Physiological acrophobia evaluation through *in vivo* exposure in a VR CAVE

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***Abstract*— Acrophobia (i.e., the fear of heights) is commonly treated using Virtual Reality (VR) applications. Patients that suffer from this clinical condition can experience extreme levels of anxiety, stress, and discomfort, even at relatively low heights. VR computer-assisted virtual environments (CAVEs) have been found to be highly immersive and successful in the treatment of acrophobia. The general method of evaluating therapy progress is through self-reported questionnaire measures. However, these are subject to participant bias. Physiological measures, on the other hand, could provide a more objective way of assessing acrophobia. To our knowledge, psychophysiological measures are not commonly used in the evaluation of acrophobes and their therapy progress within CAVEs. Thus, we present a CAVE application for acrophobia treatment, which includes a physiological feedback mechanism to assess patient progress. It also permits patient movement to facilitate increased presence and immersion. In this application, players sequentially gain access to increasing heights as they successfully progress through lesser heights, as assessed through the evaluation of their physiological responses to VR stimuli.**

Keywords—Acrophobia; Virtual Reality; Physiological Measures; Biofeedback; CAVE.

I. INTRODUCTION

Virtual Reality (VR) environments have been used for diverse types of simulations. Since these environments provide immersive simulation platforms to users—often resembling dangerous real-life stimuli without the danger—one of the most common uses of VR worlds is rehabilitation [4] and the treatment of phobias. Common phobia treatments involve the fear of flying [5] or of other biological beings [6], to name a couple of examples. The fear of heights (acrophobia), one of the phobias that may be treatable using VR environments, can cause individuals to experience high anxiety levels even at low heights. By using a computer-assisted virtual environment (CAVE), we aim to help users learn to control their anxiety by exposing them to increasing levels of height in a controlled setting, which has also been attempted in previous work [1, 7]. However, we advance previous research by using a combination of stereoscopic 3D imagery, physiological sensing equipment, and a CAVE. We were able to expose users to a realistic environment, in which they are able to physically move around, and where we can measure their psychological stress using physiological sensors.

To move to higher virtual levels in the CAVE, a user must be looking over the edge of the platform on which they are standing, and be able to keep their anxiety levels under a predetermined physiological threshold level for a set amount of time. Since dealing with fears can be stressful, we intend to make use of the space within the CAVE to provide a safe area for users to collect themselves or take a break if necessary.

II. RELATED WORK

VR environments have long been utilized to support the treatment of various clinical conditions. Their main advantage is that they expose patients to the types of situations that are causing their conditions without exposing them to physical harm.

A. *VR in Phobia Treatment*

Phobias are extreme medical conditions that can hamper someone's life. Arachnophobia (i.e., the fear of spiders) [8], social phobia [9], fear of driving [10], and fear of flying [5] are some of the conditions for which treatment has been attempted using VR technologies.

Acrophobia (i.e., the fear of heights) is the phobia that has been the main research focus of VR phobia treatment [1, 2]. The treatment of this condition generally consists of behavioural therapy, by exposing the subject to anxiety-inducing stimuli (i.e., heights) and allowing these anxiety levels to be mitigated by prolonged exposure over time. Behavioural therapy can encompass various sources of stimuli, generally of two types: imaginary, where the patient generates the stimuli by imagination, and *in vivo*, where the subject is placed in an environment of significantly observable real height [11]. Typically, *in vivo* treatment yields greater effectiveness than its imaginary counterpart [3].

After subjectively evaluating which height situations cause a patient to feel anxiety or discomfort, therapy sessions are arranged, so that the subject is able to experience a continuous process of exposure and habituation to those situations (stimuli). The process is gradual—in a sense that patients begin with a less-threatening condition (i.e., low height)—gradually moving to more challenging situations in terms of anxiety. A typical procedure in these *in vivo* sessions is, for example, to have the patient to look through a window on the third floor of a building, moving them up to higher windows on subsequent sessions as acrophobia is mitigated for the current floor (or height level). For a real world session, typical scenarios include balconies, bridges, and other similar environments.

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Coelho et al. [12, 13] found that having the patient move in an acrophobia-inducing setting causes more anxiety than therapy sessions that do not involve movement. Thus, it seems important to provide VR scenarios that allow patients to move freely, or to at least be able to move within the virtual setting. Juan and Perez [2] compare VR devices, such as HMDs and CAVEs, regarding immersion and perceived patient presence, both being technologies that allow some degree of movement. CAVEs have been found to have the highest presence score.

VR CAVEs have been used in the treatment of phobias because they allow flexibility in therapy sessions as well as patient confidentiality. Not only do patients avoid the embarrassment that can result from their phobias being publicly displayed, but they are also able to perform therapy in a scenario that is close to the *in vivo* setting—without being exposed to actual dangers. However, it seems that current therapy methods (and research results) are only based on self-reported measures, like questionnaires. While questionnaires are easy to deploy and—when containing scales—allow some level of quantification, they can be biased because of potential confounds, such as having to recall feelings or emotions after stimulus exposure. The possibility of truly real-time quantitative measures, like psychophysiological data of the patients, seems to be—to our knowledge—not yet explored, or at least not present in the acrophobia literature. Therefore, we propose a treatment scenario that uses these measures in conjunction with the relevant questionnaires used in this field.

B. Psychophysiological Measures

Psychophysiological data can be used to infer users' mental states in different scenarios, although they have become more popular recently to evaluate user experience in real-time computer applications (e.g., VR simulations, videogames) [14–16]. Moreover, it is possible to establish emotional valences based on physiological measures.

Galvanic Skin Response (GSR) gauges the level of emotional excitement or arousal of an individual, which is generally measured by two electrodes on the hands of a participant [17]. These electrodes measure the electrical current differentials stemming from the increase of *eccrine* sweat gland activity, often a consequence of excitement. However, this measure is independent in relation to the emotional valence of the stimulus. A negative affective stimulus can originate the same level of GSR activity as a stimulus of positive affective nature.

Commercial electroencephalography (EEG) solutions, such as the *Neurosky Mindwave*, can also be used to assess emotional arousal. The use of EEG allows the determination of different psychophysiological states, such as attention, relaxation, frustration, or others [16]. This product in particular allows the determination of two pre-calculated (i.e., black box) psychological states: attention and meditation. The exposure of a user to different stimuli will change both levels of the psychological states collected by this device. Thus, this method is marginally more specific than GSR: if the user is calm, then the meditation level will be high and the attention level will be low.

It is important to understand that these measures alone, without association to video footage of the patient, or to other measures, might convey little more information than the physiological intensity of the stimuli themselves. Although they are quantitative measures, they require qualitative support (because of the one-to-many and many-to-one relationships of psychophysiological actions and reactions) to truly determine what was perceived or felt while exposed to a stimulus. In the context of acrophobia treatment, the use of quantitative measures like GSR or EEG does not replace the current methods of evaluation, but rather serves to complement and enhance them. The use of validated questionnaires can then indicate the valence direction of the GSR activity level (positive or negative affective nature), or the nature of the attention and meditation states from EEG activity, making these psychophysiological measures meaningful in the context of evaluating the patients' progress.

C. Immersion

Immersion is the sense of being subdued in the virtual world of a computer application, often a video game, where a person's thoughts, attention, and goals are all focused on the application, as opposed to being concerned with anything else, such as what is going on in the room around them [18, 19]. It is closely related to the graphical realism of the virtual application or video game world and to any atmospheric sounds, both of which comprise a portion of what is called game aesthetics.

The experience of immersion is often critical to enjoyment and is made or destroyed by game aesthetics [20]. In a study about game immersion [20], the authors concluded that there can be three subsequent levels of involvement within a game: engagement, engrossment, and finally total immersion. The first level deals with the lowest stage of involvement and it is related to breaking the first barriers, such as player preferences or the act of learning game controls. The second level, engrossment, relates to the connection between the player and the game construction presented. Game construction can be seen as the craftsmanship of the game environment, its details, and its appeal to the players. The final stage, total immersion, is related to the concept of presence, where nothing else but the game or virtual world matters. Although our study was not explicitly concerned with aesthetics and its abstraction in games, there is an indication that variations in game construction may draw people into a game.

III. CAVE VR Project

Various projects have used VR in the treatment of phobias. Additionally, CAVEs have been extensively used in the creation of more immersive environments. Since acrophobia is both a common condition and a popular target of VR treatment, we have developed a project targeted at this specific phobia. The following subsections detail our implementation.

A. Architecture and Interaction

Immersiveness can alter the way we perceive imagery in virtual environments. Real perception of three-dimensional graphics can increase the effectiveness of a VR environment

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in delivering a more credible and authentic experience. Since we are dealing with acrophobia, perception of height was one of the most important factors that we took into consideration when designing our application. By using stereoscopic imagery, an immersive way of visual delivery, we aimed to deliver a more authentic feeling of height in the virtual environment that we had created.

However, sensorial authenticity might feel flawed if the provided experience is not fully immersive. There is no real sensorial authenticity in having fully stereoscopic imagery displayed on a 19” display to treat a fear of heights. Since the setting, where the treatment takes place, does not require any actual physical adjustment of height, the use of a CAVE is ideal, because it provides a fully visually immersive experience. Therefore, we integrated stereoscopic visual technology within a CAVE to achieve more credible results for the treatment of acrophobia.

Since the rapid development of the application was considered to be a requirement, our application was implemented using Unity 3D and MiddleVR.

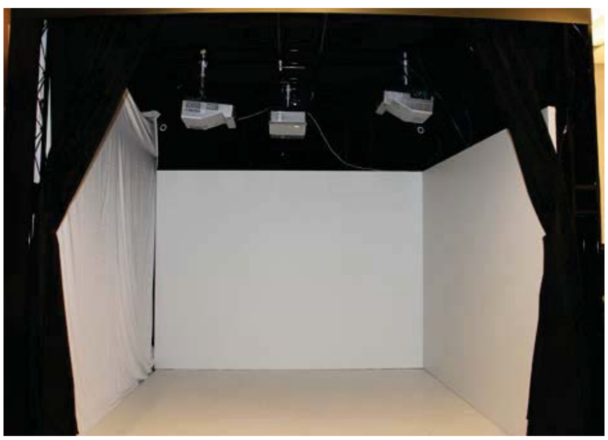

Fig. 1. Four-wall CAVE (2m x 2m), Panasonic projectors (1024x768 resolution), and Vicon IR tracking system at UOIT.

The CAVE in which our application was deployed is equipped with Vicon infrared (IR) tracking cameras (see Fig. 1). Through the use of IR tracking markers placed on a cap worn by the user, it is possible to track the user’s position within the environment. Simultaneously, the in-application camera’s perspective can be adjusted according to the user’s head movement. In conjunction with the movement tracking technology, stereoscopic 3D graphics are provided to enhance the immersion of the user. Thusly, motion tracking capability and stereoscopic glasses are the two most crucial components of interaction in the virtual setting. With them, it is possible to accurately simulate a situation in which the user navigates on the top of a building. Within such a scenario, accurate movement tracking and graphical stimuli allow the realistic introduction and simulation of anxiety-inducing contexts. For example, a user may physically ‘walk’ to the edge of a simulated roof, tilting their head to look down along the façade of the building. This provides a stimulus similar to the one that acrophobes encounter in *in vivo* therapy sessions, which maintains the immersive qualities of the real-world stimuli without exposing them to the potential danger of an actual high-altitude setting. The movement-tracking capability of the simulation serves to enhance the realism of this experience, reinforcing its viability as an effective treatment method. However, since a CAVE space can be somewhat restrictive in terms of allowing physical movement, users are also able to control their character by using an Xbox 360 controller in addition to the head tracking method (see Fig. 2).

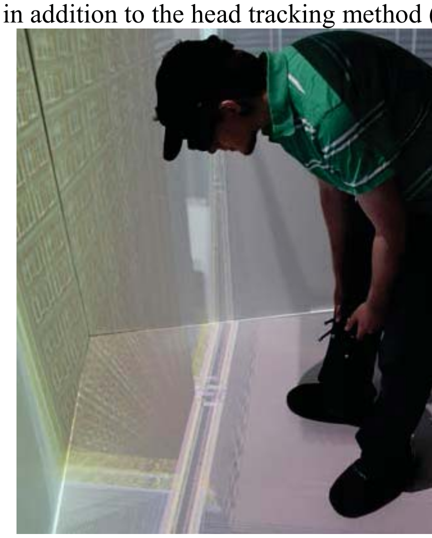

Fig. 2. Subject leaning over the top of a virtual building.

The CAVE simulation also allows for the potential to develop digitally integrated, long-term treatment programs for a fear of heights. One of the traditional ways to determine whether a patient is making progress to suppress their acrophobia is to expose them to the same stimuli repeatedly over long periods of time until they no longer feel anxious or distressed. Consequently, we propose the use of EEG monitoring in possible conjunction with repeated simulations or *in vivo* therapy as a means of identifying the user’s psychophysiological relaxation, to establish whether or not the patient is afraid of the presented stimulus. A low level of attentiveness observed alongside a moderate level of relaxation indicates that the current stimulus does not incite the symptomatic manifestation of acrophobia in the patient. By contrast, a high feeling of attentiveness accompanied by less prominent feelings of relaxation implies that the current stimulus is causing the user to experience fear.

Our current application uses the Neurosky Mindwave EEG solution (see Fig. 3), and supports five different levels of height, on top of various buildings in a cityscape setting. As the user relaxation levels increase with prolonged exposure to a building, other structures with greater height are unlocked. The user can then progress to the next building, with greater height, and be exposed to a more intense stimulus.

An attention/meditation level sample is collected from the Neurosky device periodically. Only relative levels of attention and meditation can be obtained, and not actual brainwave frequencies, because of the closed nature of the MindWave headset. Therefore, the user’s relaxation state is computed by gathering a series of samples, and determining whether the values for meditation are higher than the attention values.

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Fig. 3. Apparatus used: NVIDIA active shutter 3D Vision Pro glasses, Neurosky Mindwave Mobile, and IR tracking capable cap.

IV. Limitations and future work

The main limitation for the implementation of the architecture we propose was the short timeframe that was available for its development. Because of some ongoing maintenance within our CAVE, we could not spend as much time as we wanted fine-tuning the stereoscopic vision parameters exactly as desired. This would have to be adjusted in future iterations of this architecture, to achieve a greater sense of depth and therefore a more immersive experience.

In addition, the relaxation-based progression mechanism was not fully implemented in the presented architecture, and was replaced with a manual system of altitude unlocking. This means that the therapist was responsible for unlocking successive height levels for the patient, rather than the theoretical automatic unlocking mechanism of application-based EEG analysis that was discussed.

For future work, the addition of a more immersive environment will be taken into account. Besides the immersiveness provided by the CAVE, we plan to integrate computer operated fans that blow air into the CAVE space, to create an even more realistic experience. Future studies could examine different physiological measures, and establish a relationship between these methodologies and the acrophobia questionnaire measures suggested by the literature.

V. Conclusion

We have developed a CAVE simulation game that replicates acrophobia treatments. In this setting, several buildings are present in a simulated cityscape, from which the player or patient is able to walk on the rooftop. The player can move his head freely thanks to head tracking, so that he is able to gaze down from the edifice on which he stands, as a means of treating acrophobia. Physiological measures such as EEG are collected to successfully infer the patient's progress in terms of therapy. As the EEG relaxation levels increase over treatment time, higher buildings are made available to the patient, producing more stressful stimuli, just as in the practise of traditional *in vivo* acrophobia treatment. In the future, further development and integration of VR CAVE technology and psychophysiological measurements to supplement traditional therapeutic approaches promises to provide many new opportunities for the treatment of various clinical conditions and phobias.

Acknowledgments

We thank all the participants involved in this study. We would also like to thank Samantha Stahlke, and everyone who provided helpful comments and edits on previous versions of this document. We are grateful to our support from NSERC, GRAND NCE and SSHRC (IMMERSe, 895-2011-1014).

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