases in VR applications, in our previous approach, the available models were statically included in the developed applications. This new approach introduces the load-on-demand possibility, enabling the application to access any model made available through an online repository. Adding the possibility of dynamically loading elements brings this application to a new level of expandability, both in terms of possible phobic elements available on the application and also the number of devices that can be simultaneously active and updated. The application by accessing the repository at runtime may retrieve a list of available elements, from which the therapist may select and load the desired ones on demand. This approach allows for quick and easy updates of available phobic elements, or the addition of new ones, by simply uploading them to the repository. Once uploaded, these updates become automatically available to all devices running the application. A consequent advantage of this new feature is the possibility of bringing in models developed by third parties. Considering this possibility, a guide on how to design new elements or modify existing ones to be compatible with the application was created. This document includes information concerning element size, movements available, animation triggers, and components supported. This is expected to enable contributors outside of this project to bring their own models and designs.

4.2 Spatial sound stimulli

While for elements like spiders sound is not required, other elements, e.g. animals, produce sound and therefore should be associated with them. As examples, we may consider that a virtual frog may emit the typical "ribbit

ribbit", and a dog may bark.

In fact the introduction of spatially-located sound stimuli brings several advantages to the treatment process. The gradual exposure to sounds of a phobic element before using visual stimuli can help desensitize the person to the fear-inducing stimuli and reduce their anxiety. Also, both stimuli can be used simultaneously in order to provide an immersive and realistic experience to the patient. Additionally, allowing patients to physically interact with their phobic elements further enhances this sense of immersion and realism.

4.3 Virtual portals

Finally, the concept of virtual portals was developed and incorporated. This allows for new elements to be seamlessly integrated into the existing office architecture, providing a wider selection of phobic elements to be brought into the therapist's office regarding their size or other drawbacks existent. Patients can observe and interact with these virtual elements while the therapist retains full control over their appearance and behaviour. These portals consist of virtual doors and windows, that will be placed on physical walls or other adequate objects. These doors or windows will enable the therapist to select noises to be heard as if coming from the outside through them, in an initial exposition stage. and, at some later stages, they portals will support the visualization of the phobic elements virtually placed outside, and even enable them to enter the room by passing through them.

5 Implementation

This augmented reality application was developed utilizing the Mixed Reality Toolkit (MRTK) and Unity platform, and is specifically designed to run on the *Hololens 2* device in tandem with a computer application that puts the therapist in control of the exposure session. The objective of this application suite is to provide therapists with a new tool to use in place of in vivo exposure in a clinical setting. This allows patients to see and interact with phobic elements, while the therapist retains complete control over their appearance and behavior.

Figure 1: Therapy setup.

Figure 2: Patient view.

5.1 Paired applications

The developed solution is therefore divided into two applications, one for patient exposure and the second for therapist control. This way, the therapist has complete control over the timing and location of the phobic elements and is also capable of triggering any movement or animation when deemed appropriate. When running, the application has access to an online repository where all the phobic elements-related data is stored. By consulting the repository the controlling application provides a list containing all the available elements (figure 3) for the therapist to choose from. After selecting a desired element, the therapist can add it to the scene and have complete control over it, while the patient can observe and interact with it through the HMD liked application under the therapist's supervision and control.

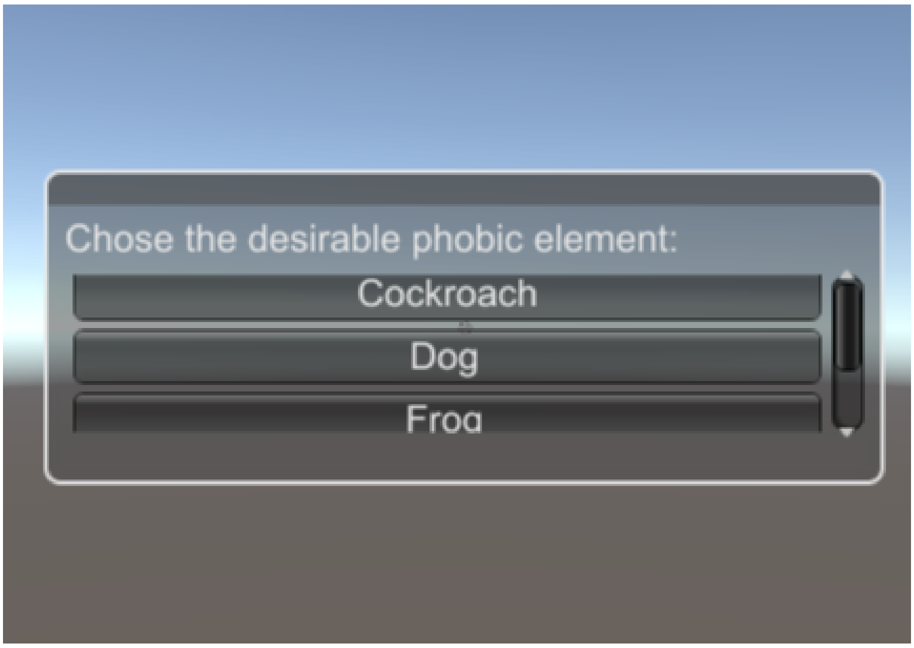

Figure 3: List of the phobic elements available.

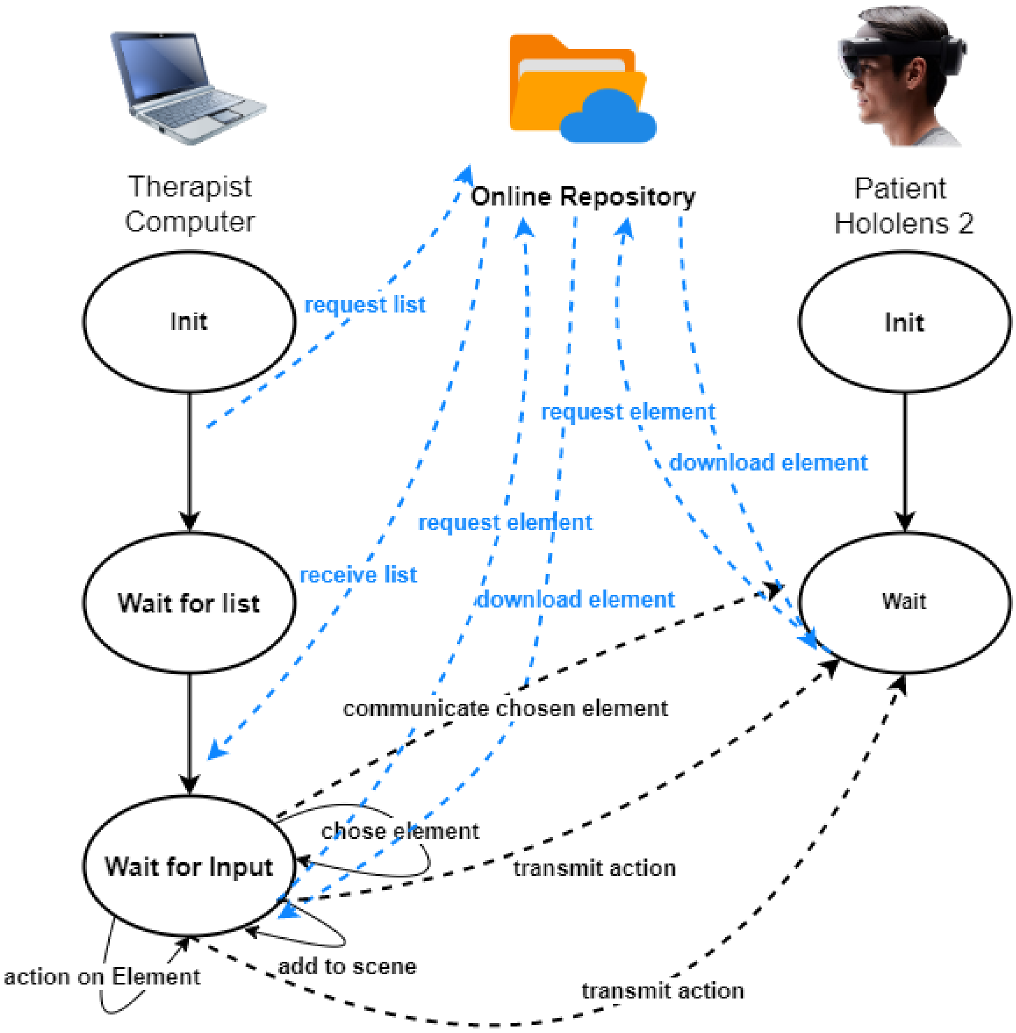

Figure 4: Communication architecture.

5.2 Dynamically loadable elements

The use of runtime loadable elements instead of having these elements present in the application project is a game changer in the versatility and expandability of this application. For this to be possible a communication architecture was designed to support the necessary interactions between all elements in the system. Figure 4 illustrates the transactions between the therapist application, the *Hololens 2* (patient) AR application, and the online repository that support both the control of the elements and their simultaneous loading on the two devices. When the therapist application is launched and detects the *Hololens 2*, the available element list (figure 3) is presented to the therapist. At this point, the therapist is able to select a desired element, whose ID is sent to the *Hololens 2*. When desired the therapist can select the location in the scene where he wants the element to appear, and, upon pressing the "add" button, both devices (computer and *Hololens 2*) download the desired element from the online repository and display them on the scene. When on the scene the therapist is able to move or delete any element. Any actions taken by the therapist are immediately communicated to the *Hololens 2*, allowing the patient to observe them in real time. Furthermore, the therapist can switch between different elements at any time, enabling them to present multiple items simultaneously on the scene.

5.3 Therapist view for the shared space

Another feature of this application is the use of a shared space between the therapist using a computer and the patient wearing *Hololens 2*. Shared spaces are highly relevant for improving communication between two or more individuals [15]. By using augmented reality and a computer, the therapist can maintain face-to-face interactions with the patient while having full control over the stimulus that he is experiencing, providing a higher level of communication and understanding between all parties involved. This is especially important in this case, as the therapist must infer many cues from observation.

5.4 Tracking the patient's eye gaze

In the dynamics of a psychotherapy exposure session, a therapist naturally pays attention to the patient's behaviour in terms of facial expressions, body language and, voice tone. It is not uncommon that a patient may get excessively focused on the phobic triggers, and thus they might be looking at it intently, tensing up, or expressing a lot of fear through their words and gestures. On the other hand, if they are avoiding looking at it altogether, they might be turning away, closing their eyes, or trying to distract themselves. This is an important cue for the therapist that is typically lost when using VR or AR technologies, as on one side the eye may be hidden by the device and it is not possible to say of the patient is looking at the virtual elements or not.

In this work, and by exploring the eye-tracking capabilities of Hololens 2, this information is transmitted and mapped in real-time into the therapist's view of the shared space.

As the patient's gaze shifts, a marker position is updated in real-time on the therapist's computer, providing them with a clear and accurate representation of the patient's response to the virtual elements within their real space.

This functionality plays a crucial role in enabling complete and functional interaction between the therapist and the patient. By providing the therapist with this data, the feature allows for a more nuanced understanding of the patient's response to the virtual elements. This information is essential for facilitating effective communication and ensuring that the therapist is able to tailor the interventions to meet the unique needs of the patient. Figure 5 shows two examples of the patient's eye gaze mapped on the therapist's view of the shared space.

5.5 Validation

For validation of this project, it's expected a real-life trial where the *Hololens 2* and computer software will be delivered to a therapist for an extended period of time. During this time the therapist will use it as a therapy tool and the results will be analyzed afterwards.

6 Conclusion

This paper presented a new and expandable alternative AR solution to *in vivo* exposure. This approach addresses some of the major problems found in the conventional in vivo exposure therapy methods such as the low ac-

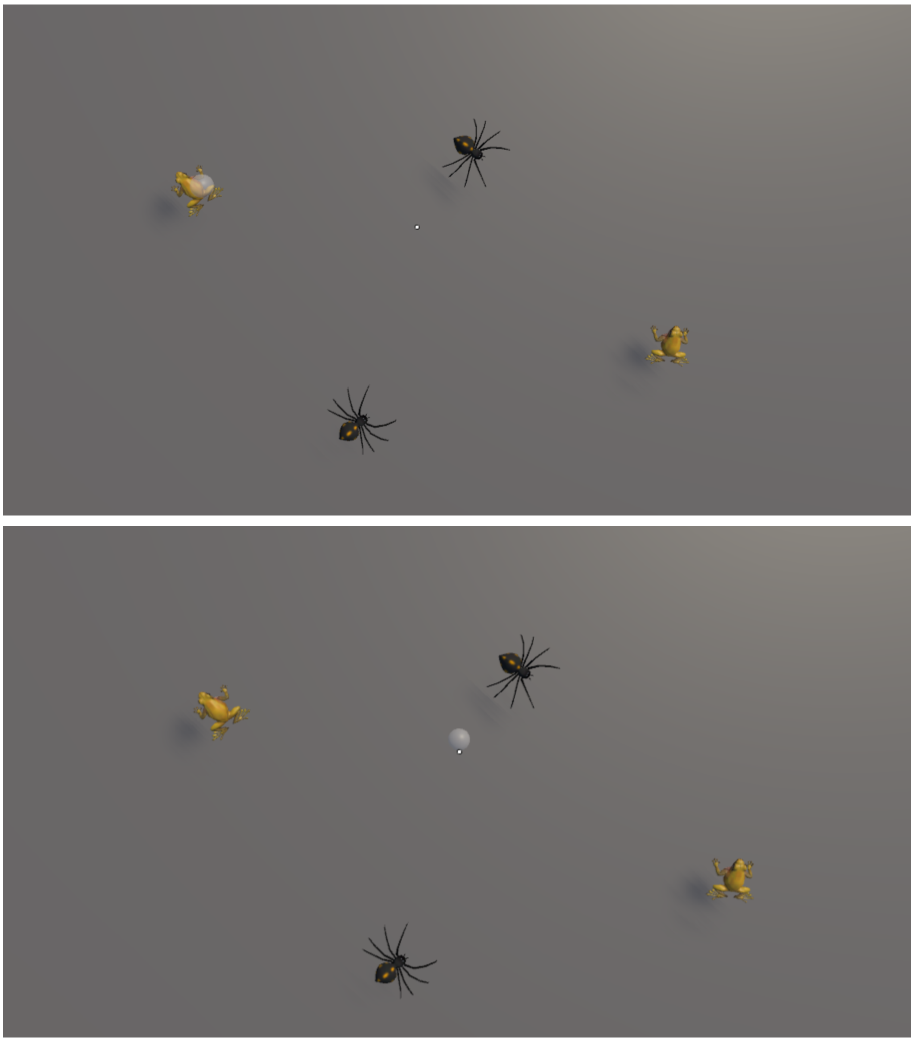

Figure 5: Mapping patient's eye gaze on the therapist's view of the shared space object: (top) focus on the top left frog, (bottom) not focused on any element.

ceptance rates, the inability of the therapist to have full control over the elements, and the space constraints present in the therapist's office. The possibility of dynamically loading exposure crafted elements from an external repository enlarges the range of therapeutic possibilities. The addition of auditory elements associated with the visual elements improves the realist and creates new opportunities for therapists to explore. The virtual portals also create an opportunity for therapists to deal with imaginative therapies approaches creating points through which a phobic element may enter the user space.

Future work will be focused on the clinical validation of the developed system in collaboration with a local hospital.

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Assessing Presence in an Improved Exposure Therapy AR Application

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Abstract

The most common treatment for phobias is in vivo exposure therapy, which has a high success rate but also comes with certain limitations, such as limited control over the phobic elements, impracticality in a conventional office setting, and a notable rate of patient refusal. Technological alternatives like virtual or augmented reality can address these drawbacks. The objective is to present the validation results of an augmented reality application that enables the loading of various phobic elements and the creation of interactive scenarios in a flexible manner. This validation aims to assess the sense of presence and realism experienced by the users during the exposure therapy sessions.

Augmented Reality, Immersive Systems, Phobias, Anxiety, Exposure therapy

1 Introduction

Excessive and irrational fear of certain stimuli or situations with personal impairment is known as a phobia. This overwhelming apprehension can cause significant distress to individuals when they encounter these triggers, despite the stimuli posing little or no real threat [1]. The literature confirms that phobias are among the most common anxiety disorders [2]. Although symptoms may differ in each individual case, certain common signs are frequently observed. These include difficulties in concentration, excessive worry about future misfortunes, experiencing tension headaches, restless fidgeting, an inability to relax, and a tendency to avoid the feared stimuli [3].

Individuals seeking treatment for phobias have access to various intervention options, such as cognitive therapy, modelling, imaginal or virtual reality exposure, and direct *in vivo* exposure. Among these, exposure therapy is frequently regarded as the primary and most effective treatment for specific phobias [2]. This therapeutic approach involves gradually and safely exposing the individual to the feared stimuli or situations, allowing them to confront and manage their fears in a controlled environment. Exposure therapy is indeed considered one of the most robust and effective methods for treating phobias. However, it is essential to acknowledge that there is a refusal rate of approximately 25% among patients who, after learning about the treatment's nature and requirements, may choose not to proceed with it [4]. Adding to this, several challenges exist when implementing exposure therapy. Among such challenges there is the inability to conduct the therapy in a typical office setting [5], and the difficulty in fully controlling the phobic elements during exposure therapy [6]. This lack of control can make the process more unpredictable and potentially unsettling for some individuals. Phobias related to animals can present unique challenges [7], as they may require specialized facilities. Moreover, in these cases expertise in handling and managing animals is crucial to ensure the safety of both the patients and therapists involved in the treatment process. Additionally, some patients and therapists may find exposure therapy with animals distressing or perceive it as cruel [8].

To address the drawbacks associated with traditional exposure therapy for phobias, technological alternatives like virtual reality (VR) and augmented reality (AR) have emerged as promising solutions. Virtual Reality (VR) has demonstrated its effectiveness as a viable substitute for *in vivo* exposure, where individuals are transported to a virtual environment to confront their phobic stimuli [5]. VR has been well-received by patients, with a significant percentage preferring it over *in vivo* exposure [2]. It has the potential to provide controlled and immersive experiences, enabling users to face their fears in a safe virtual setting. Augmented Reality (AR) offers a different approach by integrating virtual content into the real world, allowing users to interact with virtual elements in their actual environment [9]. AR provides a more naturalistic experience, as users can use their own bodies to interact with virtual objects, resulting in only minor changes to their sensory perception of reality. This can be advantageous as it avoids the cognitive burden associated with being fully immersed in a synthetic environment. Although AR is a newer and less explored method compared to VR, it has shown already positive results in phobia treatments [5] [7] [9].

Both VR and AR offer convenient immersion characteristics for treating phobias, with VR transporting users to different scenarios and AR bringing virtual elements into the user's real space. When deciding between VR and AR for a specific phobia treatment, it depends on the type of phobia and the necessary exposure. VR may be more suitable for cases of claustrophobia or acrophobia, where creating a fully immersive virtual environment is beneficial. On the other hand, AR is preferable when the phobic element can be seamlessly incorporated into the patient's surroundings, allowing for a more realistic and natural experience.

2 Related Work

In 1995, Rothbaum et al. [10] introduced one of the earliest alternatives to *in vivo* exposure for acrophobia, utilizing virtual reality. Their groundbreaking work demonstrated the efficacy of this technology in addressing anxiety disorders. By employing virtual reality, they effectively targeted acrophobia, offering a promising avenue for therapeutic interventions beyond traditional *in vivo* exposure methods.

In 2005, Côté and Bouchard [11] directed their efforts towards addressing arachnophobia using virtual reality environments that incorporated phobic elements. Their study demonstrated significant improvement in patient's symptoms after utilizing this VR-based approach.

In 2005, Juan et al. [12] made one of the first attempts to utilize augmented reality (AR) in this type of treatment. Although their work was exploratory in nature, it laid the foundation for future developments in AR-based therapeutic interventions. Notably, their study introduced the concept of having the therapist observe the exposure process through a computer monitor. This innovative approach allowed the therapist to closely monitor and guide the patient's exposure experience within the augmented reality environment.

In 2020, De Witte et al. [13] conducted a study focusing on the treatment of animal-related phobias using an augmented reality (AR) application for smartphones. They aimed to explore an alternative to traditional *in vivo* exposure therapy. However, their approach faced certain limitations, as even if the AR application successfully induced the desired fear and anxiety associated with the phobic elements, it fell short in terms of realism and interaction with those elements.

In 2013, Wrzesien et al. [14] presented an alternative approach using augmented reality (AR) through a Therapeutic Lamp (TL) to project small animals onto a surface. This method was found to be effective in the treatment of certain phobias. However, it's important to note that the use of projections instead of holograms in this context can impact the perception of realism and immersion with the phobic elements.

Patrão et al. in 2020 [15] presented a shared space AR experiment targeting arachnophobia. The application used tablets for both the therapist and the patient. While the study showed good usability and interaction, the use of tablets reduced the perception of virtual elements and made interaction with them more challenging.

Nunes et al. in 2022 [16] introduced an augmented reality (AR) solution for treating phobias, which allowed patients to interact with the phobic elements while granting therapists complete control over these elements. This approach represented a significant advancement in the field. However, the study did have certain limitations like the phobic element's flexibility, the therapist's perception of the patient's reactions, and the lack of some immersion capabilities.

This paper presents the advances on an ongoing work [17], bringing in, besides the improvements and specific refinements to the implementation, a study on the user's perception in terms of virtual elements' presence, which is considered as being fundamental for the success of exposure therapies.

3 Objectives

The objective of the current study is to validate the results of the enhanced augmented reality (AR) solution, which has the potential to be used as a substitute for traditional *in vivo* exposure therapy in a clinical setting. The developed application allows therapists to incorporate virtual representations of elements associated with each patient's specific phobia directly into their office space. The resulting AR application has the potential to seamlessly integrate the therapist's typical office environment, providing patients with a realistic and immersive experience of interacting with their phobic elements. Through it patients can confront their fears in a controlled and safe manner.

In this approach, the therapist is given full control over the augmented reality (AR) experience through a paired computer. With this control, the therapist can precisely select when each virtual element associated with the patient's specific phobia should be present or absent within the AR scene.

The therapist can also determine the exact location of these virtual elements in the AR space, allowing for a strategic setup to suit the patient's needs. Moreover, the therapist has the capability to manipulate the behavior of each virtual phobic element within the scene. This means that each virtual element behaves in a unique manner, designed specifically based on its characteristics and purpose.

Being an extension of the previous development, the improvements are aimed at addressing limitations identified in the earlier study, including the need for more diverse phobic elements, new stimuli to broaden the patient's experience, and new features to offer a deeper understanding of the patient's reactions, enabling more effective therapeutic interventions. To achieve these objectives, the study introduces the implementation of dynamically loadable elements, along with a framework for their development. This allows for a more flexible and varied selection of phobic elements, offering a richer and more tailored therapeutic experience. Furthermore, the work includes support for spatially located sound stimuli, enhancing the realism and immersion of the patient. This feature provides a complete auditory experience, further contributing to the effectiveness of the therapy. In terms of therapist support, the work implements support to track the patient's eye gaze dynamics during the exposure sessions. This enables the therapist to have a real-time representation of the patient's eye gaze on the paired computer, aiding in understanding reactions and responses during the therapy sessions.

4 Proposal

The current proposal introduces three significant new features that aim to support and expand the therapeutic possibilities while enhancing both the patient and therapist experiences.

Figure 1: Therapy setup.

4.1 Dynamically loadable models

In most VR applications, the elements included and accessible are typically hard-coded into the generated application. As a result, adding new elements necessitates modifying the original code and subsequently distributing updated versions of the application.

The range of elements required for exposure therapies can be extensive and not entirely predictable. While certain types may be more prevalent, these trends can change over time. In contrast to the previous approach, where models were statically included in the developed applications, the new method introduces a "load-on-demand" feature. This advancement allows the application to access any model made available through an online repository. As a result, therapists and users now have the flexibility to utilize a broader selection of elements, adapting to evolving needs and ensuring a more dynamic and up-to-date experience. This innovative approach addresses the limitations of the static model inclusion, offering greater versatility and potential for enhanced therapeutic outcomes.

The inclusion of dynamically loading elements elevates this application to a new level of expandability, offering benefits in terms of both the variety of phobic elements accessible and the scalability for concurrent active devices. By enabling the application to access the online repository at runtime, it can retrieve a comprehensive list of available elements. Therapists now have the flexibility to select and load desired elements on demand, tailoring the experience to each user's specific needs. This approach greatly simplifies the process of updating available phobic elements or adding new ones. All that is required is to add the updated or new elements to the repository, and they automatically become available to all devices running the application. This streamlined updating process ensures that the application stays up-to-date and relevant, benefiting both therapists and users with a constantly evolving and diverse set of therapeutic elements. Moreover, the dynamic loading capability expands the reach of the application, allowing more devices to access and use it simultaneously. This increased scalability enhances the potential impact of the application, as it can now cater to a larger number of users seeking exposure therapy, regardless of their location. Recent improvements included the support of more realistic animations of the phobic elements and the inclusion of a larger list of loadable elements containing: snakes, mice, cats, spiders, tarantulas, and frogs. This list can now be easily extended based on the procedure and module interface definition established.

4.2 Spatial sound stimulli

Incorporating sound effects to elements in the application can significantly enhance the immersive experience and add an extra layer of realism to the virtual environment. While some elements, like spiders, might not produce sound in reality, other elements can be associated with their characteristic sounds to create a more engaging and convincing simulation. For instance, when a user encounters a virtual animal, the application can now include the reproduction of natural and specific animal sounds, that, by exploring 3D sound-located sources creates the sensation of being produced by the visualised animals, and thus improving the perceived realism (and presence). This introduction of spatially-located sound stimuli in the treatment process offers multiple advantages that can significantly enhance the therapy.

4.2.1 Systematic Desensitization

By exposing the person to sounds associated with a phobic element (eventually) before introducing visual stimuli, the therapy can follow a more gradual approach. This allows the individual to become acclimated to the fear-inducing stimuli in a controlled manner. Starting with sound alone can serve as a less overwhelming initial step, preparing the patient for subsequent visual exposure. This step-by-step approach can help reduce anxiety and increase the chances of successful desensitization.

4.2.2 Immersive and Realistic Experience

The combination of spatially-located sound stimuli with visual elements creates a highly immersive and realistic experience for the patient. The interpretation of both visual and auditory cues enhances the sense of presence within the virtual environment. This heightened realism can contribute to a more effective therapeutic process, as the patient feels more engaged and connected to the virtual scenarios.

4.3 Eye gaze tracking and avoidance detection mechanism

In the dynamics of a psychotherapy exposure session, a therapist naturally pays attention to the patient's behaviour, including facial expressions, body language, and voice tone. Patients may react in various ways to phobic triggers, such as intensely focusing on them, tensing up, or expressing fear through their words and gestures. Conversely, some patients may avoid looking at the triggers altogether by turning away, closing their eyes, or attempting to distract themselves. These cues are essential for the therapist's understanding and guidance but may be lost when using VR or AR technologies, as the patient's eyes may be hidden by the device, making it challenging to determine if they are looking at the virtual elements or not. To improve the therapist's understanding of the patient's response to the virtual elements, the application includes an eye-tracking functionality. This feature allows real-time tracking of the patient's eye gaze while using the Hololens 2 while simultaneously mapping it on the therapist application, ensuring the therapist can accurately interpret their reactions to the elements in the virtual space. To provide extended support to the therapist, a mechanism for registering and displaying avoidance behaviours was integrated.

The development of this augmented reality application utilized the Mixed Reality Toolkit (MRTK) and the Unity platform, specifically designed to run on the *Hololens 2* device. The application works in conjunction with a computer application, putting the therapist in full control of the exposure session (figure 1). The primary goal of this application suite is to offer therapists a novel tool that replaces traditional in vivo exposure in a clinical setting. With this application, patients can experience a mixed reality environment where they can see and interact with phobic elements in a controlled and safe manner (figure **??**). The therapist has complete control over the appearance and behaviour of these virtual elements. This level of control empowers the therapist to tailor the exposure experience to each patient's specific needs, gradually increasing the intensity of exposure as the patient progresses through the therapy.

4.4 Dynamically loadable elements

The use of runtime loadable elements instead of preloaded elements in the application significantly enhances its versatility and expandability. Constant communication between the headset, computer, and the online repository is required to make this possible (figure 2). Upon launching the therapist application and detecting the Hololens 2, the available element list is presented to the therapist. The therapist can then select a desired element, and its ID is then sent to the Hololens 2. The therapist can also choose the location in the scene where the element should appear. Pressing the "add" button triggers the download of the desired element from the online repository to both the computer and the head-mounted device, displaying the element in the scene.

The number of dynamically loadable elements available can be easily extended by exploring the existing support in Unity for creating *asset bundles* from *prefabs* and adding them to the online repository.

4.5 The importance of observing patient's eye gaze

To enhance the therapist's understanding of the patient's response to the virtual elements, the eye-tracking capabilities of Hololens 2 are utilized. This information is transmitted and mapped in real time into the therapist's view of the shared space. As the patient's gaze shifts, a marker position is updated in real-time on the therapist's computer, providing them with an accurate representation of the patient's response to the virtual elements in their real space (figure 3). This functionality is crucial for facilitating complete and functional interaction between the therapist and the patient. It allows the therapist to gain insights into the patient's reactions, such as whether they

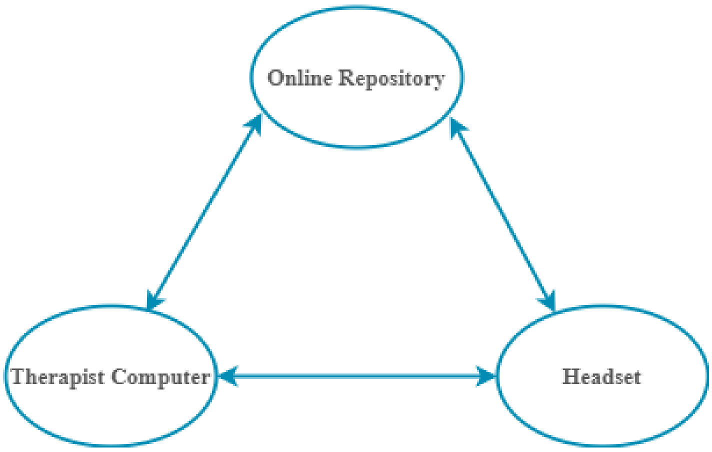

Figure 2: Communication architecture.

are avoiding certain elements, their comfort levels, and how specific movements affect them. This feature enables a more nuanced understanding of the patient's responses during the exposure therapy session. To better support the therapist, when the patient's gaze diverges from the phobic elements the event is registered and displayed on the computer screen.

5 Experiment

The main testing focus in our application is to assess the realism of the phobic elements, the sense of presence they evoke within the shared space and evaluate the spatial sound capabilities provided in the experience.

5.1 Procedure

All volunteers executed the tests in the same environmental conditions, such as light and surface, which were considered to be ideal. In (figure 4) is represented all phobic elements used in this validation.

Prior to starting the test, it is essential to calibrate the *Hololens 2* for each subject eye gaze. This calibration process is quick and simple, and it begins as soon as a new user wears the device. Upon completion of the calibration, a set of numbers were presented on the table. Each number designates a specific area where animals appear. Participants are instructed to observe

Figure 3: Mapping patient's eye gaze on the therapist's view of the shared space object: (top) focus on the snake, (bottom) not focused on any element.

Figure 4: Animal models used in testing.

the numbers in any sequence they prefer, with the corresponding animal appearing at the designated spot upon their gaze. Once all the animals were present on the table, users were encouraged to freely observe them from multiple perspectives. This segment of the test aims to evaluate the realism of the rendered elements in terms of their visual representation and their integration within the room environment.

The next stage of the test focused on assessing the realism and perceived authenticity of the movements. To achieve this, participants were instructed to place their hands flat on the surface of the table. At this point a mouse would initiate its motion towards the user's hands, gradually approaching them until it reached a proximity just before contact. Participants were encouraged to assess their perception of the mouse's approximation to their hands, evaluating the realism and accuracy of the interaction. This phase of the test aimed to collect the users' subjective experience and feedback regarding the realism of the virtual mouse's movements and their interaction with their physical presence.

The final objective of the test involved evaluating the spatial sound capabilities provided by the system. To accomplish this, users were instructed to focus their attention on the animals located in the top left corner of the table. This deliberate setup served as a distraction for the users. Meanwhile, an additional element that had not been previously observed by the users was introduced on the far bottom right side of the table, outside their field of view. The purpose of this element was to emit sound, and the goal was to observe whether the users would redirect their attention toward the sound source and accurately determine the direction from which the sound originated. This evaluation aimed to assess users' proficiency in localizing and identifying the source of the sound within the virtual environment.

At the end of the experiment, each participant filled out the Presence Questionnaire [17]. This questionnaire aims to evaluate different aspects regarding the shared space between the user and the virtual elements. It is composed of 21 items with seven dimensions: Involvement (5 items), Natural (3 items), Interface Quality (2 items), Resolution (2 items), Auditory (2 items), Haptic (2 items), Immersion (5 items). Each item is a 7-point Likert-type scale scored between "not at all" (1) and "strongly agree" (7).

6 Validation

Data analysis was performed using IBM SPSS Statistics. Descriptive statistics were computed to examine the Presence Questionnaire [17] dimensions, and Mann-Whitney U tests were performed to evaluate whether the overall sense of presence differs when comparing users with and without previous experience with AR and VR. Results are considered statistically significant when $p \leqslant .05$.

6.1 Participants

The test was executed by 23 non-phobic volunteers, 14 males (60.9%) and 9 females (39.1%) with ages ranging from 20 to 31 years old (mean age of $24.65, SD = 3.20$). The majority of the sample had previous experience with virtual reality ($n = 15, 65.2\%$). Similarly, 14 participants had previous experience with augmented reality (60.9%). Additionally, no gender differences were found regarding previous experience with virtual reality ($\chi^2_{(1)} = 0.014, p = .907$) and augmented reality ($\chi^2_{(1)} = 0.209, p = .648$).

6.2 Results

6.2.1 Involvement

This category focuses on assessing the level of user engagement and involvement during the test. It captures how actively users participate and interact with the virtual elements introduced in the test. Results shown high levels of involvement across the users ($Min = 5, Max = 7, M = 5.85, SD = 0.59$; Fig. 5).

6.2.2 Natural

The "Natural" category evaluates the extent to which the virtual elements, movements, and interactions within the system emulate natural and realistic behaviours. It gauges whether users perceive the virtual environment and its components as natural and believable. Results show high levels of perceived natural and realistic characteristics of the virtual elements ($Min = 4, Max = 7, M = 5.20, SD = 0.96$; Fig. 5).

6.2.3 Interface Quality

This category pertains to the evaluation of the system's interface quality, including factors such as ease of use, intuitiveness, responsiveness, and overall user satisfaction with the interface provided by the system. The users evaluated this category with a medium score ($Min = 2, Max = 7, M = 4.74, SD = 1.54$; Fig. 5).

6.2.4 Resolution

The "Resolution" category focuses on the clarity, detail, and visual resolution of the virtual elements and their presentation within the system. It aims to assess whether users perceive the visual elements as sharp, clear, and detailed. The overall score for this topic was reported as very high ($Min = 5, Max = 7, M = 6.39, SD = 0.62$; Fig. 5).

6.2.5 Auditory

The "Auditory" category assesses the quality and effectiveness of the system's auditory features, including spatial sound capabilities, sound clarity, realism, and overall user perception of sound within the shared space. Users perceived this dimension as very good ($Min = 5, Max = 7, M = 6.39, SD = 0.77$; Fig. 5).

6.2.6 Haptic

As previously mentioned, the "Haptic" category is not applicable in this system. However, if haptic feedback were to be included in future iterations, this category would evaluate the system's ability to provide realistic tactile sensations and haptic feedback to enhance the overall user experience and sense of presence. As expected, in this dimension the results were low ($Min = 1, Max = 7, M = 4.00, SD = 1.82$: Fig. 5).

6.2.7 Immersion

The "Immersion" category encompasses the overall user experience and perception of immersion within the virtual environment. It considers factors such as the level of engagement, the realism of the elements, sensory integration (visual and auditory), and the overall ability of the system to transport virtual elements into the real world. In this category, users reported a high level of immersion ($Min = 4, Max = 7, M = 5.71, SD = 0.80$; Fig. 5).

6.2.8 Overall Presence

The "Overall Presence" category provides a comprehensive evaluation of users' overall satisfaction, perception, and impression of the system. It takes into account the assessments made in all the previous categories, allowing for a holistic evaluation of the users' experience, system performance, and the overall sense of presence provided by the application. By considering these categories collectively, a thorough and comprehensive assessment of the system and user experience can be achieved. Results show that the experiment was perceived with a high level of presence ($Min = 5, Max = 7, M = 5.55, SD = 0.54$). Additionally, results showed a similar sense of presence between users with and without previous experience with AR ($U = 53.0, p = .557$). Similarly, there were no significant differences in the sense of presence between users with and without previous experience with VR ($U = 57.0, p = .875$).

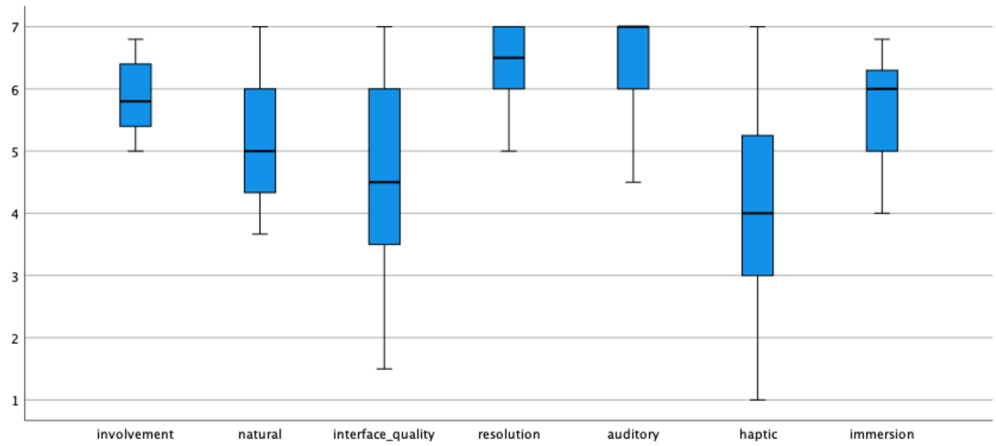

Figure 5: Answer distribution for each dimension of the presence questionnaire.

7 Conclusion

The current study aims to present the development of an augmented reality application exploring the virtual shared space between two users. The system allows the creation of distinct scenarios in a flexible and interactive way by dynamically loading several virtual elements. Additionally, this system was validated using 23 non-phobic adult volunteers assessing their sense of presence during the experience. Regarding the dimensions of the Presence Questionnaire, the results show that the users were highly engaged and involved during the experiment. Furthermore, the users perceived the virtual environment and elements as highly natural and believable. The visual and auditory characteristics of the virtual elements included in the system were rated with the highest scores, altogether resulting in a high sense of immersion. However, it is important to note that certain dimensions, such as Interface Quality and Haptic, were evaluated with medium and low scores, respectively. This result was expected given that interaction and haptic capabilities were not implemented in the system. Nevertheless, these categories contribute to the overall sensation of presence and were considered during the evaluation process. Moreover, results indicate no differences in the sense of presence during the experiment between users with and without previous experience with AR or VR. These findings highlight the utility of the AR-developed system for therapeutic proposes and encourage future studies in clinical settings.

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