Comparison of the levels of presence and anxiety in an acrophobic environment viewed via HMD or CAVE

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Abstract
People who suffer from acrophobia fear any situation that involves heights. Several Virtual Reality systems have been presented to treat this problem. This paper presents a comparison study of the levels of presence and anxiety in an acrophobic environment that is viewed using a Computer Automatic Virtual Environment (CAVE) and a Head-Mounted Display (HMD). In this environment, the floor fell away and the walls rose up. To determine whether either of the two visualization systems induced a greater sense of presence/anxiety in non-phobic users, an experiment comparing the two visualization systems was carried out. Twenty-five participants took part in this study. After using each visualization system (HMD or CAVE), the participants were asked to fill out an adapted Slater et al. questionnaire, and a Student t test was applied to the data obtained. The CAVE induces a high level of presence in users. The mean score was 5.01 (where 7 is the maximum value), which was higher than the score obtained using the HMD which was 3.59. The Student t test indicates that there are significant statistical differences. The level of anxiety was also examined at different times during the experiment. The results indicate that both visualization systems provoke anxiety, but that the CAVE provokes more anxiety than the HMD. The animation in which the floor falls away is the one that provoked the most anxiety. The results from the correlation between the anxiety and the level of presence at the three times indicated a significant correlation between the two measures.

1. Introduction
Virtual Reality Exposure Therapy (VRET) uses Virtual Reality (VR) as a tool for therapy. VR is an attractive technology for therapy since the situation can be designed according to the key elements of a specific problem, generating the same reactions and emotions in the patient that s/he would experience in a similar situation in the real world. Different environments can be generated (objects, places or situations) in which the patient experiences sensations similar to those s/he would have in a real environment, however, since the environments are computer-generated (and therefore virtual), there is no need for the patient to move to a real place. The therapist has significant control and can manipulate the virtual environments to some extent. In addition, VRET is based on the assumption that virtual environments can elicit anxiety and provide the opportunity for habituation (Rothbaum et al., 1995a). In the DSM-IV (APA, 1994), anxiety is defined as an "apprehensive anticipation of future danger or misfortune accompanied by a feeling of dysphoria or somatic symptoms of tension". This definition implies that anxiety is a future-oriented state, that causes the organism to behave so that the danger can be averted.

Several studies support the idea that emotions such as fear or anxiety, which are felt during immersion, are related to presence. The sense of presence has been defined as the psychological perception of "being in" or "existing in" the Virtual Environment in which one is immersed (Heeter, 1992; Witmer & Singer, 1998). Robillard et al. (2003) carried out a study that included participants with and without specific phobias exposed to a virtual environment. They found a significant correlation between the level of state anxiety and the level of presence experienced during immersions in the virtual environment. In a study with participants suffering from acrophobia, Schuemie et al. (2000) reported a significant correlation between the level of fear and the sense of presence during immersion. In a study with participants suffering from arachnophobia, Renaud et al. (2002) found a significant relationship between the level of anxiety during immersion and the sense of presence, and

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motor behavior in a virtual task. In another study that involved participants without phobias, Regenbrecht, Schubert & Friedmann (1998) used regressions to control the impact of other subjective variables on the sense of presence. They also deduced that the level of fear during immersion increases proportionally with the sense of presence. In a study with 31 participants suffering from snake phobia, Bouchard et al. (2008) presented a randomized within-between design with two conditions and three counterbalanced immersions: (a) a baseline control immersion, (b) an immersion in a threatening and anxiety-inducing environment, and (c) an immersion in a non-threatening environment that should not induce anxiety. The measures of presence were significantly higher in b) than in either a) or c). Their finding was not corroborated by the presence questionnaire, where scores varied significantly in the opposite direction. However, the results from the brief one-item measure of presence did support the significant contribution of emotions during the immersion to the subjective measure of sense of presence. They also found correlations between anxiety and presence.

1.1. Treatment of acrophobia using Virtual Reality Exposure Therapy

Acrophobia is an intense fear of heights and consequent avoidance of locations that are related to heights (e.g., balconies, terraces, elevators, skyscrapers, bridges, planes, etc.). People who suffer from acrophobia know this fear is excessive or unreasonable, but they still fear any situation that involves heights, even when it is other people who are in those same situations. The greatest fear is falling. The most common treatment for acrophobia is “graded in vivo exposure”. In this treatment, the avoidance behavior is broken by exposing the patient to a hierarchy of stimuli. After a time, habituation occurs and the fear gradually diminishes. Several studies have focused on the effectiveness of treating acrophobia with VR, some of which make comparisons with exposure in vivo.

In the early 1960s, psychologist Eleanor Gibson described her visual cliff experiment (Gibson & Walk, 1960). For this experiment, she created an experimental environment with surfaces of two different heights: one at surface level and one positioned a few feet below the first surface. A black and white checkered cloth was then draped over the entire surfaces. Next a large sheet of heavy clear plastic was placed to cover the entire setup, creating the perception that the floor drops sharply, even though the plastic makes the surface level physically continuous. Even though the drop was just a visual illusion, babies refused to cross a floor that appeared to drop steeply. A replication of a similar setup within a virtual environment was developed by Meehan et al. (2002). Even seasoned VR veterans had difficulty overcoming the feeling that the pit was real. Physiological signals collected from the participants during the experiments showed that the virtual cliff induced the same physiological responses as the traditional visual cliff or a corresponding real space.

Several case studies show that acrophobia can be treated effectively with VRET (Choi et al., 2001; Rothbaum et al., 1995b). Rothbaum et al. (1995b) reported the first controlled study on VRET in which 20 participants were randomly assigned to either a VRET (12 participants, 7 sessions, 35-45 minutes each) or a non-treatment control group (8 participants). They used 3 footbridges, 4 outdoor balconies, and one glass elevator as virtual worlds. VRET was found to be significantly more effective than non-treatment on all subjective measures of anxiety and avoidance. In another study, Emmelkamp et al. (2001) used a within-group design, in which standard exposure in vivo was compared with VRET. Ten participants were first treated with two 1-hour sessions of VRET followed by two 1-hour sessions of exposure in vivo. The virtual environments were a diving tower plus swimming pool and a tower building with a glass elevator. In vivo situations were a fire escape, balconies of an 18-story building, and the roof of a 5-story building. VRET was found to be as effective as exposure in vivo on all subjective measures. Nevertheless, firm conclusions about the comparative effectiveness could not be drawn because of a potential order effect; all the participants received in vivo exposure after VRET. In a different study, Emmelkamp et al. (2002) reproduced in the virtual environments, the places used in real exposure (a shopping mall, a fire escape and a roof garden). Thirty-three acrophobic patients were randomly assigned to either VRET (17 patients) or exposure in vivo (16 patients). VRET and exposure in vivo consisted of three sessions of 60 minutes. VRET was found to be as effective as
exposure in vivo in combatting anxiety and avoidance. The improvements were maintained at a 6-month follow-up. The study that is most closely related to our work was presented by Krijn et al. (2004). This study was designed to investigate the effectiveness of two different conditions of VRET, varying in the degree of presence. A CAVE was compared with a HMD. The effect of time was studied by adding a non-treatment control group. They used a building, a fire escape and a roof garden as virtual environments. The 37 patients who participated in the study were randomly assigned across the three conditions. Therapy consisted of three sessions of 1 hour each. No time effect was found for the waiting period on any measure. The participants in the non-treatment control group were randomly assigned to either CAVE or HMD after the waiting period, and their non-treatment post tests were used as pretests for the treatment conditions. The results showed that there were no differences in effectiveness between the two visualization systems on any measure. Presence was significantly higher in the CAVE, but this did not result in a more effective treatment. VRET, with either the CAVE or HMD, was significantly more effective than non-treatment. The dropout rate was high (10 out of 35 patients). The results showed that the dropouts experienced significantly less presence and anxiety in the virtual environments than the completers did. They did not find correlations between presence and anxiety during the sessions. In 2007, Krijn et al. (2007) also presented a study in which the effectiveness of VRET and VRET plus coping self-statements were compared. The results indicated that the addition of coping self-statements did not influence the effectiveness of treatment.

1.2. Augmented Reality for psychological treatments

Recently, Augmented Reality (AR) has also been presented as an available technology for treating phobias. Juan et al. (2005) and Botella et al. (2005) presented the first AR system for the treatment of phobias of cockroaches and spiders. In these works, they demonstrated that, with a single one-hour session, patients significantly reduced their fear and avoidance. Initially, the system was tested in a case study (Botella et al., 2005), and then it was tested on nine patients suffering from phobia of small animals (Juan et al., 2005). They have also proposed the use of immersive photography in an AR system for the treatment of acrophobia (Juan et al., 2006). In this system, forty-one participants without acrophobia walked around at the top of a staircase in both a real environment and in an immersive photography environment. Immediately after their experience, the participants were given the SUS questionnaire to assess their subjective sense of presence. The users’ scores in the immersive photography environment were very high. The results indicated that the acrophobic context could be useful for the treatment of acrophobia. However, statistically significant differences were found between the real and immersive photography environments.

1.3. Measures for presence

Since presence is a subjective condition, it has most commonly been measured using self-reports, either during the VR experience or immediately afterwards by questionnaires. Several questionnaires have been proposed and how to best measure presence has been discussed (Barfield et al., 1995; Ellis, 1996; Lombard & Ditton, 1997; Regenbrecht et al., 1998; Schubert, Friedmann & Regenbrecht, 1999; Sheridan, 1996; Slater, 1999; Witmer & Singer, 1998). Some attempts at measuring presence using physiological measures have also been made. Meehan et al. (2002) used a Training Room (an ordinary room with some furniture) and an adjacent Pit Room. The Pit Room had an unguarded hole in the floor leading to a room 20 feet below. On the upper level, the Pit Room was bordered with a 2-foot wide walkway. On the lower level, there was a furnished Living Room. In this environment, users equipped with a HMD practiced walking about, picking up, and placing objects in the Training Room. Then, they were asked to carry an object into the next room and place it at a designated spot. Meehan et al. hypothesized that a virtual environment would evoke physiological responses similar to those evoked by the corresponding real environment, and that a greater sense of presence would evoke a greater response. To examine this hypothesis, they conducted three experiments, the results of which support the use of physiological reaction as a reliable, valid, sensitive, and objective presence measure. The
experiments compared the participants’ physiological reactions to a non-threatening virtual room and their reactions to a stressful virtual height situation. They found that changes in heart rate, as well as changes in skin conductance to a lesser extent satisfied their requirements for a measure of presence, but changes in skin temperature did not.

1.4. Previous comparative studies between different visualization systems

Several studies related to the effectiveness of virtual environments at different levels of immersion have been reported. These studies can be divided into two groups. In the first group, we include comparisons between extreme opposites, like a CAVE and a standard desktop computer (Arns, Cruz-Neira & Cook, 1999; Gruchalla, 2004; Datey, 2002). In the second group, we include studies that analyze external factors such as field-of-view (FOV), stereoscopy, head tracking, sounds, tactile augmentation, etc. (Hendrix & Barfield, 1996a,b; Prothero et al., 1995; IJsselsteijn et al., 2001; Shim & Kim, 2004; Welch et al., 1996; Waterworth & Waterworth, 2003). The Master’s thesis by Raja (Raja, 2006) includes studies from both groups.

With regard to the first group, Arns, Cruz-Neira & Cook (1999) compared a similar application running on a desktop tool set (XGobi) with a CAVE. Similar datasets were displayed on the two systems, and the users performed a series of tasks in order to see if there were any tangible benefits of viewing datasets in an immersive environment. The authors hypothesized that viewing high dimensional statistical data would be more efficient in an immersive virtual environment. Even though the two systems differed in many respects, the authors found that some tasks requiring spatial understanding were performed more quickly in the virtual environment than on the desktop. Another study comparing a desktop with a CAVE for oil well-path editing tasks was presented by Gruchalla (2004). In this case, the systems were more similar to each other than those used in the previous case, but they still differed in many respects. Gruchalla found significantly better task performance in the CAVE. In a Master’s thesis presented by Datey (2002), the use of a desktop and an HMD to determine if an immersive virtual environment provided any benefit when spatial attributes of the data were important in task completion was presented. The author found a trend of increased task performance in the immersive condition, but this trend was not statistically significant. In this study, there were also many differences between the two systems. In the Master’s thesis presented by Raja, he presents a methodology, two information visualization applications that were developed using the CAVE, and three user studies in order to explore, examine and attempt to quantify the effects of immersion. He focused on three major components of immersion: field of view (FOV), head-based rendering (HBR), and stereoscopic viewing. He hypothesized that a high degree of FOV would result in increased task performance and user satisfaction when visualizing data represented by scatter and surface plots. He also hypothesized that HBR and stereoscopic viewing would result in increased task performance, but the effects of these components would be greater in the scatter plots than surface plots. He conducted three user studies. In the first study, an exploratory pilot study, he observed a trend in favor of using high FOV and HBR. In the second exploratory pilot study, he observed a slight trend in favor of high FOV. In the third study, thirty-two subjects performed tasks using both the scatter plots and surface plots with eight test conditions. He observed trends in favor of high levels of FOV, HBR and stereoscopic viewing in scatter plots. He also observed a slight trend in favor of HBR for surface plots, and a significant interaction effect between FOV and HBR in scatter plots for a particular task.

With regard to the second group, several researchers have indicated a significant relationship between larger FOV and greater presence (Hendrix & Barfield, 1996a). Knapp & Loomis (2004) made a study to understand the cause of distance underestimation in virtual environments, and they concluded that limited FOV of HMD is not the cause. Other analyses suggest that the subjective impression of actually being part of the virtual environment may be more important than the FOV per se (Prothero et al., 1995). Other researchers have analyzed the contribution of different aspects to the sense of presence. Hendrix & Barfield, (1996a) and IJsselsteijn et al. (2001) suggested that stereoscopy and tactile augmentation have a significant impact on presence. In addition, Hendrix & Barfield
(1996a,b) suggested that head tracking, sound, and spatialized sound also contribute to presence. In the same year, Welch et al. (1996) found that pictorial realism and interactivity increase presence to some extent. In 2003, Waterworth & Waterworth (2003) suggested that more abstract virtual environments elicit less presence than concrete ones. In 2004, Shim & Kim (2004) reported that the level of detail in the virtual environment is related to presence, although to a lesser extent than FOV. Thompson et al. (2004) studied whether or not the quality of the computer graphics mattered when judging distances in visually immersive environments. Their analyses demonstrated that perceived distance was significantly more accurate in the real world compared to three different virtual environments with graphical rendering of varying quality. They also demonstrated that distance judgments in the virtual environments did not vary much from each other.

1.5. Hypothesis, objectives and structure of the paper

The primary hypothesis of this study is that an acrophobic environment will provoke more anxiety and will induce greater sense of presence in a CAVE than in a HMD with non-phobic participants, and that a significant correlation will be found between anxiety and presence in these two visualization systems.

The first objective of this work was to develop a virtual environment and include new acrophobic situations in it. The second objective of our work was to examine the sense of presence, the anxiety level, and the relationship between them using the two visualization systems.

This paper is organized as follows. Section 2 describes the software and hardware requirements as well as the technical features of the virtual environment. Section 3 presents the results of the study for: the sense of presence, the level of anxiety and correlation between them. Finally, in section 4, we present our conclusions, the limitation of this study, and future work.

2. Material and methods

The virtual environment was built to be as realistic as possible and included the following features: stereo portrayal (as opposed to mono), realistic models and lighting, low lag, high frame rate, etc. These features contributed to an optimum virtual environment for inducing sense of presence. The virtual environment was based on a real room, which was realistically modeled with 3D Studio. Figure 1 shows the modeled room. Two changes were incorporated to the modeled room: the floor of the room could fall away and the walls could rise up. One side of the room had a brown fitted rug. A hole was modeled using the position of the rug. The surface of this hole was a brown square which was the same color and texture as the rug, so, the hole was camouflaged. Moreover, this hole had four dark walls and appeared to be very deep. This entire set of virtual elements was animated, and several sounds were added to try to induce a greater sense of presence in users (Storms & Zyda, 2000). The hole was divided into four blocks that could be moved simultaneously or independently by the experimenter at will. The present study used three possible animations. The first one consisted of dropping three of the four blocks sequentially, leaving the user standing on the only block that did not fall away. The second animation involved dropping the four blocks sequentially, where the last block to fall was the one that the user was standing on. In the third animation, the four blocks dropped simultaneously, and the user had the sensation of falling with them (elevator effect). In order to obtain this effect, the hole walls rose up while the rest of the environment remained static.

The application was developed using Brainstorm eStudio (www.brainstorm.es), which is an advanced, multiplatform real time 3D graphics presentation tool. This tool can be defined as an interface that the programmer can use to create 3D complex visualizations using tool options only without requiring OpenGL. We developed a plugin that allowed a direct import of 3D Studio models.

1) Head-Mounted Display

In our study, the application ran on a basic Windows 2000 PC (AMD XP 2600+, 1GB RAM and NVidia Gforce 6800), and allowed the user to walk around the whole room. The experimenter could
also control the position of the user and the hole animations at all times. A 5DT HMD (5DT Inc., 800 Hx600 V, High 40º FOV) was used as the visualization system. Using a screen, the experimenter could see the same scene that the user was seeing on the HMD. In order to allow the user to walk around the room, we used a GamePad (in our case the Logitech WingMan Cordless Rumblepad) and a MTx (Xsens Motion Technologies) which is a three degrees of freedom tracker that follows the user’s head movements. The tracker was firmly attached to the HMD allowing mixed navigation. In other words, the user can turn right/left in the scene by turning her/his head (or all of her/his body), and go forward or backward using the GamePad’s analogical control. Furthermore, if the user is going forward (or backward) and turns her/his head (or all of her/his body) left/right at the same time using this mixed navigation, the direction in which the user is moving changes. As a result, the navigation is more natural than using a GamePad only.

2) Computer Automatic Virtual Environment

A CAVE can be defined as an immersive stereoscopic room, which appeared for the first time in 1992 as a result of Cruz-Neira’s thesis (Cruz-Neira et al., 1992). In our work, a four-wall CAVE (front, left, right and floor) was used. This CAVE was assembled by Barco (www.barco.com). Each one of the square walls was 2.2 meters wide and active stereo images at 1280x1024 resolution were back projected onto all of them. The CAVE used active stereo images. For 3D vision, the user wore liquid crystal display glasses that were synchronized with the field sequential images using several infrared sensors located at the top of the CAVE. The CAVE also needed a tracking system that captured data regarding the position and orientation of the user’s head, thereby allowing the system to correct the user’s point of view. Other systems have used magnetic trackers, which have the great disadvantage of using wires. In our study, the CAVE had an optical tracking system, which provided the user with greater freedom of movement because s/he was not connected to a wire. An infrared mark constellation was used, which was captured (and illuminated) by four infrared USB cameras located at the top corners of the CAVE. This mark constellation was located at the top of the active glasses that the user was wearing. Tracking system robustness relied on using four cameras, since it would have been very unlikely for the mark constellation not to have been captured by any of them. The user could walk around the room by using a flystick. Another mark constellation (different from the one described above) was attached to this flystick. The flystick was also controlled by the tracking PC, and the data it generated were sent to the computer, which ran graphs via ethernet. This computer gathered the data using the same plugin mentioned above. The mixed navigation system for the CAVE used a flystick analogical control, which allows the user to go forward, backward and turn left/right. The attachment to the flystick mark constellation was also used to allow the user to turn left/right while s/he was going forward (or backward) simply by turning the whole flystick left/right. We used two computers. The first computer was a SGI Prism (Silicon Graphics, Inc., www.sgi.com). It was equipped with 16 Intel Itanium 2 processors and 8 ATI FireGL GPUs. This computer ran on SUSE Linux Enterprise Server 9, on which the Brainstorm eStudio application was run. The second computer was a desktop PC equipped with specific software that managed the complete tracking system. It sent the tracking data (position and orientation) to the computer that ran graphs via ethernet. This second computer ran Brainstorm eStudio and gathered the tracking data using a plugin. Since the SGI Prism used does not have a sound card we used the second computer for this purpose. A new C++ application was developed for this second PC to allow the person in charge of the experiments to control the virtual environment from the location of the PC. The whole system required three rooms due to the size of the visualization environment and the computer. The first room housed the first computer (computer room); the second room was where the user could view the application (visualization room); and the third room housed the second computer and all the controls (control room).
3. Results
3.1. Study

One of the objectives of this work was to test the efficacy of a virtual environment viewed using a HMD and a CAVE to induce sense of presence and to provoke anxiety in users. Another objective was to establish whether either of the visualization systems produced a greater sense of presence and anxiety in non-phobic users. Subjective presence measurements collected after exposure to the virtual environment viewed using the two visualization systems were compared. We used a questionnaire based on the one designed by Slater, Usoh & Steed (1994). Although there are several other questionnaires available, even physiological measures, we have chosen this questionnaire because of its popularity to facilitate comparisons with other studies. Subjective anxiety scores collected during the exposure to the virtual environment viewed using the two visualization systems were also compared. The correlation between anxiety and presence has also been analyzed.

Participants

Twenty-five participants took part in the study (20 males, 5 females). All the participants were Caucasian. The average age of the 25 participants was 23.44 years (S.D., 4.88). They were recruited by advertisements on the University campus, and all of them were students, scholars or employees at the Technical University of Valencia. The participants did not receive any compensation for their time. All the participants filled out the Acrophobia Questionnaire (Cohen, 1977) in order to exclude people suffering from acrophobia.

Procedure

Participants were counterbalanced and randomly assigned to one of two conditions:

a) Participants who used the HMD first and then the CAVE.
b) Participants who used the CAVE first and then the HMD.

The protocol was the following. Before the user was exposed to the virtual environment viewed using either one of the visualization systems, s/he received instructions about how to interact with the environment during the experiment. Then, a narrative was introduced to the user. We introduced this narrative in an attempt to add meaning to the experience for the participants. We had to keep in mind that the participants were non-phobic, and, therefore, we used the narrative to try and raise their interest in the experience and encourage them to look at the environment carefully. The narrative was: “You are a guard at the Technical University of Valencia and you are on duty. You have a very important mission: there is a terrorist threat. There has been a bomb threat for this building. You have
to look around carefully and inform the central guard service of any suspicious packet or bag that you locate in the rooms you have been assigned. Now you are in a room in one of the University laboratories. You have to concentrate and look for any suspicious objects. Be careful because these terrorists are extremely dangerous; they could have put booby traps in here and you may be in danger. Moreover, you have to look at everything carefully because later you have to report back to your superiors”. The participants stayed in each environment for about seven minutes. They first walked around the room for a few minutes, then, the person in charge of the study placed them in the area where the floor could fall away (the hole). Once the user was located in that place, the person in charge of the study showed the user the three animations described above. For the HMD, the user was equipped with the HMD and the GamePad. For the CAVE, the user had to be equipped with glasses, the flystick and protection (a kind of sock) for her/his feet. These socks protect the CAVE floor from damage by the users’ footwear. After using each visualization system (HMD or CAVE), the participants were asked to fill out an adapted Slater et al. questionnaire (Slater, Usoh & Steed, 1994). Hence, the participants filled this questionnaire twice. The 10 questions related to the sense of presence were as follows (the presence score is taken as the number of answers that have a score of 6 or 7). The scoring was on a scale of 1-7. Q1-Please rate your sense of being in a room (where 7 represents your normal experience of being in a place); Q2-Please rate your sense of being in a room where the floor fell away from under your feet at a given moment; Q3-Please rate your sense of being in a room where the walls rose up and confined you at a given moment; Q4-To what extent were there times during the experiment when the room was reality for you?; Q5-When you think back to your experience, do you think of the room more as images that you saw (a movie, a picture), or more as somewhere that you visited?; Q6-During the experiment, which was strongest on the whole: your sense of being in the room, or your sense of being elsewhere?; Q7-Think about your memory of being in “the room”. How similar is this memory to your memories of other places you have been today?; Q8-Think about your memory of when the floor “fell away”. How similar is this memory to your memories of other related experiences of “falling off” or “falling down”?; Q9-Think about your memory of the walls “rising up”. How similar is this memory to your memories of other related experiences of “becoming confined” or “becoming trapped”?: Q10-During the experiment, did you often think that you were actually in the room?

3.2. Data analysis

For the sense of presence, Table 1 shows the results related to presence measures. The significance level was set to 0.05 in all tests. Student t tests were applied to the scores given to all questions. The Count column shows the mean of the test count of scores of 6 or 7 among the 10 questions. The Mean column uses the mean score across the 10 questions instead. The remaining columns show mean results for the individual questions. The analysis of the data indicates that users reached a higher degree of presence in the CAVE, with means of around 5 for all questions (on a scale of 1 to 7). Moreover, all except 3 of the statistical Student t tests applied to the results showed significant differences between the two visualization systems, which indicates that the user considered the CAVE to be clearly different to (and more immersive than) the HMD. The results from questions 3, 6 and 9 do not show significant statistical differences between the two visualization systems when tests were applied. Questions 3 and 9 refer to the visual effect in which the user falls with the floor, i.e., when the walls rise up. The results indicate that users have a similar sense of presence when they are exposed to this visual effect using the two visualization systems. The same occurs for question 6, as users reported a similar sense of presence for the two visualization systems when they were asked about their sense of being in the room or elsewhere. In order to determine whether using one of the two visualization systems first has some effect on the presence measurement for the second visualization system, the sample was divided into two groups (the participants who used the HMD first and the participants who used the CAVE first) and Student t tests were applied to the scores given to all questions. No
significant statistical differences were found (see Table 2). This indicates that the order in which the participants used the visualization systems did not influence their presence scores.

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<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q7</th>
<th>Q8</th>
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<th>Q10</th>
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Student t, statistical

Table 1. Mean and standard deviation of presence scores

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<td>3.25±1.82</td>
<td>3.58±1.78</td>
<td>3.25±1.6</td>
</tr>
<tr>
<td>CAVE-HMD-2CAVE'</td>
<td>5.46±0.66</td>
<td>5.31±1.11</td>
<td>4.62±1.19</td>
<td>5±1.15</td>
<td>4.62±0.96</td>
<td>4.92±1.66</td>
<td>5.15±0.9</td>
<td>5±1.35</td>
<td>4.38±0.77</td>
<td>5±1.15</td>
</tr>
<tr>
<td>CAVE-2HMD'</td>
<td>5.75±0.75</td>
<td>6.04±0.96</td>
<td>4.71±1.48</td>
<td>4.58±1.38</td>
<td>5.17±1.19</td>
<td>5.25±1.06</td>
<td>4.51±1.24</td>
<td>5.17±1.75</td>
<td>4.33±1.67</td>
<td>5.33±1.37</td>
</tr>
</tbody>
</table>

Table 2. Comparison according to the order of exposure. (*) Scores obtained from participants who used the HMD first and the CAVE second. (+) Scores obtained from participants who used the CAVE first and the HMD second.

For the level of anxiety, the participants were asked to rate their anxiety level (scores from 0 = not anxious at all, to 10 = very anxious) at 5 different moments. These moments were: P1-Before starting the experiment; P2-When the participant was standing on one of the squares and the other 3 fell away; P3-When the 3 squares where the participant was not standing fell away and then the square where the participant was standing fell away, too; P4-When the walls rose up and participant was trapped; P5-At the end of the experiment. Tables 3 to 6 show Student t tests for the scores given in response to these questions for both visualization systems. The results from Table 3 show that there is a significant difference in the anxiety level in steps 1-3. This implies that the visualization systems do not provoke the same level of anxiety in these three steps. The CAVE provokes a much higher level of anxiety than the HMD. We have also compared the anxiety level at the moment before starting the experiment with the anxiety level during the different stages of the experiment using the two visualization systems. These results are shown in Tables 4 and 5. The results indicate that there is a significant difference between them. That is, both visualization systems provoke anxiety in participants. In order to determine whether using one of the two visualization systems first caused the participants to report more anxiety when using the second visualization system, the sample was divided into two groups (the participants who used the HMD first and the participants who used the CAVE first), and Student t tests were applied to the scores given to all questions (see Table 6). First, we compare the levels of anxiety reported when the HMD was used first to those reported after using the CAVE first. No significant statistical differences were found when analyzing steps 2-4. The values are similar, which indicates that the order of exposure does not influence the participants’ score for anxiety levels and the level of anxiety is similar no matter which of the two visualization systems is used first. For the CAVE, the results indicate that there are no significant differences in the scores given for steps 2 and 3. However, during all steps (2-4), the level of anxiety is higher when the CAVE is used after the HMD. Student t test shows that there is a significant difference in step 4. This implies that, in this case, the order of exposure does affect the user’s level of anxiety.

```
<table>
<thead>
<tr>
<th></th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMD</td>
<td>0.36±0.64</td>
<td>2.32±1.95</td>
<td>2.6±2</td>
<td>2.56±1.83</td>
<td>0.44±0.92</td>
</tr>
<tr>
<td>CAVE</td>
<td>1.16±1.49</td>
<td>4.28±2.34</td>
<td>5.64±2.6</td>
<td>2.76±1.99</td>
<td>0.76±1.2</td>
</tr>
<tr>
<td>Student t, statistical</td>
<td>3.02</td>
<td>5.78</td>
<td>7.13</td>
<td>0.56</td>
<td>2.0</td>
</tr>
</tbody>
</table>
```

Table 3. Mean and standard deviation of anxiety level
Table 4. Comparing the initial level of anxiety with the level of anxiety in steps 2-4 using the CAVE. Step 1, 1.21±1.50

<table>
<thead>
<tr>
<th></th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean±standard deviation</td>
<td>4.46±2.21</td>
<td>5.88±2.46</td>
<td>2.88±1.94</td>
</tr>
<tr>
<td>Student t, statistical</td>
<td>8.5</td>
<td>10.5</td>
<td>3.55</td>
</tr>
</tbody>
</table>

Table 5. Comparing the initial level of anxiety with the level of anxiety in steps 2-4 using the HMD. Step 1, 0.38±0.65

<table>
<thead>
<tr>
<th></th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean±standard deviation</td>
<td>2.42±1.93</td>
<td>2.71±1.97</td>
<td>2.67±1.79</td>
</tr>
<tr>
<td>Student t, statistical</td>
<td>6.36</td>
<td>7.12</td>
<td>8.03</td>
</tr>
</tbody>
</table>

Table 6. Comparison according to the order of exposure. (*) Scores obtained from participants who used the HMD first and the CAVE second. (+) Scores obtained from participants who used the CAVE first and the HMD second

<table>
<thead>
<tr>
<th></th>
<th>HMD</th>
<th>CAVE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1HMD-2CAVE'</td>
<td>1CAVE-2HMD'</td>
</tr>
<tr>
<td>Mean±standard deviation</td>
<td>0.46±0.78</td>
<td>0.25±0.45</td>
</tr>
<tr>
<td>Student t, statistical</td>
<td>2.39±2.18</td>
<td>2.25±1.76</td>
</tr>
<tr>
<td></td>
<td>2.69±2.39</td>
<td>2.5±1.57</td>
</tr>
<tr>
<td></td>
<td>2.69±2.05</td>
<td>2.42±1.62</td>
</tr>
<tr>
<td></td>
<td>0.69±1.11</td>
<td>0.17±0.58</td>
</tr>
</tbody>
</table>

For the relationship between anxiety and presence, we have used Pearson’s correlation. The null hypothesis is that the correlation coefficient comes from a population in which the correlation is 0. In order to determine if the correlation is significant, we have checked if the correlation coefficient is within the sample distribution specified by the null hypothesis with different probabilities. Table 7 shows the relationship between anxiety and presence when participants used the HMD/CAVE either first or second. In this case, we have correlated the anxiety in moments: P2, P3 and P4 with the presence questions related to these moments, Q2 and Q3. We have added a ‘+’ sign after values indicating where the correlation is higher (+). Table 8 shows the anxiety and presence correlation when participants used HMD or CAVE. Table 9 shows the relation between anxiety and presence when participants used the HMD/CAVE either first or second. We have correlated the anxiety in moments P2, P3 and P4 with the presence questions related to these moments, Q8 and Q9. Table 10 shows the anxiety and presence correlation when participants used HMD or CAVE. The results in these tables show significant correlation between anxiety and presence with a minimum significant level of 0.4 and a maximum significant level of 0.001. The only data that do not correlate belong to the group of participants that use the CAVE first and only when the walls rise up and the participants are trapped. This is an unexpected result because the rest of the groups and situations correlate. The anxiety analysis indicates that the order of exposure for step 4 affects the user’s level of anxiety. This fact could have influenced in this result. Another possible factor that could have influenced this result is the order in which the animations were experienced. When the situation where the floor falls away is experienced first, it is considered to be amazing and the realism of the animation where the walls rise up is not so amazing. For the results of this group, the correlation between anxiety and presence for the first situation was very high and perhaps the comparison between the two situations made the participants give these unexpected values. The analysis of ‘+’ signs indicates that the CAVE correlation was higher when the floor fell away and that the HMD correlation was higher when the walls rose up. The factor mentioned above could also be one of the possible reasons.
<table>
<thead>
<tr>
<th></th>
<th>1st HMD</th>
<th>2nd CAVE</th>
<th>1st CAVE</th>
<th>2nd HMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2-Q2</td>
<td>0.297 (0.4)</td>
<td>0.410 (0.2) +</td>
<td>0.681 (0.05) +</td>
<td>0.545 (0.1)</td>
</tr>
<tr>
<td>P3-Q2</td>
<td>0.246 (0.5)</td>
<td>0.578 (0.05) +</td>
<td>0.750 (0.005) +</td>
<td>0.459 (0.2)</td>
</tr>
<tr>
<td>P4-Q3</td>
<td>0.741 (0.005) +</td>
<td>0.282 (0.4)</td>
<td>0.004</td>
<td>0.306 (0.4) +</td>
</tr>
</tbody>
</table>

Table 7. The relationship between anxiety and presence when participants used the HMD/CAVE either first or second. Values in brackets mean significant level, alpha

<table>
<thead>
<tr>
<th></th>
<th>HMD</th>
<th>CAVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2-Q2</td>
<td>0.390 (0.1) +</td>
<td>0.375 (0.1)</td>
</tr>
<tr>
<td>P3-Q2</td>
<td>0.301 (0.2)</td>
<td>0.515 (0.01) +</td>
</tr>
<tr>
<td>P4-Q3</td>
<td>0.275 (0.2)</td>
<td>0.314 (0.2) +</td>
</tr>
</tbody>
</table>

Table 8. The relationship between anxiety and presence when participants used HMD/CAVE. Values in brackets mean significant level, alpha

<table>
<thead>
<tr>
<th></th>
<th>1st HMD</th>
<th>2nd CAVE</th>
<th>1st CAVE</th>
<th>2nd HMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2-Q8</td>
<td>0.328 (0.3) +</td>
<td>0.273 (0.4)</td>
<td>0.468 (0.2)</td>
<td>0.518 (0.1) +</td>
</tr>
<tr>
<td>P3-Q8</td>
<td>0.234 (0.5)</td>
<td>0.393 (0.2) +</td>
<td>0.581 (0.05) +</td>
<td>0.560 (0.1)</td>
</tr>
<tr>
<td>P4-Q9</td>
<td>0.713 (0.01) +</td>
<td>0.375 (0.3)</td>
<td>0.199</td>
<td>0.632 (0.05) +</td>
</tr>
</tbody>
</table>

Table 9. The relationship between anxiety and presence when participants used the HMD/CAVE either first or second. Values in brackets mean significant level, alpha

<table>
<thead>
<tr>
<th></th>
<th>HMD</th>
<th>CAVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2-Q8</td>
<td>0.404 (0.05) +</td>
<td>0.344 (0.1)</td>
</tr>
<tr>
<td>P3-Q8</td>
<td>0.348 (0.1)</td>
<td>0.477 (0.05) +</td>
</tr>
<tr>
<td>P4-Q9</td>
<td>0.656 (0.001) +</td>
<td>-0.014</td>
</tr>
</tbody>
</table>

Table 10. The relationship between anxiety and presence when participants used HMD/CAVE. Values in brackets mean significant level, alpha

With regard to the importance of seeing the user’s feet next to the hole where the floor falls away, the participants were asked the question: Do you think it is important that you can see your feet next to the hole where the floor falls away?. Twenty-three participants answered yes. Those participants were also asked to score this importance from 1 = Not very important, to 10 = Very important. The mean and standard deviation was: 8.78 ± 1.57. The results indicate that participants consider it important to see their feet next to the hole where the floor falls away.

Finally, Figure 2 shows some images of a participant using the CAVE, in which the three blocks of the floor next to the block on which the participant is standing are falling away.
5. Conclusions

We have developed an acrophobic environment that has been visualized using two different visualization systems (HMD and CAVE). We have also included two new acrophobic situations in the virtual environment that have not been previously reported. Our environment has provoked anxiety and has induced a sense of presence in non-acrophobic participants. The results have shown a significant correlation between anxiety and presence. As far as we know, this is the first study in which correlations between presence and anxiety in CAVEs have been reported. The HMD does not induce a high sense of presence in users, with an average score of about 3.6 for all the questions on a scale of 1 to 7 (Table 1). Besides, the CAVE induces a higher degree of presence in users, with an average score of about 5 on the same scale. Statistically significant differences have been found using Student t tests that corroborate that users do not have the same level of presence using the two visualization systems. The higher sense of presence induced by the CAVE is in line with the results reported by Krijn et al. (2004). There are several factors that could explain this situation. First, the FOV of the visualization elements since the HMD FOV is about 40 degrees, it limits user vision. This does not happen in the CAVE because the user is surrounded by the whole environment at all times with her/his own vision being the only limitation. Therefore, users have much more realistic stereoscopic vision in the CAVE; they even try to touch the elements which are shown. Larger FOV induces greater sense of presence, as was established by Hendrix & Barfield (1996a). Second, we must analyze the users’ comfort during the two experiences. This factor is very important to the user, it is clear that the glasses and flystick are more comfortable to use and allow greater freedom of movement than a HMD with all the devices and cables required. Perhaps the most important feature of the CAVE is that the user is always able to see her/his own body which acts as a permanent reference in the virtual environment. Thus, for example, the user can see her/his own feet at the edge of the hole which was confirmed as being important to our experiment participants. This study has also tried to analyze whether using one of the two visualization systems first had some effect on the presence measurement given for the second visualization system.
The results from this analysis (Table 2) seem to show that the HMD scores are not affected by the order of exposure, that is, better scores were not obtained when users used one of the two visualization systems first. In fact, scores for only five of the ten questions revealed a better result in one of the two exposure orders. The CAVE results indicate that users give a better score to this visualization system when they are exposed to it first. This happened for seven of the ten questions, although the difference was very small.

For the anxiety level, the results show that there is a significant difference between the level of anxiety felt at the moment before starting the experiment and the level felt during the different stages of the experiment. The results also show that this difference is higher when using the CAVE. There is also a statistically significant difference between the two visualization systems since the CAVE produces more anxiety. The results indicate that the animations included in the virtual environment provoke anxiety in users. This is especially the case for the animation in which the floor falls away. This implies that this kind of animation could be very useful for the treatment of acrophobia. For the correlation between anxiety and presence, the results show a significant correlation between the two measures. This result is not the same as the one obtained by Krijn et al. (2004). They did not find correlations between presence and anxiety. Our correlations between anxiety and presence have been obtained using HMDs (Schuemie et al., 2000; Bouchard et al., 2008). Schuemie et al. (2000) also used acrophobic environments. In the Schuemie et al. study, all the participants did not suffer from strong acrophobia, but at least two of them did. The differences with our study are that they did not compare the same environment in two different visualization systems. Instead, they used the same HMD and three different environments. In a more recent study, Bouchard et al. (2008) used anxious environments for patients suffering from snake phobia. They used a HMD and compared three different immersions. This study also differs from ours in many respects, but our results are in line with the correlation they found between anxiety and presence for the HMD.

The main limitation of this study is the small sample size. A larger sample would increase confidence in the results. Moreover, the specific reasons for the non-correlation between presence and anxiety from the group that used the CAVE first when the walls rise up could be identified. For this problem, special attention must be paid to this stage of the experiment. If participants gave similar scores, specific questions could be asked to clarify this point.

With regard to future works, first, presence is a subjective condition and the use of self-reports could give rise to some errors if the user does not give the correct score. As mentioned in subsection 1.3, it is possible to use physiological measures to measure presence (Meehan et al., 2002). One possible future study would be to include a contrast of the results obtained with questionnaire responses. Second, the CAVE that we used has 4 back-projected areas (3 walls and the floor) as do the great majority of CAVEs. We believe that, with 6 back-projected areas (4 walls, the floor and the ceiling), the immersion could be increased even further and the degree of presence could also be higher. Finally, since the user’s sense of presence is the defining factor in the successful treatment of acrophobia (Hodges et al., 1994) and several case studies have shown that acrophobia can be treated effectively with VRET (Choi et al., 2001; Rothbaum et al., 1995b), we plan to use the virtual environment with the two visualization systems for therapy in order to compare these results with both Krijn’s study and the results presented in this paper.

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- The Technical University of Valencia for letting us use the University CAVE.
References


