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Virtual Environments for Treating the Fear of Heights

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Can virtual environments help elicit fearful feelings so they can be treated? This article shows how therapists and computer experts used them to do just that.

User immersion in a synthetic environment distinctively characterizes virtual reality (VR) as different from interactive computer graphics or multimedia. In fact, the *sense of presence* in a virtual world elicited by immersive VR technology indicates that VR applications may differ fundamentally from those commonly associated with graphics and multimedia systems. Since the spring of 1993, we have been investigating the possibility of using virtual environments to conduct exposure therapy of individuals with psychological disorders. In this article, we describe a pilot study that used virtual reality graded exposure techniques to treat acrophobia—the fear of heights. We specifically address two issues: the extent to which we were able to make subjects feel that they were actually present in height situations, and the efficacy of the treatment conducted using virtual height situations.

BACKGROUND

Acrophobia and graded exposure

Acrophobia, a simple phobia, is characterized by marked anxiety upon exposure to heights, by avoidance of heights, and by interference in functioning as a result of this fear.[1] Behavioral therapy of acrophobia has included exposing the subject to anxiety-producing stimuli while allowing this anxiety to attenuate. These stimuli are generated through a variety of modalities including *imaginal* (subject generates stimulus via imagination) and *in vivo* (subject is exposed to real situations). Systematic desensitization, a form of imaginal exposure in which relaxation is combined with exposure, has long been effective in treating simple phobias.[2] Graded exposure is similar to systematic desensitization except that relaxation training is not involved and treatment is carried out in a real-life context.[3] In vivo graded exposure is a common and effective treatment for acrophobia and has been shown to be superior to systematic desensitization.[4]

After subjectively evaluating which height situations cause a patient anxiety, a therapist using an in vivo graded exposure approach would arrange therapy sessions for the patient to go through a process of exposure and adjustment to those situations (habituation). Patients would begin with less-threatening situations and gradually work their way up a hierarchy of more anxiety-producing ones. For example, if the patient is afraid of heights, therapy sessions might begin by having the patient look through a third floor window with the therapist present. In subsequent sessions, the patient might move up to a window on the tenth floor. Other common locations for in vivo therapy are outside stairways, balconies, bridges, and elevators.

Related work

Although the past two years have seen increasing interest in applications of virtual reality to psychology/psychopathology, few controlled studies

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document its effectiveness. A study similar to ours, conducted at Kaiser-Permanente, was reported in *CyberEdge Journal*,[5] although analytic results were not presented. In Japan, VR was used to simulate sand-play projective techniques with autistic children.[6] Again, no clinical data were presented, but the authors contended that the VR sand play was useful. A case study of a single acrophobic subject treated with virtual reality graded exposure is scheduled to appear in the fall issue of *Behavior Therapy*.[7] Preliminary results from this study have appeared as a brief report in *the American Journal of Psychiatry*.[8]

Building environments for therapy

We designed a number of virtual height situations to correspond to the types used for in vivo stimuli. Graphics workstations for this project were a number of Silicon Graphics machines, including a Reality Engine, several Indigos, and three GTX-class machines.

AMOUNT OF DETAIL. We defined real-time response as at least 10 frames per second. With a 10-fps rule as our bottom line, we then experimented with the amount of detail we could put into the image. It soon became apparent that we would have to choose between stereoscopic images with a relatively low degree of detail and monoscopic (in which both eyes see the same image) images with more realistic details provided by texture mapping. Our SGI Reality Engine provided real-time texture mapping but did not support stereo for head-mounted displays. We could provide stereo by running two machines in parallel, but none of our other machines were as fast as the Reality Engine nor did they support hardware texture mapping.

Few controlled studies document the effectiveness of applying virtual reality to psychology.

The horizontal resolution of our head-mounted display (HMD) and the nature of the environments we wished to generate were additional considerations. In the scenes that we generated, most of the important details implying that the user was in a height situation were located at least several meters away. The relative depth levels defined by discrete pixel widths in horizontal parallax for our HMD (a Virtual Research Flight Helmet with a "through-the-optics" pixel width of 0.5 centimeters) allowed only five displayable depth locations between 3 meters and infinity. Because of these considerations, we decided to render textured monoscopic images for the acrophobia treatment sessions.

THE ENVIRONMENTS. We created three virtual environments for use in the therapy sessions: an elevator, a series of balconies, and a series of bridges. We used Wavefront software[9] to perform modeling and the Simple Virtual Environment software library[10] to create virtual environments from the models.

The elevator was modeled as an open elevator (no glass, walls, or ceiling) located on the inside of a 49-story hotel (Figure 1). A guard rail was located about waist high to the occupant. To provide a greater sense of actually being in the elevator, we built an actual wooden platform with guard rails for the subject to stand on while riding the virtual elevator (Figure 2). The actual rail and elevator platform corresponded in size and position to the rail and platform the occupant saw in the virtual world. The occupants could press icons located on the virtual rail to go up, go down, or stop. Each rider held a tracker in his or her right hand (as shown in Figure 2). A virtual right hand followed hand movements so that the user could operate the virtual elevator controls. The occupant had tactile feedback in that everything appearing to be within reach from the elevator (the rail and floor) could actually be felt or grasped.

The second model consisted of outside balconies attached to a tall building (Figure 3). Four balconies were created at different heights: ground level, second floor (at 6 meters), tenth floor (at 30 meters), and twentieth floor (at 60 meters). As with the elevator, we used a wooden platform with guard rails that corresponded in position to the virtual rails on the balcony.

The third model was a canyon with bridges of different heights spanning the canyon from one side to the other. A river ran through the bottom of the canyon. The bridges varied not only in height but also in apparent steadiness. The lowest two bridges (at 7 and 50 meters) appeared safe and solid. The highest bridge (at 80 meters, dubbed the Indiana Jones Bridge by one of the subjects) was a rope bridge with widely spaced virtual wooden slats as the flooring (Figure 4). Subjects could also stand at the top of the canyon and look down on all three bridges.

EXPERIMENTAL METHOD

Measures

We constructed the screening questionnaire for this study and assessed patient inclusion and exclusion criteria. We assessed the following criteria for simple phobia according to the American Psychiatric Association's diagnostic and statistical manual:[1]

- fear of heights,
- avoidance of heights,
- belief that the fear is excessive,
- interference with normal activities due to fear,
- desire for treatment,
- desire to participate in a treatment study,
- absence of panic attacks,
- absence of a history of panic attacks, and
- absence of claustrophobia.

The acrophobia questionnaire (taken from Cohen[11]) describes 20 height situations with rating scales for anxiety (0-6) and avoidance (0-3). It yields a total score ranging from 0-180 plus anxiety (0-120) and avoidance (0-60) subscale scores. Adequate consistency and test-retest reliability have been previously demonstrated for this test, which discriminates between phobic and nonphobic subjects.[11] It has also been shown in several studies[11-13] to pick up improvements following treatment and to be better at detecting differences produced by treatment than when therapists actually take people into height situations.[11]

The attitude-toward-heights questionnaire (adapted from Abelson and Curtis[14]) assesses six categories. These

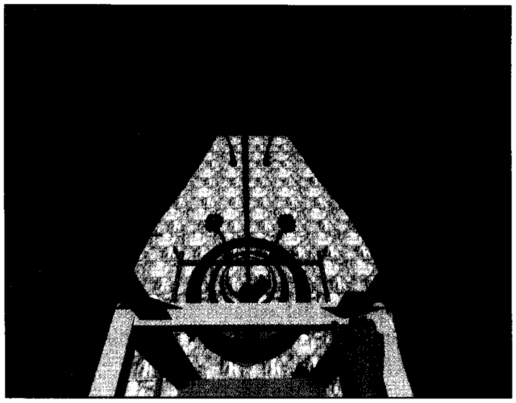
Figure 1. View from the elevator.


Figure 2. Participant riding in the virtual elevator.

include the following dimensions rated on a 0-10 semantic differential scale: good-bad, awful-nice, pleasant-unpleasant, safe-dangerous, threatening-unthreatening, and harmful-harmless.

We also constructed the fear questionnaire for this study. (One item was included from the Marks and Matthews[15] fear questionnaire to assess the degree of distress related to acrophobia.) The three situations to be used for VR graded exposure—glass elevators, outdoor balconies, and bridges—were rank ordered and rated for the amount of discomfort they produced.

During therapy sessions, subjects were asked every five minutes to evaluate their current anxiety on a scale of 0 (no discomfort) to 100 (panic-level anxiety). We will discuss these subjective units of discomfort (SUDs) further.

Subjects and procedure

We administered the screening questionnaire to 478 students in large introductory psychology and computer science classes at two Atlanta universities. Of these students, 46 were identified as possible acrophobes, 41 were contacted by phone, 31 were offered entry into the study, 20 were entered, and 17 completed the study. Of those entered, 12 were male and 18 were Caucasian, with an average age of 20 (with a standard deviation of 4.2). Students with concomitant panic disorder, agoraphobia (fear of open places), or claustrophobia were excluded because they might not be able to tolerate wearing the HMD.

Subjects were randomly assigned to either a treatment group or a wait-list control group. A pre-treatment assessment (PRE) was conducted in a group format in separate sessions for the treatment and the control groups. At that time, the study was explained, informed consent was obtained, and subjects completed all self-report scales. Control subjects were assessed at PRE, were provided no treatment, and were assessed again after seven weeks.

The first session for the treatment group, in which subjects were familiarized with the VR equipment, was conducted immediately after the assessment. They were allowed to take turns wearing the helmet and were encouraged to interact in VR by looking around a virtual room and "pressing" a button to turn its lights on and off. Treatment was then delivered in weekly individual sessions.


Figure 3. View from a balcony.

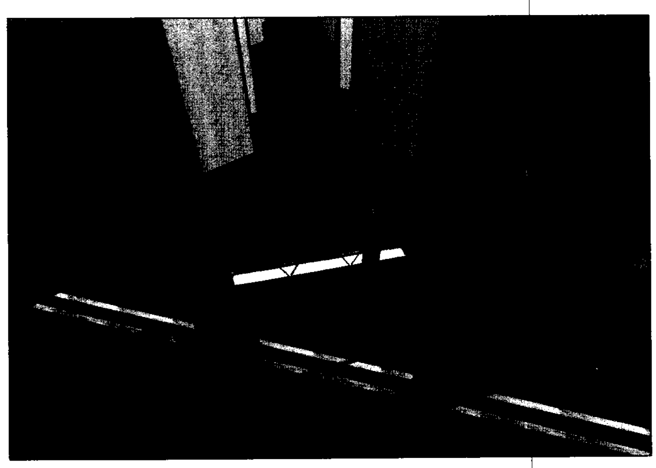
Figure 4. Bridges suspended at 7, 50, and 80 meters above a river flowing through a canyon.

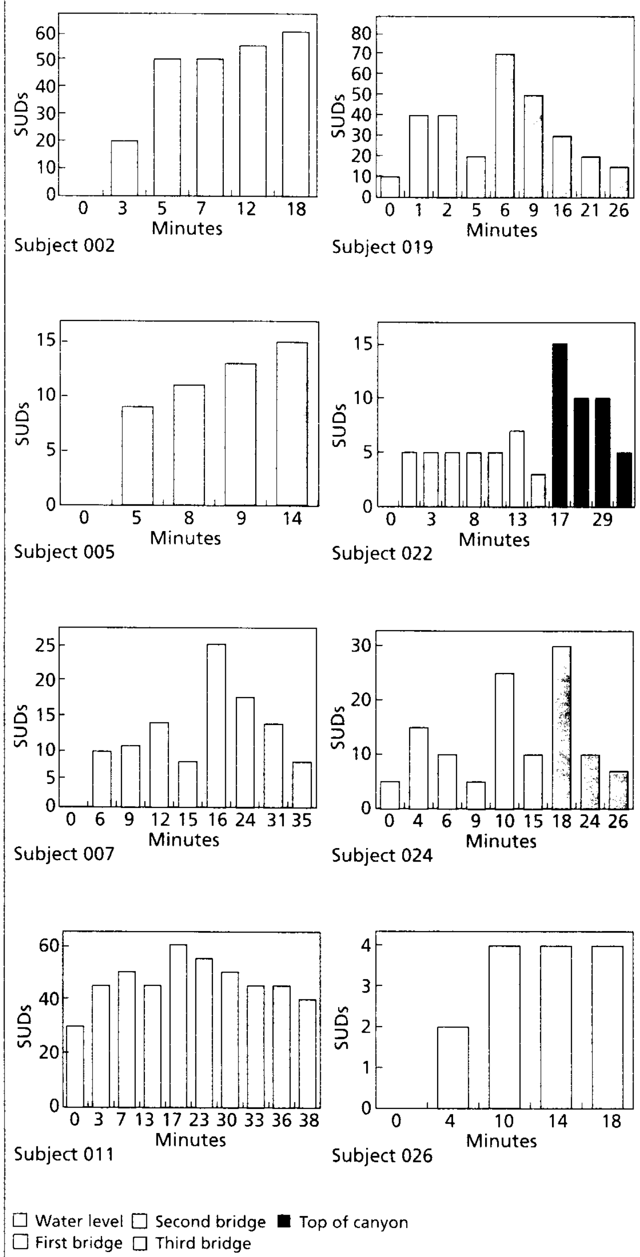

Figure 5. Subjective unit of discomfort (SUD) ratings with respect to time and bridge height during the first therapy session for the eight subjects who rated bridges as the least scary height situation.

The post-treatment assessment (POST) consisted of the same battery of questionnaires administered at PRE and was conducted eight weeks later in a group format. Assessments and treatment were provided free of charge.

Following the initial group session, individual VR graded exposure for the treatment group was conducted in seven weekly 35- to 45-minute sessions by an advanced clinical psychology graduate student. Three subjects habituated completely prior to the eighth session and were terminated early. Height situations were presented in the order determined by each subject's self-rated hierarchy completed at PRE. All sessions were video recorded and were reviewed by a supervising licensed psychologist.

Subjects were encouraged to spend as much time in each situation as needed for their anxiety to decrease and were allowed to progress at their own pace. On a video monitor, the therapist could simultaneouly see the same things as the patient did and was therefore able to comment appropriately, inquiring about the subject's feelings and so on.

RESULTS

Presence

Discussions of emotional processing theory as applied to anxiety disorders[16,17] purport that fear memories can be construed as structures containing information regarding stimuli, responses, and meaning. Therapy is aimed at facilitating emotional processing. For this to occur, it has been proposed that the fear structure must be activated and modified. For virtual environments to be effective, they must activate the fear structure and elicit fearful responses. Evoking a sense of presence in a virtual height situation is therefore essential to conducting exposure therapy.

SUD RATINGS. To measure the degree to which our subjects felt as if they were present in a physical height situation, we took SUD ratings approximately every 5 minutes during exposure. In exposure therapy using physical height situations, subjects' anxiety usually increases as they are exposed to more threatening situations and decreases as they spend time in the situation. This occurrence in virtual height situations would evidence that the subjects were experiencing the same reactions and emotions as they would in a similar physical world height situation. Figure 5 illustrates how SUD ratings varied with time and bridge height (see Figure 3) during the first therapy session for the eight subjects who rated bridges as the least scary height situation. Although the absolute SUD range varied for each subject, the pattern of decreasing SUDs over time and increasing SUDs with higher situations was clearly present.

Most subjects appeared to become immersed in the virtual environments. They often held on to the railings, letting go as they became more comfortable, then grasping them again as they progressed up the hierarchy. Sample comments for a range of sessions follow:

> Subject 007: "I'm feeling a little weak in the knees. My chest is getting tight. My palms are sweaty." (Session 2)
>
> "A lot easier than last week. Last week I was terrified." (Session 4)
>
> "This is the first time I can look down and not get that weak-in-the-knees feeling." (Session 6)

Table 1. Physical symptoms described by subjects during virtual height situations.

Symptom	Subjects 001	002	005	007	011	016	019	022	024	026
Sweating	√	√		√	√					
Abdominal discomfort (butterflies)	√			√	√		√			
Loss of balance (light-headedness)	√	√			√	√	√			
Heart palpitations	√	√				√	√			
Restlessness (pacing)								√		
Tremors (shakiness)	√				√	√	√			
Nervous/scared	√	√		√	√	√	√	√	√	
Weakness in knees	√			√		√				
Tightness in chest	√			√	√			√		
Tenseness		√				√		√	√	√
Feel physical motion sensations				√				√		√
Nausea (motion sickness)	√	√	√	√				√		
Feel like they are losing balance	√					√	√	√	√	√

"I went up the glass elevator (outside the building) at the Peachtree Plaza . . . 72 floors. I was anxious, but not as much as I used to be. It was much better. No weak-in-the-knees feeling." (Session 7)

Subject 001: "As long as I keep looking at it, it gets better than it was before." (Session 1)

"If I don't see the rail, I feel like I'm going to fall." (Session 5)

Subject 016: "Feel like I'm on the edge . . . don't like it." (Session 4)

"Feel weak in the knees . . . wanting to hold on for dear life." (Session 5)

"Feel more secure as I walk around. Not so weak in the knees. More sure of it." (Session 7)

Recording symptoms. In addition to SUD ratings, we also recorded the number and type of physical anxiety symptoms described by subjects during exposure. These included sweating, abdominal discomfort usually described as "butterflies," loss of balance or light-headedness, heart palpitations, restlessness or pacing, tremors or shakiness, feeling "nervous" or "scared," weakness in the knees, tightness in the chest, and feeling "tense" (see Table 1 for symptoms of the 10 subjects in the treatment group). In addition to these classic anxiety symptoms, some subjects also reported feeling physical motion sensations such as impact in their knees when the virtual elevator stopped descending.

Four subjects also reported nausea, and one subject actually vomited during her first virtual height experience. Nausea did not correlate to the height situations experienced as did the other symptoms but instead seemed related to simulator sickness. This simulator sickness arises from discrepancies between visual and kinetic perceptions and feels similar to motion sickness.[18,19] After we became aware of this, subject sessions were reduced from 50 minutes to 30-40 minutes, and subjects were encouraged to stop and rest at the first signs of nausea. Except for subject 005, subjects described experiencing from three to eight physical symptoms of anxiety (the mean was 5.1 with a standard deviation of 2.4).

Table 2. Means (M) and standard deviations (SD) for pre- and post-treatment.

	Treatment group				Control group					
	PRE*		POST**		PRE***		POST †		χ^2 †† (*p* value)	
	M	(SD)	M	(SD)	M	(SD)	M	(SD)		
Acrophobia questionnaire										
Anxiety	54.4	(24.4)	17.1	(11.7)	54.3	(11.4)	46.1	(15.3)	14.79	(.0001)
Avoidance	16.5	(10.8)	3.2	(2.7)	15.8	(7.8)	16.7	(7.7)	14.10	(.0002)
Total	70.9	(34.4)	20.3	(13.2)	70.1	(17.7)	62.8	(19.1)	16.14	(.0001)
Attitudes-toward-heights questionnaire										
Bad	6.6	(1.7)	2.9	(1.8)	5.0	(2.1)	5.6	(0.5)	18.91	(.0000)
Awful	6.0	(1.5)	2.9	(1.6)	5.3	(2.3)	6.0	(0.6)	14.69	(.0001)
Unpleasant	5.7	(3.1)	3.5	(1.7)	6.0	(2.4)	7.0	(1.5)	4.43	(.0353)
Dangerous	7.4	(2.5)	3.0	(2.3)	6.5	(2.6)	7.3	(1.6)	14.71	(.0001)
Threat	7.0	(2.0)	3.0	(1.9)	6.6	(2.7)	6.9	(1.9)	11.76	(.0006)
Harmful	6.8	(2.0)	2.7	(1.8)	6.1	(2.0)	6.7	(1.8)	18.31	(.0000)
Total	39.5	(10.9)	18.0	(10.3)	35.5	(12.6)	39.5	(6.4)	18.14	(.0000)
Distress from fear (from fear questionnaire)										
	4.1	(1.8)	1.9	(1.3)	3.5	(1.3)	3.3	(1.5)	9.33	(.0020)

* *n* = 12 (*n* is sample size in each cell)
** *n* = 10
*** *n* = 8
† *n* = 7

†† We tested the effect of VR treatment on the above scores by using the change-by-treatment interaction term from a repeated measures Mancova computed with the BMDP 5V computer program (*BMDP Statistical Software Manual*, Vol. 2, Dixon, ed., University of California Press, Berkeley) using the REML algorithm and compound symmetry covariants structure.

Subject 005 remarked several times that he had very poor eyesight. This, in conjunction with the limited resolution of our HMD, seemed to limit his experience of physical symptoms.

Another measure of presence was the degree to which fear and anxiety were reduced by the therapy, as next discussed.

Therapeutic effect

No pre-treatment differences between PRE and POST groups were detected on any measure or demographic variable. Table 2 presents the results of the PRE to POST assessments and the Chi-square analyses on all measures for both groups. As shown, anxiety, avoidance, distress, and all attitudes towards heights decreased significantly from PRE to POST for the treatment group but not for the control group. Examination of individual attitude ratings reveals that the means on all items were below 4.0 at POST for the treatment group, indicating positive attitudes on the semantic differential scale. In contrast, all attitudes were negative for the control group. The average anxiety ratings decreased steadily across sessions, indicating habituation.

It is important to note that seven of the 10 subjects who completed treatment had exposed themselves to height situations in real life during treatment, although they were not specifically instructed to do so. These exposures appeared to be meaningful, including riding 72 floors in a glass elevator mounted outside the Westin Peachtree Plaza Hotel and intentionally parking on the top floor of a parking deck close to the edge rather than in the center of the ground floor.

These results are comparable to those of Cohen's[11] systematic desensitization study—and are possibly more impressive. Cohen's pre-treatment anxiety and avoidance scores for treatment-seeking height phobics on the acrophobia questionnaire were 60.64 and 13.83, respectively, and are comparable to the pre-treatment scores in our study. Cohen's subjects' anxiety and avoidance raw scores decreased by 28.6 and 6.7, respectively, with systematic desensitization whereas our treatment group's scores decreased by 37.3 and 13.3, respectively. Although this is not a direct controlled comparison of VR graded exposure and systomatic desensitization, it supports the idea that VR exposure is just as effective as the more traditional type of therapy.

IN SUMMARY, OUR CONTROLLED STUDY of applying virtual reality to exposure therapy of acrophobia has yielded remarkable results. In particular, they attest to the sense of presence experienced by our subjects in virtual height situations. Subjects experienced a range of physical anxiety symptoms consistent with the apparent threat they encountered. The degree of anxiety and habituation observed would not have occurred unless the subjects felt present in height situations. In terms of emotional processing theory, the fear structures were clearly activated as evidenced by the subjects' responses during VR exposures. Subject responses were also apparently modified, as evidenced by the decrease in anxiety, avoidance, and negative attitudes toward heights. The results also support the notion that more elements of the fear structure are changed than those directly addressed in therapy. That is, stimuli and responses were directly manipulated via exposure and habituation. But the meaning associated with these elements also changed significantly (that is, they became less scared), although this is not directly addressed by the study.

These results have numerous implications. We have documented evidence for the experience of a sense of presence in an immersive virtual environment. We have also shown that a person's perceptions of physical- world situations and behavior in the physical world can be modified by experiences in a virtual world. We have provided initial controlled study support for applying virtual reality to the field of psychology/psychopathology and the treatment of psychological disorders.

Within the realm of exposure treatment for anxiety, virtual reality graded exposure may have wide applicability. Many stimuli for exposure are difficult to arrange or control, and when exposure is conducted outside of the therapist's office, it becomes more expensive in terms of time and money. Conducting exposures with virtual airplanes for flying phobics or virtual highways for driving phobics without leaving the therapist's office would make better treatment available to more sufferers. In addition, patients who have difficulty imaging and therefore are not good candidates for imaginal exposure may benefit from specifically programmed images. An additional advantage is that VR exposures can be made as extreme as necessary (like placing a subject on a mile-high balcony), providing for overcorrection of the fear and avoidancee. ▮

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