Journal of Technology in Human Services

ISSN: 1522-8835 (Print) 1522-8991 (Online) Journal homepage: https://www.tandfonline.com/loi/wths20

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To cite this article: Vangelis Metsis, Grayson Lawrence, Mark Trahan, Kenneth S. Smith, Dan Tamir & Katherine Selber (2019) 360 Video: A prototyping process for developing virtual reality interventions, Journal of Technology in Human Services, 37:1, 32-50, DOI: 10.1080/15228835.2019.1604291

To link to this article: https://doi.org/10.1080/15228835.2019.1604291

Published online: 10 May 2019.

JOURNAL OF TECHNOLOGY IN HUMAN SERVICES
2019, VOL. 37, NO. 1, 32–50
https://doi.org/10.1080/15228835.2019.1604291

360 Video: A prototyping process for developing virtual reality interventions

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ABSTRACT

Virtual reality (VR) has emerged as a promising technological intervention for anxiety disorders. However, there are no existing standards and best practices to evaluate the effectiveness of environments to achieve their intervention goals. The purpose of this study was to develop a VR intervention for student veterans with social anxiety disorder and test feasibility utilizing a three-stage development model. The development of a therapeutic VR environment may benefit from an interdisciplinary collaboration of researchers from various fields of study. Utilizing three stages of prototyping with two virtual reality platforms, fully immersive video ($n = 6$) and three-dimensional (3-D) immersive virtual reality ($n = 8$), the research team designed an intervention for student veterans with social anxiety disorder, testing bio-reactivity of participants. Results of prototyping include user feedback validating increased stress levels and increased bio-reactivity specifically in galvanic skin response and heart rate elevation. Implications include the use of 360° video for prototyping 3-D virtual reality interventions.

ARTICLE HISTORY
Received 26 September 2018
Accepted 3 April 2019

KEYWORDS
Virtual reality; 360° video; prototyping; intervention; veteran; social anxiety

Introduction

In the United States, there are approximately 25% of veterans suffering from some form of mental health diagnosis (Trivedi et al., 2015), with potentially 3.6% of military populations meeting diagnostic criteria for social anxiety disorder (SAD; Grant et al., 2005; Kashdan, Frueh, Knapp, Hebert, & Magruder, 2006; Watson & Friend, 1969). SAD is a persistent fear of social or performance situations in which a person is exposed to unfamiliar people and/or potential scrutiny from others (American Psychiatric Association & others, 2013). For student veterans transitioning onto college campuses, social anxiety can cause challenges with integration and pursuit of higher education goals (Vogt et al., 2017; Trahan et al., 2019). Virtual Reality (VR) environments have been used to study and treat

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a variety of psychological disorders, including social anxiety in the general population (Chesham, Malouff, & Schutte, 2018). As useful as VR environments are for studying and treating social anxiety, they are extremely time-consuming and expensive to create, especially in academic settings lacking the experience of the gaming industry in designing realistic graphical environments. As these environments require time and resources for creation, it is in the best interest of research to prototype environments, thus reducing costs associated with time and design workload while maximizing usability. To maximize responsiveness requires multiple iterations of design and testing with a scientifically staged developmental process for collecting user feedback to determine whether an intervention is feasible to intervene with a specific problem set or population.

To address the multiple layers of design required for the application to address the social or behavioral problem, including engineering of software and hardware, reactivity in various domains of participant experience, and behavioral outcomes related to the problem, VR research may also require an interdisciplinary team, composed of computer science, communication, and graphic design, and social sciences including social work and psychology, to work together to prepare, design, and implement VR interventions. Interdisciplinary research in virtual interventions has received little literature attention, although some teams are recognizing the necessity of cooperative research endeavors (Lövquist, Shorten, & Aboulafia, 2012). An interdisciplinary process may increase the potential for research flexibility and development of specific virtual environments to address social and behavioral problems. Furthermore, the establishment of this interdisciplinary team may facilitate a prototyping process that combines multiple inputs and response to those inputs from various orientations.

The goal of this research was to establish an interdisciplinary research process to create therapeutic VR environments by defining roles of the different stakeholders, evaluate the use of 360° video as a rapid prototyping technique by collecting and documenting early user feedback, collaboratively design, and develop environments most suitable for effective subject assessment and intervention, and evaluate bio-reactivity to environments to determine feasibility for future intervention. Immersive 360° video is one potential option for prototyping environments to ensure that three-dimensional (3-D) virtual reality environments (VRE) stimulate response and fulfill outcomes desired by a specific intervention. Three hundred sixty degree video is similar to a fully immersive movie. During the recording of the video, every direction of view is recorded at the same time using an omnidirectional camera or a collection of cameras. During playback, participants are fully immersed in the scene by utilizing a VR headset to experience 360° of video. Moving their head around at different directions, allows the users to see different fields of view, similar to what someone would experience when moving their head to look at different directions in real life. By rapid prototyping as many evidence-based scenarios as possible with time and budget constraints utilizing 360° video, the team aims to prioritize environments that have evidence of inducing a physiological and emotional response. This work uses the diagnosis and treatment of social anxiety in returning war veterans as the case study for establishing a development process and evaluating the effectiveness of 360° video as a staged approach for designing 3-D VR interventions. Within the structure of a multiphasic method, 360° video was initially employed to record the environments that were portrayed, by the test subjects, as the most common to induce anxiety. Subsequently, test subjects were exposed to these 360° recordings using a headset which projected video and audio. In the following sections, we elaborate on the methodology for collecting user feedback, creating the 360° video and VR environments, and for evaluating their suitability as a means of diagnosis and therapeutic intervention.

Methodology

Overview: In this section, we address the problem of identifying the requirements and developing a VR environment intended to be used for intervention therapy in an academic setting. The methodology followed resembles the general approach of Systems Development Life Cycle, including the stages of Planning, Analysis, Design, and Implementation (Zhang, Carey, Te'eni, & Tremaine, 2005). However, due to the unique type of customers and the purpose of the developed product, each stage requires a nonstandard, interdisciplinary approach. The main customers of our case study are student veterans suffering from social anxiety. These customers cannot be accessed directly by the technical design and development team to identify and elicit the requirements of the VR system to be developed. Social work researchers interacting with the patients is the secondary group of customers of such a system. In this situation, social work researchers adopted a dual role, serving both as customers of the system, and as part of the planning, requirements elicitation, and design team. In addition, communication design and computer science researchers supervised the 360° video and VR design and development process, while social work provided input about design and features based upon qualitative data collection (Trahan et al., 2019).

Planning stage

The study was conducted at a large public university in the southern United States, and approval was granted from the Institutional Review

Board. During the planning stage, researchers from the fields of social work, computer science, and communication design came together to define the problem and the characteristics of the target subjects of the intervention therapy (Trahan et al., 2019) outlines the planning process in full detail. A purposive homogenous sampling procedure was utilized to recruit student veterans with social anxiety/avoidance for interviews. Eleven hundred student veterans registered at the university were contacted by e-mail during the spring and fall semesters of 2017. The e-mail explained the purpose of the study, described the research team and the VR lab, and included a link to the prescreen survey. The prescreen survey included informed consent, demographic information, medical history including mental health and substance abuse, military experience, the SAD (Watson & Friend, 1969), and information about the procedure of the study. Eligibility criteria included post-911 active duty and reporting on a pre-screen survey intermediate level social anxiety score of four or higher for males and one or higher for females (Watson & Friend, 1969). Exclusion criteria included severe untreated mental health diagnosis (e.g., schizophrenia, bipolar disorder). In a pool of 122 prescreen surveys, 14 participants ($n = 14$) were randomly selected to complete a semistructured interview on their experiences with social anxiety.

Analysis stage

Requirements elicitation

Participants completed the intake battery, which included demographic items, the SAD (Watson & Friend, 1969), Combat Experiences Scale (CES; Keane et al., 1989), the Post-traumatic Stress Disorder (PTSD) Checklist for The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V [PCL-5]; Blevins et al., 2015; Weathers, Litz, Herman & Keane, 1993; Weathers et al., 2013), and the Motion Sickness Scale (Reason & Brand, 1975). Semistructured interviews consisted of 14 questions developed by the research team about the participant's experience of social avoidance/anxiety and took approximately 15–20 min to complete. Items were conceptualized around constructs related to the SAD (Watson & Friend, 1969) but also included specific places, situations, and groups that create anxiety, sensations associated with experiences, level of discomfort, strategies utilized for adaptation, consequences on personal and professional relationships, and effects on student performance and experience (Trahan et al., 2019). Physiological data were collected from test subjects to be used as quantitative measures of experienced anxiety, in accordance with previous research (Kurniawan, Maslov, & Pechenizkiy, 2013). More information about the process of collecting the physiological data can be found in the Evaluation section. Interviews were audio- and video-recorded by the research team and transcribed by a third-party transcription service. Themes were then analyzed using a phenomenological theory perspective. Analysis followed procedure based upon phenomenological theory and theme development (Moustakas, 1994). Specific to designing and implementing VREs, participants were asked about specific places that would stimulate low, medium, and high levels of anxiety. After themes from this question were analyzed by the research team, environments including a classroom, a grocery store, and a crowded on-campus public area were identified as moderate to highly stimulating for social anxiety symptoms in student veteran populations (Trahan et al., 2019).

Settings

The main quad (Figure 1) at the center of the (Anonymized) university campus is a high-traffic environment, especially when classes are dismissed. From previous qualitative interviews, loud noises and crowded areas were indicated as anxiety producing. Large classroom environments produced anxiety for respondents because of the sheer number of people in the room. As some students could be located behind them or out of sight, some veterans reported considerable distress in large classroom settings. From qualitative themes related to proximity, the research team theorized that elevators might create anxiety due to enclosed space with limited exits. Furthermore, a student veteran may be enclosed in this space with a person that may trigger anxiety due to physical appearance, gender, or other factors. Large grocery stores were indicated to be anxiety producing because of the number of people in the store, as well as the wide variety of shelving

Figure 1. Quad foot traffic between classes (8/30/16).

that could block the veteran's line-of-site, number of safe exits, and interaction with grocery store employees.

To test the efficacy of these environments in creating anxiety, a three-stage method was introduced, including design, implement, and evaluate for determining the effects of exposure using both qualitative user feedback and quantitative bio-signal response (Zhang et al., 2005). Each environment previously identified would need to be rendered in 3-D graphics program and programmed by software developers. While VR environments would allow for the most flexibility to change elements such as the number of people in the environment, sounds that trigger anxiety, or custom interactions that may produce anxiety for a specific participant, the research team could not extrapolate dosage for stimulating anxiety from the initial research. Questions of research interest included: What is the threshold of student density in a classroom that produces anxiety? What levels of grocery store noise is necessary to induce distress? What types of avatars might evoke the greatest concerns and anxious response? As VR environments are complex (many people, number of products on the shelf, etc.), furthermore, the potential for developing interventions that do not induce reactivity for future exposure interventions necessitate evaluating through a process to determine feasibility. The goal of a three-stage process for prototyping was to quickly validate research questions without the need for expensive and time-consuming software development and 3-D rendering of many assets.

Design stage

Rapid prototyping as a methodology

Rapid prototyping (RP) is a common software methodology employed to quickly and iteratively design a software product (Gothelf & Seiden, 2016). The primary function of RP is to validate hypotheses, as quickly and with as little actual programming as possible, with a testable artifact (Warfel, 2009). Each prototype created increases in fidelity, with the next iteration incorporating lessons learned from the previous prototype user test. By user testing each prototype, lessons can be learned about usability and acceptance so that improvements can be made over multiple iterations (Knapp, Zeratsky, & Kowitz, 2016). A rapid prototyping stage utilizing 360° video and photos was used to facilitate the design stage and collect early feedback from test subjects. Finally, a set of protocols were established for evaluation of the developed interactive VR environment from a technical perspective as well as with regards to its effectiveness in achieving the goal of therapeutic intervention.

Following an interdisciplinary collaborative discussion of common environments reported by participants, the research team identified grocery stores, crowded walkways or thoroughfares, and high-density classrooms as common environments where veterans experience moderate to intense social anxiety symptoms. Standards for the specification of these environments included the utility of the environment for inducing anxiety, a common environment reported by many customers, and the feasibility of developing this environment in VR. Test subjects were immersed in the 360° video and provided early evaluation and feedback about the features and events that tended to trigger their symptoms.

360 Video and techniques used

It was theorized that 360° video could be used as an RP technique to quickly and inexpensively validate VR environments without the need for time-consuming and expensive software development and 3-D-rendering of multiple complex environments. Three hundred sixty degree video uses a specialized camera to shoot video in such a way as to allow for users to see around an environment as if they were standing in the projected environment. When placed in a head-mounted display (HMD) such as the Oculus Rift (Desai, Desai, Ajmera, & Mehta, 2014), participants were able to look up, down, behind, and in front of them. This creates an immersive experience (Jennett, et al., 2008) for the user.

Equipment used. Our equipment for this exploration consisted of two 360° cameras: GoPro Omni, and Nikon KeyMission 360. Both cameras are able to film video and still images in full 360°. The Omni's resolution is much higher (8k resolution compared to the Nikon's 4k) so it is much more suited to showing final video in a high-quality HMD, while the output from the KeyMission is more suited to viewing on a smartphone using a head-mounted holder (e.g. Google Cardboard).

Software used. The primary software used to stitch from the Omni was Kolor Autopano Video Pro (AVP). This software allows the six separate video files collected from the individual GoPro cameras mounted in the Omni to be imported and stitched into one video. AVP allows for horizon and rotation correction, among other things necessary for video editing all of the environments. In addition, Adobe Premiere was used for the final editing of the timeline, color correction, and audio of the footage. The KeyMission did not require stitching as the camera produces video already stitched together.

Implementation stage

Prototyped environments and production

To evaluate whether subjects had a similar anxiety response to a virtual representation of these situations and locations, researchers collected

Figure 2. (Left) Student research assistant setting up audio and Omni in the quad (10/25/2016). (Right) Screen capture from 360° Quad Video (n.d.). Retrieved from https://www.youtube.com/watch?time_continue=20&v=wR1JUlYvDX4.

imagery (photos and video) in 360° video to evaluate anxiety response. The research team intended to capture real-life situations and environmental situations like the ones described by test subjects; thus, these images and videos did not involve any actors or any predefined scripting or staging. To maximize the actual experience, researchers invested considerable time and attention focused on filming, including time of day and decisions about movement within the space. Certain scenarios (e.g., local grocery store) required extra steps, such as corporate permission to record.

Examples of the 360° video data capturing process

University Quad Environment. (Anonymized) University's quad is a hub of activity on the campus, with thousands of students walking from class to class. Between every class period, a mob of students meet, talk with friends, rush to their classes, recruit for sporting events, fundraise for clubs, and many other activities. This area of the campus produced high levels of anxiety in text subjects due to crowding and movement.

The GoPro Omni was placed on a tripod in the middle of the quad (Figure 2, left). In addition, a Sony audio recorder with a sound muffler for wind reduction was used to collect sound in the environment. The first recording of 5 min was completed at a time where there were few students in the quad (Figure 2, right). A second recording was completed right before classes let out, increasing the number of students visible to the participants. The last recording was completed as classes let out, completely filling the quad with students, bicycles, and other activity.

University auditorium classroom environment. Large classrooms can frequently hold 200+ students in close quarters. Such environments appeared to cause anxiety to several participants, therefore, a 360° recording process, similar to the one in the quad was followed to record an Art History lecture. Omni and a sound recorder were placed in the middle of the room on a tripod, positioned at eye level. The first filming was of the classroom

Figure 3. Screen capture from large classroom environment video. Retrieved from https://www.youtube.com/watch?v=C5RR8LPqkTE.

filling with students coming into class, the second filming was of the professor lecturing (Figure 3), and the last was of the students leaving the classroom.

Grocery store environment. The grocery store environment was the most complicated of the environments produced in 360° video. Several factors made this environment particularly challenging, including the need for a mobile camera, the large size of the store, and the inability to brief store shoppers prior to capture to avoid interference with production. To plan the video shoot, filming permission was obtained from the unit director of a large grocery store (anonymized). A week before the shoot, researchers walked through the store, taking notes, sketching out the floorplan, and planning the fixed route the camera would travel.

Variables, such as crowd size, noise level, and types of noises, and areas of the store, more prone to causing anxiety all needed to be validated. Researchers were uncertain about the extent to which these variables would induce anxiety in the subjects tested. To capture as many variables as possible, a route through the store was planned to capture images and noises expected to produce anxiety. Researchers considered variables including the height of shelving (which might create a feeling of claustrophobia), the openness of areas such as the produce section (which was theorized to be less anxiety-producing due to increased sightlines), and areas of potential congregating within the space (Figure 4, left).

Multiple practice-runs through the store were completed using a monopod and the smaller, Nikon KeyMission camera zip-tied to a shopping cart. The KeyMission was chosen for the practice filming because the footage from that camera is much easier to review in the field than the GoPro, which has no viewfinder. Footage from the Nikon, however, can be immediately reviewed on a smartphone or laptop. The practice runs consisted of

Figure 4. (Left) Interior large grocery store environment with light customer traffic in warped 360° view. (Right) Student research assistant preparing for a store walkthrough with Nikon KeyMission 360 (9/01/2017).

a complete shopping trip through the store, starting with the produce section—where the camera operator picked up items and placed them in the cart, all the way through the planned aisles and finalizing with payment and interpersonal interaction at the cash register.

While reviewing the footage of the first run, the researchers noted that there was too much vibration from the hard-plastic wheels on the shopping cart, highlighting the need for shock absorption. As the research team was in the field, we improvised with materials we could find at the store: researchers secured the foot of the monopod using a backpack as a shoulder sling and a half-deflated toy football under the monopod as a shock absorber (Figure 4, right). A final test run through the store was completed to test the new rig and the final production passes were completed using the GoPro camera for increased resolution for display in the HMD.

Evaluation stage

360° Environments

For continuity, six study participants ($n = 6$) were immersed in 360° environments using the same equipment as the one intended to be used in the interactive VR environments (Oculus Rift). These participants completed a prescreen and an intake questionnaire and were screened for traumatic brain injury and motion sickness. Study participants met the inclusion criteria for the study (Table 1). Upon these participants meeting criteria, they were invited to experience 360° environments that stimulate social anxiety to collect user feedback on their experience. This process provided early feedback for resolving technical difficulties, as well as pinpointing specific aspects of the environments that induced anxiety, which may have not been identified during the initial interviews.

Each environment provided a variety of insights that guided the design and development process of the later stages. For example, one of the primary lessons learned from the quad environment was that some study

Table 1. Description of sample ($N = 14$).

	360° Video ($n = 6$)		3-D VR ($n = 8$)		Total	
	n	%	*n*	%	*n*	%
Gender						
Female	2	33.3	0	0	2	14.3
Male	4	66.7	8	100	12	85.7
Race/Ethnicity						
Caucasian	3	50	7	87.5	10	71.4
Hispanic/Latino	1	16.7	0	0	2	14.2
Other	1	16.7	1	12.5	2	14.2
Employment						
Full time	1	16.7	2	25	3	21.4
Part-time	2	33.3	3	37.5	5	35.7
Unemployed	3	50	3	37.5	6	42.9
Military branch						
Army	3	50	6	75	9	64.3
Marines	3	50	1	12.5	4	28.6
Air Force	0	0	1	12.5	1	7.1
Current military status						
Active duty	1	16.7	0	0	1	7.1
Reserves	3	50	2	25	5	35.7
Retired	2	33.3	5	62.5	7	50
Missing	0	0	1	12.5	1	7.1
Years served in military						
0–5	2	33.3	4	50	6	42.8
6–10	1	16.7	3	37.5	4	28.5
11–15	3	50	0	0	3	21.4
16+	0	0	1	12.5	1	7.1
Number of deployments						
0	1	16.7	1	12.5	2	14.3
1	1	16.7	2	25	3	21.4
2	4	66.7	3	37.5	7	50
3+	0		2	25	2	14.3

Note. VR = virtual reality.

participants mentioned that they would not naturally stand in the middle of the quad; but rather, they would actively walk through it or sit down at one of the benches located on the side of the walkways. Inconsistencies in video stitching caused distractions among the participants and interfered with the level of immersion. Low crowd density within the grocery store reduced anxiety response. Absence of loud or specific noises, such as ambient music or children reduced anxiety. Participants noted that the pace of the video was much more rapid than their usual pace when shopping in a grocery store.

Qualitative theme data was collected from 360 video exposure within four environments about specific environmental cues that induced anxiety and discussed by the research team. These themes were documented for future VR development, including proximity to others within the space (i.e., crowding), referencing of suspicious looking individuals in the space, and concern about movement and pace provided researchers with data points to use for developing the 3-D environment. A further review of specific details in previous qualitative interviews indicated factors that may induce anxiety, such as sight lines around corners, amount of engagement with other people, and a focus on task goals to avoid feeling and experiencing anxiety. At the conclusion of the user testing of all four environments, and analyzing the data from the user testing session, it was determined that the grocery store environment was the most effective environment for stimulating emotional responses and provided the richest environment for a variety of stimuli. Furthermore, the research team decided that it was a common experience that most student veterans may face in their day-to-day life.

VR design

The advantage of a fully 3-D rendered and programmed VRE over 360° video, is that the researchers can fully customize the experience for participants through asset modeling and software development. During the study, some participants' anxiety levels were heightened by very specific stimuli, including specific sounds, the physical appearance of people in the video, and other factors. By utilizing 3-D models and software development in Unity3D (Unity Technologies, 2018), the research team would be able to create a much more dynamic environment that could be better customized for individual's anxiety triggers. For example, some veterans in the study described certain facial features, types of dress, and behaviors such as prolonged eye contact or staring. Furthermore, unlike 360° video, a 3-D VR environment adds the ability for users to interact with the environment as opposed to just observing it.

Lessons learned from the 360° prototyping were incorporated into the design of the 3-D VR prototype. These lessons included the addition of a higher number of people in the store in the form of avatars, representing distressing physical features or behaviors commonly reported as anxiety producing, and the delivery of stress-producing noises either randomly or on demand. The 360° prototype was used by the software development team as a blue-print to begin designing this version of the environment. This reduced the amount of time it took to create the 3-D layout of the store, as they could always refer to the video when necessary. In order to further decrease the time required to create this prototype, a mixture of stock 3-D models was purchased from various online sources. Custom designed 3-D models created by the development team were also used.

Hardware used. The development of VRE has been a challenge for many years. Recently, in the last decade, major engineering breakthroughs have occurred to give support to the manufacturing of consumer-grade VR headsets of the likes of Oculus Rift and HTC VIVE (Moro, Stromberga, & Stirling, 2017). Due to the availability of VR hardware, game engines and video software began utilizing the hardware. The nature of VR is to immerse the user by giving more freedom of choice and encompassing the user's senses with virtual content (Miller & Bugnariu, 2016). This leads to potentially better research data but also causes old methods of data collection to be reviewed and compared against new ones. Because the technology is so new, new methods of design, prototyping, and development must also be created.

For the needs of this project, a wall projection system and an Oculus Headset (Desai et al., 2014) were utilized. Oculus Touch Controllers were used as an interaction interface for further immersion in our subjects. The Virtual Reality Tool Kit (vrtk.io, 2018) was utilized in our project to facilitate touch controller compatibility with the Unity3D engine. By introducing mechanics that were more in line with real-life movement, the subjects were able to focus on their environment instead of controlling their character (Martinez-Hernandez, Boorman, & Prescott, 2017). Other objects in the environment were designed to behave naturally to the subjects' hand gestures. For example, users could grab baskets or doors by their handles and pick up food items using the Oculus touch controllers. Unfortunately, using joystick controllers to interact with the environment and move within the virtual space is not the most natural way of performing these tasks compared to the physical world. However, to date, there are no better proven solutions to serve that purpose. More natural ways of locomotion (e.g., Omni and Infinadeck treadmills) and interaction with the virtual world (e.g., Microsoft Kinect) are currently being investigated; however, such solutions are still experimental, lack accuracy, and are not suitable for a large variety of applications.

Software used. iClone 7 (Reallusion, n.d.) is a real-time 3-D animation software package. Character Creator, a package provided by iClone, generates high polygon 3-D avatars with customizable clothing options. The ability to morph the 3-D avatars faces and body helped create realistic models quickly for use in Unity3D. Unity3D (Unity Technologies, 2018) is a 3-D game engine that allows for the development of cross-platform 2-D/3-D applications. The flexibility and openness of Unity3D has led to its extensive use in academic research applications in VR. For example, Yang, Zhang, and Duan (2015) created a BCI simulated application system based on Unity3D.

Production. Using Unity3D, one Oculus headset, two Oculus motion sensors, and two Oculus touch controllers, a team of five computer science students of varying programming skill levels worked for 4 months. Several existing 3-D models were gathered from third-party sources, available online, to speed up the modeling process, and Reallusion's iClone 7 and

Character Creator software were used to generate 3-D avatars (see Figure 5). The Virtual Reality Toolkit (VRTK) was used to quickly develop basic movement and controls. Furthermore, artificial locomotion was used for the movement. Objects that could be picked up were highlighted yellow to indicate to the user of their ability to interact.

Evaluation of the VR environment. Through close collaboration between the social workers and the design and development team, the requirements of a VR environment simulating a grocery store were established. The grocery store VR environment developed as a case study was iteratively and incrementally evaluated in terms of usability and in terms of meeting the requirements specifications by the social work researchers, who acted as the intermediate link between the end users (veterans with social anxiety) and the engineering team. After the development of the VR grocery store, the veterans were immersed in it and were instructed to attempt to complete the purchase of a few grocery items, as they would do in a real store. Eight test subjects ($n = 8$) were invited to participate in a VR exposure experiment, simulating a real-life shopping experience. Again, veterans were randomly selected from a pool of 122 prescreen surveys, with eight veterans meeting study criteria (Table 2). User feedback and physiological bio-signal responses were collected to assess the usability and emotional state of the participating subjects during their VR exposure.

Before each experimental session, the test subject could interact with the equipment in a sandbox or tutorial VR environment to become familiar with the controllers and the general feeling of immersion using a VR headset. A secondary purpose of the sandbox interaction with the VR was to

Figure 5. Snapshots of the VR environment during an experimental session. Three stages of the session are shown: the beginning of the session in the parking lot of the grocery store (left), shopping process (middle), check out at register (right).

Table 2. Clinical scores on student veteran intake measures.

Scale	360° Video ($n = 6$)		3-D VR ($n = 8$)		Total	
	M	*SD*	*M*	*SD*	*M*	*SD*
SAD	14.66	3.82	18.12	1.8	16.64	3.24
PCL-5	42	13.07	48	17.27	45.64	16.08
CES	12.3	13.77	18.12	11.40	15.85	12.26

Note. VR = virtual reality; SAD = social anxiety disorder; CES = combat experiences scale.

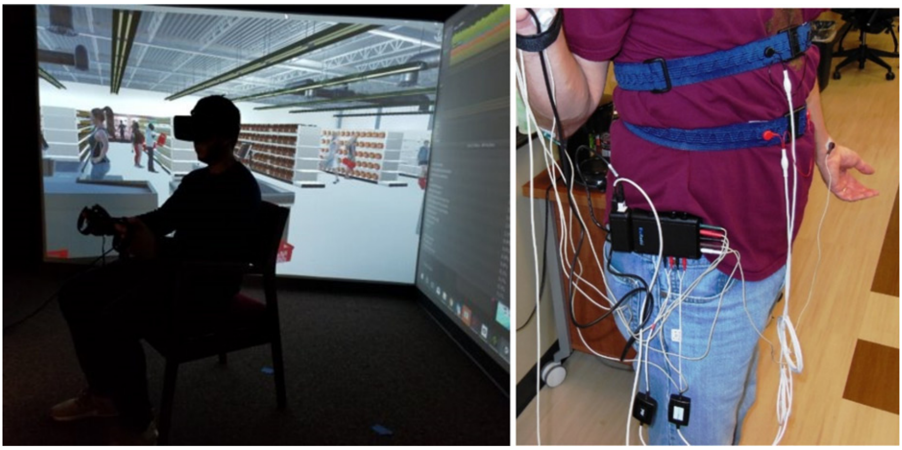

Figure 6. A test subject going through a VR grocery shopping session (left), and a photo showing the placement of sensors for physiological data collection (right). The test subject is immersed in the VR environment by using a VR headset. The wall projection is used for the researchers to monitor the subject's activities inside the environment.

help the user overcome a possible initial awe factor induced by the unfamiliarity with the VR technology. During the simulated grocery shopping session, subjects started from the parking lot of the store, they entered the store, navigating the VR environment using the provided controllers and they completed a shopping routing, purchasing a set of specified items. Figure 6 (left) shows a test subject going through a shopping routing while immersed using a VR headset and holding the VR controllers. Figure 5 shows three snapshots of the VR environment captured during one of the sessions.

Qualitative feedback was collected from the test subjects in the form of open-ended questions and scale questions, regarding the perceived level of immersion, level of anxiety experienced, as well as other questions, such as scale of motion sickness caused by the environment. Physiological measurements, as well as self-reports of test subjects and researcher observations, validated the initial hypothesis that immersion to VR environments causes an emotional response like real-life situations. Table 3 shows a list of the types of physiological bio-signals collected, whereas, Figure 6 (right) shows a photo of the sensor placement. The BioRadio physiological monitoring device (GL Neurotechnologies, 2018), by Great Lake Neurotechnologies, was used for collecting the data.

Although a detailed quantitative analysis is outside the scope of this article, early analysis of bio-signals showed a mean increase of 25.3% in Galvanic Skin Response (GSR) and 6.3% in heart rate (HR), compared to baseline, during face-to-face interviews of the test subjects with the social work researchers, and a corresponding 22.7% increase in GSR and 10.8% increase in HR during VR immersion sessions at the grocery store

Table 3. Physiological bio-signals collected during studies.

Physiological signal	Location
Electromyography (EMG) Zygomaticus "smile" muscle	Right cheek
Electrodermal Activity (EDA)	Right index & pointer finger
Electrocardiogram (ECG)	Left and right wrists
Chest respiration (RIP)	Chest strap
Abdomen respiration (RIP)	Stomach strap
Peripheral temperature	Right pinkie finger
Heart rate via PulseOx	Right ring finger
Blood volume (PPG) via PulseOx	Right ring finger
Blood oxygen (SpO2) via PulseOx	Right ring finger
Body acceleration and rotation	Right hip

Table 4. Physiological response variations in galvanic skin response (GSR) and heart rate (HR) of subjects during virtual reality (VR) sessions compared to baseline.

Subject	Max % increase in GSR	Mean % increase in GSR	Max % increase in HR	Mean % increase in HR
S1	58.5	31.1	32.9	7.0
S2	60.6	26.4	29.9	8.8
S3	39.6	18.5	18.6	8.2
S4	41.1	16.3	127.8	30.2
S5	68.0	33.0	17.1	6.5
S6	29.0	11.0	11.3	3.7
Means	49.5	22.7	39.6	10.8
Medians	49.8	22.4	24.2	7.6

environment. Table 4 shows the maximum and mean increase in GSR and HR per subject during the exposure to the VR sessions. Note that due to imperfect sensor attachment and signal artifacts, only data collected from six out of the eight participants in the VR experiments were considered clean enough to be included in this analysis. Prior to exposure of the VR grocery store, *baseline values* for the GSR and HR were collected from all participants. During baseline data collection, subjects remained stationary with casual interaction with the researchers. Data was then collected during exposures to the VR grocery store. The maximum and mean increases were calculated using the following formulas:

Max % increase GSR = (MaxGSRobserved - baselineGSR)/baselineGSR*100

Mean % increase GSR = (MeanGSR - baselineGSR)/baselineGSR*100

Similar for the HR.

The results show a consistent increase in GSR and HR, although of varying levels for each subject, among the test subjects during both the face-to-face interviews and VR sessions. Similar changes in physiology in both GSR and HR were observed both during planning stage interviews about socially stressful situations and exposure to the VR grocery stores. GSR and HR fluctuations were observed for most subjects. While GSR and HR are known to be good indicators of stress response (Kurniawan et al., 2013), it is unclear to what degree this anxiety was caused by the actual environment or by other factors. However, it does appear that the combination of self-reported stress, as well as fluctuations in bio-signals, indicate that the VR grocery store does incite anxiety in the specified population, indicating a potential for future use as a tool for intervention.

Limitations

This prototyping process and the study of VR interventions to our specific population of student combat veterans has limitations. Due to the comorbid nature of SAD (American Psychiatric Association & others, 2013) with other conditions such as mood disorders and PTSD, we cannot conclude that the environments prototyped are solely for the treatment of social anxiety. To further ensure that these treatments are specifically tailored to the dimensions of social anxiety, a Structured Clinical Interview for the DSM-V (SCID-R; First, Williams, Karg, & Spitzer, 2015). From the initial study of experiences of student veterans with SAD (Trahan et al., 2019), environments were chosen by researchers based on low, medium, and high anxiety levels. Ideally, these conclusions would have been member checked to ensure the validity of the environment chosen. Limitations of 360° video in large crowds included the inability to fully script crowd dynamics and interactions. This resulted in areas of the video that had to be edited out due to interference from the crowd, or verbal comments from spectators regarding the film crew's activities. An additional limitation of the 360° cameras utilized was the lack of stabilization on moving shots. This additional movement has the tendency to create motion-sickness in those who are particularly susceptible to it. Lastly, the software used to stitch the six different camera outputs into one 360° video does not allow for the removal of all stitching lines from the video, creating hard edges in some areas of the video resulting in hard-edge lines where two cameras overlap. Sometimes, these hard-edge lines were located in the user's field of view, which reduced the feeling of immersion for the user.

Conclusion and future research

This work presented a methodology for the design and development of VR environments for therapeutic intervention research in an academic setting. The stages of planning, requirements elicitation, design, implementation, and evaluation were discussed. Software and equipment used, as well as the value created by utilizing 360° video as a first step before moving to full 3-D rendered and programmed VR environments were explained. This process is replicable for the creation of other similar environments for therapeutic intervention in controlled settings, minimizing the risks of real-life exposure while simulating characteristics, otherwise difficult to replicate in real life. The proposed methodology involves domain experts, outside of the technical engineering team, in the design and evaluation process. Further research is required for a quantitative and clinical evaluation of the effectiveness of VR environments in producing the desired clinical outcomes compared to traditional methods. Likely, a combination of traditional methods and VR-enabled interventions might achieve the best possible outcome.

Funding

The authors would like to thank students Caleb Pase, Erik Martinez, Benjamin Garrard, Benjamin Munoz, and Kevin Kim for their valuable contribution in the development of the 360 Video and VR environments. This work has been supported in part by the Texas State University Multi-disciplinary Internal Research Grant (MIRG).

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