A serious VR game for acrophobia therapy in an urban environment

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***Abstract*— Much of the costs and dangers of exposure therapy in phobia treatment can be removed through virtual reality (VR). Exposing people to heights, for instance, might sound easy, but it still involves time and money investments to reach a tall building, mountain or bridge. People suffering from milder forms of acrophobia might not even be treated at all, the cost not being worth it. This paper presents a prototype that allows exposure therapy to be done in a controlled environment, in a more comfortable, quick and cheaper way. By applying acrophobia questionnaires, collecting biophysical data and developing a virtual reality game, we can expose volunteers to heights and analyze if there is any change in their fear and anxiety levels. This way, regardless of the initial anxiety level and phobia severity, we can check if there is any post-therapy improvement and verify if virtual reality is a viable alternative to real-world exposure.**

Keywords— virtual reality, phobia, exposure therapy, biophysical, immersion

I. Introduction

Our purpose was to create a virtual environment for treating fear of heights, a phobia that is very common and easily reproducible in VR, but, on the other hand, not the easiest or the most comfortable to be treated by in-vivo exposure. We wanted to create an application which demonstrates the utility of a virtual world, as well as one which may realistically be used in a professional environment. This project represents a prototype, a demonstration of an urban environment meant to treat fear of heights. The objective is to determine the viability of such an application and to analyze the data collected in the hope of finding improvements in the users' anxiety levels. Although the prototype is functional, it has not been verified for professional use or treatment by any psychologist.

Due to unforeseen circumstances related to Covid-19, we could not proceed with our scheduled testing on volunteers. Therefore, all the results and feedback presented in the paper have been obtained from colleagues who possess HTC Vive VR glasses at home and accepted to test the game.

II. Related work

Treating phobias by means of exposure therapy emerged in the 1950s [1]. South African psychologists and psychiatrists first used exposure as a way to reduce pathological fears such as phobias and anxiety-related problems. Moreover, they brought their methods to England in the Maudsley Hospital training program. The first study using virtual reality for treating a psychological disorder was published in 1995 [2].

VR technology has been considered for medical use for quite some time [3][4][5]. A lot of research has been done in order to determine the effectiveness of VR treatment for anxiety disorders. Overall, various meta-analyses have shown that VR is an effective therapy tool, due to its lasting effects that generalize to the real world [6].

In what concerns video games, due to the continually decreasing prices of VR headsets, a great number of applications have been developed. On top of that, developing games in smaller teams or as a hobby has become much more popular, and a lot of people now own powerful smartphones to run basic VR apps [7].

While most of these games are intended for entertainment, however, they can still be considered as good examples of virtual reality simulations. "Fear simulator" [8] is a simple VR game which places the player in a scary scenario. The developers intended to convey realistic scenarios and sounds in order to fully immerse the player. The game contains 12 scenarios, including claustrophobia, acrophobia, arachnophobia and a few others. Unfortunately, the game does not seem to be very interactive, as the player either stands still, looks around, or is placed on rails and moves automatically. Some scenarios are more terrifying and realistic than others. The game was developed in 2019 and it has a few downloads and some mixed reviews. "Late Night Shop" [9] is a first-person horror puzzle game. This game can be applied for fear of mannequins or human-like figures – automatonophobia. The feeling of unease comes from the mannequins that move. They change their positions or follow the player when s/he is not looking at them, creating a sense of anxiety and the unknown.

"Walk the Plank VR" [10] has a fairly simple concept: the player rides an elevator to the top of a building and then walks on a plank that becomes narrower the further s/he goes. The game uses the sensors in the smartphone to move

the player in VR as s/he moves in real life. "VR Heights Phobia" [11] has the same concept. However, in this game, the player navigates a maze of planks. The goal is to reach the lower levels of the building by navigating on the spiraling planks. The movement is done by tracking the movements of the player in real life.

A similar game, rendered on a head-mounted display, is called "Richie's Plank Experience" [12]. The player rides an elevator to the top floor of a tall building and walks on a plank outside, looking down at the traffic and birds. This game has been developed to be used in events, exhibits, gatherings or any situation in which multiple people could be involved and entertainment/psychological experience might be required. The use of a plank in real life improves the experience and increases the player's immersion. The exposure may be too extreme for someone suffering from acrophobia, as in professional therapy scenarios it is required to have a more calming environment in order to obtain efficient results. Nevertheless, the game is still a good example of VR immersion that triggers physiological and psychological responses.

Two realistic environments (a mountain and a city view) are presented in [13]. The interaction is ensured by Kinect motion detection. Gear VR along with a Samsung mobile phone are used as Head Mounted Display (HMD) kit. 20 subjects have been divided into two groups: one group underwent real-world exposure for two months and the other went through virtual exposure for the same amount of time. The results revealed that the anxiety levels dropped from 64% to 40% in the case of the second group.

ZeroPhobia [14] contains six animated modules with explanatory voice-over and a virtual therapist, mobile VR games with the setting in a theatre hall (where the user could climb a ladder, repair the platform, look down on objects situated on the floor) and 360 degrees videos, controlled by the user's gaze. The results of an experiment in which 66 subjects participated showed that the optimum practice time in VR was around 25 minutes, increased exposure time does not result in increased benefit and that there was an important decrease in self-reported anxiety between levels and after treatment.

Virtual Reality Exposure Therapy is able to induce anxiety responses in the people suffering from acrophobia [15]. 10 subjects (5 with acrophobia and 5 from the control group) have been presented with a virtual 3D model of a city, containing a walkway between two buildings at the 5th floor and a view from the roof of a seven-story building. There was also observed a positive correlation between the anxious behavior and the reported fear level. The authors suggest that an increase of 15 bpm (or more) in the heart rate, from baseline to VR exposure to heights, can be considered a successful indicator of anxiety.

The study presented in [16] evaluated verbal and behavioral fear responses inside a CAVE device, simulating a height-related environment (a hilly landscape with a metal structure in the middle, containing four platforms situated at different heights above ground), where stereoscopic images have been projected on the walls and on the floor. The results of an experiment with 99 participants showed that the projection increased immersion and fear responses, but it did not affect the sense of presence.

Concerning the best interaction modalities, the research of Kiritikos et al [17] showed that the highest feeling of presence was obtained while using Motion Recognition Cameras, compared to Hand Controller systems, for 20 study participants, in a virtual environment on the topic of acrophobia. The subjects had to execute three consecutive tasks – walk across a room and exit on the balcony, reach the balcony railing and catch an object hanging at a particular distance from the balcony's railing. Motion tracking transferred the responsibility of interaction from the user to the system, improving in this way immersion and presence.

Motion tracking ensured by the Kinect device is also implemented in the study of Suyanto et al [18]. The game Acrophobia Simulator contains three different scenes – a river, a city and a mountain. The game was tested with 10 participants who recorded a reduction of their phobia level.

E-virtual reality is also efficient for the acrophobic population [19]. Six acrophobic users went through three remote sessions, followed by three traditional sessions in the presence of a therapist. The virtual environment consisted of the view from the balcony of an office situated at high altitude in an office building. The virtual and the real-world sessions elicited the same level of anxiety, measured using specific questionnaires and physiological responses (heart rate).

The level of acrophobia has been automatically estimated by analyzing EEG data from 66 subjects who played the game Ritchie's Plank Experience in a virtual environment. The users were exposed to heights virtually, while standing on a real plank. The deep learning model achieved an average accuracy of 88% for detecting the volunteers' acrophobia level [20].

The VR simulator described in [21] is not dedicated to therapy, but to companies which want to test if their workers developed acrophobia. The virtual environment is composed of an aerial device with a moving platform and a virtual ladder placed on top of an electric pole, at 11.6 meters above ground. It contains buildings, moving cars, rocks and other natural elements, such as moving clouds. The user can see his/her hands in the virtual environment due to the HTC Vive trackers.

III. Brain activity in acrophobic subjects

The brain activity in the prefrontal cortex (PFC) was examined for 13 acrophobic subjects who were asked to walk on a virtual plank at a height of 6 meters above ground [22]. After the first exposure to stimuli, the activity in the dorso-lateral prefrontal cortex (DLPFC) and medial prefrontal cortex (MPFC) decreased and then increased to normal after the third (and final) session of exposure. This means that the acrophobic subjects succeeded to reappraise the fear-eliciting stimuli following the therapy sessions. There was an increase in the oxygenated hemoglobin level (HbO) in the left DLPFC, which supports the idea that positive stimuli are processed in the left hemisphere and negative stimuli are processed in the right hemisphere [23]. Also, the left DLPFC is activated when there is done a

memory effort in the direction of recalling positive information [24].

People suffering from phobias exhibit a decreased activation in DLPFC and MPFC and an increased activity in the amygdala when exposed to fear-provoking stimuli [25] [26]. DLPFC and MPFC inhibit the activity of the amygdala and mediate the reappraisal of negative emotions [27] [28]. There is a negative relationship between the activity of the DLPFC and MPFC and that of the amygdala, in both healthy and phobic subjects [29]. The healthy patients have an increased activity in the DLPFC and MPFC while perceiving fear-eliciting stimuli [30] [31].

The study presented in Paquette et al [32] showed that there was a significant activation in the right DLPFC in patients suffering from spider phobia before cognitive behavioral therapy when presented with phobogenic stimuli. Left occipital gyrus activation has been noticed in the case of control subjects when exposed to fearful stimuli and in the case of the phobic participants, after the CBT sessions. An activation in the right PFC was observed by Johanson et al [33] when the subjects have been exposed to a video presenting living spiders.

By taking into account Davidson's model of approach-withdrawal, we consider that in order to reappraise negative emotions which are processed in the right hemisphere, the patient should commute his/her cortical activity to the left hemisphere which processes positive emotions. As the left hemisphere is responsible with mathematics, logic, sequencing and thinking in words, we consider that short exercises, quizzes, riddles and verbal working memory tasks (which activate especially the left DLPFC) are effective for increasing the use of the left half of the brain, in particular the left prefrontal cortex.

IV. Relaxation techniques

Positive emotions are useful for coping with stressful situations [34] [35]. Instead of suppressing their emotions, people should direct their affect towards solving problems or constructive actions [36]. Emotion-focused therapy [37] is based on the following principles: *emotion awareness* – people should become aware of what they feel, *emotion regulation* – based on self-toleration and self-soothe, which involves an activation of the parasympathetic nervous system to regulate heart beat and breathing and *transforming emotion*, which means changing one emotion with another, through positive imagery or relaxation techniques [38].

The review of Pizzoli et al [39] divides the user-centered VR applications into: "relaxing VR", "engaging VR" and "personalized VR". "Relaxing VR" promotes the use of relaxation techniques such as breath control, muscle relaxation, listening to music, peaceful, non-arousing scenarios, nature-based environments, natural sounds, warm and calm voices, in order to induce positive states and relieve stress. "Engaging VR" enables the user to interact with the virtual content in order to acquire skills or to cope with negative stimuli in therapeutic interventions. The VRET applications are based on systematic desensitization, by combining gradual exposure and relaxation techniques [40]. "Personalized VR" targets autobiographical memories, personal experiences, pre-existing needs, memories and preferences. They enhance affective states, immersion, sense of presence and provide a vivid interpretation of the experience [41] [42] [43]. Adaptive virtual reality, part of "personalized VR", focuses on adapting the virtual content according to the user's states at any moment of interaction, by analyzing physiological measurements, reported affective states and observed behavior.

Music has a modulating effect on the anxiety responses of acrophobic subjects who have been exposed to heights in a virtual scenario where they ascended and descended along a 350 meters tall building in an exterior elevator [44]. Realism was enhanced by adding background noise from the moving elevator. The music was relaxing, instrumental, with a tempo of around 50 bpm, presented at a volume of 60 dB. The composition parameters have been inspired from the work of Pelletier et al [45] and Zentner et al [46], who also found that music reduces stress and anxiety, but this can depend on factors such as age, type of stress, musical preference and experience. Yamamoto et al [47] showed that listening to the preferred music during in vivo exposure to emotion-eliciting stimuli reduces anxiety in the case of people suffering from animal phobia. Also, listening to the favorite relaxing music after a mentally challenging task reduced anxiety, compared to the group who did not listen to music at all or listened to rock music.

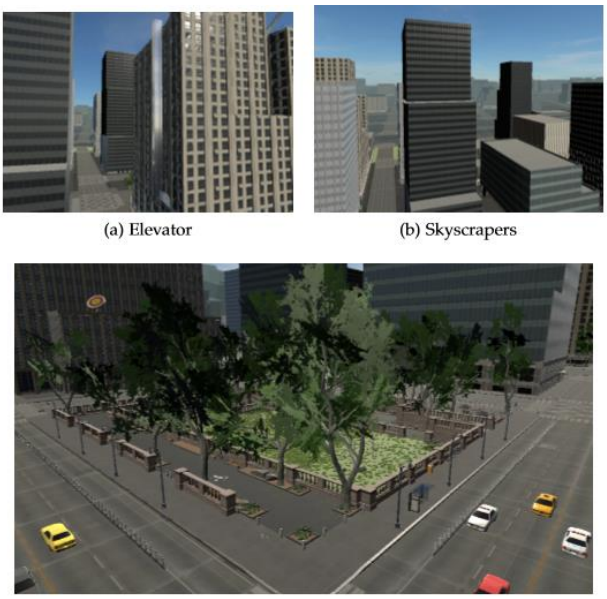
V. The VR game for acrophobia therapy

Our serious VR game aims to expose people to heights in an urban environment. The player's goal is to reach the top of a building. The genre is a single-player, first-person VR simulation that is meant to be challenging and anxiety-inducing. The serious game provides an environment that triggers the player's anxiety response and helps them cope with it. The serious game is a simulation of an urban environment and it is meant to be as realistic as possible, while still having a few elements of gamification that ease the player's exposure (Fig. 1). The main target audience is composed of people suffering from a form of acrophobia, regardless the severity level. The setting is a modern, urban environment which contains cars, buildings, skyscrapers, parks and elevators.

The game is played from the first-person perspective, through a VR headset display – it is adapted for both HTC Vive and Oculus Rift. The camera freely follows the player's head movements.

The player can progress in the serious game at his/her own pace and is free to navigate as desired. The player's goal is to reach the top of the tower (Fig. 2) and to overcome his/her fear of heights.

The main character can perform the following gameplay actions: look around, move (either by walking using the controller or by teleporting), answer questions by looking at the desired option, open an interactive menu which offers a relaxing modality (a favorite quote, image or song), collect stars (Fig. 3) throughout the game, fire a crossbow, and ride an elevator (Fig. 4).



(a) Elevator (b) Skyscrapers

(c) Park and Cars

Figure 1. The elements of the game

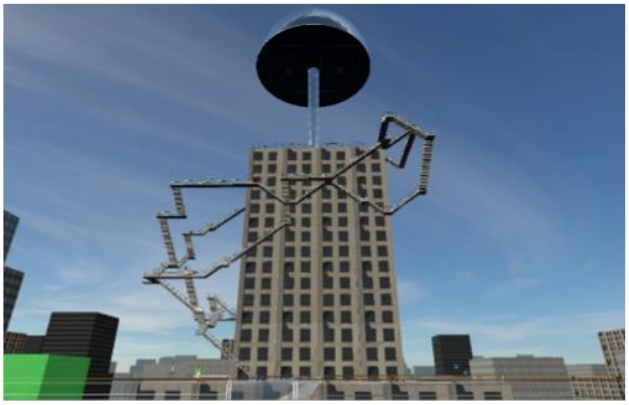


Figure 2. The dome

In addition, the player can also: exit the game at any time, teleport from one quiz to another in case s/he does not wish to navigate through the whole game, and change the favorite quote, image or song from outside the game. The player has a controller in the right hand which facilitates all the interaction in the game.

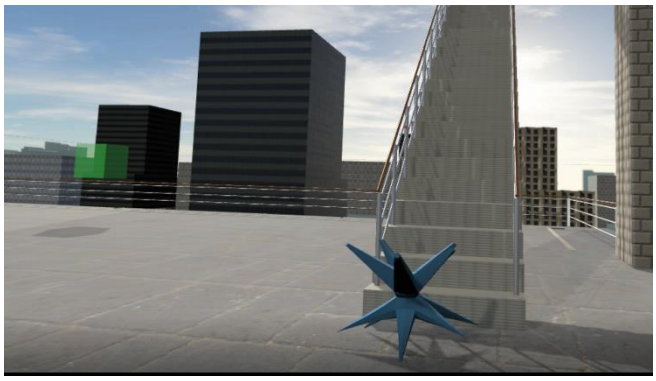


Figure 3. Stars collected in the game

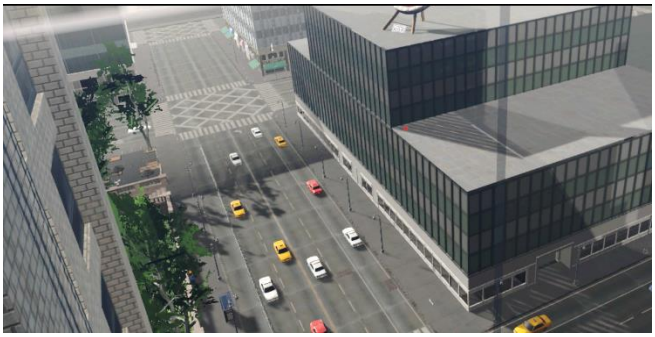


Figure 4. View from the elevator

The game can be completed in about 10-15 minutes, but realistically it can take much longer than that. It completely depends on the player's speed and anxiety levels, making him/her slower in some sections. The player is dropped in front of a building and there are some stairs to the left. S/he starts by answering a short questionnaire and a mathematical quiz and then heads towards the stairs and begins his/her climb up the building. The short psychological questionnaire is composed of four questions:

- *How scary do you find the environment?*

Possible answers: 1 (lowest), 2, 3, 4 or 5 (highest)

- *Ratings of valence, arousal and dominance* using self-assessment manikins [48], with 5 possible answers. Valence ranges from positive to negative, arousal ranges from not excited to very excited and dominance ranges from low dominance to high dominance, representing the degree of control exerted over the perceived emotion.

The mathematical quiz aims to distract the user from the game by activating his/her logical thinking and deactivating the emotional hemisphere. The player should respond to three simple math exercises: additions of numbers composed of 2 digits. The sum of the two numbers does not exceed 100. After the mathematical quiz, the short psychological questionnaire (composed of the 4 emotional ratings) is applied again. Throughout the game there are 10 stops like this. The player is given the following informal description of the game:

The green box in front of you at the start is the questionnaire/math quiz trigger, just enter it and the questions will pop up. Once answered, it is time to move forward, heading towards the stairs; you can collect a star by passing through it or by grabbing it with your hand. Movement is done either by teleportation or by pressing the D-pad - depending on this you will either teleport up the stairs or climb them. The stairs lead to a floor containing furniture, another questionnaire/math quiz and an elevator. After answering the quiz, you can head towards the elevator, press the button and start riding it upward. You are dropped on a balcony where more stars and quizzes await you. On the other side you can find a crossbow, a small target, and a few bigger ones spread across the building's rooftop. Feel free to shoot a few arrows to relax. By now, you have probably noticed the giant maze of stairs leading all the way up to the top. Along the stairs there are multiple paths

available and there are a few stops with quizzes. On the roof there is a quiz and a final elevator that leads to the dome on top. The dome contains the final quiz and an option to fly has been unlocked for you. All the answers have been recorded at this point and you can exit the game.

The Unity game engine has been used for developing the application. The code has been written in C# and HLSL shader language for the effects and for the glass windows in the game scene. We have also used the Simplygon framework for dynamically generating levels of detail for the models in the scene. The game runs on Windows and can be controlled with HTC Vive or Oculus Rift through SteamVR.

Before the game is actually run, a file is required to be generated for the user. It has a particular format meant to be read by the application and sets up the serious game. This file contains the user's name, age and gender. The next lines contain the names of the favorite song, image and quote files they wish to be loaded as relaxation modalities. The relaxation modalities can be loaded at any time. The next line contains the difficulty of the in-game math questions and the last line represents the player's current acrophobia severity: low, medium or high. The acrophobia severity index for each user results after completing specific acrophobia questionnaires.

All of the answers the user gives are recorded in a special file. This file contains the user's id, session number and name. It also contains the date and time of the start of the session, followed by all the answers and timestamps of when the answer was given. The final lines of the file show the number of stars the user has collected throughout the game, as well as the total number of correct math answers. The first number is the number of correct novice questions answered, followed by medium and expert. Depending on the initial math difficulty set, some values are supposed to remain zero. The timestamps are measured in milliseconds since the UNIX epoch (January 1, 1970 00:00:00 UTC). This is for synchronization with the Shimmer3 GSR+ Unit sensor which measures heart rate and electrodermal activity.

VI. Evaluation

A thorough evaluation with people suffering from acrophobia was planned for March 2020. Unfortunately, due to the Covid-19 pandemic we could not proceed any further with the tests. Given these circumstances, the game has been tested with 4 users (students and teachers), aged 24-32, three females and one male, who have a HTC Vive device at home. The sample size is small, but it still proves the concept and shows how the results could be interpreted and used. Each user has filled in a form [49] which contains three questionnaires. The first one refers to heights interpretation [50], the second one to visual height intolerance [51], and the last one is the acrophobia questionnaire which is split in two: anxiety and avoidance questionnaire. For one user we have collected biophysical data: Galvanic Skin Response (GSR) and Heart Rate (HR) in a resting baseline position and during gameplay.

A. *Heights Interpretation Questionnaire*

We have assigned the following points to each of the possible responses:

• Not likely: 1 point • Unlikely: 2 points • Somewhat likely: 3 points • Likely: 4 points • Very likely: 5 points

There are 2 sets of 8 questions each. Thus, the minimum number of points for the questionnaire is 16 points and the maximum number is 80. There are 3 acrophobia levels:

• Low: 16 - 37 points • Medium: 38 - 58 points • High: 59 - 80 points

The questions are imagination experiments in which the respondents are placed in environments that could trigger an anxiety response. For instance, a balcony on the 15th floor of a building. The respondents have to answer with the likelihood of certain scenarios happening, for example fainting, falling or having a panic attack.

The results for each user were:

• User1: 34 points [Low acrophobia] • User2: 37 points [Low acrophobia] • User3: 26 points [Low acrophobia] • User4: 24 points [Low acrophobia]

B. *Visual Height Intolerance Severity Scale*

The questionnaire is based on a set of eight questions for determining the severity of Visual Height Intolerance. Users 1, 2 and 4 had low visual height intolerance and User 3 had medium height intolerance.

C. *Acrophobia Questionnaire*

The acrophobia questionnaire is composed of 2 parts: Anxiety questionnaire and Avoidance questionnaire. By assigning points to all possible responses and by counting them, we obtained that all 4 users had low anxiety and avoidance levels.

D. *Biophysical experiment*

User1 has played the game twice. The second time s/he played the game, the biophysical data (GSR and HR) have been recorded using the Shimmer3 GSR+ Unit [52]. Before gameplay, the biophysical data have been recorded in a resting baseline session with a duration of 3 minutes. The average GSR baseline was 0.99 microSiemens and the average HR baseline was 63.82 bpm. During gameplay, we saved the user responses and timestamps corresponding to the moments of time when the responses were provided. These timestamps have been aligned with those saved by the Shimmer application and then we computed an average of GSR and HR for each game trial. We subtracted the baseline GSR and HR from these averages.

E. *Results*

We observed that there was no statistical difference between the valence-arousal-dominance responses provided before and after answering the mathematical questions, in a one-way ANOVA test for independent measures at a significance level of 0.05. There is no significant difference between the GSR data either. The mean heart rate during gameplay was higher with 4.52 bpm than the baseline, and,

after answering the mathematical questions, it was higher with 9.78 bpm. The mean HR was higher after answering the mathematical questions ($p = 0.045$) with 5.26 bpm.

Before answering the math questions: there is a strong negative correlation between valence and GSR ($R = -0.96$), a strong positive correlation between arousal and GSR ($R = 0.87$), and a strong negative correlation between dominance and GSR ($R = -0.89$). There is no correlation between valence, arousal and dominance and HR.

After answering the math questions: there is a strong negative correlation between valence and GSR ($R = -0.9$), a strong positive correlation between arousal and GSR ($R = 0.84$) and a moderate negative correlation between dominance and GSR ($R = -0.59$). There is a moderate positive correlation between valence and HR ($R = 0.6$), a strong negative correlation between arousal and HR ($R = -0.84$), and a moderate positive correlation between dominance and HR ($R = 0.65$).

After finishing the game, the users answered a game experience questionnaire [53]. 3 out of 4 users responded that the length of the game was `just about right' and they passed through all the quizzes. All users agreed that the questions related to the emotional state were helpful and intuitive and that the game is helpful for relieving anxiety. Only 2 users used the relaxation modalities (favorite song, quote, image). Just one user played with the crossbow and commented afterwards:

I loved the interaction with the crossbow, I even managed to shoot stars with it. However, the fly option did not work for me. I would have loved even more minigames, some of them obligating me to stand on the edge of the building / look down and see how I perform with that level of stress. Minigames are needed for both diminishing the stress level and making the session more entertaining and engaging.

VII. Conclusions

Given the fact that the game has been tested only by 4 users due to COVID-19 outbreak, the sample size was too small to draw any conclusions. Another unfortunate aspect is that a baseline session could not be performed and only one of the four users had the opportunity to use the heart rate and galvanic skin response sensor.

Due to time constraints and the lack of a controlled lab procedure, all of the testers had to use their personal devices and special commands/features had to be introduced into the game. These allow users to teleport to the quizzes in-game without having to pass through the whole level. Some PCs might not be powerful enough to run the serious game, reducing the game time to only a couple of minutes; a normal session can run up to 40 minutes. However, at least one of the users has confirmed to walk the whole level. These commands will be disabled for future releases as they do not produce the desired exposure to the player. Most of the game was skipped this way and the answers to the questions may not be accurate.

Given the reasons presented above, the data gathered throughout the experiments cannot be taken into consideration for further studies. However, this does not imply that they are worthless. The users have stated that the application was indeed triggering an anxiety response in some locations, especially in the ones towards the end of the game. Secondly, the data collected and analyzed proved that the application can be used for data gathering and testing. With a larger sample size, a proper certified supervisor who has had previous experience with exposure therapy, and multiple sessions for each user, we can prove the effectiveness of the application. Control groups can also be taken into consideration.

In what concerns future directions, the game needs more optimization on the graphical and rendering part. Next, small game immersion features could be added. At this moment the city feels fairly empty, with no other people being present. The cars visible on the street do not move or interact with the player. The city is explorable, but no interaction exists outside the main building.

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