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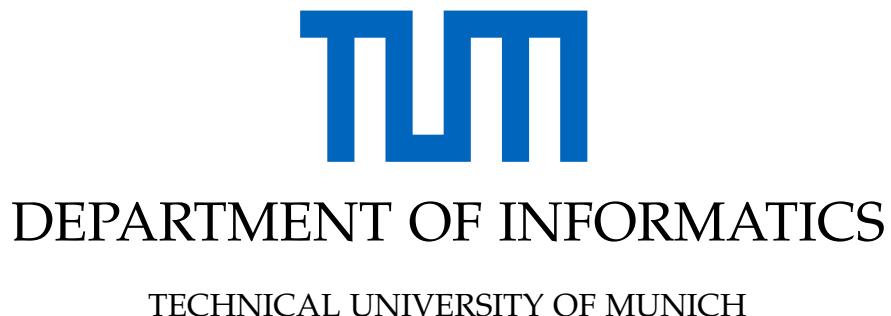
TECHNICAL UNIVERSITY OF MUNICH

Bachelor's Thesis in Informatics: Games Engineering

**An AR Serious Game about  
Obsessive-Compulsive Disorder**

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## An AR Serious Game about Obsessive-Compulsive Disorder

### Ein AR Serious Game über Zwangsstörungen

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I confirm that this bachelor's thesis in informatics: games engineering is my own work and I have documented all sources and material used.

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# **Abstract**

Obsessive thoughts and compulsive behaviors affect most people at some point in their lives, however, when they form an endless cycle of anxiety which triggers obsessions that are neutralized by compulsions, obsessive-compulsive disorder (OCD) is most commonly the underlying reason. Approximately 2.3% of the general population has OCD, but often people with OCD suffer in silence because they feel ashamed of their condition and/or are reluctant to seek professional help. Many patients also remain untreated due to a lack of well-trained therapists. Therefore, different self-help techniques have been developed to reduce OCD symptoms. Among them is the application of serious games.

Another alarming fact is that many people have misconceptions about OCD or have never heard of it. Even diagnosed patients sometimes find it difficult to understand OCD and its treatment approaches. Hence, it is imperative to spread awareness and educate both healthy people and patients about the disorder.

The following study focuses on the implementation of an Augmented Reality Serious Game about OCD which incorporates self-help techniques and offers an educational section. For this purpose, different scientific papers and applications for treating OCD and similar disorders were reviewed. Based on their analysis, an AR game was developed and the game idea was evaluated by healthy people and OCD patients. The results indicated that the game was well-received by both groups, but because of the limited numbers of participants and the inability to conduct an in-person evaluation, more extensive research is needed.

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# 1 Introduction

It is common for people to ask themselves whether they have locked the door once they leave the house or turned off the stove. However, there are also people who attach unhelpful meanings to such thoughts like "I haven't locked the door, I am going to get robbed." or "The stove is still on, my house is going to explode.". As a result, these people feel very anxious and distressed and are likely to go back and check the door or the stove. This action relieves their anxiety, but the next time they go out, they still receive the same intrusive thoughts and repeat the checking process. The cycle occurs even more frequently and starts affecting their daily life. This is an example of how the cycle of despair of obsessive-compulsive disorder (OCD) develops [1.1][1]. Obsessive-compulsive disorder (OCD) is a clinical condition that occurs when a person gets caught in a cycle of obsessions and compulsions[2]. Obsessions are intrusive thoughts like "I haven't locked the door, I am going to get robbed." or images visualizing distressing events. Compulsions are repetitive behaviors or thoughts that a person uses to neutralize the obsessions like checking numerous times whether the door is locked. Approximately 2.3% of the population has OCD with the average age of onset being 19.5 years old[3]. At such an age, it is common for adolescents to feel reluctant to share their experience with the disorder because of shame. Furthermore, even older patients often attempt to conceal their symptoms out of fear that revealing them will lead to severe disapproval. As a result, many patients do not seek medical help and remain untreated. This fact has outlined the necessity to develop self-help treatment techniques that can substitute in-person sessions with a therapist. For that purpose, bibliotherapy and self-help groups are organized, online and telephone consultations are offered and computer applications are developed.

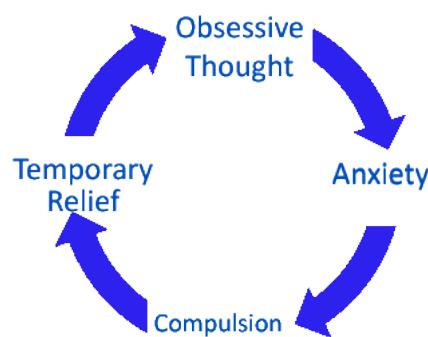


Figure 1.1: OCD Cycle

Serious games are an innovative approach which has been used for the treatment of different medical conditions such as anxiety, depression, phobia, panic disorder and eating

disorders. In the context of medical treatment, they combine entertainment and treatment techniques to help patients improve their symptoms. Their efficiency has been proven in many studies, therefore, different games have been developed to help treating OCD patients. Ricky and the Spider[2.4.2] and OCfree[2.4.4] are illustrative examples which not only incorporate self-help techniques but also educate patients about the disorder. The popularity of video games among children and adults makes them a perfect candidate for spreading awareness about OCD and for enhancing the motivation of patients to go through therapy. Their accessibility and low cost reduce the negative impact of the shortage of well-trained specialists and provide a treatment opportunity for people who do not have the resources or desire to attend therapy sessions.

Another innovation which has successfully been used to treat medical conditions is Augmented Reality (AR). AR is an immersive technology which combines the real and virtual world by integrating 3D virtual objects into the real environment in real-time[4]. It has numerous advantages over traditional non-immersive technologies like creating a sense of presence and higher levels of realism and offering a safe and controllable environment for treatment procedures. These advantages have been used in the development of AR applications for the treatment of Attention Deficit Hyperactivity Disorder (ADHD), cockroach phobia and acrophobia - fear of heights. However, the use of AR in treating OCD is still insufficiently studied. No applications or games incorporating AR have been specifically developed to reduce OCD symptoms. Nevertheless, it has been proven that AR is capable of triggering anxiety and compulsions in patients with cleaning OCD symptoms [5]. For this purpose, different AR stimuli were designed and evaluated such as a sealed plastic bag full of garbage and bread with mold.

Virtual Reality (VR) is a better-studied technology used in the treatment of psychological disorders. It differs from AR by creating an entirely computer-generated virtual world. Like AR, VR is highly immersive and offers a safe and controllable environment, however, its development costs are higher and there are also certain limitations imposed by the need for a VR headset. There are VR applications which have been developed for assessing and treating OCD, but they lack the inclusion of an educational part.

To be efficient and successful in substituting in-person therapy sessions, self-help applications for OCD, independent of the used development technology, have to apply the right treatment approach. There are two types of treatment approaches for OCD - psychological and pharmacological. The pharmacological approach includes the prescription of antidepressants like serotonin reuptake inhibitors, whereas the psychological approach applies exposure-based procedures and cognitive behavioral therapies. The cognitive behavioral therapy (CBT) with exposure and response prevention (ERP) is the most studied and effective approach used not only during in-person therapy sessions but also in serious games and computer applications.

## **1.1 Research Topic**

Because of the fact that there are no developed applications which use AR to treat OCD symptoms, this thesis focuses on the analysis and implementation of an AR serious game about OCD. The advantages of AR and serious games are incorporated and analyzed regarding the following aspects:

- Is AR successful in triggering anxiety and compulsions in OCD patients during the game?
- Is the chosen treatment approach effectively applied in the AR serious game?
- Do OCD symptoms improve after playing the game?
- Does the game provide sufficient and understandable information about OCD to the players?

Before these questions are answered and the game implementation is explained, the existing research of the topic will be presented and reviewed in the next chapter.

## 2 Related Works

### 2.1 Obsessive-Compulsive Disorder

As it was briefly explained in chapter 1, obsessive-compulsive disorder (OCD) is a clinical condition with recurrent obsessions and compulsions that negatively affects individual's life and functionality in areas such as work, school, social activities and family matters. Obsessions are defined by two essential features [6]:

- they are recurrent and persistent thoughts, impulses or images which are intrusive and cause great anxiety or distress
- the affected person attempts to ignore, suppress or neutralise them with some other thoughts or actions (i.e., by performing a compulsion)

Common obsessions are thoughts about suffering from a severe disease or getting contaminated by different objects, images of harming loved ones, doubts that one has not locked doors, closed windows or switched off electrical appliances and fears about sexual orientation [7].

Compulsions are urges to perform different rituals that the individual feels compelled to do in response to an obsession. They conform to strict rules which are created by the individual and aim to reduce stress and prevent some feared events. Their incompleteness causes the affected person great anxiety because of the incoming dreaded consequences of the feared events. However, these behaviors or mental acts do not have a realistic connection to what they are trying to prevent. Some common compulsions include excessive hand washing and cleaning, checking things such as locks on doors numerous times, repeating actions in a certain sequence such as turning on and off switches three times and turning left two times and then right another two times before going to bed, grouping and ordering items in a specific way by color or size.

According to the Diagnostic and Statistical Manual of Mental Disorders and OCD (DSM-5) [6], obsessive-compulsive disorder can be diagnosed with the following criteria:

- Presence of obsessions, compulsions or both
- The obsessions or compulsions are time-consuming or cause significant distress or impairment in social, occupational or other important areas of functioning.
- The obsessive-compulsive symptoms are not attributable to the physiological effects of a substance or another medical condition.

- The disturbance is not better explained by the symptoms of another mental disorder.

There have been many debates among researchers regarding the different approaches to subtyping obsessive-compulsive disorder. The most popular method for identifying OCD subtypes groups OCD patients by their observed symptoms. Early symptom subtypes were characterized by the patient's compulsive behavior - Lewis, 1936 [8] distinguished between people who experienced washing compulsions and such who experienced checking compulsions. Hodgson and Rachman, 1977 [9] formed four main types of obsessional-compulsive rituals - checking, cleaning, slowness and doubting. Leckman et al., 1997 [10] suggested five symptoms - obsessions and checking, symmetry and ordering, cleanliness and washing and hoarding. The Yale-Brown Obsessive Compulsive Scale Symptom Checklist (Y-BOCS [11]) is the most commonly used symptom measure which contains more than 50 OCD symptoms and organizes them into obsessions and compulsions.

In the next section, five subtypes of OCD will be described following the book "Obsessive-Compulsive Disorder: Subtypes and Spectrum Conditions" [12] and the paper "A critical evaluation of obsessive-compulsive disorder subtypes: Symptoms versus mechanisms" [13], both written by Abramowitz, McKay and Taylor:

- contamination and washing/cleaning
- harm obsessions and checking rituals
- symmetry, ordering and arranging
- obsessions without overt compulsions
- compulsive hoarding

## 2.2 Obsessive-Compulsive Disorder: Subtypes

### 2.2.1 Contamination and washing/cleaning

There are two distinct groups of OCD patients with washing rituals. The first one includes patients feeling discomfort because of contamination possibilities and the second one contains patients who fear harming themselves or others as a result of contamination. Affected people in the first category focus on the feeling of contamination and wash or clean excessively to reduce it. Patients in the second category focus on dealing with the consequences of contamination. They wash or perform checking rituals to prevent perceived danger. Severe case patients from both groups sometimes perform washing compulsions so often that they inflict self-harm upon themselves by damaging their skin because of the excessive washing.

### 2.2.2 Harm obsessions and checking rituals

Harm obsessions and checking rituals vary greatly among patients. Checkers have intrusive thoughts about the infliction of harm like the ignition of fire and the occurrence of robbery

and believe they might increase the likelihood of such events by thinking about them. Because of that, they perform different rituals to lower the possibility of these feared situations. There are patients with unwanted aggressive or sexual thoughts or images who constantly check to see if they have actually acted upon these impulses. Others overestimate the likelihood of making mistakes or believe they might be responsible for possible disasters. Therefore, they check to ensure such mistakes did not happen. In comparison to washers, checkers experience thought-action fusion because of which they believe that thoughts or impulses are equally bad as the events they describe [14].

### **2.2.3 Symmetry, ordering and arranging**

Individuals with symmetry, ordering and arranging rituals strictly follow uniformity and precision rules. They want things to be symmetrical or placed in a certain way, often grouped by size or color, and feel dissatisfaction or anxiety when objects are not perfectly even. One distinctive feature of patients with symmetry, ordering and arranging rituals is that they do not experience fear and anxiety of not engaging in their rituals. That distinguishes them from individuals with OCD symptoms such as washing or checking because their compulsions are aimed at preventing harm or disastrous events. Not performing the compulsions causes such people great distress because of the consequences of the feared events.

### **2.2.4 Obsessions without overt compulsions**

Affected people from this subtype do not have apparent compulsions. They obsess over themes such as sex, harm, violence and religion. Such patients believe that the distressing thoughts they have are dangerous and have some important meaning, hence they try to control them with mental rituals and neutralizing thoughts. It is common for such individuals to recite positive words after having a negative or dangerous thought, to count and pray. They can also be reluctant to talk about and share their intrusions due to feelings of shame and guilt. As a precaution, this group of patients often avoids triggers of feared events. For example, if a person has involuntary sexual thoughts, he or she avoids coming into contact with attractive people.

### **2.2.5 Hoarding**

It has been widely debated whether hoarding should be considered a symptom of obsessive-compulsive disorder because it can also be seen in numerous other psychological and psychiatric conditions. However, studies have shown that it appears most frequently in individuals with OCD, present in about 30% of the cases [15]. Hoarding is defined as the acquisition of items that appear to be of little value to others. Individuals who collect such items also experience difficulty in discarding them because they fear that they might need these possessions in the future. Excessive emotional attachment to objects can also be observed in patients with hoarding symptoms to the point that decision-making and organisation are hindered.

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## 2.3 Treatments for Obsessive-Compulsive Disorder

Despite the diversity of the above-mentioned OCD subtypes, little research has been conducted on how each subtype specifically responds to different treatment approaches. Therefore, this section will describe the existing treatments for obsessive-compulsive disorder in general.

OCD treatments can be divided into psychological and pharmacological approaches [16]. Psychological interventions include exposure-based procedures and cognitive behavioral therapies, whereas pharmacological methodologies use antidepressants like serotonin reuptake inhibitors (SRIs). In severe OCD cases, a combination of both approaches can be used or when patients do not respond well to psychological treatments alone.

### 2.3.1 Pharmacological approaches

Numerous medications have been used in the treatment of OCD patients. Different studies have shown the existence of a neurochemical basis for OCD [17]. It has been concluded that OCD patients have a lower level of serotonin than healthy people and that serotonin offers relief to OCD symptoms. Therefore, serotonin re-uptake inhibitors (SRIs) such as clomipramine and fluoxetine have been prescribed to patients. 75% of the cases of individuals taking clomipramine have indicated improvement after five weeks. However, these medicines can have side effects such as nausea, headache, tremor, gastrointestinal complaints and insomnia. Furthermore, only a few of the treated people with medication alone show no OCD symptoms after completing the SRI course. Because of that, specialists recommend medication to be combined with cognitive behavioral therapy.

### 2.3.2 Psychological approaches

Cognitive behavioral therapy (CBT) includes related treatment procedures that vary in the extent to which they emphasize behavioral techniques, cognitive techniques and the way they are integrated [12]. The most studied approach is exposure and response prevention (ERP) and it has been proven to be among the most efficient approaches for treating OCD [18]. It reduces the fear which is associated with obsessions by explaining that negative intrusive thoughts are normal for most people. It also minimizes the urge to avoid triggering situations and to execute rituals. ERP is a therapist-guided intervention that encourages patients to deliberately confront situations and triggers they usually avoid for their obsessions and compulsions to emerge. After being exposed to them, individuals are asked to not act upon the respective intrusive compulsions. The purpose of this resistance from completing rituals is to show patients that obsessions are not truly dangerous and that anxiety subsides on its own even if the compulsions are not performed [19]. When patients repeatedly witness that the feared consequences do not happen, they start to link the obsession with this nonoccurrence and their anxiety and distress get greatly reduced. Moreover, this realization changes their behavior because they no longer feel the urge to complete a ritual as a response to an obsessional thought.

Because ERP uses exposures to stimuli, it also causes high levels of anxiety in patients. To reduce this effect, another approach for treating OCD has been studied by researchers - cognitive therapy (CT). It is based on the idea of identifying, challenging and changing distressing thoughts and beliefs [20]. CT emphasizes that intrusive thoughts are experienced by most people and they develop into obsessions when the individual specifies them as threatening or highly significant. One method used during CT is challenging the overestimation of responsibility that the patient feels for the occurrence of the feared event. For that, the pie-technique is introduced during which the patient has to list and evaluate the contribution of all factors that cause the catastrophic event and then insert them into a pie chart. The patient's own contribution should be entered at the end at the remaining part of the pie chart. This encourages the individual to focus on the contribution of other factors and to be able to see that his or her responsibility is much smaller than originally thought.

A recent development in the treatment of OCD is the acceptance and commitment therapy (ACT). It aims to teach patients to be present at the moment despite intrusive thoughts, distress and urges to perform rituals. This is accomplished through acceptance of these events, seeing obsessions as experiences rather than as rules, being aware of the present moment, understanding that there is an unchanging sense of self that cannot be harmed and is always present, encouraging one's therapeutic work towards meaningful areas of life and performing committed actions which focus on behavior change [21, 22].

All of the above-discussed OCD treatment approaches require the presence and guidance of a therapist. Because of that and the shortage of well-trained OCD therapists, many patients remain untreated. Furthermore, some individuals feel ashamed because of their intrusive thoughts and compulsions and are reluctant to share their experiences. These factors have outlined the need for self-help approaches that are more accessible and at the same time still as efficient. Bibliotherapy and self-help groups are organized, online and telephone consultations are offered and smartphone and computer applications are developed. Different studies have indicated that telephone-based ERP delivers results which are comparable to face-to-face ERP sessions [23]. Computer- and telephone-based CBT has been proven as efficient in treating phobias, depression and different addictions and disorders. A fully interactive computer program called Behaviour therapy steps (BTSteps) has been developed, which teaches its users how to perform self-ERP in nine steps - the first four steps focus on self-assessment for OCD and the rest guide patients like a therapist would do on how to perform effective ERP on their own. The effectiveness of BTSteps has been observed during various tests [24].

As the focus of this thesis lies on the usage of games as a treatment approach for OCD, a more detailed review of existing games and applications which have been developed to treat OCD and other psychological disorders will be presented in the next section.

## 2.4 Games and Applications for OCD and other psychological disorders

The undeniable influence of computers and video games on people's daily routine has outlined the application of serious games in treating disorders. Serious games have a purpose other than pure entertainment [25] and, in the context of healthcare and medicine, provide different treatment possibilities and medical education in combination with gameplay elements. Taking into consideration the potential of computer games for health purposes and the proved effectiveness of CBT as a treatment approach for different disorders as well as its computerized applications, several video games have been developed using CBT to enhance treatment compliance and promote health-related behaviour change.

### 2.4.1 Treasure Hunt

One such game is Treasure Hunt [26]. It was created at the Department of Child and Adolescent Psychiatry of the University of Zurich to support treatment of 8 to 13 year old children with various disorders, among which OCD was also present. It has six levels which correspond to a certain step in CBT and represent basic concepts such as the distinction between thoughts, feelings and behavior, the influence of thoughts on feelings and the distinction between helpful and unhelpful thoughts. Treasure Hunt is not designed as a self-help game but should be played under the supervision of a therapist. It supports regular therapy by offering electronic homework assignments which children have to solve between therapy sessions. Some therapists also use it during sessions as a reinforcement for the children's therapy response. A study of the game revealed that it is also useful for explaining treatment approaches of CBT and enhancing the motivation of children for going through psychotherapy [27]. Therapists benefit from Treasure Hunt because they can better structure their sessions with it and it is easier for them to make contact with their young patients because playing a game offers a less direct way of communication. This aspect is particularly important for the treatment of introverted children who do not want to talk to the therapist and for adolescents who are reluctant to seek help for mental problems.

Another advantage of Treasure Hunt is its simplicity regarding the technical level. It uses 2.5 D graphics, has few animations and requires only a Flash compatible internet browser. That makes it easily accessible since no installation is required.

The results of the evaluation on the applicability and appropriateness of Treasure Hunt reveal that more than 2000 professional child therapists from 37 countries use the game either in their practice or out of interest in learning about video games for child psychotherapy. Therapists from English-, German- and Dutch-speaking countries report using the game regularly during their sessions. 98.6% of the children who participated in the evaluation of the game stated that they liked the usage of Treasure Hunt during their treatment and the majority appreciated the game as it was with only 33% suggesting the addition of more levels with more tasks.

### 2.4.2 Ricky and the Spider

While Treasure Hunt is a game targeted at young patients with different disorders, Ricky and the Spider is a game created for children with obsessive-compulsive disorder and is meant to support their cognitive-behavioral treatment [28]. It was also developed at the Department of Child and Adolescent Psychiatry of the University of Zurich and, similarly to Treasure Hunt, it is not a self-help game and should be played under the guidance of a therapist. It explains OCD and the CBT treatment approach with the story of the Spider and the ladybug Ricky. The Spider is the antagonist of the game and represents the OCD. She controls the life of insects like Ricky, which live nearby, by asking them to perform specific tasks and rituals. Ricky can only hop in a distinct pattern and if he does not, he gets threatened by the Spider that horrible things will happen to him. Another ladybug called Lisa has to count all her dots before she falls asleep each night. By placing such demands and promising terrible consequences if they are not fulfilled, the Spider creates obsessions and passes them on to the insects along with compulsions.

Dr. Owl is another character who explains the CBT techniques to Ricky and Lisa during the eight levels of the game. In the first level, Ricky and the other ladybug describe the beginnings of their disorder and ask the owl for help. In the second level, the owl introduces the concept of a thought filter that prevents absurd thoughts from passing through and explains how the Spider has damaged Ricky's and Lisa's thought filters. The third level provides Ricky and Lisa with four strategies to fight the Spider and respectively the OCD - to be kind to themselves, to have the courage to change, to be patient and to have a helper. In later levels, the child who plays the game has to choose the strategy that will be most suitable in a specific situation. Level 4 focuses on the creation of compulsion maps that contain all the rituals compelled by the Spider. Ricky and Lisa then have to rate how difficult it is for them to disobey these demands. The child is also asked to create a compulsion map. These four levels cover the psycho-education part of the game and after their completion, the child needs to solve a worksheet as homework. The next three levels encourage Ricky and Lisa to disobey the Spider, starting by not performing the least difficult task listed in the compulsion map. In such a way, the ERP approach is introduced. The homework exercises for the child after these levels also focus on the exposure and response prevention and are determined by the therapist.

Since it was created, Ricky and the Spider has been sold to 56 child psychiatric institutions or practitioners in different countries. An evaluation of the effectiveness of the game was conducted among thirteen therapists and fifteen children with OCD. It revealed that all children liked the game and its story helped them better understand OCD. They also reported that their OCD symptoms considerably improved after the treatment with the game, which was also confirmed by their therapists. Apart from being a useful tool for explaining OCD and CBT to children and enhancing their motivation for therapy, several therapists also used the game to explain OCD and CBT to parents.

### 2.4.3 RAW HAND

The above-described games are targeted at children and include elements like the spider and the ladybug characters that are appealing to younger patients. However, OCD is a disorder that also affects adults and it is imperative to examine a game which was developed for an older target group. One such game is RAW HAND [29]. It is a serious mobile game which uses ERP and enhances the selective attention of patients by asking them to pause before completing a final task. This type of attention allows people to respond selectively to important features of their environments while ignoring features which are of little or no importance [30], thus lowering the influence of obsessions. The game's targeted age groups are teenagers to 40s.

Another difference between RAW HAND and Treasure Hunt and Ricky and the Spider is that the latter require the guidance of a therapist and are not self-help games, whereas RAW HAND teaches individuals how to perform ERP between therapy sessions or on their own if they do not go through therapy at all.

RAW HAND also takes into account the OCD subtypes, in particular contamination/-cleaning, doubt about harm/checking, symmetry/ordering, counting and unacceptable thoughts/mental rituals. There are five games [2.1a], each focusing on one specific OCD subtype. At the beginning of the game, the patient chooses one of the games and is asked to perform exposure and response prevention tasks. In the contamination/washing game, the patient has to remove germs from the character's hand until only one germ is left. The patient is then asked to wait for 5 seconds before removing it so that his or her selective attention is improved. In the doubting/checking game, the patient has to touch different items until the number 1 is shown on the screen and then needs to stand up for 5 seconds and not interact with the game. The symmetry/ordering game asks patients to arrange books on a bookshelf by size and color and wait for 5 seconds before arranging the final book. The ERP approach in the numbering/counting game requires patients to type a number that preoccupies their thoughts. Then so many eggs as the number suggests appear on the screen and subjects have to touch them so that they can hatch. Once only one egg remains unhatched, they again should wait for 5 seconds before touching the last egg. The last game about unacceptable thoughts/mental rituals asks individuals to type a word which preoccupies their thoughts. The word then gets multiplied on the screen and 10% of the new words are written with a different spelling. The subject is expected to touch only the words with the original spelling.

RAW HAND was tested by three patients with OCD and all of them reported improvement of their symptoms and said they would recommend it to other patients with OCD. Another study concluded that 3 weeks of serious gameplay improved OCD symptoms as well as depressive and anxiety symptoms [29].

### 2.4.4 OCfree

OCfree is a mobile therapy program for treating patients with obsessive-compulsive disorder which uses CBT with ERP [31]. It consists of three categories: education, quests and serious games.

The education category has different sessions and teaches about OCD symptoms, causes and treatments, how to analyze obsessions and understand strategies for dealing with OCD. It also outlines some factors for change and explains the cognitive therapy.

The quest category provides homework exercises to patients that relate to each education session - for example, assessing obsessions and compulsions by answering questions, understanding false beliefs related to obsessions, practicing postponing anxiety and performing imaginary ERP via voice recording.

The game category offers seven casual games - a shooting game, break block game, germ-removing game, doubting and checking game, symmetry and ordering game, numbering and counting game and mental ritual game. The shooting game confronts the player with aliens that shoot projectiles. The player controls a spaceship and needs to destroy the aliens. The spaceship is displaced with an object that the patient wants to avoid such as a knife, germ or airplane. The break block game displays bricks on the screen and the player has to break them by bouncing a ball. There is a word behind the bricks which the player has to type before the game and it should be associated with an obsession he or she has. Once all the bricks are destroyed, the word disappears. The rest of the games are similar to the ones in RAW HAND [2.4.3]. In the germ-removing game, the patient has to remove germs from the character's palm until only one germ is left and then wait 5 seconds before removing it. In the doubting and checking game, the player should touch an object on the screen until a number appears and then wait 5 seconds before the last touch. The symmetry and ordering game asks patients to arrange books by their color and size and wait before placing the last one. The numbering and counting game spawns eggs according to a typed number by the player, who should then hatch them and wait when only one remains. The mental ritual game multiplies a word written by the player and changes its spelling. Only the original word should be touched by patients.

The effectiveness of OCfree was evaluated with two test groups - an offline CBT group and a CBT group using OCfree. The offline CBT group had to visit a psychiatrist once a week and was given homework for each session. The OCfree CBT group also had to meet with a psychiatrist each week but OCfree was used during each meeting instead of the traditional CBT approach. Patients from this group needed to complete different parts of the application as homework. 10 people from the OCfree group rated the overall satisfaction of the app - it received 3.4 stars out of 5, with 1 being the lowest and 5 being the highest score. Some of the dissatisfaction resulted from errors in the program. Patients that gave higher stars stated that OCfree helped them to better understand OCD. 50% of the reviewers said that they would like to continue using the program and 70% wanted to recommend it to other people with OCD. The evaluation also showed that the OCfree program was as effective as the offline CBT for the improvement of OCD symptoms and even more effective in reducing anxiety.

#### 2.4.5 VR Games

The above-discussed games have been proven to improve OCD symptoms in patients, however, they are either computer- or mobile-based and do not offer immersion, which could greatly benefit the treatment of OCD. Virtual reality (VR) is an innovative candidate for assessing

and treating OCD that allows patients to have the perception of being physically present in a virtual environment. It is composed of interactive computer simulations that detect the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the virtual world [32]. These features of VR allow patients with difficult and dangerous to simulate obsessions like fear of flying or fire to confront them using the ERP approach in a safe and controllable environment. Furthermore, VR lowers the anxiety levels of patients during therapy because they know that VR simulations can be turned off at any time, which is not possible with real-life exposure. VR-based exposure therapy has been developed and successfully applied for the assessment and treatment of various mental problems such as anxiety disorder, post-traumatic stress disorder, attention deficit in children, driving and social phobia [33]. Moreover, VR offers patients the possibility to directly rate their symptoms, thus excluding an intervention of a therapist and decreasing the influence of shame, which patients might feel because of their symptoms.

A VR game to assess OCD symptoms has also been developed. It is used by therapists to provoke and measure OCD symptoms and includes the OCD subtypes contamination fear and cleaning compulsions, doubt and checking compulsions and symmetry obsessions and ordering compulsions [34]. Patients play the game from a first-person perspective and navigate through a house with OCD-related items such as a dirty sink and a messy table - figure 2.1b shows the different sections of the virtual house. There are items for each OCD subtype covered in the game. When patients encounter such an item, they have the option to either interact with it or dismiss it and go to the next section of the house. If they choose to interact with the object, a first-person video of the interaction is shown to them and they have to rate their emotional response to it, which includes the level of anxiety, tension and uncertainty and the urge to perform a compulsion. After that, individuals again have the option to repeat the interaction or proceed to the next item. This process can be repeated as long as the patient wishes and each emotional response and the amounts of interaction are recorded by the game. If interactions are performed more than once, they are classified as compulsions. The rating of the emotional response is done via the visual analogue scale (VAS), which allows patients to rate the intensity of their sensation on a scale, here from 0 to 10. The game also tracks some physiological measurements like the heart rate and the skin conductance level.

The effectiveness of the game in assessing OCD symptoms was evaluated with two groups - one consisting of people with primary diagnosed OCD by a psychiatrist and a healthy control group. The evaluation showed that playing the VR game significantly increased the anxiety and tension as well as the urge to perform compulsions but not the uncertainty in both test groups. Furthermore, the level of anxiety was higher for the OCD patients compared to the healthy group and they performed more compulsions. The study also indicated that performing compulsions during the VR game decreased the provoked emotions afterward.

While the above-described game focuses only on assessing OCD symptoms, the next presented VR game is used in the treatment of compulsive hoarding. Even though compulsive hoarding is classified in DSM-V as a distinct disorder, its status as an OCD subtype was also

## *2 Related Works*

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considered when creating and evaluating the suggested VR game [35]. As it was mentioned in section 2.2.5, hoarding is characterized by excessive collecting of objects that might appear as useless to normal people but to OCD patients they have significant meaning. Different studies have proved that the standard ERP is not that effective in treating hoarding as it is in treating other OCD symptoms [36]. Moreover, hoarders are reluctant to allow others to enter their personal space, which additionally hinders the treatment process. VR provides an alternative way by offering highly visual virtual environments that could be designed similarly to the patient's home.

The creators of the discussed VR game [35] developed two VR environments - an experimental and a control one. They simulated the homes of the patients in the experimental by inserting images of objects that belonged to them. The control environment was created in the same way, however, the objects did not belong to the participants. Before using the VR game, all patients went through 24 sessions of inference-based therapy (IBT). IBT is an OCD treatment approach that aims to discover the initial doubting inference of patients and prove it wrong, thus invalidating the disbelief and mistrust caused by it [37]. After the IBT, the participants in both environmental groups received 5 VR sessions using the game which were monitored by psychologists. The first one allowed them to familiarize themselves with the virtual environment and to rearrange the objects in a way that is similar to their home environment. The second one asked patients to form a plan for sorting through their actual homes based on the objects present in the virtual environment. In the remaining sessions, patients had to virtually dispose of objects based on the degree of distress they caused them. They were then asked to re-evaluate the anxiety and discomfort they felt. During the last session participants also had to discuss relapse prevention techniques with their therapist. The only difference between the two groups was regarding the task completed at home - control participants were asked to discard one object at their will instead of an object which they selected from the virtual environment and belonged to them.

The evaluation of the VR game concluded that both groups experienced anxiety during the VR sessions, with participants from the experimental group experiencing significantly more anxiety than the control group during the action-taking tasks because of the incorporation of personal objects. After the VR sessions, the level of clutter in the homes of participants in the experimental group decreased, however, it increased in the control group. This fact suggests that VR helps people discard more objects from their actual homes when they are represented in the virtual environment. Furthermore, an improvement of the compulsive hoarding symptoms was also observed in both groups.



Figure 2.1: OCD Games

#### 2.4.6 AR Applications

Augmented reality (AR) is another immersive technology providing an innovative alternative to traditional treatment approaches for different disorders and phobias. It combines the real and virtual world by introducing 3D virtual objects that coexist with real objects in the real world and are interactive in real-time [38]. The main difference between AR and VR is that VR does not allow the user to see the real world, completely replacing it with a virtual one, whereas AR supplements the real world. Different devices support AR such as handheld devices, display systems and projection displays. Modern smartphones and tablets use their cameras and sensors like accelerometer and GPS to capture the surrounding environment and then insert virtual elements into it. There are two standard approaches for incorporating AR content into the real world - marker-based and markerless. The marker-based approach requires an image that is scanned by the device and the virtual content appears on top of this image. The markerless approach scans the surrounding environment and inserts the virtual elements based on the environment's real features.

AR has numerous applications in areas such as entertainment, education, architecture and medicine, however, very few studies have examined the application of AR in the treatment of psychological disorders, with existing literature mainly focusing on the treatment of specific phobias such as phobias for small animals and acrophobia [39]. Like VR, AR offers a safe and controllable environment for exposure-based therapy. However, AR does not require designing and implementing the whole virtual world, but only a few virtual objects. Thus, the development cost of an AR application is lower compared to a VR application. Furthermore, AR allows the user to be present in the real world environment and even use his or her body to interact with the virtual objects, which creates a better sense of presence and a higher level of realism [4]. Taking these advantages of AR over VR into consideration, Botella et al. (2005) assessed an AR application developed for treating cockroach phobia [40]. It uses the marker-based approach and a head-mounted display to determine patients' position and orientation and then inserts virtual cockroaches in front of them. The therapist can choose the number of cockroaches, their size and movements and whether the patient is ready to kill some cockroaches. This can be done with two instruments - a fly swatter and a cockroach killer. Each instrument has an attached marker which tracks whether it is near a cockroach marker or not. The evaluation of the application was conducted in a single case study and it followed the one-session therapist-directed exposure defined by Öst [41]. It revealed that at the beginning of the single AR session with prolonged exposure the system triggered anxiety in the patient, however, it was significantly reduced after one hour of interaction. The patient's fear and avoidance of cockroaches also decreased and she was able to approach and kill live cockroaches. Later research on the same AR application confirmed these initial results [42].

An AR system for the treatment of acrophobia - fear of heights - has also been developed [43]. It uses immersive photographs that can spin 360 degrees in any direction to trigger fear. Different locations are available for examination by the patient such as a view of a stairwell from the second and third floors and images taken from a window of a high building. The first evaluation of the system concluded that immersive photography was able to provoke a

high level of presence in patients, however, this presence was not as optimal as in the real world because patients were able to discover the differences between the real location and the immersive image. Data about the effectiveness of the AR application in treating the phobia is still missing.

An AR-Game environment called "AR-Therapist" has been created for patients with Attention Deficit Hyperactivity Disorder (ADHD) [44]. ADHD is a heterogeneous developmental disorder which causes hyperactivity and difficulty to pay attention in younger patients and time-management and organizational problems in older people. Cognitive behavioral therapy is one of the most effective approaches for treating the disorder and it is also applied in "AR-Therapist". Patients and therapists need to create profiles for the application to start the treatment process. Therapists have to specify their experience level and define the AR-based game that will be played by patients. ADHD patients often find concentrating on a specific task difficult and because of that, "AR-Therapist" offers a concentration game which simulates two 3D balls - one target ball and another non-target ball. The patient needs to hit the target ball within a specified time period and if the hit is not correct or the time ends, the total number of tries the patient has to finish the session is reduced. If the time from the beginning of the trial until hitting the target decreases, it is an indication that the patient's concentration has improved. An evaluation of "AR-Therapist" has shown that playing the game increases the ability of patients to concentrate and correctly choose a predefined object.

Even though no relevant paper was found which suggests an AR application or game for treating OCD, Batista et al. (2021) [5] examined the development of AR stimuli for patients with cleaning OCD symptoms and their ability to trigger anxiety and compulsions. They discovered that objects with germs, viruses or fungi such as rotten food and dirty items cause high levels of anxiety and distress in patients and provoke their cleaning rituals. Based on their findings, they designed and evaluated four AR stimuli - a sealed plastic bag full of garbage, bread with mold, rotten meat and sports shoes with dirt on them. Patients with cleaning OCD symptoms and healthy people were asked to observe the four objects for two minutes and then move their hands as close to them as possible. The results showed that the four stimuli caused higher anxiety levels in the OCD patients than in the control group. It was also revealed that the bread with mold and the rotten meat were more distressing than the garbage bag and the shoe because they were edible objects. High levels of presence were reported by both groups and this fact, along with the observed levels of anxiety, confirms the effectiveness of AR-based ERP.

## 2.5 Analysis and Definition of Guidelines

The reviewed papers in this chapter have outlined some important guidelines for the development of a successful game or application for treating OCD. The advantages of using an AR- and VR-based CBT and ERP over traditional approaches have been confirmed by various studies. Both technologies are immersive and allow the creation of a safe and controllable environment, which can also simulate dangerous and rare obsessions and compulsions. AR offers a better sense of presence because it incorporates virtual objects into the real world

and allows participants to use their bodies to interact with them. Furthermore, both AR and VR have been proven to successfully trigger anxiety and compulsions in OCD patients. Mobile and computer games are also effective in applying CBT and relieving OCD symptoms. Successful examples of such games educate patients about the disorder and explain and apply CBT with ERP. They also include homework assignments which patients have to solve. Some of the games require the guidance of a therapist, but some teach self-help techniques.

For this thesis, the following guidelines for the development of a game for treating OCD are defined, which are derived from the examined games and applications in this chapter:

- incorporation of AR
- inclusion of an OCD educational part
- application of CBT with ERP
- implementation of games based on the different OCD subtypes

The usage and implementation of these guidelines will be presented in the next chapter which will introduce and explain in detail my own idea for an AR-based serious game for OCD.

# **3 Implementation**

The analysis of the existing scientific papers, applications and games for treating OCD has outlined the need to create an AR-based serious game for OCD patients. Therefore, I propose a mobile game which follows the specified guidelines from the previous chapter and is developed to relieve OCD symptoms, as well as to educate both patients and healthy people about the disorder.

## **3.1 Platforms**

To ensure the quality and accessibility of the game, numerous development and design decisions needed to be taken. Among them was the choice of an underlying game engine, a platform for AR and a 3D computer graphics application. Unity, AR Foundation and Autodesk Maya were respectively used for the implementation of the game and the creation of a 3D mascot which is used as a visual representation of obsessive-compulsive disorder.

### **3.1.1 Unity**

Unity is a cross-platform game engine that supports desktop, mobile, console, virtual and augmented reality development. It allows easy creation of user interface elements, as well as complex 2D and 3D environments. Unity's compatibility with Windows, Android and AR Foundation made it a perfect candidate for the implementation of my game idea.

### **3.1.2 AR Foundation**

AR Foundation is a framework for augmented reality development which is offered by Unity and supports Google's ARCore, Apple's ARKit, Magic Leap's LuminSDK and HoloLens' Mixed Reality Toolkit SDK. It allows developers to build AR applications and deploy them across multiple AR devices. Because of that, I can create my game for both iOS and Android devices with only one codebase. AR Foundation offers features like device and plane tracking, plane detection and raycasting to detected planes, which form the basis of my game.

### **3.1.3 Autodesk Maya**

To make my game visually pleasing and create a 3D representation of OCD, I used Autodesk Maya to model, rig, texture and shade a 3D mascot. The role of the mascot, how it looks and changes during the game will be presented in the next section.

### 3.2 The Mascot

The mascot was created to visually represent OCD and its subduing influence over OCD patients in the course of playing the game. There are four versions of the mascot which can be seen in figure 3.1. The game starts by opening a start menu, in which the first and last versions of the mascot are shown. The first version represents OCD in its most severe case, where the influence over the player is the highest. I have used dark brown, big horns and a relatively scary face to make the mascot intimidating and emphasize the high levels of anxiety and distress which OCD causes in patients. This version of the mascot is the one that explains the rules of the first level of the game which is designed for the OCD subtype symmetry, ordering and arranging. Since this level is the introductory one, the mascot needs to be as intimidating and imposing as possible. The last version of the mascot is light brown, has no horns and its face is friendly and smiling. The game concludes with this mascot and its contrast to the first mascot aims to show how greatly the impact of OCD can be reduced with the application of the ERP treatment approach within the AR-based serious game. The other two versions of the mascot are intermediates. The second mascot is shown after the symmetry level is finished. It differs from the first version only in its color, because completing only one level is far from enough to cause a significant improvement in OCD symptoms and, thus, a greater visual change between the mascots is not necessary. Respectively, this version explains the rules of the second level, which focuses on the hoarding subtype. The third mascot is displayed to the players after they complete the hoarding level. It also introduces the third and final level for the subtype contamination and washing/cleaning. Here the horns are smaller compared to the second version since bigger horns represent a greater threat.



Figure 3.1: Mascot versions - subduing influence from left to right

### 3.3 The Lexicon

The start menu not only introduces the player to the two main versions of the mascot and to the option to start the first level of the game, but it also has a button for the OCD Lexicon. The purpose of this lexicon is to provide the most important information about the disorder to both patients and healthy players. It consists of three sections - OCD symptoms, OCD subtypes and OCD treatment approaches. All of the information which is included in the lexicon is gathered from medical papers and websites and there is a link in each section which references the sources. The links are crucial for the game because they verify the displayed information and suggest valuable sources for a more detailed explanation of OCD. I have included the lexicon because almost all of the analyzed games and applications for OCD in chapter 2 confirmed the effectiveness of an educational part in explaining OCD and the chosen treatment approach to patients. Therapists who incorporated Ricky and the Spider [2.4.2] in their sessions also used the game to explain OCD and CBT to parents. Taking these facts into consideration, I believe that a game which includes a lexicon and has different levels focusing on the OCD subtypes would be successful in explaining OCD to both patients and people who have never heard of the disorder before. Whether this hypothesis is valid or not will be examined in chapter 4. Figure 3.2 shows the first view of the OCD symptoms section. There the disorder is explained with the so-called "OCD cycle of despair" in which the connection between obsessions and compulsions is shown as a never-ending cycle. In the next view, which can be reached by pressing the forward arrow in the bottom right corner, the difference between obsessions and compulsions is described and an example of an obsessive thought (I haven't locked the door) is given along with the compulsion (I must check the door three times) which it triggers.



Figure 3.2: The OCD cycle of despair

In the OCD subtypes section, the five subtypes analyzed in [2.2] are explained with their most common obsessions and compulsions. For each subtype, representative pictures are included to visualize the information and because it has been proven that pictures are remembered better than words [45]. Furthermore, I believe that a description combined with images and a game level which is based on the specific OCD subtype will be beneficial in explaining the disorder and will also ensure long-lasting understanding. Figure 3.3 shows the information menu about the subtype contamination and washing/cleaning.



Figure 3.3: Contamination and washing/cleaning info menu

Since the most common obsessions of this subtype are about being dirty or contaminated, a picture of a plastic bag full of garbage is displayed - garbage is one of the first associations to dirt and contamination sources that comes to mind and is often avoided by OCD patients. Among the most performed compulsions are excessive cleaning and hand washing, therefore, images of cleaning supplies and washing hands are included.

The remaining four OCD subtypes have similar menus to the one shown in figure 3.3. The harm obsessions and checking rituals menu contains a picture of a door lock, a window and a gas kettle because this subtype is characterized by obsessive thoughts about the infliction of harm and the triggered compulsive rituals include repeatedly checking physical objects to make sure they are turned off, closed or locked. The symmetry, ordering and arranging subtype is visualized with a pile of books that is perfectly even, a collection of pencils ordered by height and gummy bears sorted by color. The purpose of these images is to demonstrate the different arrangement rules that control patients from this subtype. Since the subtype obsessions without overt compulsions triggers mental rituals that are hard to be described with pictures, I have listed some positive words like "happy" and "kind" to represent the neutralizing thoughts of negative contemplations. Praying and counting are also common for

this subtype, thus, an image of praying hands and a thought bubble with numbers in it are displayed. OCD patients with hoarding symptoms worry that throwing away items will have negative consequences and because of that they collect and retain objects for far too long. This subtype can easily be visualized with a stack of various objects and an overcrowded room.

The last part of the lexicon presents the different OCD treatment approaches. Following section 2.3, I have introduced the pharmacological and the psychological approaches. However, since both intervention types include numerous procedures, I have limited the examples to the most studied approaches only, namely the cognitive behavioral therapy and the serotonin re-uptake inhibitors as it can be seen in figure 3.4. Since the medical terminology used to explain the SRIs is too complex to be understood by non-medical people, I have only described the CBT. Furthermore, the analysis of the scientific papers for treating OCD has concluded that CBT with exposure and response prevention is the most effective treatment technique to be incorporated in games and applications. Because of that, I have also used it in my game and have explained it. The link icon which can be found at the top right corner of the menu is crucial for this section of the lexicon since more detailed information about the different OCD treatment approaches is missing and should be provided to players. The CBT explanation menu can be reached by clicking somewhere on the CBT textual field. After that, a new window is displayed to the players in which the most important characteristics of CBT and ERP are listed.

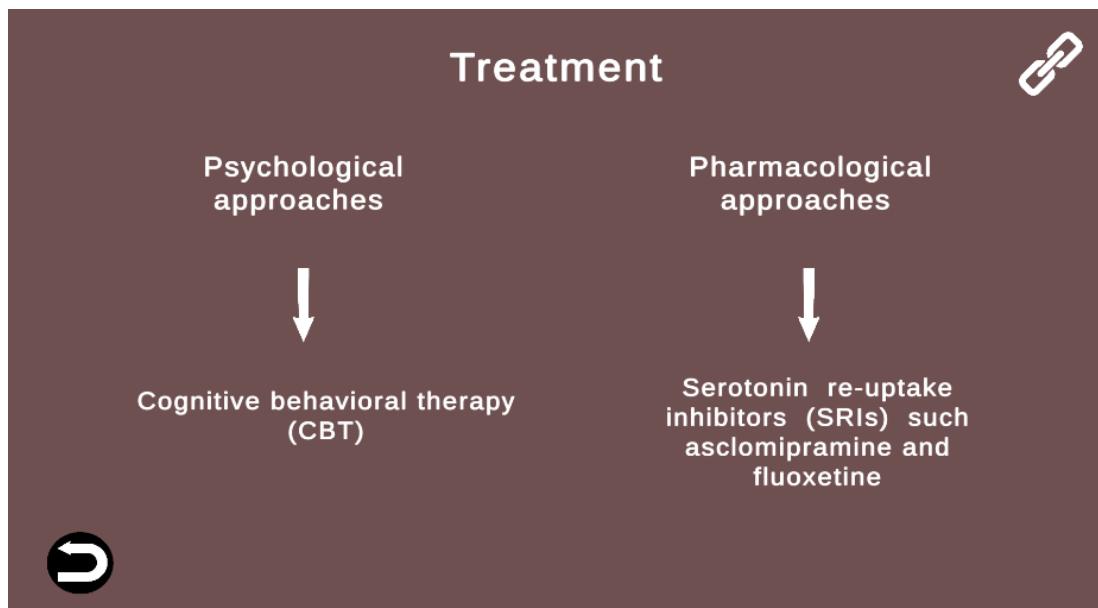


Figure 3.4: OCD treatment approaches menu

### 3.4 Game Levels

So far, I have only demonstrated how the second guideline from section 2.5 - the inclusion of an OCD educational part - has been incorporated in my game via the lexicon. In it, I have also introduced the CBT with ERP, which corresponds to the third guideline, however, I have not explained how the treatment approach is applied in the game. In the following section, I will elaborate on how I have used the advantages of AR and CBT with ERP to create three levels, each focusing on one of the OCD subtypes symmetry, ordering and arranging, hoarding and contamination and washing/cleaning.

Before I explain the three game levels in detail, I want to present the general structure of a level. Each level starts with an introduction to the level-specific rules which are designed to conform to the obsessions and compulsions of the OCD subtype in focus. They are presented by the current version of the mascot. For example, the rules of the first level are described by the darkest and most intimidating version of the mascot, because no other game level has been played so far and the influence of OCD over the player is at its highest. Respectively, the second level rules are introduced by the second version of the mascot because the first level has already been completed and a decreased control of OCD over the player is assumed. The mascot is the one to instruct the player because it is the visual representation of OCD and the rules are created in such a way that they resemble what an OCD patient will feel compelled to do in reality or what intrusive thoughts he or she will get in a real-life situation. After the player is familiarized with the rules, a mini-game which applies CBT with ERP is started. During it, the player is exposed to triggering conditions and is asked to perform certain actions, which follow the ERP technique. To ensure immersion and use the player's own environment with which he or she has already formed a connection, AR has been incorporated in all mini-games. Once the current mini-game is finished, which means that the player has successfully performed ERP and has fought against the influence of OCD, an analysis menu is displayed. In it, the next version of the mascot is shown, which is more welcoming and captures the subdued control of OCD. Along with the mascot, an encouraging message is presented that either contains information about what additional tasks have been performed or congratulates the player for finishing the level. The next level begins with the version of the mascot from the analysis menu of the previous level. It is also worth mentioning that before every mini-game is started, the player has the option to go back to the start menu and access the lexicon to refresh his or her knowledge about the specific OCD subtype or the treatment approach.

Now that the general structure of a level has been explained, the next three subsections will focus on the details of the three levels of the game.

#### 3.4.1 Level 1: "Symmetry, ordering and arranging"

The first level of the game is based on the OCD subtype symmetry, ordering and arranging. As it has been mentioned in the general description of the levels, this first level starts with the scariest and most imposing version of the mascot. Figure 3.5 shows the mascot and the rules of the mini-game.

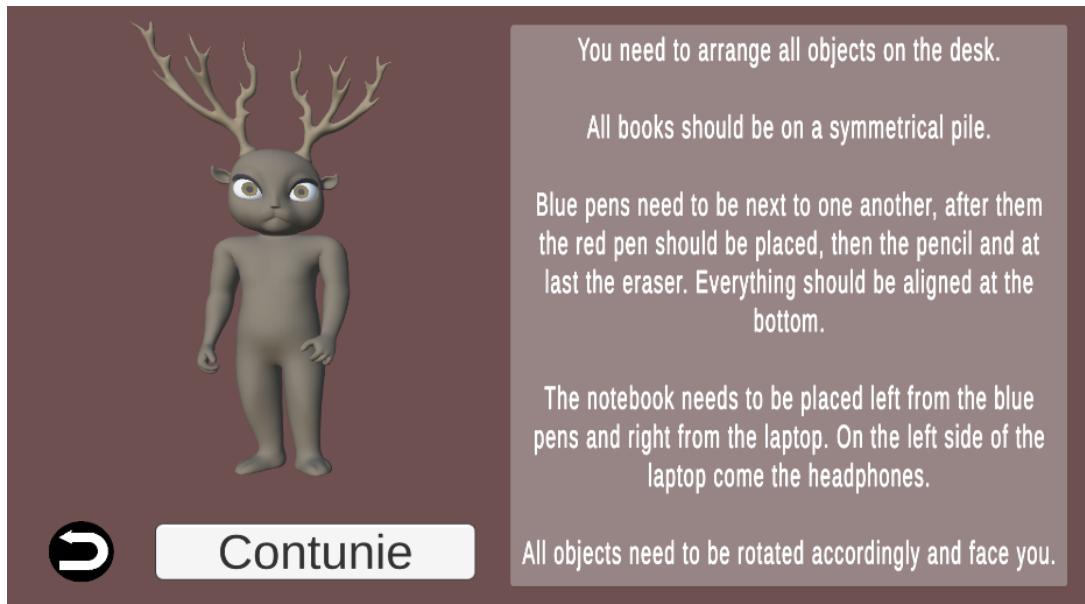


Figure 3.5: Level 1 rules

The rules explain how the objects included in the mini-game need to be placed and rotated. In other words, the OCD mascot specifies how he demands the objects to be placed and rotated. I have used some common items which can be found on a desk at home or at work like books, writing supplies and electrical appliances. The rules have been derived from some typical OCD arranging compulsions. The first rule about the positioning of the books represents the compulsion to group related objects and, if their shape is the same, to form a symmetrical and perfectly even pile. To trigger this compulsion, I have used three books which have the same amount of pages and do not differ in height or width. The second rule contains three underlying compulsions - to group related objects together, in this case, the writing supplies, to sort objects by color and to order objects by descending height. The second compulsion is triggered by the inclusion of two blue pens and a red one and the third one - by the different heights of the items. The three pens have the same height and are larger than the pencil and the pencil is larger than the eraser. Since the writing supplies are meaningless without a notebook, I have also added one and included the next rule. The notebook is bigger than the pens and, thus, has to be placed before them. Because it is common to take notes while working on a laptop, the notebook should be placed on the right side of the laptop. Headphones are almost always connected to laptops and because of that, the rule also specifies the remaining left side of the laptop as the position of the headphones. To follow these rules, the player also needs to rotate some of the objects. Not all items are specifically mentioned in the rules. In that case, the player has the freedom to position them as he or she wishes, but rotation might still be expected. By pressing the back button, the start menu is loaded and players have the chance to revisit the lexicon. The continue button respectively starts the mini-game.

Once the mini-game is started, the player is asked to scan his or her desk for the objects to be placed on it. For this purpose, AR Foundation provides a very useful feature, namely the plane detection service of the AR Plane Manager. When a horizontal plane is detected, a plane game object representing the detected plane is created to help the player keep track of the scanning process. One downside of this service, however, is that the detected planes do not necessarily have a regular shape and the rectangular surface of a desk cannot be ensured. To check whether a detected plane is possibly a desk surface, I use the physical size of the plane in meters to calculate its bounding box area, which represents the rectangular area that fully encloses the plane. Afterward, I compare this value with the standard office desk area, which is around 1.2 square meters. I also compare the length and width of the plane with the standard desk dimensions which are around 1.56m long and 0.76m wide. These values allow me to place all my objects without intersections on the plane, however, it can still not be guaranteed that an actual desk has been found because such planes can be detected on different flat surfaces like the floor, for example. In case a plane with the specified dimensions cannot be found or the detection process freezes, the player has the option to restart the scanning, which will delete all detected planes so far and start the scanning anew.

Figure 3.6 shows the thirteen unordered desk items that are placed on a successfully detected plane. All items except the router and the printer are mentioned in the level's rules. An info button can also be seen at the bottom right corner. Its purpose is again to show the arrangement rules to the player since the mascot expects a specific order which might be forgotten during the mini-game. I have tried to find and use realistic models for the objects to enhance the feeling of immersion which AR brings to the player.

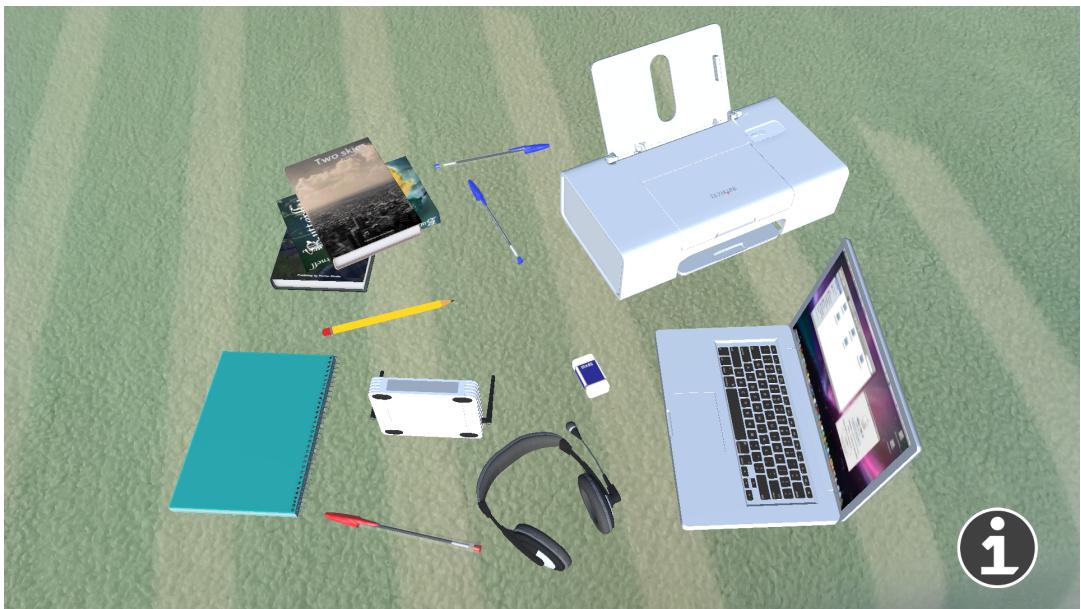


Figure 3.6: Unordered desk items

After the unordered desk items are placed on the surface, the player can start arranging them based on the mascot rules. For that purpose, the desired object first needs to be selected by the player. The selection is an easy process which detects the player's first touch position on the screen. Then a ray is created from the camera through the detected screen point. If the ray intersects one of the desk items, it gets selected and can be rotated and moved accordingly. The ray cannot interact with the UI elements like the info button, which prevents them from getting moved from their original position or rotated. The distinction between performing a rotation or movement gesture is made based on the number of touches which are detected throughout the current frame.

For the rotation, the player needs to use two fingers because I have specified the rotate gesture as a dual touch gesture. The object which is currently selected is rotated according to the delta angle of the vector from the first touch to the second touch. Since the objects need to be rotated around different axes, I have created three groups determined from the required rotation axis - for example, the router needs to be rotated first around its local X-Axis and then around the local Y-Axis and is the only object that needs two rotations, thus, it is in a separate group. To determine whether the item has been rotated correctly, I check its current rotation and the expected one and if their difference is less than six degrees, the object is marked as correctly rotated. Because it can be difficult for players to reach the correct rotation, an indicator is displayed on the top left corner of the screen whenever an item is rotated and it shows whether the rotation is valid or not. In figure 3.7 the valid rotation of the laptop can be seen along with its indicator. The two touch positions are also displayed along with the directions of the vector between both touches.



Figure 3.7: Rotation of the laptop

The movement process requires only one touch, but the item again needs to be selected beforehand. There is also an indicator showing whether the position is correct or not. The objects can only be moved along the X and Z world plane. For that purpose, the touch inputs from the current frame and the previous one are retrieved, the direction of the drag between these two inputs is computed and then converted to an orientation on the X and Z plane. After that, the position of the selected object is modified based on the drag direction. Since the items are spawned on a desk surface, their movement needs to be limited only within the surface area. This can easily be achieved with a ray from the object towards the desk plane and a variable which stores the last allowed position. If the ray intersects the desk plane, the movement is valid and the object and the last allowed position variable are updated. Otherwise, the object remains at the last allowed position.

To check whether the items are arranged according to the mascot rules, in other words, according to the OCD compulsions, again rays have been used. For example, the three books need to form an even pile and because of that, it is checked whether the rays from the four corners of a top book intersect a book below. The pens also have a specific order since they are grouped by color and should be perfectly even. Thus, a ray from the top and bottom of each pen is cast and the intersected object is checked. In the case when an item does not have a specified position like the printer and the router, its position is directly marked as valid. Figure 3.8 depicts the ordering of the writing supplies with the leftmost pen being the currently selected item.

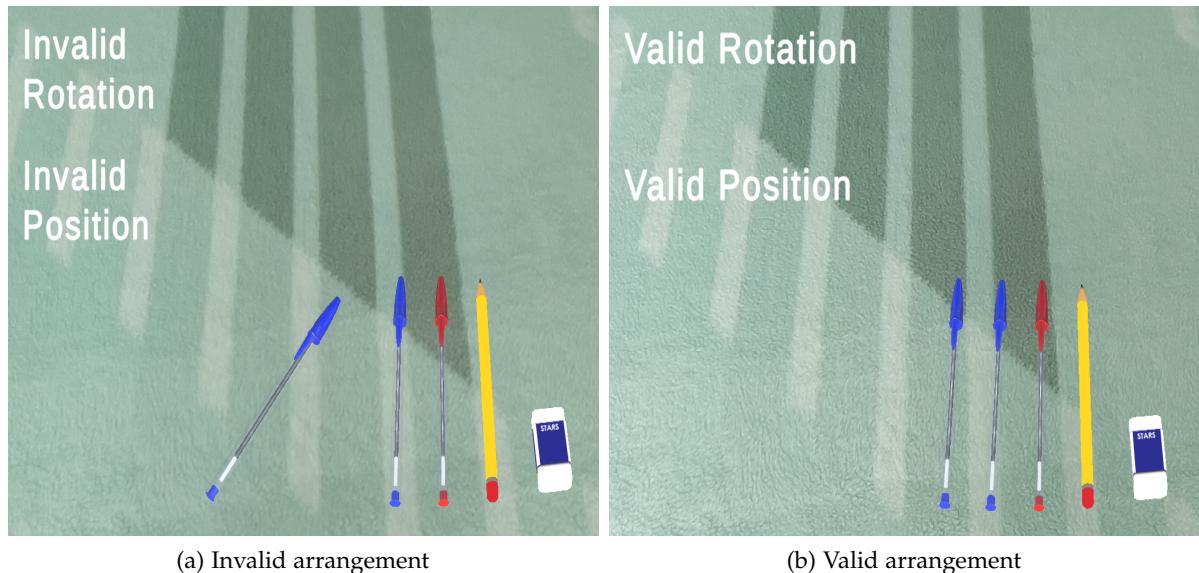


Figure 3.8: Position of the writing supplies

Following the guidelines from section 2.5, this level uses the Exposure and Response Prevention (ERP) treatment approach. The purpose of the unordered desk items shown in figure 3.6 is to expose the player to the triggering conditions of the symmetry, ordering and arranging subtype. After the exposure, players who have symptoms of this OCD subtype will

feel the urge to perform ordering rituals, specified with the mascot rules in this level. Healthy players will not experience the need to reply with compulsions to the exposure, however, they still have to arrange the items in order to proceed with the game, which will make them more familiar with this subtype. While OCD patients order the items, they will reduce the anxiety triggered by the chaos on their own desk. However, the purpose of this level is to improve the subtype symptoms and not only offer temporary relief to the distress caused by the game itself. For that, the response prevention part of ERP is most important and I have used it as follows. When only one object remains out of order - it can either be wrongly rotated, incorrectly placed or both - players are forced to wait five seconds before they are able to interact with it. During this time, no items can be selected and, thus, rearranged. The purpose of these five seconds is to show patients that nothing bad will happen to them if they resist the compulsions. This approach has been applied in RAW HAND [2.4.3] and OCfree[2.4.4] and since both applications have been positively rated by OCD patients, I have also incorporated it in this level. In figure 3.9 it can be seen that the laptop is incorrectly rotated, whereas all other items have valid positions and rotations. Thus, the player now has to wait the respective amount of time which is also displayed on the screen. After the five seconds pass, the laptop can be rotated and, since all objects are arranged according to the mascot rules, this level is over and the analysis menu is displayed. In it, the next version of the mascot congratulates the player about successfully arranging all objects and waiting five seconds before ordering the last one. The player can then proceed with the next level, which will be described in detail in the next section.

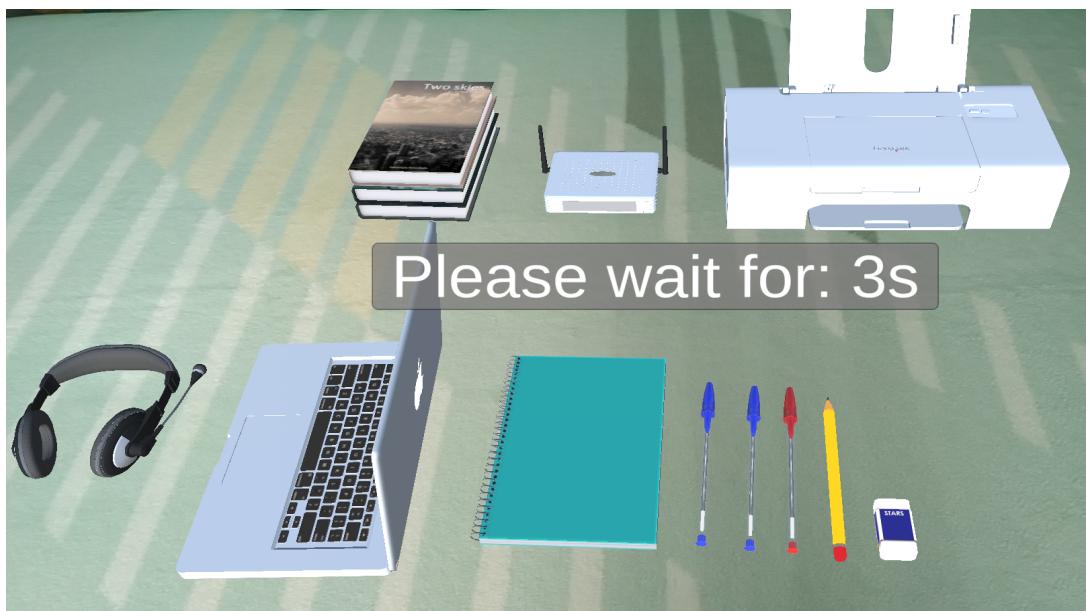


Figure 3.9: Response Prevention

### 3.4.2 Level 2: "Hoarder"

This level focuses on the OCD subtype "Hoarder" and is introduced by the second version of the mascot, which was also displayed in the analysis menu of the previous level. Following the general structure of a level described in 3.4, this version of the mascot specifies the rules of the hoarding mini-game, which can be seen in figure 3.10. In this level, however, the rules are not expectations which the mascot imposes on players but descriptions about his daily life.



Figure 3.10: Level 2 rules

As it has been explained in section 2.2.5 and the Lexicon, patients with hoarding symptoms worry that throwing away items will have negative consequences and, because of that, they collect and retain objects for far too long. Some of these possessions might appear to be of little or no value to others. Dumpsters and bins are also avoided since they are associated with the act of disposal. These characteristics of the hoarding subtype are summarized with the first two rules. The third sentence presents one of the less well-known OCD symptoms, which is not typical for hoarders in general, but allows another opportunity to defy the control of OCD in the mini-game and is also related to the game idea - the movement compulsions [46]. Patients with such compulsions move in symmetrical or special ways - for example, they always step within road tiles and never cross their boundaries. Because the mascot represents all facets of OCD, he also has movement compulsions - he always follows patterns on roads and never steps on their boundaries. Since the strength and influence of the mascot are dependent on the player's actions, the defiance to perform his movement compulsions and the act of disposing of objects make him weaker, as it is stated in the last rule. Once players familiarize themselves with the hoarding rituals of the mascot, they can either continue with the mini-game or go back to the main menu and revisit the Lexicon.

The mini-game starts by asking the player to scan the floor or any other surface. Once the detection is successful a placement indicator is displayed, which snaps to the surface and helps the player keep track of the detected planes and spawn objects on top of it. It is instantiated from the center of the screen and can be controlled by moving the device. Figure 3.11 shows the placement indicator along with all items that need to be arranged somewhere in the room. I have used objects that might seem useless like an old cardboard box, only one shoe from a pair, a fidget spinner or a stack of magazines to emphasize the fact that hoarders find value in all sorts of items. To form a connection with the items, the player first needs to place them wherever he or she wishes by tapping on the desired object. It is then spawned on top of the placement indicator and can be moved and rotated. The movement and rotation follow the exact same procedure as defined in the first level. Players can freely position and rotate an item because, in such a way, the process of interacting with a newly acquired object is simulated. For healthy people, it might not matter much how their useless possessions are arranged, but OCD patients with hoarding symptoms always find a designated place for them. Since the displayed objects are new and different from the ones used in the symmetry level and the game uses AR to incorporate them into the player's real environment, it is imperative to let hoarders take their time and place everything according to their own surroundings. The high levels of immersion which AR provides combined with the freedom to arrange the objects from the game among your real possessions play a vital role in triggering hoarding obsessions and compulsions.

One difference from the first mini-game, which can be spotted in figure 3.11, is the absence of an info button. Since this mini-game does not require a specific order of the objects, all of the gameplay instructions are displayed at the top of the screen in a similar way to the "Place the items" instruction.

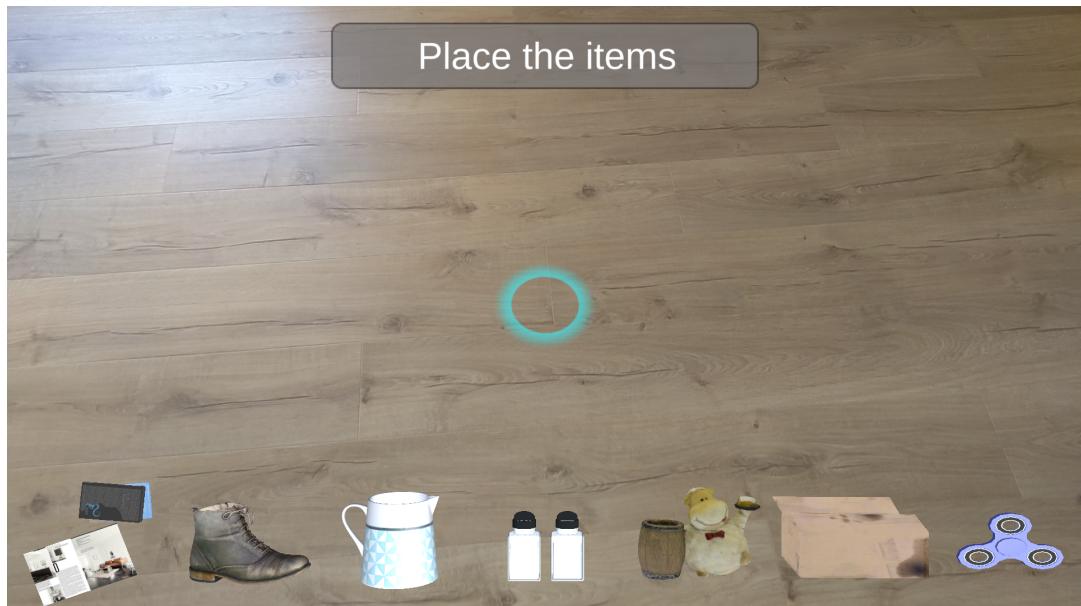


Figure 3.11: Placement indicator and items

Once all objects are placed, the player also needs to position a dumpster which will be used for the disposal act. Picture 3.12a shows the dumpster along with the arranged objects. The dumpster can also be moved and rotated and, if tapped on the top, opened. With the appearance of the dumpster, OCD patients from this subtype are exposed to the triggering situation of having to throw away their virtual possessions. This is an important stage of the mini-game since here the ERP treatment approach is also used and for it to be successful patients need to be connected to the displayed objects. Therefore, the positioning process was introduced before placing the dumpster.

In picture 3.12a the "Draw Road" button can also be seen. When pressed, it allows players to create a road from the position of each item to the dumpster. For the appearance of the road, the Trail Renderer component of Unity was used, which renders a trail of polygons behind a moving object, in this case, the placement indicator. I have applied a simple color to the polygons without specifying any patterns along the road because finding a common triggering pattern among patients is nearly impossible since each individual reacts to patterns differently. Therefore, it is only checked whether the player is currently on the road or not. Figure 3.12b shows the game scene after the road has been drawn. Players can also redraw it as many times as they want because I wanted to give them the chance to create a road they would want to follow in the real world. The road is important for the last two rules of the mascot because if the player spends much time away from it, he or she will have performed additional steps to fight the disorder, even though they are not connected to the hoarding symptoms. The respective amount of time spent away from the road is displayed in the analysis menu of this level.

After the road is drawn, the gameplay continues with the collection of the to be disposed of items, namely all virtual objects which have been arranged so far.



Figure 3.12: Scene before the disposal act

All virtual objects are placed among real objects in the player's own environment and throwing them away in the mini-game simulates how the process would happen in reality - the individual needs to navigate to the respective item, pick it up, go to the dumpster, open it, dispose of the item and close the dumpster. The exact same procedure is followed in the game. Players have to collect all objects and while doing so, they can choose to walk on the drawn road or not. After all objects are collected, they should go to the dumpster, open it and discard everything. The disposal act is depicted in figure 3.13. Once an item is picked up, which happens by tapping on it, it appears at bottom of the screen. After all objects are collected, a scope is positioned at the center, which helps players take a better aim at the dumpster. Tapping on an item from the list below sends it flying through the scope and, because of the physics which is applied, the item falls realistically. The disposal act is the moment when the response prevention is conducted. It differs from the way it has been executed in level 1 because now players are not asked to wait before completing a compulsion but to act against a compulsion. The compulsion here is the reluctance to throw away objects because of the intrusive thoughts that they might be needed in the future or discarding them might lead to terrible consequences. Making OCD patients throw away the items counteracts the response of keeping them for far too long. The advantage of using AR for incorporating 3D objects into the real environment instead of creating a complete virtual world as described in section 2.4.5 provides patients with hoarding symptoms the opportunity to experience the disposal act among their real surroundings. I believe that once hoarders witness that the discarded virtual items are not needed anymore and nothing bad happens, they would start associating their AR experience with real-life and be one step closer to disposing of their actual belongings.



Figure 3.13: The disposal act

To emphasize the future uselessness of the discarded objects, at the end of the mini-game the mascot appears driving a garbage truck that collects the dumpster and drives it away.

Response prevention can also be applied if the player decides to not follow the road from the items to the dumpster, but since this is not related to the hoarding subtype, it is only optional and does not affect the gameplay. However, if patients decide to cross the borderline of the road and spend less time on it, they are additionally reducing the influence of OCD and are congratulated on that in the analysis menu. There the next less intimidating version of the mascot is displayed along with the seconds which the player has spent away from the road.

#### 3.4.3 Level 3: "Contamination and washing/cleaning"

The last level of the game addresses the contamination and washing/cleaning OCD subtype. However, it differs from the previous levels by having two playable versions - the first one was created with AR Foundation and the second one with the Vuforia SDK. Both versions start with the same menu in which the rules of the following mini-game are explained. Similar to the second level, these rules are not expectations imposed on the player but describe some typical symptoms for this subtype which the mascot experiences. In figure 3.14 the third variant of the mascot can be seen along with his obsessions and compulsions. Since the most common obsessions of patients from this subtype include fears of being dirty or contaminated and the triggered compulsions are excessive cleaning or avoiding places which are perceived as dirty or contaminated, the mascot states his hatred and fear of bacteria and dirty objects. To avoid getting contaminated and spreading disease to others, he always cleans himself and his possessions to kill any present bacteria.

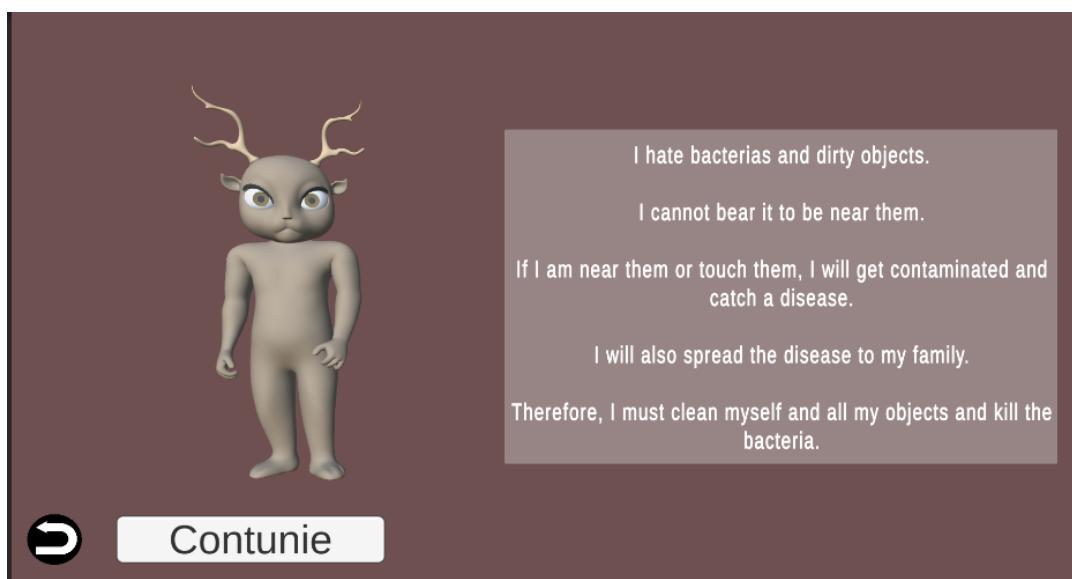


Figure 3.14: Level 3 rules

The following two sections will explain in detail the two developed mini-game versions as well as the differences between them.

### **AR Foundation Version**

Because the previous two levels were implemented with AR Foundation, the first version of the contamination and cleaning/washing level was also developed with AR Foundation. Upon getting familiar with the rules, the player starts the mini-game by pressing the continue button showed in figure 3.14. After that, a surface needs to be scanned for the bacteria on it to be revealed. For that purpose, AR Foundation's plane detection is used, however, its limitations, which are mentioned in section 3.4.1, again influence the game. Even though both vertical and horizontal planes can be used, only flat surfaces can be detected instead of complex 3D objects. This is the case because this level, as well as the whole game, was implemented on a Windows machine and tested with an Android device and only Apple's ARKit offers object detection and tracking. Despite this fact, the level of presence of players is still improved because they see and interact with their real environment, which is a major advantage compared to the purely virtual scenes created in RAW HAND[2.4.3], OCFree[2.4.4] and the VR applications[2.4.5]. Players can scan their actual beds, desks, tables, walls, floors, etc. and since they already have formed a connection with them, it is easier to create OCD triggering conditions by placing 3D virtual bacteria on top of them. The positions of the bacteria are randomly generated within the area of the detected plane and, if the plane's boundary increases, more bacteria get instantiated. For this purpose, Unity's Polygon Collider 2D is used. It is adjusted to fit the shape of the detected AR plane and used to check whether a random 2D position is within its bounds or not. The players also have the option to rescan the surface because the detection process might sometimes produce undesirable results like too small a plane or a plane that does not cover the desired surface. Once they are pleased with the scanned surface, they can press the continue button, which will stop the detection process.

Since this mini-game uses AR to spawn bacteria on top of the actual belongings of players, I believe it will be efficient in triggering obsessions and compulsions in OCD patients with contamination and cleaning/washing symptoms. The treatment approach applied in this level is again ERP with the completion of the scanning process and the positioning of the bacteria representing the exposure part of the technique. The response prevention is realized by asking the player to place a finger among the bacteria, which will make the closest ones move towards the touch position and disappear once it is reached. This simulates the contamination process which OCD patients from this subtype fear. Ten seconds need to pass with the finger being placed among the bacteria. During this period, OCD patients have to fight the urge to remove their finger and not interact with the contaminated surface. A similar approach is used in RAW HAND and OCFree, however, there the player has to remove germs from a virtual character's hand until only one germ is left and then wait five seconds. Since both games make the player remove the germs and it has also been proven that AR applications with virtual killing are able to help patients with phobias for small animals, the next stage of my mini-game is focused on killing the virtual bacteria with a cleaning detergent. Figure 3.15

shows the scene once the ten seconds have passed and the cleaning detergent is displayed. By tapping on it, the bottle shoots a spray and, if a bacteria is positioned in front of the scope, it gets killed and is removed from the surface. Once all bacteria are killed, the mini-game is successfully finished and the last and most welcoming version of the mascot congratulates the player for completing the whole game.



Figure 3.15: AR Foundation Version

### Vuforia Version

As it has been mentioned in the previous section, AR Foundation poses certain limitations when it comes to object detection and tracking. Since bacteria do not only live on flat surfaces and the objects which are associated with dirt and contamination often have a complex shape, it was imperative to improve the first version of the contamination and cleaning/washing level in order to make it more realistic and relatable to OCD patients with such symptoms. Therefore, I used the Vuforia Engine because it allows developers to build Augmented Reality applications for Android and iOS within Unity and supports object tracking and detection. Vuforia offers three methods for this purpose - model targets, object targets and model targets created from 3D scans [47]. The object targets are created by scanning physical objects, however, an additional app and object scanning images are required, which makes the method unsuitable for the objectives of my game. The model targets from a 3D scan are also created from physical objects but hardware-aided scanning is needed, which complicates the process. Thus, I have decided to use model targets because they can easily be created from corresponding CAD (computer-aided design) models and do not need images or scanning.

This version of the level starts with the same rules introduced in figure 3.14, however, the corresponding mini-game cannot directly be started because additional instructions for the gameplay are needed. It has to be mentioned that this version of the level was implemented

in a separate project due to compatibility issues between the newest version of Unity and Vuforia. Therefore, the previous two subtype levels and the lexicon cannot be accessed from it. Since model targets are used for object tracking, the real environment of the player has to be analyzed beforehand for his or her belongings to be classified. The classification is required because the right model targets need to be used in the following mini-game and not every object present in the real environment might have a corresponding digital model target. For example, I have only specified four objects which can be used in the game - glasses, phone, book and laptop. I have decided to use them because they are among the most common belongings of people and their shape is relatively universal, which allows the usage of only one model target per item - the model target tracker can tolerate some deviations between the physical and digital model. The model target database can also be expanded with many different targets, however, for this thesis, I believe the four incorporated objects are enough to test the effectiveness of the level in helping OCD patients.

The classification process is realized with the help of neural networks. Neural networks derive meaning from complicated or imprecise data such as images and can be used to extract patterns and detect objects [48]. Unity offers the Barracuda package, which is a neural network inference library that can run neural networks on both the GPU and CPU. The neural network has to be in ONNX (Open Neural Network Exchange) format and trained for the application. Since the objects in the player's environment need to be classified before the mini-game of this version can start, I have used a pre-trained ONNX model for image classification. The mascot explains in a second menu that players need to scan their possessions to check whether they are contaminated or not. It is also stated that the scanning process is thorough, therefore, the items need to be positioned in front of the device camera long enough for the bacteria to be detected. This is necessary because the neural network might need a longer time to classify the objects depending on the parameters of the used mobile device. Whether an item is marked as contaminated or not depends on its inclusion in the model target database - items that have a corresponding digital model target are labeled as having bacteria, whereas, those that are not in the database are categorized as being clean. In my mini-game, only glasses, phones, books and laptops are marked as contaminated. Figure 3.16 displays the bacteria detection process. Since a model target for the remote control is not present in the database I use in the level, no bacteria are found on it. However, bacteria are detected on the glasses because they have an existing digital model.

The classification process works as follows - first, the image from the device camera is retrieved. Then it is scaled and cropped to meet the input requirements of the ONNX model - for example, the image file dimensions need to be set to 224x224 and the pixel values need to be converted from [0 - 255] to [-1.0 - 1.0]. Afterward, the neural network is executed with the preprocessed image pixels and the object with the highest probability of being depicted in the image is classified with one of the labels with which the network has been trained. This process is executed every 80th frame because it is computationally expensive and might overload some devices. Once an object is labeled by the neural network, it is checked whether it is part of the model target database. If that is the case, it can be used in the following mini-game for the OCD treatment approach. Otherwise, it is marked as uncontaminated

and does not have any further application. With the used database in the current version of the level, the mini-game can be continued once a phone, a book, a laptop and glasses are successfully classified and categorized as having bacteria. When these objects are detected, the execution of the neural network is stopped and the next scene is loaded.



Figure 3.16: Bacteria Detection Process

The next scene focuses on the classified glasses. To detect and track them in real-time, Vuforia offers a 2D guide view which outlines the shape of the desired object. This guide view is created from the CAD model of the item and once it is aligned with the real physical object from the environment, the tracking process is started. Figure 3.17 shows the 2D guide view of the glasses. After the tracking process is initiated, the physical object can be augmented with virtual content. In this mini-game, 3D virtual bacteria are positioned over all items. Their initial positions are fixed and cover the shape of the tracked object. Because the bacteria are placed on actual objects that belong to players, OCD patients with contamination and cleaning/washing symptoms are exposed to the triggering conditions of seeing their possessions being contaminated. Moreover, because of the object tracking feature offered by Vuforia, this version of the mini-game is not limited to only flat surfaces but supports 3D complex shapes. Being able to interact with such complex objects is crucial for the level of anxiety that an OCD patient will experience during the exposure phase of ERP. The response prevention phase is realized by asking the patients to interact with their objects. In the scene with the glasses, the player has to place a finger among the bacteria for five seconds. For that purpose, a ray is created going from the camera through the touch position and it is checked whether it intersects the glasses or not. The model target of the glasses is created from a CAD model of real physical glasses, therefore, a virtual 3D model with a similar shape is already present and can be used for the intersection.



Figure 3.17: 2D Guide View Of Glasses

Since the glasses are the first item which is introduced in the mini-game, the germs remain static and should not be killed after the five seconds are over. There are also only four of them because I have tried to adjust the anxiety level which will be triggered in patients based on the number of items they have already interacted with. Therefore, the waiting time and the number of the displayed bacteria increases in the second scene where the tracked object is the phone. The detection process is the same as with the glasses - the physical phone has to be aligned with the displayed 2D guide view for the bacteria to appear. A finger again needs to be placed among the bacteria, however, now 10 seconds need to pass before it can be lifted. The germs remain static and do not have to be killed. In the next scene, which focuses on the book, the bacteria start to move towards the touch position and disappear once it is reached. As it has already been explained in the AR Foundation version, this simulates the contamination process and is an important part of the response prevention stage. The movement of the bacteria towards the finger position could cause greater distress than a static environment, therefore, the waiting time has not changed compared to the previous scene and the bacteria should not be killed. Once the number of displayed germs reaches a predefined limit, more germs get randomly spawned over the object. Since the book is the third item which patients have to interact with and they have already successfully applied the ERP treatment technique during the previous scenes, the book scene confronts them with a more difficult response prevention approach, namely having to resist the urge to remove their finger while germs move towards it. Only in the fourth and last scene where the laptop is being tracked the displayed germs need to also be killed after the wait time has passed and the germs have moved towards the touch position. The killing process is left for the last object because it is assumed to cause the greatest anxiety in OCD patients and the applied ERP from the previous scene should prepared them to deal with the triggered distress and

apply the respective response prevention actions. In figure 3.18 the already tracked laptop can be seen with the placed bacteria over it and the displayed detergent spray bottle. The killing process is the same as described in the AR Foundation version - the player has to tap on the detergent bottle and it will shoot a spray towards the scope. If there is a bacteria in front of the scope, it will be killed and removed from the laptop. When all germs are killed, the congratulation menu with the last variant of the mascot will be displayed and the level will have successfully been finished.

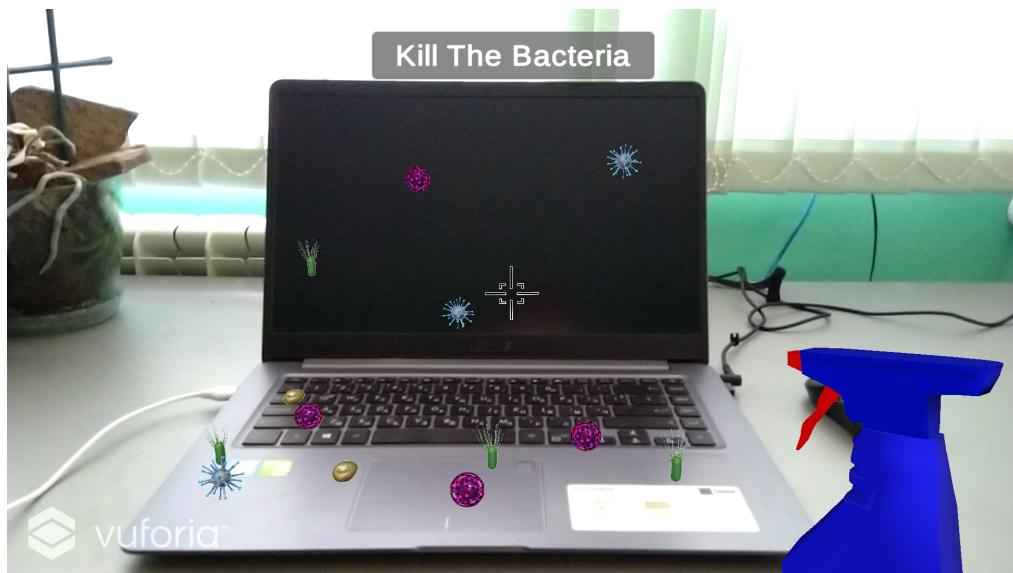


Figure 3.18: Contaminated Laptop and Detergent Bottle

Since there are only four objects that can be detected and tracked in this version of the level, their order has been predefined. However, if the model target database is expanded with many different models, the used items in the scenes can be randomly selected. The level of anxiety triggered by the exposure and response prevention techniques will still be adjusted depending on the number of items players have already interacted with.

The immersiveness which AR offers to players and the ability to augment real physical objects that belong to them create numerous possibilities for the application of AR in treating OCD and other disorders. In this chapter I have introduced and described the AR-based serious game for OCD, which I have developed during this thesis and its main objectives - to educate both healthy people and people that suffer from OCD about the disorder, to incorporate AR and CBT with ERP to help patients reduce their symptoms and to create game levels based on different OCD subtypes. The next chapter will discuss the effectiveness of the game in achieving these objectives by presenting the results and the way an evaluation of the game was conducted.

# **4 Evaluation**

The research topic introduced in chapter 1.1 and the derived development guidelines from section 2.5 have outlined the need to create an evaluation form which can be answered by both healthy people and people who suffer from OCD. This survey aimed to assess the ability of my AR game to educate about the disorder, to trigger anxiety and compulsions in OCD patients and to apply CBT with ERP as a treatment approach. Another aspect was also defined in the research topic section, namely the effectiveness of the game to improve OCD symptoms, however, since such improvements depend on different factors like the severity of the symptoms and the motivation of the person and there is not an exact time point after which significant decrease in OCD symptoms should be expected, this aspect was left out of the evaluation and the following discussions.

## **4.1 Evaluation form and participants**

The evaluation was conducted with an online survey which has two versions depending on whether the participant suffers from OCD or not. This is determined with the first question, which also differentiates between healthy people who know about the disorder and such that have not heard of it before. Since it was not possible to conduct an in-person survey due to the limitations imposed by Covid-19, the survey was published in different social media websites, OCD self-help groups and chats and healthcare forums. In it, representative videos of the developed AR game were included along with short descriptions introducing the game idea of each level and the applied treatment approach. A video about the lexicon was also added because it plays a crucial part in the educational process. The game was still under development when the survey was published, therefore, a playable version was not offered to the respondents. The video about the contamination and washing/cleaning subtype covered only the AR Foundation version of the miniigame because the Vuforia version was in the early stages of implementation.

23 people in total participated in the evaluation - 10 people had OCD, 12 already knew about it and only 1 person had never heard of it before. Due to the limited number of participants as well as the fact that the people who suffer from OCD were not asked about the severity of their symptoms, what kind of obsessions and compulsions they experience and what type of treatment approaches they have already gone through, if any, the results might not be representative enough. Therefore, a future evaluation with more respondents who also have the option to play the final version of the game is needed and might produce different results than the ones discussed in this chapter.

## 4.2 Results

The results from the conducted survey will be discussed in the following two sections which analyze the reviews received by respondents with and without OCD.

### 4.2.1 Respondents without OCD

As it has been mentioned in section 4.1, 13 participants without OCD evaluated the game - 12 of them knew about the disorder and only 1 person was introduced to it by the survey. To discover the general opinion of the respondents about the ability of games to educate about medical conditions, they were asked to evaluate their effectiveness regarding that matter on a scale from 1 to 5, with 1 being very ineffective and 5 very effective. The results showed a positive attitude towards the ability of games to educate about medical conditions with the average score being 3.77. Only two people gave a score below 4 which indicates that games are well-accepted as a possible educational technique.

The next survey question introduced the lexicon with its three sections. The participants were asked to grade its informativeness again on a scale from 1 to 5, with 1 being very uninformative and 5 very informative. The average score was 4.38 and it suggests that the included information in the lexicon was educative and not overwhelmingly complex. Since there was a distinction between people who already knew about OCD and such that did not, it was imperative to analyze the ability of the lexicon to provide long-lasting knowledge to uninformed people, as well as new information to those familiar with the disorder. The person who was not familiar with OCD gave a score 2 out of 5 for the likelihood that he or she would remember the information from the lexicon, with 1 being very unlikely. Because there is only one answer to this question, no conclusions can be derived about the actual effectiveness of the lexicon to present new information in a long-lasting manner. 91.7 % of the people who knew about OCD, however, stated that they have learned something new from the lexicon which suggests that the lexicon provides information beyond the well-known facts about OCD.

The next section of the evaluation presented the symmetry, ordering and arranging mini-game. The respondents had to answer three questions whose purpose was to assess the overall effectiveness of the mini-game in explaining the OCD symptoms of this subtype to healthy people. Figure 4.1 shows the results of the participants who were already familiar with OCD. As it can be seen from the diagram, the mini-game received positive reviews regarding its ability to explain the symmetry, ordering and arranging subtype. The combination of the mini-game with the lexicon is also believed to provide long-lasting knowledge about the disorder. An interesting observation about this statement is that the person who did not know about the disorder before the survey also agreed that the mini-game combined with the lexicon could present the information in a long-lasting manner.

A similar survey section was created for the hoarding mini-game, however, the results showed rather mixed opinions. 6 out of 12 respondents were somewhat skeptical about the effectiveness of the mini-game in explaining the hoarding subtype and the behavior of patients who suffer from such symptoms. Despite that, the majority of the participants (75%)

positively rated the combination of the mini-game and the lexicon as diagram 4.2 depicts. These tendencies could also be observed in the answers of the person unfamiliar with OCD

The last questions in the evaluation were about the contamination and washing/cleaning mini-game. It received generally positive reviews, which can be seen in figure 4.3. 75% believed they better understood OCD and people who suffer from it after watching the presented video, the remaining 25% were mostly neutral with only one person strongly disagreeing. The same conclusion can be reached about the effectiveness of the mini-game in explaining this OCD subtype. The positive attitude towards the combination of the mini-game and the lexicon can again be observed with 83% (strongly) agreeing that it would be effective in providing long-lasting knowledge about OCD. This mini-game was also well-received by the person who was not familiar with OCD. One respondent shared his/her concern within a general feedback about the possibility of OCD patients from this subtype to perceive the place where they were playing the game as contaminated because of the virtually incorporated bacteria and feel an urge to clean it afterward.

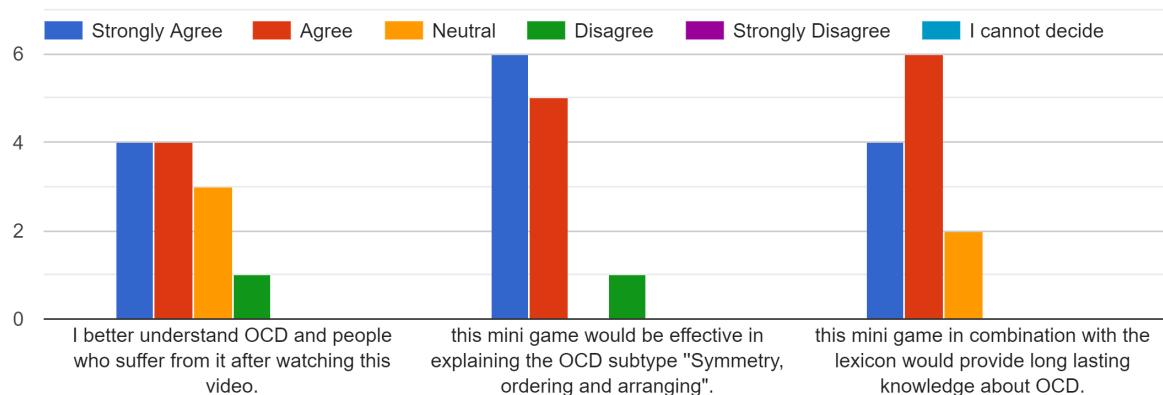


Figure 4.1: Diagram For "Symmetry, ordering and arranging" mini-game

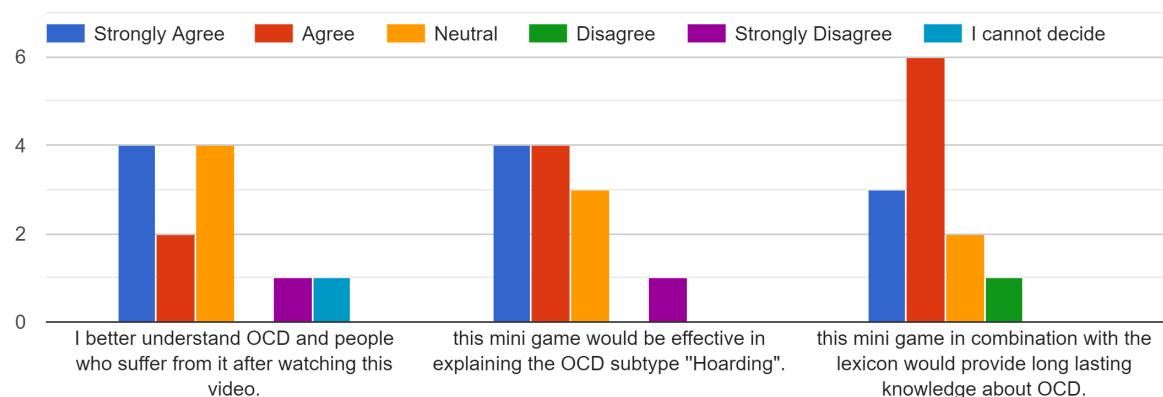


Figure 4.2: Diagram For "Hoarding" mini-game

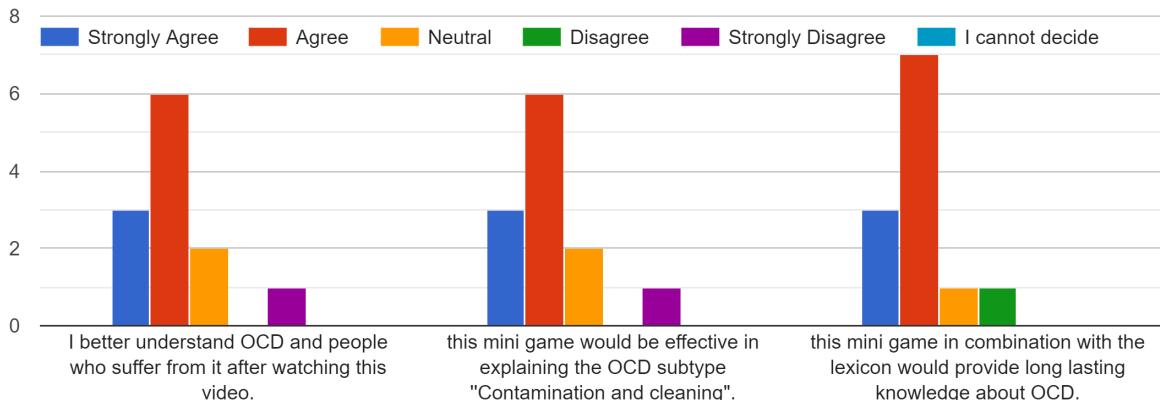


Figure 4.3: Diagram For "Contamination and washing/cleaning" mini-game

#### 4.2.2 Respondents with OCD

10 people suffering from OCD participated in the evaluation. The first question they were asked was whether they go to therapy or not because it is an important factor for the effectiveness of the applied treatment approach in the game. The option to not answer was also available, however, everyone replied - 60% were going through therapy at the time the survey was taken and 40% were not. The respondents who were seeing a therapist could optionally share their satisfaction with their progress during therapy. On a scale from 1 to 5, with 1 being very unsatisfied and 5 very satisfied, the average score of the 6 answers was 4.0. Those who were not going through therapy could also optionally share their reasons behind this decision with the only answer being - "The severity of my symptoms doesn't justify the high costs of therapy." 100% of the participant stated their wish to try a self-help game for improving their OCD symptoms.

The next survey section introduced the lexicon. The respondents were asked to grade its informativeness on a scale from 1 to 5, with 1 being very uninformative and 5 very informative. Similarly to the participants without OCD, the average score here was 4.40. The following question aimed to determine whether the lexicon would actually be used in the game or not. The results showed that 60% would use it, 30% weren't sure and 10% would not use it. From the people who were not seeing a therapist, everyone except one would use it. The only "No" answer came from a person who was going through therapy. These results indicate that the lexicon is important and useful for people with OCD, even though some of them are seeing a therapist.

After the evaluation of the lexicon, the respondents with OCD were introduced to the symmetry, ordering and arranging mini-game with the same short video and description, which the healthy participants saw. They were asked to rate the intensity of the anxiety they felt while watching the clip on a scale from 1 to 10, with 1 being very light/I didn't feel any and 10 very intense. The average score was 6.0, which shows that the mini-game successfully triggered anxiety in patients, however, it is worth mentioning that the answers could not be grouped in clear clusters. This highlights the differences between people who suffer from

OCD and the way they react to triggers. A possible reason for this diversity could be that some of the respondents do not experience symmetry, ordering and arranging symptoms or they only have mild symptoms, which would explain why the exposure to the unordered desk items did not cause high levels of distress in them compared to the people who gave a higher intensity score. The next question asked the participants whether they were relieved after all items were arranged with 70% saying "Yes", 10% "No" and the rest stating that they would have felt relieved if they could have arranged them as they wanted. These results indicate that the caused anxiety from the mini-game was successfully reduced throughout the gameplay but they also outline an improvement suggestion, namely the option to use personalized ordering rules instead of predefined ones. Due to the fact that the waiting time explained in section 3.4.1 plays a central role in the ERP treatment approach applied in the game, the respondents had to assess three statements about the five seconds before the last item could be arranged. The results can be seen in figure 4.4. 80% of the participants were distressed during the waiting time and wanted to arrange the item, which confirms the ability of the mini-game to trigger ordering obsessions and compulsions. However, only 40% thought that something bad will happen because of the inaction. The same 40% realized with the passing time that nothing bad will happen, which suggests the effectiveness of the applied ERP technique.

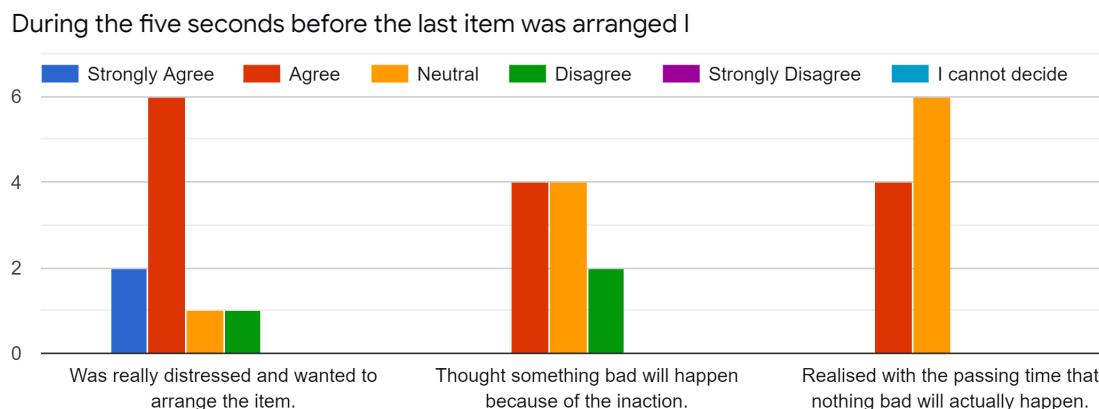


Figure 4.4: Diagram For "Symmetry, ordering and arranging" mini-game (OCD Respondents)

The next section of the evaluation presented the hoarding mini-game. The respondents with OCD were again asked to rate the intensity of the anxiety they felt while watching the presented video on a scale from 1 to 10. The average score this time was 4.8 with no clear clusters. The second question was about their reluctance to discard the virtual items if they played the game. 6 out of 10 people confirmed that they would be reluctant to throw away the objects, however, 2 people stated they would not have problems with that and 1 said that he/she was not sure. There was also a participant who said that his/her answer depended on whether the dumpster was already open or not - if it was closed, he/she would not want to touch it. It could be concluded that this person might have contamination symptoms since dumpsters are normally associated with dirt and bacteria. The participants who would not be reluctant to discard the items and the one who was not sure might have not connected

with the virtual objects or the severity of their hoarding symptoms, if they have any, might not be that high. The last questions about the hoarding mini-game focused on the feelings of the respondents after the objects were discarded. As it can be seen in diagram 4.5, the game received rather mixed reviews regarding that matter. 60% of the respondents were not distressed because of the possible future value of the discarded items. 50% also did not feel relieved because nothing bad had happened after the disposal, which might be due to the fact that they did not find the game stressful at all or the applied ERP technique was not enough to relieve the caused anxiety. However, the other half of the people suffering from OCD found it relieving that no dreaded consequences had followed, which suggests that the treatment approach was successfully incorporated.

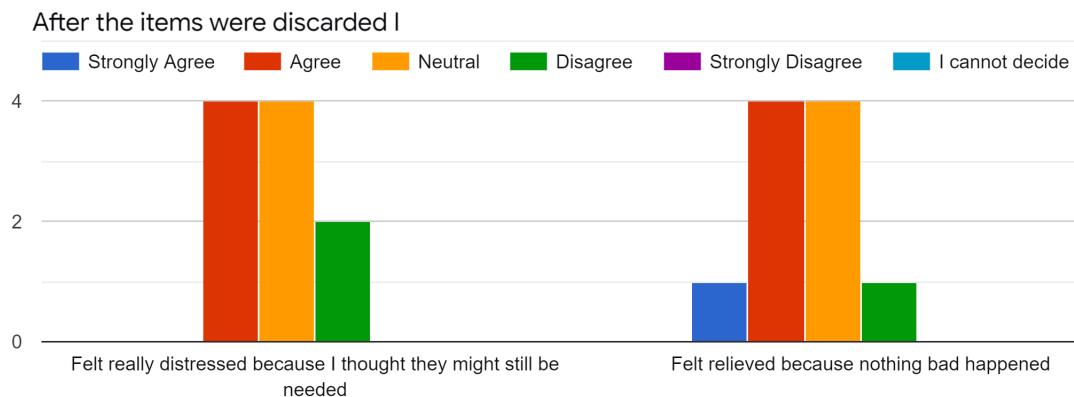


Figure 4.5: Diagram For "Hoarding" mini-game (OCD Respondents)

A similar survey section was created for the last mini-game about the contamination and washing/cleaning subtype. The average intensity of the anxiety people felt while watching the uploaded video of the AR Foundation version of the game was 7.1. The same scale was used as described in the previous two paragraphs. This result ranks the contamination and washing/cleaning mini-game as the most distressing one for the respondents with OCD. It also suggests that the Vuforia version might receive even a higher score because it is not limited to flat surfaces only but supports the detection and tracking of complex 3D objects, however, further research about this hypothesis is required. The high score could also be explained by the possibility that the majority of the participants experiences more severe contamination and washing/cleaning symptoms compared to the other OCD subtypes. As it can be observed in figure 4.6, 90% of the respondents stated that it would be distressing for them to see all these germs on their belongings. These answers indicate that the used 3D virtual bacteria and their incorporation into the real environment successfully trigger obsessions and compulsions and are effectively applied in the exposure stage of ERP. 70% would also find it hard to keep their finger placed among the bacteria. Furthermore, 7 out of 10 participants would find the killing of the bacteria relieving. These two observations imply that the response prevention technique used in this mini-game is able to relieve the caused anxiety from the triggering conditions.

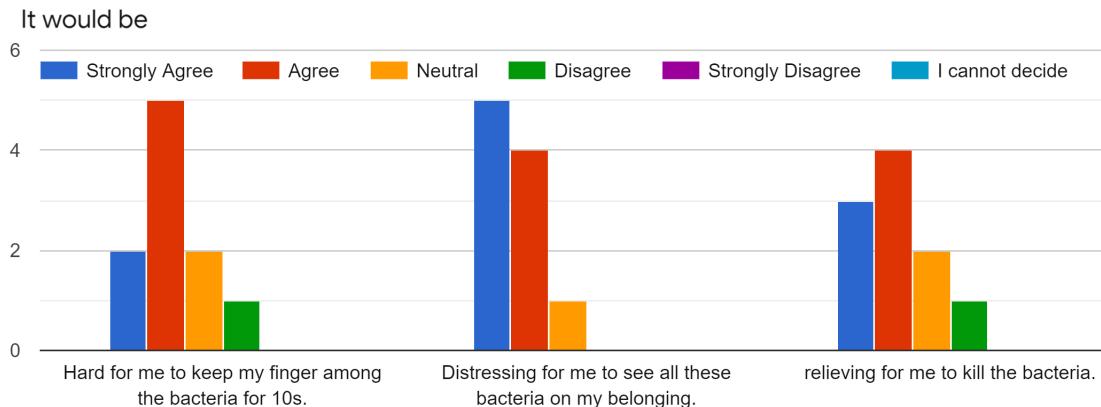


Figure 4.6: Diagram For "Contamination and washing/cleaning" mini-game (OCD Respondents)

The general feedback of the respondents with OCD can be summarized as follows:

- The game would benefit if all OCD subtypes have corresponding mini-games instead of only three of them.
- The symmetry, ordering and arranging mini-game would be more effective if the player specifies the ordering rules and they are not predefined.
- The game would benefit if the mini-games are not so specific and only targeted for the most common subtypes. A way to personalize the levels would be appreciated.

## 5 Conclusion and Future Work

Obsessive-compulsive disorder (OCD) is a medical condition which affects thousands of people around the world. Their daily life is impaired by recurrent distressing thoughts and repetitive behaviors, however, many do not receive proper treatment out of shame, financial difficulties or lack of medical specialists. Different treatment approaches exist like the prescription of antidepressants, cognitive behavioral therapies (CBTs) with exposure and response prevention (ERP) and acceptance and commitment therapies, but they require the presence and guidance of a therapist. Self-help approaches have been created that are more accessible and still efficient. Among them are bibliotherapies, self-help groups and computer- and telephone-based CBTs.

The technological advancements of recent years have outlined the application of video games in enhancing treatment compliance and promoting health-related behavior change. The effectiveness of video games which apply CBT with ERP in improving OCD symptoms has been proven in numerous studies. The advantages of Virtual Reality (VR) have already been used for the creation of OCD self-help games, however, the potential of Augmented Reality (AR) technologies in treating OCD is still to be researched. The ability of AR to trigger obsessions and compulsions in OCD patients with contamination and washing/cleaning symptoms has been confirmed in some studies, but no fully developed AR application has been proposed for the treatment of OCD. Therefore, during this thesis, an AR-based serious game about OCD was implemented and analyzed. Its objectives are to educate both healthy people and OCD patients about the disorder, to incorporate AR and apply CBT with ERP in order to improve OCD symptoms and to create mini-games based on the different OCD subtypes.

A lexicon is included in the game whose purpose is to fulfill the first objective - to provide an educational section. The evaluation of the game revealed that the lexicon was well-accepted by all respondents and believed to be highly informative. It was also concluded that the lexicon in combination with the developed mini-games would be efficient in bringing long-lasting knowledge about OCD.

The rest of the objectives are realized within the three implemented mini-games, which focus on the OCD subtypes "Symmetry, ordering and arranging", "Hoarding" and "Contamination and washing/cleaning". The immersiveness and the ability to add virtual content into the real world, which AR offers, were used in the mini-games for the application of the ERP treatment approach. The analysis of the already developed games that apply ERP helped me to outline the most effective techniques, create their AR alternatives and adjust them for each level. The evaluation of my game suggested that the implemented AR mini-games would be effective in triggering anxiety in people suffering from the respective OCD symptoms. The "Contamination and washing/cleaning" mini-game was rated as the most distressing

mini-game, followed by the "Symmetry, ordering and arranging" mini-game. The "Hoarding" mini-game received rather mixed reviews with some respondents with OCD stating that the disposal of the virtual items would neither be distressing nor relieving. However, the assessment of the other two mini-games revealed that the applied ERP treatment techniques would be effective in reducing the triggered anxiety.

The general feedback received from the evaluation outlined some improvement suggestions which I would like to address and realize in the future. So far, the game offers mini-games for only three of the OCD subtypes. Therefore, not all people suffering from OCD could benefit from it. Mini-games about the subtypes "Harm obsessions and checking rituals" and "Obsessions without overt compulsions" could be designed and included. The option to create personalized levels would also be extremely advantageous because often OCD patients do not belong to only one subtype but have various symptoms which could be addressed in a single mini-game. Furthermore, some obsessions and compulsions are too specific to be categorized and are triggered by conditions that are difficult to predict.

The mini-game about the "Symmetry, ordering and arranging" subtype could be improved by offering players the option to specify the arrangement rules themselves instead of using the predefined ones. This could greatly increase the effectiveness of the applied ERP because patients would order the virtual items according to their own obsessions and then be asked to wait before performing a compulsion they would actually experience with real physical objects. The object detection and tracking feature of Vuforia could also be used in this mini-game to enhance its immersiveness by offering patients the chance to apply ERP with their actual possessions. However, currently, Vuforia only offers the tracking of a single object but, hopefully, they would also improve their tracking methods and offer simultaneous multiple object tracking in the future.

The "Contamination and washing/cleaning" level currently supports only four objects that can be classified as contaminated by the neural network. This is an easy to fix limitation by expanding the model target database used in the mini-game with more items. They could then be classified by the running neural network and grouped by relatedness for the creation of different stages. For example, a "bathroom" stage could be designed during which typical bathroom furniture could be marked as contaminated and covered with virtual bacteria. The currently used neural network is also trained to detect around thousand objects, however, some of them are not suitable for the mini-game. A possible improvement could be to find a better-suited neural network or personally train one.

The "Hoarding" level could also benefit from the object tracking feature of Vuforia. Instead of discarding random objects, the player's environment could be scanned. If an item is detected that has a corresponding model target, the 3D virtual model of it could be discarded or even the tracked physical object. The drawn road could as well be further improved with different patterns, however, they would somehow need to be specified by patients. For example, before the mini-game starts a sample could be drawn, which would then be applied to the road, or a collection of different patterns could be offered with the option to select one.

The AR-based serious game about OCD will continue to be worked on in the future to implement the above-discussed suggestions.

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