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THESIS TITLE

DEVELOPMENT OF A VIRTUAL REALITY EXPOSURE THERAPY SYSTEM: AN EXAMPLE OF OBSESSIVE-COMPULSIVE DISORDER

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COMMITMENT

I declare that this thesis was written in Manisa Celal Bayar University, Faculty of Engineering Department of Computer Engineering in accordance with academic and ethical rules, and all the literature information used is included in the thesis with reference.

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CONTENTS

LIST of ABBREVIATIONS

AI	Artificial Intelligence
CBT	Cognitive-Behavioral Therapy
ECG	Electrocardiography
ERP	Exposure and Response Prevention
ET	Exposure Therapy
FoV	Field of View
GSR	Galvanic Skin Response
MR	Mixed Reality
OCD	Obsessive-Compulsive Disorder
PTSD	Post-Traumatic Stress Disorder
SUS	System Usability Scale
UX	User Experience
VR	Virtual Reality
VRET	Virtual Reality Exposure Therapy

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ABSTRACT

M. Sc. Thesis

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With the developing technology, virtual reality technology has started to take its place in our lives. This technology, which has found its place in many fields from health to law, education to tourism, offers innovative solutions in different sectors. Virtual reality glasses have started to be used in the field of psychotherapy, keeping pace with the advancing technology. Virtual Reality Exposure Therapy (VRET) offers a more accessible, convenient and safer environment than traditional exposure therapy in the treatment of many anxiety disorders such as phobias. While many VRET solutions tout their efficacy in therapy, there has been little large-scale uptake. There are no guidelines for developing these solutions, so there is no standardization across solutions. There is therefore a need for safe, commercially viable VRET solutions that are practically effective and can be used in most exposure therapies. Based on this, we have developed a scalable and manageable VRET application.

This study offers an innovative solution from both a clinical and technological point of view, presenting a generic VRET framework that is not only limited to a specific domain, such as obsessive-compulsive disorder, but is also applicable to other anxiety disorders. Furthermore, a system has been developed that allows the expert to actively follow the process and customize the therapy according to individual needs. In these aspects, our study is considered as an important step that can promote the widespread use of VRET.

Keywords: Virtual Reality Exposure Therapy, Therapy, Virtual reality, Exposure Therapy, Obsessive-Compulsive Disorder

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ÖZET

Yüksek Lisans Tezi

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Sanal gerçeklik teknolojisi, gelişen teknolojiyle birlikte hayatımızda yerini almaya başladı. Sağlıktan hukuka, eğitimden turizme kadar birçok alanda kendine yer bulan bu teknoloji, farklı sektörlerde yenilikçi çözümler sunmaktadır. Sanal gerçeklik gözlükleri, psikoterapi alanında, ilerleyen teknolojiye ayak uydurarak, tedavilerde kullanılmaya başlanmıştır. Sanal gerçeklik maruziyet terapisi, fobiler gibi çok sayıda anksiyete bozukluğunun tedavisinde geleneksel maruz bırakma terapisine göre daha erişilebilir, daha uygun ve güvenli ortamlar sunmaktadır. Birçok sanal gerçeklik maruziyet terapisi çözümü, terapi etkinliğini göz önüne serse de geniş ölçekte kullanımı çok azdır. Bu çözümleri geliştirirken tam olarak bir kılavuz olmadığından, çözümler arasında da bir standardizasyon yoktur. Bu nedenle pratik olarak etkili, çoğu maruziyet terapisinde kullanılabilecek halde güvenli, ticari olarak uygulanabilir sanal gerçeklik maruziyet terapisi çözümlerine ihtiyaç vardır. Bu amaçla, sanal gerçeklik maruziyet terapisi uygulamasında ölçeklenebilir ve yönetilebilir bir çalışma yaptık.

Bu çalışma hem klinik hem de teknolojik açıdan yenilikçi bir çözüm sunarak, sadece obsesif-kompulsif bozukluk gibi belirli bir alanla sınırlı kalmayan, aynı zamanda diğer anksiyete bozukluklarında da uygulanabilir, genel bir çerçeve ortaya koymaktadır. Ayrıca, uzmanın süreci aktif bir şekilde takip edebilmesine ve bireysel ihtiyaçlara göre terapiyi özelleştirmesine olanak tanıyan bir sistem geliştirilmiştir. Bu yönleriyle çalışmamız, sanal gerçeklik maruziyet terapisinin yaygın kullanımını teşvik edebilecek önemli bir adım olarak değerlendirilmektedir.

Anahtar Kelimeler: Sanal Gerçeklik Maruziyet Terapisi, Terapi, Sanal gerçeklik, Maruz Bırakma Terapisi, Obsesif-Kompulsif Bozukluk

2025, 67 Sayfa

CHAPTER 1- INTRODUCTION

1.1 MOTIVATION

Virtual reality glasses, which have started to take their place in our lives with the rapidly developing technology today, have progressed significantly in recent years. Today, in the treatment process of many psychiatric disorders, exposure therapy is applied in which people are exposed to environments related to their disorders in a controlled manner**.** Exposure therapy is an effective treatment for anxiety disorders, but there are challenges in its implementation and effectiveness [1]**.** Many therapists have concerns about safety, tolerability and accessibility. Exposure therapy is therefore not adequately implemented [2]**.** The high cost, time-consuming processes, the difficulty of realizing the application in a controlled environment, and the inability to always create scenarios in real life that suit the needs of the individual limit the use of exposure therapy. At this point, virtual reality technology, which has developed rapidly in recent years, emerges as a tool that can solve these problems. Virtual reality exposure therapy (VRET) aims to overcome the limitations of traditional methods in the virtual world by preparing a safe, accessible and controllable environment where therapy patients can face their fears.

Virtual reality technology will change the challenges of traditional exposure therapy, creating scenarios that can be configured and repeated according to the needs of individuals, making the therapy process more easily applicable and manageable. This is expected to increase individuals' motivation to participate in the treatment process. Moreover, by providing therapists with full control over the process, it significantly increases the effectiveness of treatment and the benefit that individuals receive from therapy. This flexibility and accessibility of virtual reality technology can make exposure therapy accessible to a much wider audience.

1.2 THE SCOPE OF SYSTEM

Our aim in this study is to combine traditional exposure therapy with emerging technology to provide an accessible, cost-effective and safe way of delivering exposure therapy. For this purpose, we need solutions that can bring virtual reality and exposure therapy to a feasible level. Exposure therapy is a broad treatment modality that can be used for many different disorders. One of our aims in this study is to develop a standardized system that covers elements such as therapy duration, frequency, user interaction methods, physiological measurement tools, scales and evaluation criteria necessary for the effectiveness and accuracy of the therapeutic process. The system, which will be developed with an infrastructure suitable for many therapies, will offer a more interactive solution by allowing the therapist's control screens and guidance. Despite the generic VRET framework, the main focus of this thesis in terms of scenarios is “Obsessive-Compulsive Disorder” related to cleanliness, since it is a common disorder which has severe effects in society.

1.3 CHALLENGES

Development of a generic, managable and cost-effective VRET framework has certain challenges. First of all, it is a critical requirement that the system is integrated in such a way that different hardware and software components, such as VR glasses, biosensors and therapist’s control panels work together and can be controlled according to certain parameters. Customized software solutions are needed to ensure instant data and image flows and to ensure that these components work in harmony. Possible disruptions in this process may cause therapists to be unable to intervene on time and this may have negative effects on the patient. This makes data and image transfer a challenging task.

Another important challenge is that the specialists and patients who will use the system do not have enough previous experience with this type of technology. The adaptation of users to the technology is an issue that needs to be carefully addressed throughout the process and requires a holistic solution that includes both technical and educational approaches.

1.4 SUMMARY OF THE CONTRIBUTIONS

The key contributions and advantages of this study are outlined below:

- A generic and customizable framework for virtual reality exposure therapy has been developed, which provides an accessible and cost-effective alternative to traditional exposure therapies.
- The framework was developed under the supervision of mental health domain experts. Hence, it includes use cases and scenarios compatible with real life.
- The proposed tool includes scenarios, environments, and tasks that are customized for OCD related to cleanliness disorder, for which VRET applications are not very common yet.
- Doctor control panels in the system allow therapists to have full control over the therapy and conduct personalized therapies. In addition, therapists can monitor the progress of the patients throughout the therapy sessions.
- The system is integrated with biosensors such as galvanic skin response (GSR) and electrocardiography (ECG) which are crucial for monitoring the physiological responses of the patient during sessions.
- Compared to the majority of the VRET systems, the proposed system is interactive in which the therapist can assign tasks to the patient to interact with the environment.
- The interaction methods used for object manipulation and navigation tasks were determined based on formal experimental studies that evaluate user experience.
- The research also provides insights into the design and implementation of VR systems for therapeutic purposes, including hardware selection, user interaction analysis, and system usability evaluation.

1.5 OUTLINE OF THE THESIS

This thesis is organized as follows: Chapter 2 includes background information about VR, mental health and the use of VR in mental health applications. In Chapter 3, the design issues about hardware selection and interaction methods are elaborated. Chapter 4 presents the prototype of our VRET application. In Chapter 5, the qualitative and quantitative results of the study are discussed, and the system performance is analyzed. Lastly, Chapter 6 wraps up the study with a summary, limitations, and future research directions.

CHAPTER 2- BACKGROUND

2.1 VIRTUAL REALITY (VR)

Virtual reality (VR) technology enables users to experience a fully computer-generated environment as if it were real, with applications in entertainment, education, healthcare, and training (N., 2023). VR, which involves users in a simulated world by affecting their senses such as sight, hearing and sometimes even touch, has evolved rapidly in recent years. In healthcare, VR applications range from surgical training and patient rehabilitation to pain management and therapy[4]. VR technology can do so many things. It's really impressive how it works in different areas. In education, VR provides immersive learning environments that improve understanding of complex concepts [3]. Industrial applications include simulations for training without risking damage to machinery [5].

VR technology is increasingly being applied across various healthcare domains. In surgical training, VR simulators provide immersive opportunities for medical students to practice their skills without risk to patients [6]. One of the most innovative uses of VR technology in healthcare is its contribution to therapeutic processes. VR-based therapies have shown effectiveness in treating anxiety disorders, post-traumatic stress disorder (PTSD), phobias, and obsessive-compulsive disorder (OCD) by providing controlled, safe environments for exposure therapy [7]. The devices that make this experience possible play a decisive role in the success and spread of virtual reality technology. In particular, high-resolution displays, sensors that can precisely track movements and systems that provide a sound experience surrounding the user make virtual reality devices different from ordinary technological products. These devices aim to take users out of the real world and provide an experience in artificial environments that are created completely virtually and feel very close to reality. Virtual reality applications, which initially emerged only in the entertainment sector, are now being used in many different fields such as health, education and professional development. For example, devices such as Oculus Quest or HTC Vive offer a wide range of uses, from lawsuits to surgical training. Moreover, wireless and portable models developed in recent years have made the technology more accessible and convenient, making virtual reality solutions appeal to a wider audience. These next-generation VR systems aim to enhance user experience through wireless connectivity and multi-user environments [8]. VR technology is increasingly being applied across various healthcare domains. In surgical training, VR simulators provide immersive opportunities for medical students to practice their skills without risk to patients[6]. One of the most innovative uses of VR technology in healthcare is its contribution to therapeutic processes. VR-based therapies have shown effectiveness in treating anxiety disorders, post-traumatic stress disorder (PTSD), phobias, and obsessive-compulsive disorder (OCD) by providing controlled, safe environments for exposure therapy [7]. The devices that make this experience possible play a decisive role in the success and spread of virtual reality technology. In particular, high-resolution displays, sensors that can precisely track movements and systems that provide a sound experience surrounding the user make virtual reality devices different from ordinary technological products. These devices aim to take users out of the real world and provide an experience in artificial environments that are created completely virtually and feel very close to reality. Virtual reality applications, which initially emerged only in the entertainment sector, are now being used in many different fields such as health, education and professional development. For example, devices such as Oculus Quest or HTC Vive offer a wide range of uses, from lawsuits to surgical training. Moreover, wireless and portable models developed in recent years have made the technology more accessible and convenient, making virtual reality solutions appeal to a wider audience. These next-generation VR systems aim to enhance user experience through wireless connectivity and multi-user environments [8].

2.2 MENTAL HEALTH AND OBSESSIVE – COMPULSIVE DISORDER

Mental health is defined as the ability to regulate thoughts, feelings, and behaviors, and is an integral part of overall health [9]. A healthy mental state is a fundamental element that enables an individual to realize his/her potential and to establish harmonious relationships with his/her environment. Rapid changes in modern society have led to an increase in mental health problems due to various factors. Research suggests that postmodern societies face evolutionary changes resulting in increased stress at both individual and population levels [10].

In this context, mental health problems faced by modern societies can deeply affect the quality of life and functionality of individuals. One of the disorders in the field of mental health, Obsessive Compulsive Disorder, in short OCD, stands out. OCD creates significant difficulties at both individual and social levels.

OCD is a severe and chronic mental health condition that affects all aspects of a person's functioning [11]. Research indicates that OCD is associated with broad impairments in executive function, including deficits in memory, attention, flexibility, inhibition, verbal fluency, planning, and decision-making [12], [13]. It has been supported by meta-analyses that there are significant problems in visuospatial memory, verbal memory, executive functions and verbal fluency, and that the recall of complex visual stimuli is the most prominent among these effects.

OCD affects 1-3% of the population, typically emerging in adolescence or early adulthood [14]. Especially when it occurs during adolescence or early adulthood, it causes negative consequences in a wide range of areas, from individuals' educational life to their social relationships. Common themes include contamination fears and cleaning rituals [15]. The disorder can significantly interfere with daily functioning, academic performance, and social relationships [16]. OCD is considered a neurobiological disorder, affecting one in 40 adults [17]. The disorder's impact on children and adolescents is notable, with an estimated prevalence of 1 in 200 in this age group [16].

Cognitive-Behavioral Therapy (CBT) with Exposure and Response Prevention (ERP) is widely recognized as the most effective psychological treatment for Obsessive-Compulsive Disorder (OCD) [18], [19]. Research suggests that ERP is more effective than other active treatments, particularly pharmacotherapy, in relieving symptoms of OCD [19], [20]. This finding highlights the need to increase access to treatment and the importance of making ERP available to a wider range of patients.

Exposure therapy is an effective treatment for anxiety disorders, particularly PTSD, that involves confronting fear-inducing stimuli in safe environments [21]. The therapy employs different techniques such as in vivo exposure, VR exposure, and systematic desensitization [22]. The treatment can be adapted for various types of fears, including animal-related phobias, social concerns, and health anxieties [23].

2.3 LIMITATIONS OF EXPOSURE THERAPY

Among traditional therapy methods, especially Exposure Therapy (ET), is an effective treatment for anxiety disorders, particularly PTSD, but faces challenges in implementation and patient adherence [24]. For example, real-life exposure therapy for flight phobia is often expensive, logistically challenging and potentially embarrassing for patients [25]. Institutional barriers and treatment settings can undermine exposure therapy's effectiveness [26]. Main limitations of the traditional exposure therapy are listed below:

- **Environment Issues:** Finding the right space for treatment can be a difficult, expensive and unmanageable problem. Sometimes these spaces are difficult to access or even unavailable. For example, it can be difficult to get a ticket at the appropriate time for a patient who has a fear of flying and the specialist who will manage the therapy.
- **Safety Risks:** Keeping patients safe during therapy is not always easy. For example, in a high building, there are physical risks such as falls and injuries, which can cause serious problems during the therapy process.
- **Motivational Challenges:** Some patients do not want to participate in therapy because they are afraid of facing their fears. This can reduce the effectiveness of the therapy and prolong the process.
- **Limited control over the therapy:** In a real environment, therapist has not full control over the environmental variables. For instance, the therapist cannot control the situations that a person with social anxiety has to face in public.

All these limitations can negatively affect both patient compliance and the overall success of the treatment. This can limit the effectiveness of the therapy.

2.4 BENEFITS OF VR EXPOSURE THERAPY

Traditional exposure therapy can cause patients to face both practical and emotional barriers in the implementation process. This clearly highlights the need for innovative, sustainable and effective approaches. One of the prominent solutions in this field has been VRET, which provides a safe, flexible and replicable environment to support individuals to overcome their fears.

Studies have shown that VRET can produce significant behavioral changes in real-life situations, comparable to traditional exposure therapy [27]. Also, VRET gives therapists the chance to create situations that are hard or even impossible to set up in real life. For example, they can simulate an airplane cabin or a busy public place. This shows that VRET could really help improve traditional exposure therapy and make it more accessible for people.

Virtual Reality Exposure Therapy (VRET) has emerged as a promising technology-driven approach for treating anxiety disorders. According to experimental studies, it offers comparable efficacy to traditional in vivo exposure [28]. Moreover, VRET allows therapists to tailor exposure tasks to individual patients, making treatment more acceptable and less intimidating [29]. The technology enables precise control over stimulus intensity and duration, facilitating emotional processing and fear structure modification [30].

The rapid development of VR technology has not only revolutionized the fields of entertainment and education but has also driven transformative innovations in health and psychotherapy. These advancements enable the creation of highly immersive, dynamic, and interactive environments that can be tailored to individual needs, providing an unprecedented level of precision and control in therapeutic applications. Among these groundbreaking innovations, the development of adaptation algorithms to personalize VRET configurations stands out, offering significant potential to enhance both treatment efficacy and ease of use for therapists [31]. Despite limitations in legacy VR systems, studies have generally reported positive outcomes for VRET in treating various anxiety-related disorders, including specific phobias, PTSD, and generalized anxiety disorder [32].

2.5 VRET SYSTEMS IN THE LITERATURE

A systematic review of current studies on mental health reports that VR has demonstrated its ability to treat different types of specific phobias, whereas augmented reality is only effective in treating animal phobia [33]. [34] review the VRET studies on the treatment of agoraphobia, social phobia, and specific phobias including acrophobia, arachnophobia, claustrophobia, dental phobia, blood injection, PTSD, and fear of flying. In their analysis, they also report the success rates of the VRET treatments for each type of phobia. According to these results, VRET is most effective in the treatment of acrophobia, claustrophobia, and blood injection, with a success rate of 100%. On the other hand, agoraphobia and arachnophobia have success rates of 40%. [35] aim to extract guidelines for the effective implementation of VRET in phobias, by reviewing the current literature. They suggest that VRET should be used as a complementary tool to in vivo exposure therapy and the duration of VRET sessions should be kept short by increasing the frequency of the sessions. They also suggest that the patients should be familiarized with the VR setting by enabling many scenarios. Another important conclusion they draw is that the more virtual reality mimics reality in terms of graphical resolution, scenario diversity and dynamic adaptation to patient behavior, the greater its impact will be.

The review by [36] demonstrates that VR is effective in provoking realistic responses to feared stimuli, particularly for anxiety, and that the immersive nature of VR is ideal for pain management. They highlight the importance of high FPS rates to mitigate the side effects of VR such as nausea and disorientation. [37] investigate the key requirements, challenges and solutions for the effective design and development of VRET systems. They emphasize the significance of psychologist involvement in the design, therapist-led therapy sessions, controlled intensity levels, usability evaluations, and selection of hardware and software tools.

According to [38], although there is general consensus for anxiety disorders, there is a lack of published empirical evidence for other mental disorders. Despite the widespread acceptance of VRET systems for phobias, VRET studies for OCD are relatively scarce, as summarized below.

In a recent study [39], a VR home environment to provoke OCD symptoms of “contamination/cleaning”, “symmetry/ordering” and “fear-of-harm/checking” was designed. Then in their follow-up validation study [40], this VR home environment was tested on OCD patients and their subjective responses regarding anxiety levels, sense of presence and simulator sickness were assessed. According to the experimental study, they claim that this VR home environment is suitable for the treatment of OCD patients. A study by Torrao et al. describes a serious VR game design for OCD therapy

[41] validate VR as a viable mechanism for ERP in contaminarion OCD, through a user study. In addition to VR, mixed reality (MR) environments, where the patient's actual space is augmented with virtual contamination, have recently been applied for OCD [42].

As the literature review indicates, more research is needed on the effective design and use of VRET systems, particularly for OCD. The literature reviewed stresses the importance of psychologist involvement in design, therapist control over therapy, levels of immersion and presence, and optimized system performance for greater interactivity.

CHAPTER 3- MATERIALS AND METHODS

This study focuses on the design, development, and evaluation of a VRET system for the treatment of specific psychiatric disorders such as OCD. In particular, the technical performance of the interaction methods used in virtual reality environments and their effects on the user experience were evaluated in detail. The initial system was created to evaluate various virtual reality interaction techniques and see how these techniques may be improved for therapeutic uses. Future therapeutic scenarios and content created especially for OCD were to be based on this technique.

In the first phase of the development process, the technical infrastructure of the virtual reality technology was analyzed in detail. Criteria such as the way users interact with the system, the ease, efficiency and suitability of these methods for therapeutic applications were taken into consideration. In addition, feedback obtained from the user experience was carefully examined and improvements were made on both the technical aspects and user-friendly features of the system. These analyses not only increased the effectiveness of the current design, but also provided guiding data for the development of future therapeutic content.

3.1. HARDWARE SELECTION AND ITS ROLE IN VR THERAPIES

Nowadays, the healthcare industry makes extensive use of virtual reality (VR) technology, particularly for the treatment of psychiatric problems. The characteristics of the hardware utilized are crucial to the effectiveness of sensitive procedures like treating obsessive compulsive disorder (OCD). Every component of the VR hardware is notable for having a direct impact on patient comfort, therapeutic efficacy, and application simplicity.

3.1.1. COMPONENTS OF VR HARDWARE

3.1.1.1. SCREEN RESOLUTION

The clarity with which the user perceives the virtual environment is determined by the screen resolution of virtual reality headsets. Particularly in therapies with delicate scenarios and intricate images, higher resolution produces a less pixelated image, making the experience more genuine. For instance, the HTC Vive Pro 2 delivers a superior visual quality with a resolution of 2448x2448 pixels per eye, whilst the Oculus Quest 2 offers a resolution of 1832x1920 pixels per eye. Users can better focus on the virtual world and benefit from the therapy thanks to the higher resolution.[1]

3.1.1.2. FIELD OF VIEW (FoV)

One crucial element that affects how widely a user perceives the virtual world is the virtual reality headset's viewing angle (FoV). Although most VR systems give FoV values between 90° and 130°, the human eye's normal angle of vision is about 210°. For instance, the Sony PlayStation VR gives an angle of about 100°, but the Valve Index model offers a broader virtual area with a 130° viewing angle. The user might feel more "immersed" and draw themselves deeper into the virtual world with a broader viewing angle. Virtual reality can be an effective treatment for psychiatric disorders, including anxiety, by providing a sense of immersion. [43]

3.1.1.3. REFRESH RATE

Refresh rate, which is measured in Hertz (Hz), is the number of times per second that the display refreshes the image. Higher refresh rates allow visuals to move more smoothly and naturally. This significantly reduces the likelihood of users experiencing discomfort such as dizziness or nausea. For example, the Oculus Quest performance. Especially in therapeutic VR applications, such high refresh rates contribute to a comfortable and long-lasting experience for users.

[1] https://www.digitalcitizen.life/what-screen-resolution-or-aspect-ratio-what-do-720p-1080i-1080p-mean/

3.1.1.4. POSITION TRACKING

Position tracking is a feature that determines how accurately VR headsets detect the user's head and body movements. Devices with built-in tracking, such as the Oculus Quest 2, offer the user a wireless experience, which allows therapy to take place in a more natural and free way. Oculus' built-in position tracking accurately tracks the user's head movements and body positions, making movements and interactions in the virtual world more realistic. This offers a significant advantage, especially in the treatment of OCD, as the accuracy of interactive scenarios in therapy plays a critical role in its effectiveness.

The wireless nature of Oculus gives the user more freedom to move around the virtual environment. This allows the therapist to interact more flexibly. For example, in the treatment of OCD, high accuracy in tasks such as holding and moving objects in the virtual world or accurately performing a specific movement can increase the success of treatment. The user can concentrate on the treatment without interfering with the therapy's organic flow thanks to Oculus' accurate location tracking, which also helps the user navigate the virtual environment more successfully. Because the user feels more at ease in the virtual environment and the therapeutic process is more effective when their actions are precisely reproduced, this function is a huge convenience during the course of therapy.

3.1.1.5. ERGONOMICS AND WEIGHT

Long-term use requires ergonomic design and lightweight construction. Heavy equipment can cause tiredness and pain to the user. The Oculus Quest 3 is ergonomic because to its lightweight construction of 515 grams, whereas devices such as the HTC Vive Pro 2 are heavier but contain capabilities designed for professional use. In OCD therapy, user comfort and gadget mobility are crucial elements influencing therapist and patient choices.

Table 1 Comparison of Different VR Glasses

VR Model	Screen Resolation	FoV	Refresh Rate	Position Tracking	Weight	Price
Oculus Quest 3	2064x2208	110°	120 Hz	Built-in	515 g	Medium
Oculus Quest 2	1832x1920	90°	90 Hz	Built-in	503 g	Medium
HTC Vive Pro 2	2448x2448	120°	120 Hz	External stations	850 g	High
Sony PlayStation VR	960x1080 (per eye)	100°	120 Hz	External camera	600 g	Low
Valve Index	1440x1600	130°	144 Hz	External stations	809 g	High
HTC Vive Eye	2448x2448	120°	120 Hz	External stations	850 g	Very High
Google Cardboard	Resolation of the mobile phone	90°	Depends on the mobile phone	Depends on the mobile phone	Lightweight	Very Low
Apple Vision Pro	4K resulation	120°	90 Hz	Built-in	620 g	Very High
Pimax 8K	3840x2160	200°	90 Hz	External stations	1000 g	Very High

3.1.2. HARDWARE SELECTION IN THERAPEUTIC APPLICATIONS

The features of the chosen hardware determine how well VR systems treating OCD work. High-resolution and refresh-rate devices let users to concentrate entirely on virtual worlds, and ergonomic and lightweight designs improve comfort over extended usage. While professional systems like the HTC Vive Pro 2 are appropriate for more complex therapies with superior graphics and more functionality, portable variants like the Oculus Quest 3 with integrated location tracking provide advantages in terms of simplicity of use.

The VR equipment used in this study was chosen to facilitate participants' adjustment to virtual reality surroundings as well as their technical proficiency. The gadgets' ergonomics, position monitoring, and user-friendly designs were designed to make the participants' experiences easier. Assessing the efficacy of the interaction techniques in the scenes and gathering information on how these techniques may be improved for therapeutic applications were two further goals of the hardware selection process. Therefore, we have used Oculus Quest 3 in this study (Figure 1)

Figure 1 Meta Quest 3

3.2 SELECTION OF INTERACTION METHODS

The proposed system is an interactive application in which the patients will be assigned specific tasks to perform. For instance, the patient will be asked to collect the rubbish in the environment and put them into a bin. The main tasks that the users will perform are selecting some objects in the environment and navigating to a specified location in the scene. For each task, there are several alternatives for interaction methods such as using bare hand gestures or VR glasses' built-in controllers. Each interaction method has some benefits along with some drawbacks. A comprehensive usability analysis should be conducted to identify the best interaction method for each task. For this purpose, a pilot user study was carried out as described in the subsequent sections.

3.2.1 OBJECTIVES OF THE PILOT STUDY

In this study, we try to understand how practical and effective different interaction methods such as hand tracking and VR controllers are for the user in virtual reality environments. In particular, we aim to compare which method is more comfortable for common gestures such as interacting with objects and moving around the scene (e.g. teleportation).

The hand tracking technology built into VR devices offers an interaction by detecting users' natural hand movements. In contrast, VR controllers offer a different experience by providing physical feedback. The main aim of our study is to develop a virtual reality-based exposure therapy system for obsessive-compulsive disorder and to evaluate the effects of different control methods on the user experience. For example, we focus on questions such as which interaction method can be learned faster by users, which is more intuitive or less tiring.

We also aim to understand how the results of this study can contribute to the field of therapy, especially in the treatment of disorders such as obsessive-compulsive disorder. By examining how users interact with VR technologies and how quickly they adapt to them, we want to get an idea of which methods are more effective and practical in therapies. As a result, our goal is both to understand these interaction methods in virtual reality and to offer ideas on how these methods can be improved in applications.

In summary, there are two main research questions in this pilot study:

(1) Which interaction method (using bare hands or VR controller) is better for object selection tasks, in terms of usability?

(2) Which interaction method (using bare hands or VR controller) is better for teleportation tasks, in terms of usability?

3.2.2 PARTICIPANTS

Ten individuals were chosen for this study in order to assess virtual reality (VR) interaction techniques. Certain eligibility requirements were taken into consideration for research participation, and participants were recruited voluntarily. Participants in the research varied in age from 18 to 35, and efforts were made to guarantee a fair distribution of both genders and VR experience levels.

Regarding VR experience, participants were split into two primary groups: those who had never used VR technology before and seasoned users who were acquainted with it. This variety made it possible to thoroughly assess how various user profiles interacted in virtual reality settings. The absence of participants with significant motor or visual problems was considered in order to assess the interaction approaches for objectivity.

Table 2 Participant Demographics

	Count	Percent
Total Participant	10	
Gender		
Male	7	%70
Female	3	%30
Age		
18 – 23	4	%40
23 – 28	5	%50
29 – 35	1	%10
Daily Use of Technology		
1 – 3 Hour	1	%10
3 – 5 Hour	5	%50
5+ Hours	4	%40
Motivation to Work with VR Technology		
Low Moticvation (1 – 2)	1	%10
Medium Moticvation (3)	4	%40
High Moticvation (4 – 5)	5	%50

In conclusion, this study included participants of different ages, genders and levels of VR experience. This diversity allowed us to better understand how different users interact in virtual reality environments. The participants' interest in the study and the feedback they provided contributed significantly to the completion of the research.

3.2.3 SCENES USED IN THE PILOT STUDY

In this study, the virtual environments in which the VR tests will be conducted were prepared using the Unity program. In order to enable the participants to interact with different control mechanisms and prepare for the tests, two separate scenes were designed, each offering a different experience: a motion (teleportation) scene and an interaction scene with objects. In these scenes, participants were trained before the tests so that they could familiarize themselves with both the technologies used and the content of the tasks.

3.2.3.1. TELEPORT/MOVEMENT SCENE

The movement scene was designed in a historical museum. Participants were guided in two different ways to move freely around predetermined points in the museum: using VR controllers or natural hand gestures. During the training, the points were moved in a shuffled order so that participants could learn to move freely with both methods.

In the test phase, this free movement was replaced by a specific order. Participants had to visit a total of 20 points in order. Teleportation method was used to provide movement, which was realized with a point-based movement mechanism (teleport point). This mechanism facilitated users to quickly move to certain points in the VR environment.

3.2.3.2. OBJECT INTERACTION SCENE

A playground theme was used to prepare the object interaction scenario. At a table throughout the training phase, participants engaged with three distinct items that are often encountered in daily life. The participants learned how to use both control techniques to engage with these items, which were presented in a varied sequence.

14 distinct objects were set out on the table during the test phase, and the degree of difficulty was raised. The participants were instructed to arrange these items in order of color as they were designed in four distinct hues. This procedure was created to

assess how well both control strategies performed on tasks involving object manipulation and categorization.

3.2.4. PROCEDURE

All participants received five minutes of information regarding the study's goal and procedure prior to the study's commencement. Participants were told that all data would be processed anonymously and that they might withdraw from the research at any time. The participants' confidence and motivation to engage in the study were guaranteed by this information procedure.

At the beginning, the subjects filled in a pre-assessment survey to gather information about demographic and technological level. The questions in the pre-assessment survey are given in Appendix-A.

The study was conducted using a within-subjects design, in which all the subjects performed all the tasks. However, the order of use of the VR controller and hand tracking was randomized between subjects to prevent possible bias and learning effects.

Before starting the experimental process, the participants were given the opportunity to familiarize themselves with both interaction methods (controller and bare hand). Participants were allowed to practice with each method for a short period of time to familiarize themselves with these systems. At this stage, the main differences between the interaction methods were explained and possible questions were answered. After the participants had reached a basic level of proficiency in both methods, the experimental process began.

3.2.4.1 TRAINING PHASE

Before starting the test, the participants were trained on how to perform the tasks given first in the object interaction scene and then in the teleportation/movement scene. The training phase was organized according to the control method and the tests were administered immediately after the training.

Object Interaction Training: In this phase, participants were asked to interact with three objects that can be encountered frequently in daily life in a mixed order (Figure 2). The aim was to familiarize the participants with the control methods and to enable them to use the objects in a natural way. Participants completed these tasks using VR controllers and natural hand gestures separately.

Teleportation/Movement Training: In the teleportation/movement scene, participants experienced this method by moving freely at randomly determined points in a historical museum (Figure 3). During the training, the order of the points was kept mixed, and it was aimed for the participants to learn how to move using both the VR controller and natural hand movement.

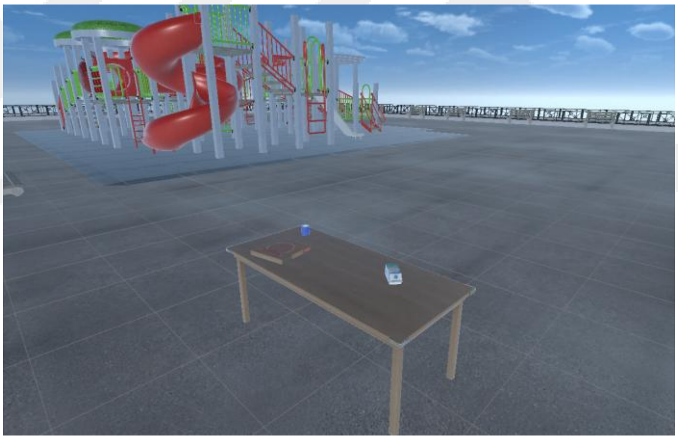

Figure 2 Object Interaction Training Scene

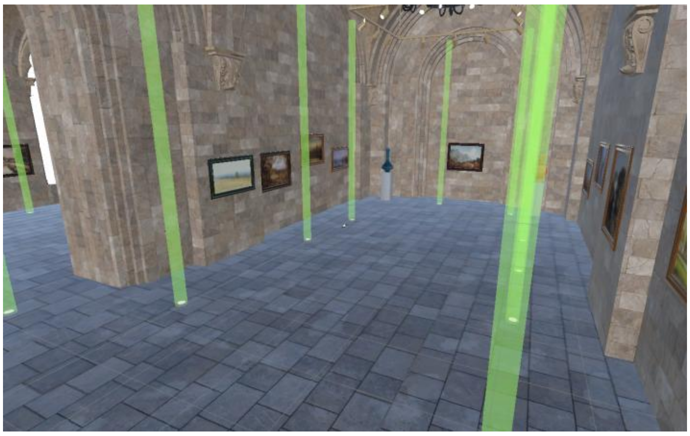

Figure 3 Teleportation Training Scene

3.2.4.2 TEST PHASE

After the completion of the training based on the control method, the participants proceeded to the test phase. In this phase, object interaction and movement tasks were applied more systematically.

Object Interaction Test: Participants were asked to classify 14 different objects into four different colors (Figure 4). The objects were placed on the table in a mixed manner and they were asked to complete the color sorting task using both control methods.

Teleportation Test: The participants visited a total of 20 predetermined points on the museum stage in a sequential manner (Figure 5). At this stage, how long they spent at each point and whether they traveled in the correct order were recorded by using teleportation method (teleport point).

Figure 4 Object Interactıon Test Scene

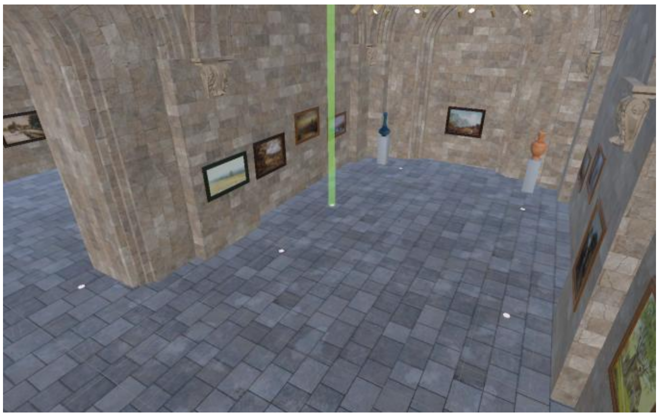

Figure 5 Teleport/Movement Test Scene

3.2.5 DATA COLLECTION PROCESS

A variety of objective and subjective data were collected during the tests. Objective data, such as accuracy and time, was gathered automatically, while subjective data was obtained through questionnaires.

Automated Data Collection

During the tests, all participants' movements and interactions were recorded in log files using scene-specific algorithms. These logs include crucial parameters for assessing participant performance and the effectiveness of the employed interaction techniques. These logs contain the following important metrics:

- Interaction tool used (VR controller or natural hand gesture),
- Time between missions,
- Total time spent on scene,
- Correct classification of objects,
- Whether it reaches the right point in the action scene and the time spent at each point.

The first item recorded in the logs was the interaction tool (natural hand motion or VR controller). Furthermore, time-related information was recorded, including the amount of time spent in the overall scenario and the intervals between actions. The participant's ability to accurately segregate the items into their respective colors was recorded for the object interaction scene. For the movement scene, information such as whether the participant reached the correct point, from which point he/she moved, and how long he/she spent at each point was collected.

These recordings were structured in accordance with the algorithms specific to both scenes, and the data collected was used to comparatively analyze both interaction methods and participants' performance.

User Experince Surveys

After conducting the test phase, the subjects immediately filled in online surveys including some usability related questions. The responses to the questions were taken in Likert scale form (1-Strongly disagree to 5-Strongly agree). At the end of each test session (2 tasks x 2 interaction methods = 4 times), two different questionnaires were filled in by the subjects.

The first survey, given in Appendix-B, includes task specific questions and is prepared based on (Nicola Capece et al., 2023). Since the participants are Turkish, the language of the survey was Turkish. All the survey questions are given in Appendix. English versions of the first survey questions (Appendix-B) and their target measurement are given in Table 3.

Table 3 User Experience Survey Questions

No	Question	Target Measurement
Q1	The task was easy to fulfil.	Ease of use
Q2	My interaction with the environment seemed natural.	Natural interaction
Q3	The environment responded adequately to my actions.	System responsiveness
Q4	Controlling the system was tiring.	Physical strain

The second questionnaire was System Usability Scale (SUS) which is very common in UX evaluation (Demirkol & Seneler, 2018). It includes 10 questions measuring several aspects of usability and learnability (Appendix-C).

Observations and Interviews

The subjects were told to use think-aloud protocol, and they were observed during training and test sessions. They were also asked to freely express their additional observations, comments, and recommendations after and during the sessions.

CHAPTER 4- VRET SYSTEM PROTOTYPE

In the previous chapters, we discussed the role of various components of VR technology, including device features and interaction methods for health and therapeutic processes. Given these insights, we have developed a prototype for the VRET application. This chapter will explain this prototype, including an overview of the system architecture, the scenarios and scenes it encompasses, and the integration of biosensors.

4.1 SYSTEM ARCHITECTURE

The VR application software we created is the key element of the therapeutic process in our system design. It enables active participation in the virtual exposure therapy process and interaction when the user enters the virtual reality environment. Our work in VRET therapy aims to provide an organized structure, unlike the unpredictable conditions seen in standard exposure treatments. Therapy processes are therefore carried out more reliably and efficiently.

The ability of counselors to actively participate in the treatment is one of the most important advantages of the VR application. Counselor screens are integrated into the frame to monitor the user in real time and make adjustments as needed during the treatment. In addition to changing the scenes, these screens give counselors full control over the treatment process.

At the same time, some biological variables can be used to measure how successful the VR application is. In addition to the VR application, there is a biosensor module that can measure the user's physical characteristics in real time. GSR and ECG constitute this biosensor module. The biosensor module processes the information it receives from the user and sends it to the counselor screens. It is important to understand the user's physical reactions during the therapy process and to apply the right treatments.

Figure 6 presents in detail the comprehensive system architecture that brings together the biosensor module, database, consultant screens, and VR application. The system enables data from the sensors to be processed wirelessly via an API and stored in a database. While this data is displayed on the therapist's monitoring screen, it is also integrated into the VR software, allowing the therapy to be shaped instantaneously.

Photon infrastructure is used for real-time communication, enabling instant data sharing between the VR environment and counselor screens. While the user is guided to specific scenes in the VR environment, the therapist can track the user's biometric and behavioral data during this process. Thus, the system offers a more flexible, measurable and personalized structure compared to traditional therapy methods.

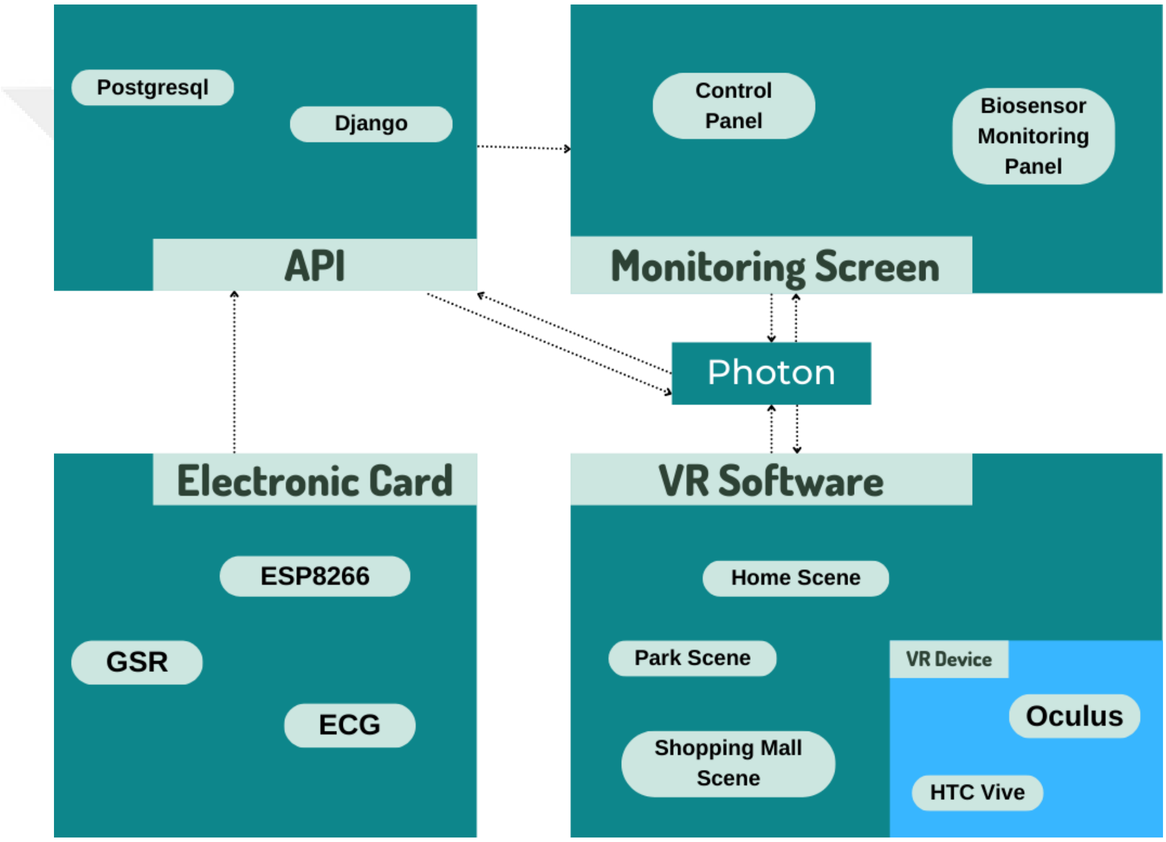

Figure 6 System Architecture

This architecture enables the therapeutic process to be carried out in a data-driven manner and offers a scalable solution that can reach a wider user base regardless of the clinical setting.

In summary, VR software is not just a therapeutic tool but a complete platform that uses cutting-edge technology to enhance user outcomes. Through the integration of data analysis, real-time interaction, and personalized feedback, the system raises the bar for VR exposure therapy. This innovative approach not only increases the reliability and efficacy of treatments, but also provides a scalable framework for future studies in mental health.

4.2 PROTOTYPE SCENES

Virtual environments designed with detailed and realistic scenes can elicit emotionally significant responses in patients with OCD related to fear of contamination [44]. A contaminated virtual environment can induce anxiety in individuals with OCD, supporting its use as a therapeutic tool [45]. In this context, VR technology offers a unique opportunity to enable individuals to safely confront their fears. In our study, different scenes were created that users may encounter in daily life and that may trigger their obsession with cleanliness. These scenes were designed in detail to target the pollution-related dimensions of OCD.

Scenes are carefully designed to enhance visual realism and user experience, guided by mental health domain experts such as psychiatrists and psychologists. Familiar locations from everyday life, such as a park, a shopping mall and a hospital waiting room, were chosen to expose users to different levels of pollution. In each scene, users are encouraged to touch certain objects, complete tasks and spend time in different conditions to make the therapeutic process more effective. In the design of these scenes, both visual and functional elements were designed to most closely reflect their real-world interaction.

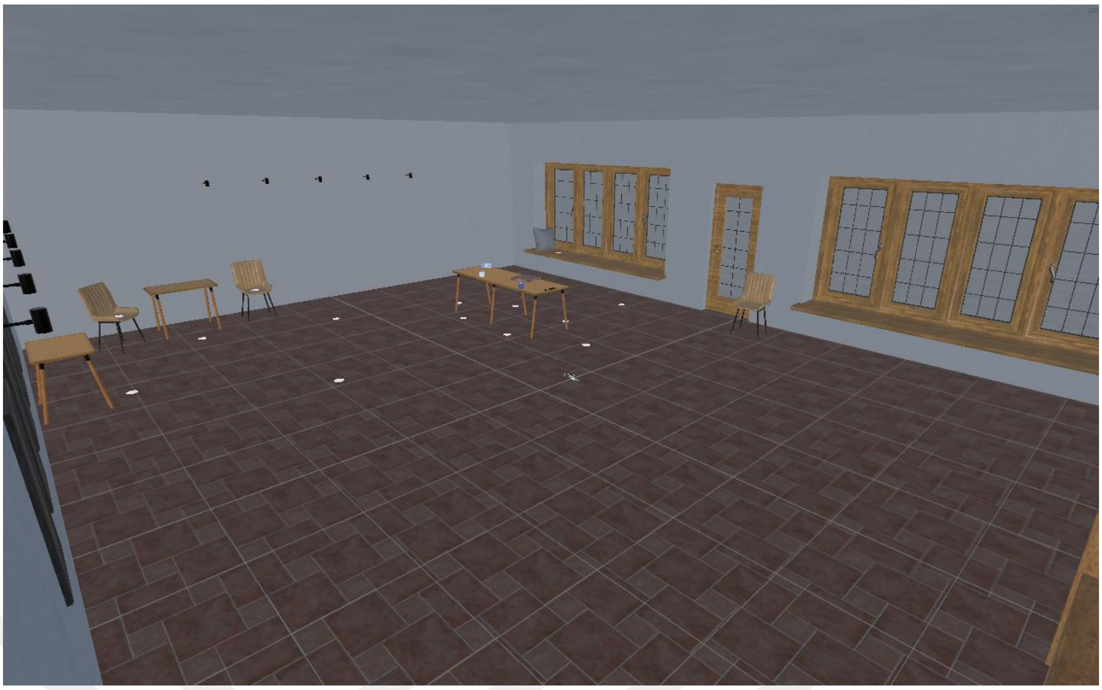

Figure 7 Intro scene for VR

Each time the app is opened, users are greeted with an initial scene designed as the first step in the therapy process. This scene aims not only to familiarize users with the VR environment, but also to create a sense of “safe space” for them.

The scene consists of two parts: a free movement area where the user can explore freely and a restricted area where it is possible to teleport to certain points. Furthermore, the possibility of interacting with objects within the scene offers the user the opportunity to connect more naturally with the virtual environment. The design and structure of this scene is visually presented in Figure 7. The stage is designed with wooden details, window arrangements and a minimalist layout to create an atmosphere that is both realistic and reassuring.

This initial scene allows the doctor to make the necessary preparations before starting the main stages of the treatment process. As the user gets used to the VR headset and basic interactions, they will always see a clean and organized environment, giving the impression that they are comfortable and safe.

The park scene is designed as one of the scenes that the doctor can choose according to the needs of the patient during the treatment process. This scene provides controlled exposure to factors such as pollution, disorder and social interaction as part of OCD therapy. The stage consists of details such as benches, playground, public toilets and different human characters.

In this interactive scene, patients can engage in tasks such as picking up trash, cleaning dirty areas, organizing scattered objects or interacting with them. All these elements aim to support patients to experience a controlled exposure to their obsessions and to develop stress coping skills.

The design of the park scene is planned in detail to maximize the therapeutic effect. Experts can change the level of pollution and other elements on the fly during therapy, thus optimizing the treatment process according to the patient's needs. This feature makes the stage a dynamic therapy tool and provides a personalized treatment environment for each patient. The general layout and features of the scene, together with its interactive elements, are presented in detail in Figure 8.

Figure 8 Park scene for OCD therapy with adjustable interactive features

Figure 9 Hospital Waiting Room

The hospital waiting area scene shown in Figure 9 presents an environment designed with the details of a real-life waiting room. The scene features organized seating areas, information boards, a water dispenser and large glass windows. The space provides opportunities for interaction to observe and develop patient habits related to hygiene and orderliness.

The stage is dynamic and contains elements that can be changed at the therapist's discretion. For example, certain elements of pollution (stains, garbage) placed on the floor or the presence of people allow the patient to adapt to different scenarios. Patients are actively involved in the scene through tasks such as removing objects from the floor or indirect interactions with the scene.

This space simulates situations that the patient may frequently encounter in their daily life, providing both a natural exposure and a safe learning environment. The therapist can adjust the layout and difficulty level of the scene to suit the patient's progress, thus ensuring an individualized experience.

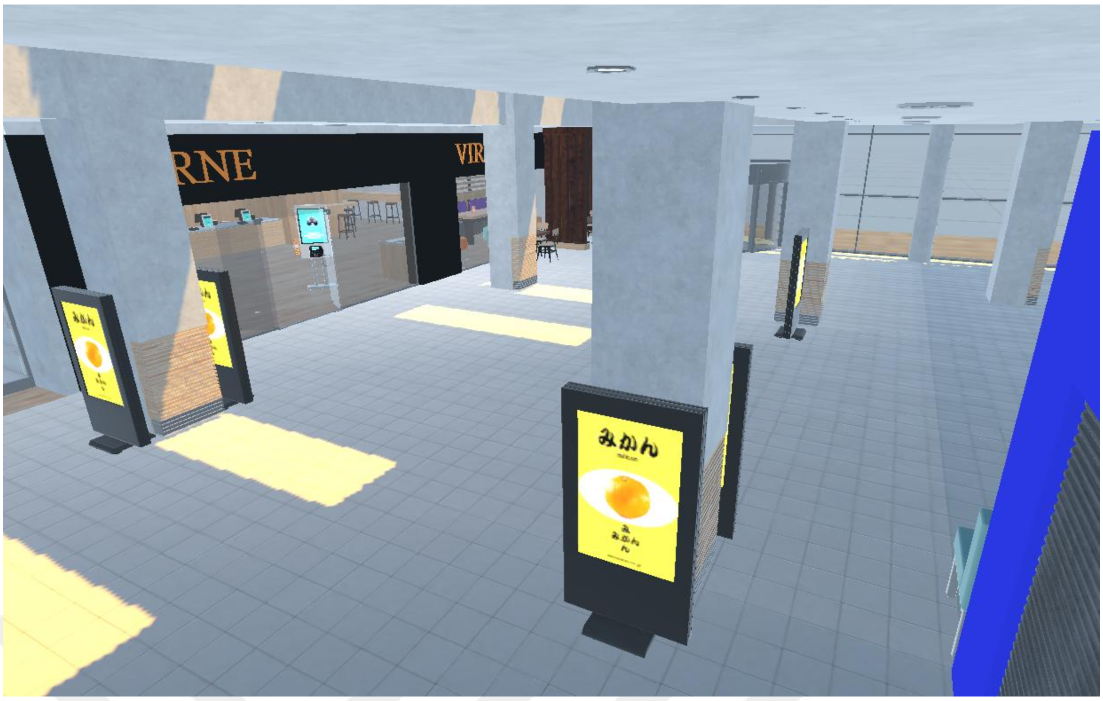

Figure 10 Shopping Mall Scene

The shopping mall environment shown in Figure 10 is designed to help patients better adapt to their daily lives. This environment includes different spaces such as a café, food court and market. The aim is to allow patients to face real-world situations in a safe environment.

The tasks in the scene are designed to be very simple and user-friendly. For example, there are easy tasks in the café area, such as picking up a dropped napkin and throwing it in the trash can, or organizing a misplaced tray in the dining area. In the grocery section, simple gestures can be made, such as putting a dropped box back or picking up a product from the shelves. Such tasks allow patients to easily interact with the scene and adapt to the process.

The scene can be adapted to different scenarios according to the doctor's guidance. The density of people can be increased, some trash can be added to the floor. Thus, the elements that trigger the patient's anxiety are slowly and safely incorporated into the therapy process. One of the most important advantages of this environment is that it allows situations commonly encountered in daily life to be safely experienced in a virtual environment. Through simple tasks, patients can improve their stress coping skills and feel more prepared when faced with similar situations in the real world.

4.2 SCENARIO EXAMPLES

This study used VR-based exposure therapy to create various scenarios to treat OCD. These scenarios aim to mimic real-life hygiene-related conditions that are often encountered by people with obsessive-compulsive behaviors about cleanliness and provide them with a safe, immersive environment to feel and control their anxiety. The scenarios listed in Table 4 are organized therapeutic experiences that guide users through various environments where they are increasingly exposed to pollution-related stressors.

Park Scenario:

The user is initiated into therapy in a public park while encountering environmental pollutants such as litter and waste. The scenario includes activities such as walking around the park, picking up litter from the ground, and throwing it into a trash can. These actions expose the user to contamination triggers while working within predefined parameters such as litter density, level of pollution, and direct contact with the waste. Controlled exposure allows the user to gradually desensitize to the anxiety caused by dirty environments.

Shopping Mall Scenario:

This scenario simulates a busy shopping mall where the user interacts with public seating and dining areas. The process involves purchasing food from a self-service restaurant, selecting a table, and considering the cleanliness of their surroundings. The key challenge in this scenario is deciding whether to sit at a table that appears dirty or to seek an alternative. The parameters of this scenario include environmental cleanliness, perception of hygiene, and human density, and help individuals manage their anxiety around public spaces and shared objects.

Grocery Scenario:

In this scenario, the user is immersed in a grocery environment where they engage in shopping activities. The user selects products, interacts with various surfaces, and performs cash transactions at a checkout counter. By repeatedly interacting with money and the environment in a virtual environment, the user can build resilience and reduce avoidance behaviors associated with public commerce and financial transactions. All these scenarios help people with OCD to face their daily challenges safely. Using VR, they can face their fears and feel less anxious.

Table 4 Sample Scenarios

Sample Scenario 1	
Disorder	Cleanliness Obsession, OCD
Scene	Park
Scenario Steps	1. Walk around the park. 2. Pick up the garbage on the ground. 3. Open the trash can and throw it in.
Parameters	Contact with garbage and trash, Pollution Level, Garbage Density
Sample Scenario 2	
Disorder	Cleanliness Obsession, OCD
Scene	Shopping Mall
Scenario Steps	1. Walk around. 2. Go somewhere to eat. (Get it with self-service.) 3. Find a table and sit down. 3.1 If there is garbage on the table, leave it on another table.
Parameters	Environmental Pollution Level, Hygiene Perception, Human Density
Sample Scenario 3	
Disorder	Cleanliness Obsession, OCD
Scene	Market
Scenario Steps	1. Walk around the market. 2. Buy some materials. 3. Go to the cash register and pay.(money exchange)
Parameters	Human Density, Money exchange

4.3 CONTROL PANELS FOR THERAPISTS

This app offers a unique structure that enables therapists to both manage sessions and create therapy environments tailored to patients' needs. First, the user login screen provides a secure access mechanism and allows only authorized users to log in. (Figure 11)

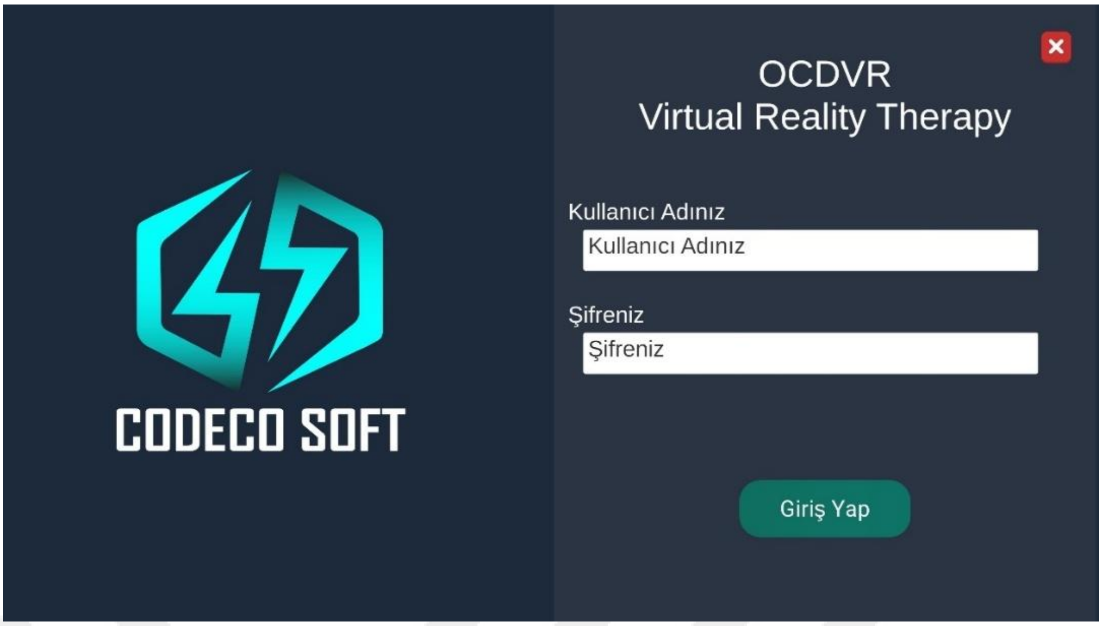

Figure 11 Doctor Login Screen

Figure 12 Treatment Initiation Panel

This screen makes it easy for therapists to log in with a username and password, while protecting the confidentiality of patients' information. After the login process, the therapist is directed to the patient selection screen (Figure 12).

Figure 13 Dynamic Scene Control Panel

This screen allows patients to join the system with their protocol numbers and allows the therapist to manage sessions quickly and systematically. However, the most important feature that distinguishes the application from other software is the dynamic control panel and instant follow-up screen (Figure 13). In these panels, the therapist can adjust the elements of the scene in real time (e.g. amount of garbage, traces of blood, interactive objects) while simultaneously monitoring the biosensor module data paired with the device on the screen. By allowing the same scene to be adjusted to suit different patient levels through the panels, it makes therapy personalized and more effective. In addition, with the biofeedback values received from the patient, it allows the therapist to analyze the patient's instant physiological reactions and manage the therapy process more precisely.

This level of flexibility, which is not available in other software, gives therapists the opportunity to optimize their treatment processes. For example, the therapist can increase or decrease the level of pollution in the scene according to the patient's capacity to cope with stress. The application thus offers a modern solution that supports each stage of therapy in accordance with individual needs.

4.4 BIOSENSORS AND THEIR FUNCTIONS

In the VRET application we prepared, various biosensors are used to monitor the physiological states of patients throughout the treatment and provide instant feedback. Figure 6 shows how the system combines biosensors such as Galvanic Skin Response (GSR) and Electrocardiography (ECG) to measure the patient's physiological and emotional responses.

An important source of information to maximize the effectiveness and timing of therapeutic interventions is the observation of physiological responses such as changes in anxiety levels. The user's heart rate and rhythm are monitored using an ECG sensor (Figure 14).

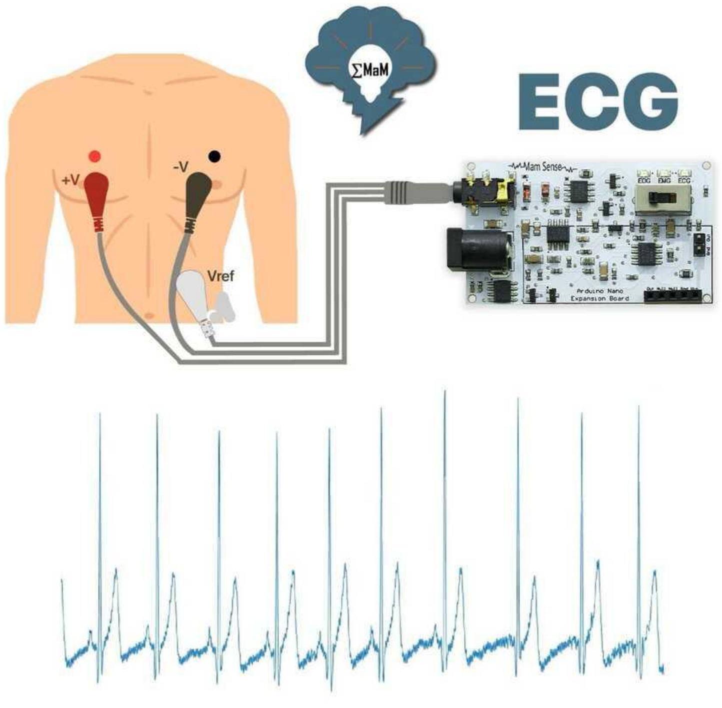

Figure 14 ECG Measurement System

Skin conductance is measured using a GSR sensor to assess the patient's stress level in real time (Figure 15). This physiological data enables the identification of stressful or relaxing moments within the virtual environment, providing valuable insights into the patient's emotional and physiological reactions. By analyzing these responses, the therapist can make more informed decisions about adjusting the therapy to better suit the individual's needs.

The biosensor module, designed for continuous physiological data collection and analysis, operates over a wireless microcontroller-based system and securely transmits data over the internet. This ensures real-time monitoring and seamless integration with the VR application, allowing therapists to track the patient’s condition dynamically throughout the session. For instance, the system detects and records fluctuations in physiological responses when a patient with cleanliness obsession is exposed to a contaminated environment.

Furthermore, all collected biometric data is stored in a remote and secure database, where it is systematically analyzed to assess the overall effectiveness of the therapy. This database not only helps in evaluating the patient’s progress but also aids therapists in tailoring future therapy sessions based on measurable, data-driven insights. By leveraging this technology, the system enhances the precision of exposure therapy, ensuring a more controlled and personalized approach to OCD treatment.

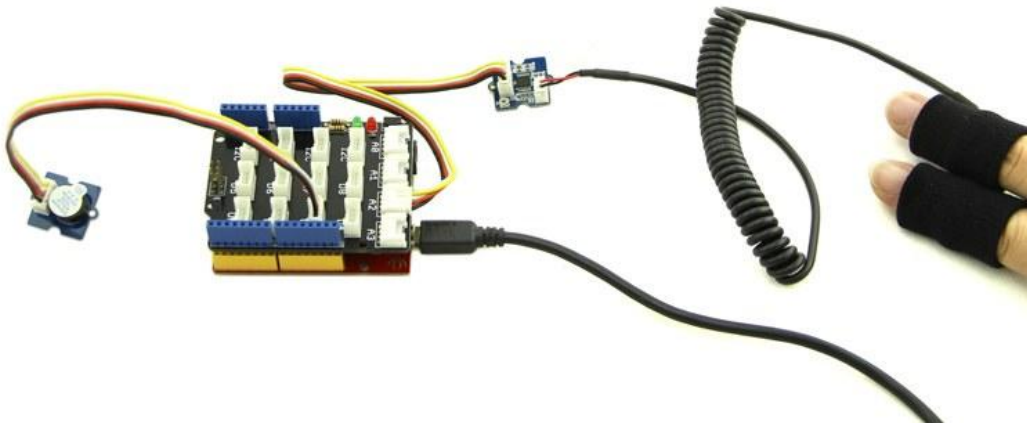

Figure 15 GSR Sensor

Below is a pseudocode based algorithm that explains the part of the sensors that receives and transmits data.

Step 1. The biosensor card is started in access point mode.

Step 2. The user makes the necessary settings for the connection to the Wi-Fi network from the web interface.

Step 3. With the information received from the user, the biosensor card tries to connect to the Wi-Fi network.

Step 4. The necessary processes for ECG and GSR measurements are started.

Step 5. Send the measurement data to the server in JSON format every 10 seconds.

Step 6. Restart as Access Point if the Wi-Fi connection is lost.

With the help of this biosensor integration, the Virtual Exposure Therapy App can better control therapeutic processes and provide a personalized experience to the user.

CHAPTER 5- RESULTS & DISCUSSION

This chapter presents and discusses the results of the study, including the quantitative analysis of the pilot user study described in Chapter 3 and the system performance.

5.1 ANALYSIS OF THE PILOT STUDY

The data collected during the pre-assessment process provides a detailed account of the participants' performance in the object interaction and gesture tests. This analysis addresses the effects of control methods (VR controller and natural hand gesture) on speed, accuracy, user experience and interaction quality. All collected data was automatically recorded by scene-specific algorithms and the following findings were made.

5.1.1 OBJECT INTERACTION TEST ANALYSIS

This test was designed to assess participants' ability to interact with objects in a virtual environment. Participants used both the VR controller and natural hand gestures to classify 14 different objects in four different colors.

Task Performance Metrics

Speed and accuracy are the most important objective metrics to evaluate task performance. Task completion time and task accuracy rates were used for this purpose. Task completion time was automatically measured and recorded for each participant, as the total time spent to complete the object classification task. Task accuracy, as the ratio of correct classifications to the total number of objects, was also automatically calculated and recorded. The results are presented in Table 5. Hand gestures led to about 14 % faster interactions on average. High correct classification rates were observed in both control methods.

Table 5 Task Performance Metrics

Interaction Method	Task Completion Time	Task Accuracy
Hand Gestures	1 minute and 30 seconds	95 %
VR Controller	1 minute and 45 seconds	94 %

The results were also analyzed statistically. First, the Shapiro-Wilk test was applied to determine whether the data was distributed normally (Table 6). Since the p-values for time variable in both the hand and the controller are above 0.05, we can conclude that time data exhibits a normal distribution. However, for the accuracy variable, we see that the data series for controller violates the normal distribution, as the p-value is less than 0.05. For the time variable, we can apply a parametric test, while for the accuracy variable, a non-parametric test should be used since one of the data series (the controller) is not normally distributed.

Table 6 Object Interaction Task – Shapiro-Wilk Test Results

Data Series	Statistic	P-Value	Normal Distribution
Time (hand)	0.9726	0.9146	Yes
Time (controller)	0.9625	0.8141	Yes
Accuracy (hand)	0.8511	0.0598	Yes
Accuracy (controller)	0.7883	0.0104	No

Statistical analysis results are given in Table 7. For the first dependent variable, time, the difference was found to be statistically significant ($p < 0.05$). Nevertheless, there was no statistically significant difference in accuracy, as the p-value is higher than 0.05. Hence, one can conclude that using hand gestures for object selection task is faster than using controllers. In terms of task accuracy, both methods performed similarly.

Table 7 Object Interaction Task – Statistical Analysis

Dependent Variable	Statistical Test	Statistic	P-Value
Time	Paired Samples T-Test	-17.7767	2.560e-08
Accuracy	Wilcoxon Signed-Rank Test	8.00	0.0830

Subjective Response Metrics

In addition to the objective task performance metrics, subjective response metrics were gathered through several user questionnaires. The results of these questionnaires are presented below.

The first user experience questionnaire included the task specific questions given in Appendix B. The results of this questionnaire were visualized using comparative box plots for each question as shown in Figure 16.

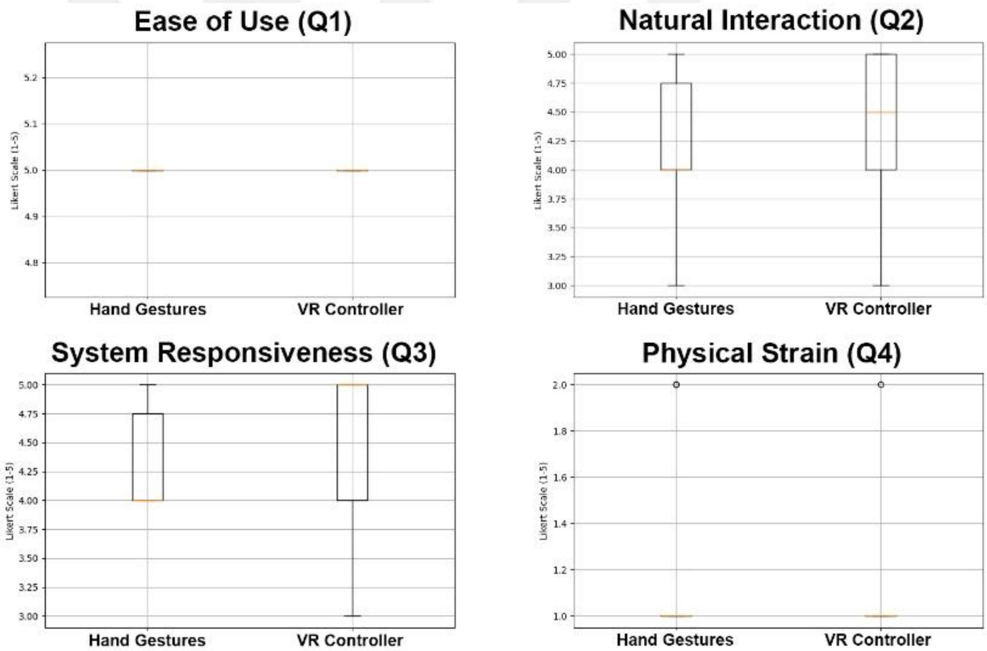

Figure 16 Box plot visualizations for the task specific user experience questionnaire

The survey results provided highly positive feedback for both methods, in general. As can be seen from the box plots, the responses vary within a narrow range. For question 1, which measures the ease of use, all the participants rated the system with a score of 5, for both interaction methods. In question 4, regarding the physical strain, all the participants selected the response of 1, corresponding to the lowest level of physical strain. Although both interaction methods have high grades for the naturalness of the interaction (question 2) and system responsiveness (question 3), the VR controller method was found to be better as it has a higher median value.

The results of the System Usability Scale tests were used to calculate the SUS scores for each participant according to the procedure below. Average SUS scores were then calculated for the whole sample (Table 8).

- For odd numbered questions, subtract 1 from the user response
- For even numbered questions, subtract the user response from 5
- Sum these converted responses of each question

Table 8 Average SUS Scores

Interaction Method	Object Interaction Task	Teleportation Task
Hand Gestures	91,50	82,50
VR Controller	91,25	88

A SUS score above 85 is considered to indicate excellent usability [46]. Consequently, the system was found to be quite effective in terms of learnability and usability, regardless of whether the interaction method used was hand gestures or a VR controller, for the object interaction scene.

Additional Observations

According to the qualitative feedback gathered from users through interviews and think-aloud protocol, the following observations were seen:

- Several participants reported some delay in object grasping and releasing during classification with the controller. These sensitivity issues may have contributed to the slow use of the controller.
- The hand control method was evaluated by the participants as a fast and natural interaction method for object interaction in general.
- Some participants remarked that the controller required an initial learning curve. However, most subjects quickly learned to use hand gestures for grasping as it is natural and intuitive.

- Some participants expressed a need for haptic feedback during grasping to better recognise when they had reached the object and that they found it irritating to grab the space rather than the object.

5.1.2 TELEPORT / MOVEMENT TEST ANALYSIS

The teleportation scene was designed as a test requiring participants to visit 20 designated points in a virtual museum environment in sequence. In this process, the performance differences between both methods were evaluated using the VR controller and bare hand movements.

Task Performance Metrics

As the objective metrics to measure the task performance, task completion time and task accuracy rates were used. Task completion time was automatically measured and recorded as the total time taken to complete the teleportation tasks for each participant. The teleportation task required the users to navigate to the pre-defined points in a specific order. If the user unintentionally navigated to a point other than the target location, this was counted as an incorrect navigation, and the task accuracy was automatically calculated as the ratio of the number of correct navigations to the total number of navigation points. These measurements are given in Table 9. Participants who used the VR controller in the teleportation scene completed their task faster than those who used bare hand gestures.

Table 9 Task Performance Metrics

Interaction Method	Task Completion Time	Task Accuracy
Hand Gestures	60 seconds	90 %
VR Controller	40 seconds	100 %

First, the normality of the data was verified using the Shapiro-Wilk test (Table 10). For the time variable, the data was normally distributed ($p > 0.05$), and we can conduct a parametric test. However, accuracy variable did not exhibit normal distribution, so we need a non-parametric test.

A paired samples t-test was applied to check the statistical significance of the differences between hand and controller usage for the time variable, and Wilcoxon signed rank test was applied for the accuracy variable. According to the statistical test results given in Table 11, the difference between hand and VR controller results for task completion time is statistically significant at $p < 0.01$ level. Therefore, we can deduce that the VR controller provides a faster interaction method for teleportation tasks compared to using bare hands. The advantage of the VR controller is also notable for its accuracy ($p < 0.05$).

Table 10 Teleportation Task – Shapiro-Wilk Test Results

Data Series	Statistic	P-Value	Normal Distribution
Time (hand)	0.9068	0.2602	Yes
Time (controller)	0.9544	0.7207	Yes
Accuracy (hand)	0.6122	0.0001	No
Accuracy (controller)	1	1	Yes

Table 11 Teleportation Task – Paired Samples T-test Results

Dependent Variable	Statistical Test	Statistic	P-Value
Time	Paired Samples T-Test	6.8380	0.0001
Accuracy	Wilcoxon Signed Rank Test	0	0.0268

Subjective Response Metrics

For the task specific user survey, the results were again visualized using box plots (Figure 17). For the teleportation task, the VR controller method outperformed the bare hand gestures method in all questions. Yet, the results for hand gestures are also quite positive. The gap between the interaction methods is remarkable, especially for the ease of use (question 1). For the naturalness of the interaction (question 2) and the responsiveness of the system (question 3) the difference is also visible. In terms of physical strain, both methods had a low rate, but hand control was generally found to be more tiresome.

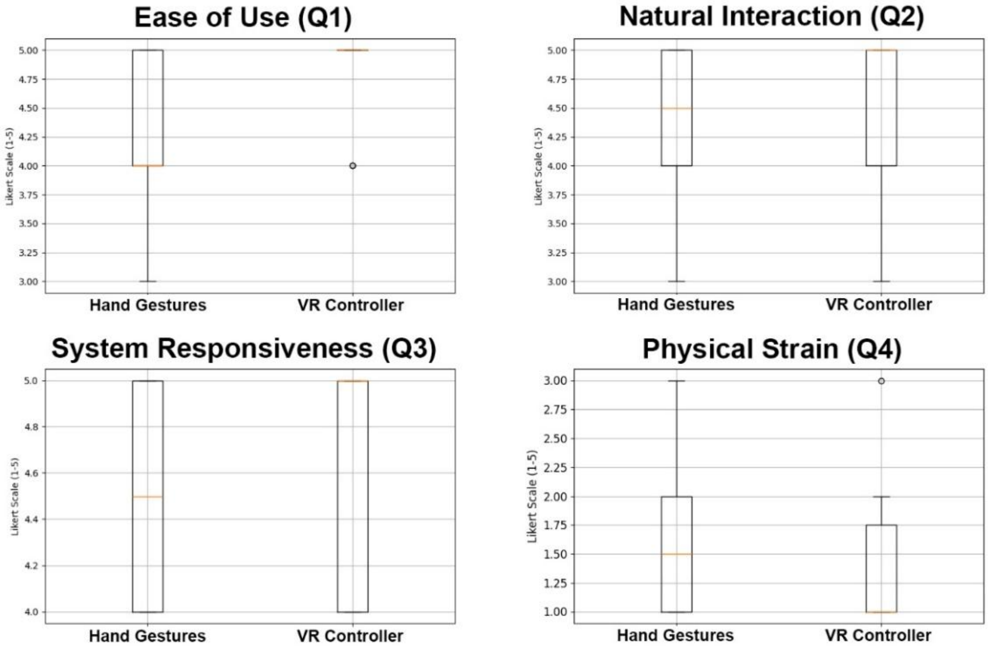

Figure 17 Box plot visualizations for the task specific user experience questionnaire

SUS scores for the teleportation scene are also given in Table 8, for both interaction methods. Both SUS scores are over 80 %, which is an indicator of a very good usability. However, the SUS score for the hand gesture interaction method is relatively lower than that of the VR controller method. It can be concluded that the VR controller is better than hand control for teleportation tasks, concerning usability and learnability.

5.1.3. GENERAL EVALUATION AND DISCUSSION

The pilot study gave us important insights into the interaction design of the VRET system, despite the small sample size. First of all, the effectiveness of an interaction method highly depends on the nature of the task.

Using bare hand gestures is faster than VR controllers in object selection tasks. This is probably due to the similarity of the gesture to our daily lives. Some discrepancies between the subjective responses and our observations were seen. In the survey, the VR controller was rated relatively higher than the hand gestures regarding naturalness. However, we observed that the users quickly discovered the object selection gesture without any training, and they also stated that it was easy to learn and perform the gesture. The task performance metrics are also in support of this observation. We think lack of haptic feedback is effective in the relatively lower naturalness score of the hand gestures.

Note that the object interaction tasks in the test do not require precise selection and manipulation of the objects and movement of the user to another location. Thus, these results may not hold for such kinds of scenes.

For the teleportation task, the VR controller outperforms the hand gestures according to objective and subjective metrics. This should be due to the unnaturalness of the teleportation gesture since there is no matching between the real world. The findings show that the VR controller is more effective in tasks that require dynamic movement. The controller stood out with its ergonomic design, fast movement and consistent user experience.

When we compare the results of the object selection task with those of the teleportation task, we notice that the SUS scores are lower and there is a higher variance in the user responses for the teleportation task. This may be due to the more challenging nature of the teleportation task, which alters the viewpoint and may negatively impact spatial awareness. In addition, teleportation is not a natural activity that we experience in our daily lives.

In conclusion, the results suggest that controllers should be preferred for teleportation tasks, and hand gestures are more effective in object selection in general. Nevertheless, the scenes that require both teleportation and selection tasks should be analyzed further for the usage of both interaction techniques together. If the scene does not require navigation to distant locations, hand gestures for object selection and a real walking metaphor for navigation might be the best combination. Another option is to enable both interaction methods for each task and let the user choose one of them.

Despite the significant findings of the pilot study, there are several limitations. The results do not reflect the long-term use of the system and other important aspects of user experience, such as cognitive load, presence, and cybersickness. Two-handed interaction is also worth testing separately.

5.2. SYSTEM PERFORMANCE ANALYSIS

The performance of the developed VR-based therapy environment was evaluated by analyzing the system resource usage for different scenes. In this analysis, parameters such as the number of triangles, the number of vertices, draw calls (batches), shader passes (SetPass Calls) and shadow casters were monitored. Table 12 summarizes these values for the main scene and three different therapy environments:

Table 12 Scene Parameters

Scene Parameters	Main Scene	Park Scene	Shopping Mall Scene	Hospital Waiting Room Scene
# Triangles	778.6K	163K	668.6K	257.7K
# Vertices	604.3K	184.1K	879.5K	348.8K
# Batches	650	766	1397	677
SetPass Calls	236	103	712	205
Shadow Casters	500	356	1110	538
# Visible Skinned Meshes	25	0	25	5

As the values in the table indicate, the scenes varied in terms of polygon and vertex densities. Depending on the scene, the usage of system resources differed:

- The Main Scene has the highest polygon count (778.6K). This shows that it creates an environment where visuality is at the forefront for the therapeutic process.
- The Park scene has the lowest polygon load (163K triangles, 184.1K vertices), which is an indicator of the open space structure and relatively low object density.
- The Shopping Mall scene has the highest vertex and draw call values (879.5K vertex, 1397 batches). It is seen that it is a scene increased by the interior design and the density of people.
- The Hospital Waiting Scene creates a medium system load with 257.7K polygons and 348.8K vertex. However, it is seen that it creates a relatively higher load in terms of lighting and shading with 538 shadow casters and 205 shader passes.

In the performance analysis, how the scenes use system resources was examined in detail. According to the data summarized in Table 13, the FPS value remained constant at 72 in all scenes, which allows high interactivity. This shows that the VR experience is smooth, and the graphics processing load is managed in a balanced way by the system.

Table 13 System Performance Metric

Metrics	Main Scene	Park Scene
Frame Rate (FPS)	72	72
CPU Utilization (Overall)	47%	40%
GPU Utilization	92%	93%
GPU Frequency	509 MHz	599 MHz
CPU Frequency	1920 MHz	1920 MHz
GPU Level	5	5
Eye Buffer Width	1196	2029
Eye Buffer Height	1264	2145

However, there are significant differences between Home Scene and Park Scene in terms of CPU and GPU usage. While the CPU usage was measured as 47% in Home Scene, it dropped to 40% in Park Scene. This shows that Home Scene requires more load from the processor. When looking at the GPU usage, a high load was observed in both scenes, measured at 92% in Home Scene and 93% in Park Scene.

The measurements show that the GPU frequency of Park Scene increased to 599 MHz, while it remained at 509 MHz in Home Scene. This proves that Park Scene requires more graphics processing power and the GPU operates at a higher frequency to meet this load. In addition, the rendering resolution of Park Scene (2029 × 2145) is significantly higher than Home Scene (1196 × 1264). This difference suggests that Park Scene contains more visual details, which leads to higher system resource usage.

This data shows that scenes affect system performance not only with polygon and vertex density, but also with factors such as resolution, shading, and GPU load. Especially in scenes with higher resolution, increasing GPU frequency shows that the system adapts to the graphical processing requirements. Therefore, it will be important to carefully adjust the rendering resolution, reduce unnecessary shader operations, and use appropriate techniques to balance the GPU load to optimize performance.

CHAPTER 6- CONCLUSION

Our VRET program was created to give counselors a safe and controllable exposure treatment while also addressing the uneasiness and uncontrollability that patients in traditional exposure therapy faced. Regardless of the patient's level when they start therapy, the approach we have created attempts to offer a customized and flexible treatment experience. In challenging psychiatric diseases like OCD, this method enables the therapy process to be conducted more successfully, sustainably, and cooperatively between the patient and counselor.

Through specially designed displays, the counselor may manage anything that could impact the patient from the start of treatment until the finish. Comparing this to standard exposure therapy, a safer, more manageable, and more customized treatment experience is provided. Furthermore, the system offers a cost-effective solution that increases therapy process efficiency and avoids time waste for both the patient and the counselor.

Working with mental health professionals, we implemented several interaction techniques during the system development process with the goal of boosting therapeutic efficacy. We carried out experiments that included assessments of factors including physical weariness, system flexibility, and simplicity of use in order to establish the fundamental framework of the system that would be constructed. To give a thorough analysis, we integrated task-oriented Likert-based questions with the System Usability Scale during this review procedure.

6.1 LIMITATIONS

In contrast to conventional exposure therapy, the VRET system was created to offer a more accessible and economical treatment option. Conventional approaches are frequently tedious to regulate, time-consuming, and hard to get. Thus, the VRET system seeks to address these issues. Nevertheless, throughout the development process, we unavoidably ran upon several usage restrictions.

Since the developed system operates through a head-mounted virtual reality headset, some patients may find it difficult to accept this method due to their hygiene concerns. This is one of the most significant factors that may limit the use of the system, especially in patient groups where cleanliness concerns are intense. The obsession with cleanliness is one of the potential limitations of the VRET solution we prepared, and it is one of the fundamental obsessions of OCD. Therefore, sanitizing the hardware is crucial before the VRET sessions.

Another limitation is that although a general simulation has been developed, it cannot fully reflect the complex situations that a person may encounter in real life. For example, a crowd in a shopping mall can be simulated in a virtual environment; however, details such as people coming towards you or the feeling of colliding with some of them are not developed enough to be conveyed realistically enough with current virtual reality technology.

6.2 FUTURE WORK

First of all, although the system was developed in consultation with mental health experts at every stage, it should be systematically evaluated by experts in terms of usability. Feedback from different expert groups can greatly improve the practical applicability and user-friendliness of the system.

The biosensors used in the current prototype are operating at a primitive level. In order for the system to become more usable, it is necessary to increase both the accuracy rate of the sensors and to provide a more ergonomic design. This is an important step for users to be able to use the system comfortably for long periods of time.

As the system continues to develop, it is planned to add customizable panels so that therapists can evaluate the patients' condition in more detail before and after sessions. Thanks to these panels, disorder-specific scales and questionnaires can be easily filled out, which will allow the patient's progress to be followed more systematically.

Apart from this, our system currently consists of several scenes. However, these scenes need to be increased in number and made more detailed in order to better adapt to different real-life situations. For example, new scenes targeting different types of obsessions can be added. This expansion will allow the system to appeal to a wider group of patients.

Furthermore, larger studies with real patients are needed to evaluate the effectiveness of the system. These clinical tests will help us understand not only whether the system works, but also the experiences patients and therapists are having.

In addition to VR, mixed reality (MR) environments should be explored for exposure therapy. MR environments blend the patient's actual surroundings with virtual elements. With the availability of MR glasses like HoloLens and Apple Vision Pro on the market, this technology may offer new perspectives in treatment.

One important future research direction is the application of Artificial intelligence (AI) techniques in this field. AI, particularly in the form of generative AI, has the potential to revolutionize the field of mental health care by enabling automated therapy sessions. However, more research is needed to explore the application of AI techniques in this field.

APPENDIX

APPX. A- Pre-survey Tests

Q1 – Aşağıdaki sağlık durumlarından herhangi birine sahip misiniz?

☐ Baş ağrısı ☐ Baş dönmesi ☐ Vertigo ☐ Mide bulantısı

☐ Görme problemleri ☐ Kas-iskelet sistemi rahatsızlıkları ☐ Hiçbiri

☐ Diğer

Q2 – Eğer gözlük kullanıyorsanız gözlük türünüz nedir?

◯Görme bozukluğu için gözlük/lens ◯ Koruyucu gözlük/lens

Q3 – Hangi elinizi daha fazla kullanıyorsunuz

◯ Sağ El ◯Sol El ◯ İkisini Eşit Derecede

Q4 – Teknolojiye olan genel ilgi düzeyiniz nedir?

Hiç ilgim yok ◯◯◯◯◯ Çok ilgim var

Q5 – Günlük teknoloji kullanım süreniz nedir?

◯ 0 -1 Saat ◯ 1- 3 Saat ◯ 3 -5 Saat ◯ 5+ Saat

Q6 – Daha önce VR teknolojisi kullandınız mı?

◯ Evet ◯ Hayır

Q7 – Eğer VR kullandıysanız, VR Teknolojisiyle hangi amaçla ilgilendiniz?

◯ Oyun ◯ Eğitim ◯ İş ◯ Eğlence ◯Diğer

Q8 – Aşağıdaki cihazlardan daha önce kullandınız mı?

☐ VR Gözlük (Oculus – HTC Vive – Apple Vision Pro – Cardboard)

☐ Konsol Oyunları (Playstation – Xbox) ☐ Akıllı Telefon Oyunları

Q9 – Kontrol cihazlarıyla(joystick, oyun kolu vb.) deneyim seviyeniz nedir?

Hiç deneyimim yok ◯◯◯◯◯ Çok deneyimliyim

Q10 – VR Teknolojisi ile çalışmaya yönelik motivasyon seviyeniz nedir?

Hiç ilgim yok ◯◯◯◯◯ Çok ilgim var

APPX. B – Task Survey

Q1 – Görevi yerine getirmek kolaydı.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q2 – Ortam ile etkileşimim doğal görünüyordu.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q3 – Gerçekleştirdiğim eylemlere ortam yeterince tepki verdi.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q4 – Sistemi kontrol etmek yorucuydu.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

APPX. C. System Usability Scale

Q1 - Bu sistemi sıklıkla kullanmak isteyeceğimi düşünüyorum.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q2 - Bu sistemi gereksiz bir şekilde karmaşık buldum.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q3 - Bu sistemin kullanımının kolay olduğunu düşündüm.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q4 - Bu sistemi kullanabilmek için daha teknik bir kişinin desteğine ihtiyaç duyacağımı düşünüyorum.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q5 - Bu sistemdeki çeşitli fonksiyonları iyi entegre edilmiş buldum.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q6 - Bu sistemde çok fazla tutarsızlık olduğunu düşündüm.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q7 - Birçok insanın bu sistemi kullanmayı çok çabuk öğreneceğini sanıyorum.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q8 - Bu sistemin kullanımını çok elverişsiz buldum.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q9 - Bu sistemi kullanırken kendimden çok emin hissettim.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

Q10 - Bu sistemde bir şeyler yapabilmek için öncelikle birçok şey öğrenmem gerekti.

Hiç katılmıyorum ◯◯◯◯◯ Tamamen katılıyorum.

REFERENCES

[1] M. G. Craske, M. Treanor, C. C. Conway, T. Zbozinek, and B. Vervliet, “Maximizing exposure therapy: An inhibitory learning approach,” *Behaviour Research and Therapy*, vol. 58, pp. 10–23, Jul. 2014, doi: 10.1016/j.brat.2014.04.006.

[2] N. R. Farrell, B. J. Deacon, L. J. Dixon, and J. J. Lickel, “Theory-based training strategies for modifying practitioner concerns about exposure therapy,” *J Anxiety Disord*, vol. 27, no. 8, pp. 781–787, Dec. 2013, doi: 10.1016/j.janxdis.2013.09.003.

[3] Shreenikesh N., “360-DEGREE VIRTUAL REALITY,” *International Scientific Journal of Engineering and Management*, vol. 02, no. 04, Apr. 2023, doi: 10.55041/ISJEM00274.

[4] M. Javaid and A. Haleem, “Virtual reality applications toward medical field,” *Clin Epidemiol Glob Health*, vol. 8, no. 2, pp. 600–605, Jun. 2020, doi: 10.1016/j.cegh.2019.12.010.

[5] L. Lhotska, J. Adolf, and J. Dolezal, “Virtual Reality in Research and Education: A Case Study,” in *2019 29th Annual Conference of the European Association for Education in Electrical and Information Engineering (EAEEIE)*, IEEE, Sep. 2019, pp. 1–6. doi: 10.1109/EAEEIE46886.2019.9000435.

[6] L. Li *et al.*, “Application of virtual reality technology in clinical medicine.,” *Am J Transl Res*, vol. 9 9, pp. 3867–3880, 2017, [Online]. Available: https://api.semanticscholar.org/CorpusID:21387409

[7] A. “Skip” Rizzo, S. T. Koenig, and T. “Brett” Talbot, “Clinical Virtual Reality: Emerging Opportunities for Psychiatry,” *Focus (Madison)*, vol. 16, no. 3, pp. 266–278, Jul. 2018, doi: 10.1176/appi.focus.20180011.

[8] J. Ahn, Y. Kim, and R. Kim, “Virtual Reality-Wireless Local Area Network: Wireless Connection-Oriented Virtual Reality Architecture for Next-Generation Virtual Reality Devices,” *Applied Sciences*, vol. 8, no. 1, p. 43, Jan. 2018, doi: 10.3390/app8010043.

[9] D. Bhugra, A. Till, and N. Sartorius, “What is mental health?,” *International Journal of Social Psychiatry*, vol. 59, no. 1, pp. 3–4, Feb. 2013, doi: 10.1177/0020764012463315.

[10] P. Cianconi *et al.*, “Psychopathology in postmodern societies,” 2015. [Online]. Available: https://api.semanticscholar.org/CorpusID:152250019

[11] L. Abrahams, “The Facts: Obsessive Compulsive Disorder.,” *South African Medical Journal*, vol. 100, no. 10, p. 650, Oct. 2010, doi: 10.7196/SAMJ.4489.

[12] N. Benzina, L. Mallet, E. Burguière, K. N'Diaye, and A. Pelissolo, "Cognitive Dysfunction in Obsessive-Compulsive Disorder," *Curr Psychiatry Rep*, vol. 18, no. 9, p. 80, Sep. 2016, doi: 10.1007/s11920-016-0720-3.

[13] H. R. Snyder, R. H. Kaiser, S. L. Warren, and W. Heller, "Obsessive-Compulsive Disorder Is Associated With Broad Impairments in Executive Function," *Clinical Psychological Science*, vol. 3, no. 2, pp. 301–330, Mar. 2015, doi: 10.1177/2167702614534210.

[14] M. Cervin, "Obsessive-Compulsive Disorder," *Psychiatric Clinics of North America*, vol. 46, no. 1, pp. 1–16, Mar. 2022, doi: 10.1016/j.psc.2022.10.006.

[15] D. A. Gorman and E. Abi-Jaoude, "Obsessive–compulsive disorder," *Can Med Assoc J*, vol. 186, no. 11, pp. E435–E435, Aug. 2014, doi: 10.1503/cmaj.131257.

[16] E. H. Cook, "Obsessive-Compulsive Disorder in Children and Adolescents," *J Neuropsychiatry Clin Neurosci*, vol. 3, no. 2, pp. 229–231, May 1991, doi: 10.1176/jnp.3.2.229.

[17] B. M. Hyman and C. Pedrick, "The OCD Workbook: Your Guide to Breaking Free from Obsessive-Compulsive Disorder," 1999. [Online]. Available: https://api.semanticscholar.org/CorpusID:142404614

[18] J. S. Abramowitz, B. D. Brigidi, and K. R. Roche, "Cognitive-Behavioral Therapy for Obsessive-Compulsive Disorder: A Review of the Treatment Literature," *Res Soc Work Pract*, vol. 11, no. 3, pp. 357–372, May 2001, doi: 10.1177/104973150101100305.

[19] J. E. Reid *et al.*, "Cognitive behavioural therapy with exposure and response prevention in the treatment of obsessive-compulsive disorder: A systematic review and meta-analysis of randomised controlled trials," *Compr Psychiatry*, vol. 106, p. 152223, Apr. 2021, doi: 10.1016/j.comppsych.2021.152223.

[20] C. Ferrando and C. Selai, "A systematic review and meta-analysis on the effectiveness of exposure and response prevention therapy in the treatment of Obsessive-Compulsive Disorder," *J Obsessive Compuls Relat Disord*, vol. 31, p. 100684, Oct. 2021, doi: 10.1016/j.jocrd.2021.100684.

[21] B. O. Rothbaum and A. C. Schwartz, "Exposure Therapy for Posttraumatic Stress Disorder," *Am J Psychother*, vol. 56, no. 1, pp. 59–75, Jan. 2002, doi: 10.1176/appi.psychotherapy.2002.56.1.59.

[22] R. Guo, "Exposure Therapy for Phobia Treatment," 2021. doi: 10.2991/assehr.k.211209.253.

[23] J. S. Abramowitz, B. J. Deacon, and S. P. H. Whiteside, "Exposure Therapy for Anxiety: Principles and Practice," 2010. [Online]. Available: https://api.semanticscholar.org/CorpusID:143170064

[24] B. O. Rothbaum and A. C. Schwartz, "Exposure Therapy for Posttraumatic Stress Disorder," *Am J Psychother*, vol. 56, no. 1, pp. 59–75, Jan. 2002, doi: 10.1176/appi.psychotherapy.2002.56.1.59.

[25] L. F. Hodges, B. O. Rothbaum, B. Watson, G. D. Kessler, and D. Opdyke, "A virtual airplane for fear of flying therapy," in *Proceedings of the IEEE 1996 Virtual Reality Annual International Symposium*, IEEE, 1996, pp. 86–93. doi: 10.1109/VRAIS.1996.490515.

[26] C. B. Becker, N. R. Farrell, and G. Waller, "Addressing the Impact of Different Settings and Institutional Resistance," in *Exposure Therapy for Eating Disorders*, C. B. Becker, N. R. Farrell, and G. Waller, Eds., Oxford University Press, 2019, pp. 195–204. doi: 10.1093/med-psych/9780190069742.003.0018.

[27] N. Morina, H. Ijntema, K. Meyerbröker, and P. M. G. Emmelkamp, "Can virtual reality exposure therapy gains be generalized to real-life? A meta-analysis of studies applying behavioral assessments," *Behaviour Research and Therapy*, vol. 74, pp. 18–24, Nov. 2015, doi: 10.1016/j.brat.2015.08.010.

[28] P. D. Seuling, N. S. Czernin, and M. A. Schiele, "Virtual Reality exposure therapy in the treatment of public speaking anxiety and social anxiety disorder," *Neuroscience Applied*, vol. 3, p. 104074, 2024, doi: 10.1016/j.nsa.2024.104074.

[29] D. Boeldt, E. McMahon, M. McFaul, and W. Greenleaf, "Using Virtual Reality Exposure Therapy to Enhance Treatment of Anxiety Disorders: Identifying Areas of Clinical Adoption and Potential Obstacles," *Front Psychiatry*, vol. 10, Oct. 2019, doi: 10.3389/fpsyt.2019.00773.

[30] S. Page and M. Coxon, "Virtual Reality Exposure Therapy for Anxiety Disorders: Small Samples and No Controls?," *Front Psychol*, vol. 7, Mar. 2016, doi: 10.3389/fpsyg.2016.00326.

[31] J. Heyse *et al.*, "An adaptation algorithm for personalised virtual reality exposure therapy," *Comput Methods Programs Biomed*, vol. 225, p. 107077, Oct. 2022, doi: 10.1016/j.cmpb.2022.107077.

[32] T. Oing and J. Prescott, "Implementations of Virtual Reality for Anxiety-Related Disorders: Systematic Review," *JMIR Serious Games*, vol. 6, no. 4, p. e10965, Nov. 2018, doi: 10.2196/10965.

[33] G. Albakri *et al.*, "Phobia Exposure Therapy Using Virtual and Augmented Reality: A Systematic Review," *Applied Sciences*, vol. 12, no. 3, p. 1672, Feb. 2022, doi: 10.3390/app12031672.

[34] J. R. S. Freitas *et al.*, "Virtual Reality Exposure Treatment in Phobias: a Systematic Review," *Psychiatric Quarterly*, vol. 92, no. 4, pp. 1685–1710, Dec. 2021, doi: 10.1007/s11126-021-09935-6.

[35] M. Krzystanek *et al.*, “Tips for Effective Implementation of Virtual Reality Exposure Therapy in Phobias—A Systematic Review,” *Front Psychiatry*, vol. 12, Sep. 2021, doi: 10.3389/fpsyt.2021.737351.

[36] S. W. Jerdan, M. Grindle, H. C. van Woerden, and M. N. Kamel Boulos, “Head-Mounted Virtual Reality and Mental Health: Critical Review of Current Research,” *JMIR Serious Games*, vol. 6, no. 3, p. e14, Jul. 2018, doi: 10.2196/games.9226.

[37] H. e Zainab, N. Z. Bawany, W. Rehman, and J. Imran, “Design and development of virtual reality exposure therapy systems: requirements, challenges and solutions,” *Multimed Tools Appl*, vol. 83, no. 2, pp. 6137–6160, Jan. 2024, doi: 10.1007/s11042-023-15756-5.

[38] J. Asiain, M. Braun, and A. J. Roussos, “Virtual reality as a psychotherapeutic tool: current uses and limitations,” *Br J Guid Counc*, vol. 50, no. 1, pp. 1–28, Jan. 2022, doi: 10.1080/03069885.2021.1885008.

[39] A. Francova, B. Darmova, P. Stopkova, J. Kosova, and I. Fajnerova, “Virtual Reality Exposure Therapy in Patients with Obsessive-Compulsive Disorder,” in *2019 International Conference on Virtual Rehabilitation (ICVR)*, IEEE, Jul. 2019, pp. 1–2. doi: 10.1109/ICVR46560.2019.8994404.

[40] I. Fajnerová, A. Francová, K. Taranzová, B. Darmová, E. Kosová, and P. Stopková, “Virtual reality environment for exposure therapy in obsessive–compulsive disorder: a validation study,” *Virtual Real*, vol. 27, no. 3, pp. 2691–2701, Sep. 2023, doi: 10.1007/s10055-023-00837-5.

[41] A. Torrao, J. Natario, P. Carvalho, C. Silva, and F. Silva, “A VR Game for Obsessive-Compulsive Disorders Therapy,” in *2021 International Conference on Graphics and Interaction (ICGI)*, IEEE, Nov. 2021, pp. 1–8. doi: 10.1109/ICGI54032.2021.9655282.

[42] L. Lohse, L. Jelinek, S. Moritz, J. Blömer, L. Bücker, and F. Miegel, “Efficacy of exposure and response prevention therapy in mixed reality for patients with obsessive-compulsive disorder: study protocol for a randomized controlled trial,” *BMC Psychol*, vol. 11, no. 1, p. 113, Apr. 2023, doi: 10.1186/s40359-023-01116-3.

[43] J. L. Maples-Keller, B. E. Bunnell, S.-J. Kim, and B. O. Rothbaum, “The Use of Virtual Reality Technology in the Treatment of Anxiety and Other Psychiatric Disorders,” *Harv Rev Psychiatry*, vol. 25, no. 3, pp. 103–113, May 2017, doi: 10.1097/HRP.0000000000000138.

[44] Z. E. Garcia-Batista Sr *et al.*, “Design and Validation of Virtual Environments for the Treatment of OCD related to fear to contamination (Preprint),” Mar. 19, 2020. doi: 10.2196/preprints.18800.

[45] M. Laforest, S. Bouchard, A.-M. Crétu, and O. Mesly, “Inducing an Anxiety Response Using a Contaminated Virtual Environment: Validation of a

Therapeutic Tool for Obsessive–Compulsive Disorder," *Frontiers in ICT*, vol. 3, Sep. 2016, doi: 10.3389/fict.2016.00018.

[46] J. Brooke, "SUS: a retrospective.," *J Usability Stud*, vol. 8, no. 2, 2013.