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Effects of Stereoscopic Viewing on Presence, Anxiety and Cybersickness in a Virtual Reality Environment for Public Speaking

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Abstract

In this study, we addressed the effect of stereoscopy on presence, anxiety and cybersickness in a virtual public speaking world, and investigated the relationships between these three variables. Our results question the practical relevance of applying stereoscopy in head-mounted displays for virtual reality exposure therapy (VRET) in a virtual public speaking world. In VRET, feelings of presence improve the efficacy (B. K. Wiederhold & M. D. Wiederhold, 2005). There are reports of a relatively large group of dropouts during VRET at low levels of presence in the virtual environment (Krijn, Emmelkamp, Olafsson, & Biemond, 2004). Therefore generating an adequate level of presence is essential for the success of VRET. In this study, eighty-six participants were recruited and they were immersed in the virtual public speaking world twice: once with stereoscopic rendering and once without stereoscopic rendering. The results showed that spatial presence was significantly improved by adding stereoscopy, but no difference for reported involvement or realism was found. The heart rate measurements also showed no difference between non-stereoscopic and stereoscopic viewing. Participants reported similar anxiety feelings about their talk and similar level of cybersickness in both viewing modes. Even though spatial presence was significantly improved, its statistical effect size was relatively small. Our results therefore suggest that stereoscopic rendering may not be of practical importance for VRET in public speaking settings.

1. Introduction

Social phobia is frequently identified as one of the most prevalent phobias (Klinger et al., 2004). About 13% of the US population and 9.3% of the adult Dutch population meet diagnostic criteria for social phobia at some point in their lives (de Graaf, Ten Have, van Gool, & van Dorsselaer, 2011; Kessler et al., 1994). In social or performance situations, individuals with social phobia are afraid of being embarrassed and judged by others. They are hypersensitive to criticism, negative evaluation or rejection, and have a low self-esteem or feel inferior. When confronted with a social interaction, they almost always experience symptoms of anxiety such as racing heartbeat, sweating, discomfort, shaking hands, etc. (Kessler, Stein, & Berglund, 1998). As a consequence, they may avoid being exposed to any social situation. As such, they have difficulty in making social networks and in more severe cases, they may drop out of school, be unemployed and not seek work due to their fear for job interviews, have no friends, (American Psychiatric Association, 2000).

A common treatment for social phobia is cognitive behavioural therapy, in which patients are exposed to anxiety-provoking social situations. Several authors have shown that cognitive behavioural therapy is an effective form of treatment with positive follow-ups at 6 months and at 5 years (Heimberg et al., 1990; Heimberg, Salzman, Holt, & Blendell, 1993). Seventy-five percent of people suffering from social phobia who completed treatment may experience an alleviation of their symptoms (Heimberg, et al., 1990; Heimberg et al., 1998). Generally the treatment can be accomplished in an actual physical situation (in vivo) or by having the patient imagine the stimuli (in vitro). A third option is exposure in virtual reality, referred to as virtual reality exposure therapy (VRET). In VRET, the anxiety provoking elements are displayed in a virtual environment. Such a virtual environment is computer generated by integrating real-time computer graphics, body tracking devices, visual displays, and other sensory inputs (Emmelkamp, Bruynzeel, Drost, & Van der Mast, 2001).

Meta-analyses on existing VRET treatments indicate that VRET is as effective as exposure in vivo (Gregg & Tarrier, 2007; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008). For example, Strickland et al. (1997) reported that participants showed a significant reduction of anxiety symptoms and an increased ability to face phobic situations after virtual therapy. Controlled studies showed that VRET may be as effective as exposure in vivo for acrophobia (Emmelkamp, et al., 2001), agoraphobia (Choi et al., 2005) and fear of flying (Emmelkamp, et al., 2001; Rothbaum et al., 2006). Clinical applications, in which virtual reality is currently used include treatment of post-traumatic disorder, eating disorder, and pain management (Anderson, Rothbaum, & Hodges, 2001).

For social phobia, most studies focus on the fear of speaking in front of a virtual audience (Anderson, Zimand, Hodges, & Rothbaum, 2005; Harris, Kemmerling, & North, 2002; Slater, Pertaub, Barker, & Clark, 2006). Results so far are encouraging. Patients showed significantly reduced anxiety after exposure to an audience of avatars in virtual reality (Anderson, et al., 2005; Harris, et al., 2002; Lister, Piercey, & Joordens, 2010).

In VRET, presence has been considered the principal mechanism that leads to the experience of anxiety (B. K. Wiederhold & M. D. Wiederhold, 2005). Earlier studies reported that the degree of presence depended mainly on aspects of the technological device, such as the fidelity of sensory components, the field of view, and the occurrence of stereoscopy. In addition, presence depended on the nature of the required interaction, on the task, and on individual differences (e.g., IJsselsteijn, de Ridder, Freeman, & Avons, 2000; Juan & Perez, 2009; Krijn, et al., 2004; Schuemie, 2003; Witmer, Jerome, & Singer, 2005). In this paper, we focus on one particular aspect of presence, namely on the effect of stereoscopy.

Stereoscopic rendering in displays permits the perception of objects floating in front of or behind the display plane as a consequence of screen disparity, i.e. the rendering of a slightly different image for the left and right eye, respectively. Screen disparity translates into binocular disparity, i.e., the difference between the two eyes’ views as a consequence of their horizontal displacement. Binocular disparity is a major cue for depth perception in humans (Howard & Rogers, 2002). In the current study, we investigate whether in a virtual world designed for exposure to a public speaking situation feelings of presence can be raised by adding stereoscopy. Furthermore, we investigate whether the assumed increase in presence can generate more anxiety in people.

One drawback of VRET, however, is that some people experience cybersickness in the virtual environment. It may reduce the usage of virtual reality. Sharples et al. (2008) investigated virtual reality induced symptoms, and reported that 60-70% of the participants experienced an increase in cybersickness after virtual reality exposure. Likewise some viewers of stereoscopic displays experience visual discomfort (Lambooij, Fortuin, Ijsselsteijn, Evans, & Heynderickx, 2010), possibly resulting in cybersickness type of symptoms. Thus, it may be hypothesized that people experience more cybersickness in a virtual reality world with stereoscopic rendering than with non-stereoscopic rendering. The difference in reported cybersickness caused by stereoscopic rendering is also studied in this paper.

In the current study, 86 participants were immersed in the virtual public speaking world twice: once with stereoscopic rendering and once without stereoscopic rendering. A neutral world was used at the start of each experimental session in order to get the baseline for the heart rate measurements. Questionnaires were administered before and after each virtual reality exposure. It was anticipated that the virtual public speaking world elicited a fear response which would be indicated by an increase in heart rate (Lister, et al., 2010). In addition, it was hypothesized that presence, anxiety and cybersickness would be higher in the stereoscopic viewing condition than in the non-stereoscopic viewing condition.

2. Background literature

The concept of presence is very broad. Generally it covers three aspects: spatial presence, social presence and co-presence (IJsselsteijn, 2004). Spatial presence is defined as “the sense of being in the virtual environment rather than in the environment in which they are physically located” (Witmer & Singer, 1998). In Slater’s recent work, spatial presence is called ‘Place Illusion’, which is a key component that contributes to realistic responses in a virtual environment (Slater, 2009). Social presence refers to the phenomenon that people feel that the interface of a given medium can provide some sense of access to other people's mind (IJsselsteijn, de Ridder, Freeman, & Avons, 2001; Lombard & Ditton, 1997). Co-presence is defined as the feeling of being together with others in a computer generated world at the same time even though people are in separated places. Co-presence is considered as the intersection of spatial presence and social presence (Tam, Renaud, Vincent, Martin, & Blanchfield, 2003). In the present study we will limit ourselves to spatial presence which only involves the user and the virtual environment without communication with other real people.

Gamito et al. (2010) showed that in VRET efficacy is higher for people who experience higher levels of presence. High levels of presence are, however, not always achieved for all participants. Krijn et al. (2004), for example, reported that 10 out of 37 participants were excluded from their experiment. The excluded patients experienced significantly lower levels of presence in the virtual environment than the completers did. Thus, one solution to reduce the number of dropouts seems to be an increase in the level of presence in patients.

Earlier studies have shown that stereoscopy can improve peoples' feelings of presence in a virtual environment (Cho, et al., 2003; Freeman, Avons, Meddis, Pearson, & IJsselsteijn, 2000; Hendrix & Barfield, 1995; IJsselsteijn, et al., 2001). IJsselsteijn et al. (2001), for example, found a significant effect of stereoscopy on presence, but not on involvement in a virtual world representing a rally car. Hendrix and Barfield (1995) found a significant improvement in presence and in interactivity with the virtual environment as a consequence of introducing stereoscopy, but they did not found an increase in overall realism of the virtual environment. Cho et al. (2003) tested the effect of stereoscopy on realism and spatial presence and found a significant improvement on both. Finally, Freeman et al. (2000) also found a positive effect of stereoscopic presentation on behavioral presence which was measured based on the magnitude of postural responses.

The most important consequence of feelings of presence in VRET is the evoked anxiety. Some studies found significant correlations between presence and anxiety (Price & Anderson, 2007; Schuemie et al., 2000), but others did not (Krijn, Emmelkamp, Biemond, et al., 2004; Seay, Krum, Hodges, & Ribarsky, 2001). It was suggested that in VRET some level of presence is needed, as it was reported that patients were excluded from VRET due to their absence of aroused anxiety in combination with significantly lower levels of presence (Krijn, Emmelkamp, Biemond, et al., 2004). However, Price and Anderson (2007) suggested that presence might be a necessary, but not sufficient requirement for the success of VRET. Therefore, to what extent a higher level of presence can generate more anxiety and whether a higher level of presence can improve the outcome of VRET is not clear so far. Results of previous studies were not always conclusive (Juan & Perez, 2009; Krijn, Emmelkamp, Biemond, et al., 2004; Miyahira, Folen, Stetz, Rizzo, & Kawasaki, 2010). For example, in one report (Krijn, Emmelkamp, Biemond, et al., 2004) no difference was found in experienced anxiety and treatment outcome for acrophobia between a head-mounted display (HMD) with a lower level of presence and the CAVE technology with a higher level of presence. Another study (Juan & Perez, 2009), however, did report a difference in presence and anxiety between these two technologies. Therefore, the relationship between presence and anxiety was further explored in our study.

One unintended side effect of using virtual reality is the conflict between visual and proprioceptive senses which may lead to cybersickness (Kim, Kim, Kim, Ko, & Kim, 2005). The reported results about the relationship between cybersickness and presence are controversial. Witmer and Singer (1998) found a significant negative correlation between cybersickness and presence, while Slater et al. (1993) and Busscher et al. (2011) found a positive correlation between these two. Earlier studies also reported significant correlation between anxiety and cybersickness (Busscher, et al., 2011; Kim, et al., 2005).

The above surveyed studies were conducted in different application areas using different display systems. Most importantly, none were conducted in the social phobia domain. Earlier results might not be generalizable to VRET for social phobia as the task might be much more cognitively demanding, and as a consequence stereoscopy may be unattended. Individuals may focus their attention mainly on their task rather than on what is presented in the virtual environment. Therefore, it is necessary to know for VRET treating social phobia, whether visual cues of stereoscopy can improve the sense of presence, giving people higher illusion of 'being in the virtual environment', and as a consequence, evoke more similar responses as experienced in a real-world situation. Hence, the relationship between presence, anxiety and cybersickness needs to be elucidated in the social phobia domain.

3. Method

3.1. Participants

Eighty-eight, 35 female and 53 male, students and staff from the Delft University of Technology participated in the experiment. Their ages ranged from 18 to 70 years old with the mean being 28.0 (*SD* = 6.3) years and the median being 26 years. Two participants were removed from the data set because they did not perform the task according to instructions. All participants were naive with respect to our hypotheses. Written informed consents were obtained from all participants. Each participant received a small gift for their contribution. All experiments were done in accordance to local ethical customs, Dutch Law, and the Declaration of Helsinki.

3.2. Apparatus

An eMagin Z800 head mounted display (HMD) was used to display the virtual worlds to the participants (Figure1 A). It has been used widely before in the virtual reality domain (Garner, Clarke, Graystone, & Baldwin, 2011; Morris, Louw, & Crous, 2010; Steinicke, Bruder, Hinrichs, & Steed, 2010; Yabuki, Miyashita, & Fukuda, 2011). The HMD displayed a virtual image comparable to viewing a105-inch display at 3.66 meters and the visual field spanned 40 degrees diagonally. The resolution of the right and left display was 800*600 (horizontal*vertical) pixels with a refresh rate of 60Hz. The angular resolution of the Z800 HMD was 2.4 arcmins per pixel, and it could display a minimum depth of 0.16 meters when the viewing distance was 3.66 meters for an average interocular distance of 6.3cm [2]. Therefore, it could display clear stereoscopy which should be easily detectable for our participants. The participant's head position was tracked at a 125 Hz update speed. Sound was played through desk mounted speakers. The virtual worlds were all made using WorldViz's Vizard 3.0 software.

The current experiment was set up in the virtual public speaking domain. According to Hall's (1966) research, social distance between people is reliably correlated with physical distance, and the physical distance used for public speaking ranges from 3.7 to 7.6 meters. There were five animated avatars (two women and three man) dressed casually sitting in a virtual room, and the distances between the participants and the avatars were specifically set within the distance range for public speaking. The back wall was 6.8 meters away from the main view of the virtual environment. In the centre of the room, there were five avatars sitting around a table facing the participant, at distances ranging from 2.91 to 3.14 meters away from the main view of the virtual environment (Figure1 B). As a result, the avatars were 6.57-6.80 meters away from the participants in life-size. One of the avatars gave instructions to the participant at the beginning and the end of the session. In order to elicit emotional engagement to enhance presence in people, the attitude of the avatars was manipulated (as previously proposed by Slater et al. (1999)). We changed the attitude of the avatars over time between three

[2] The angular resolution of eMagin Z800 HMD is comparable to the high resolution, often used nVisor SX60 (1280*1024) HMD of which the angular resolution is 2 arcmins per pixel, and the angular resolution of Z800 HMD is even better than the angular resolution of ProView SR80 (1280*1024) which is 2.95 arcmins per pixel.

different states: (1) a positive attitude, where all the avatars showed an interest in the talk by looking at the participant; (2) a neutral attitude, where some of the avatars were interested in the talk while others were not; and (3) a negative attitude, where none of the avatars showed interest in the talk, instead they were looking away, stretching their arms, talking amongst each other or falling asleep. A pre study, in which 16 participants were asked to rate the attitude of the audience from 0 (negative) to 100 (positive) showed that the attitudes of the avatars were indeed perceived as intended ($F(2,14) = 38.722$, $p < 0.001$). The negative attitude was significantly lower than the neutral ($t(15) = 5.331$, $p < 0.0001$) and positive ($t(15) = 7.288$, $p < 0.0001$) attitudes. The mean and standard deviation of the scores on the positive, neutral and negative attitude were $M = 57.19$, $SD = 5.08$; $M = 50$, $SD = 7.01$; $M = 20$, $SD = 4.52$ respectively.

“Figure [1A] here” “Figure [1B] here”

3.3. Measurements

3.3.1. Presence questionnaires

Two presence questionnaires, designed to measure the sense of presence in virtual reality environments were used, namely: the Igroup Presence Questionnaire (IPQ) (Schubert, Friedmann, & Regenbrecht, 2001) and the Slater-Usoh-Steed (SUS) questionnaire (Slater, Usoh, & Steed, 1994). The IPQ comprised 14 items rated on a seven-point Likert Scale. The scores on the 14 IPQ items were mapped onto three subscales, namely *Involvement* (the awareness devoted to the virtual environment), *Spatial Presence* (the relation between the virtual environment and the physical real world), and *Experienced realism* (the sense of reality attributed to the virtual environment). It also contained one item, which assessed the general feeling of being in the virtual environment.

The Slater-Usoh-Steed (SUS) (Slater, et al., 1994) questionnaire consisted of six questions and it was based on variations of three themes: 1) sense of being in the virtual environment, 2) the extent to which the virtual environment became the dominant reality, and 3) the extent to which the virtual environment was remembered as a place. Participants scored each of the six questions on a seven-point Likert Scale. The overall score of SUS was obtained by counting the number of questions whose score was 6 or higher. The questions were adapted to our particular virtual reality scene. As an example, the question “During the time of your experience, did you often think to yourself that you were actually in the virtual environment?” was modified to “During the time of your experience, did you often think to yourself that you were actually in a public speaking room?”

3.3.2. Personal report of confidence as a speaker

To inquire about any anxiety the participants might have experienced during their talk in the virtual public speaking world, a modified version of the Personal Report of Confidence as a Speaker (PRCS) questionnaire was used (Paul, 1966). The PRCS questionnaire assessed whether participants agreed or disagreed on 30 statements. An example statement is “I am in constant fear of forgetting my speech.” The PRCS was scored by counting the number of answers indicating anxiety. It was used as a screening test for everyday experienced fear of speaking. In order to be used as a post-test measurement of the degree of anxiety related to speaking in the specific virtual environment, the PRCS needed to be modified. Modification was accomplished by changing some of the tenses, and by removing inappropriate questions which referred only to the general situation. For example, the statement above was changed into “I was in constant fear of forgetting my speech”. Inappropriate statements such as “I look forward to an opportunity to speak in public” were deleted. The modified version of PRCS consisted of 16 items and it was also scored by counting the number of answers indication anxiety.

3.3.3. Cybersickness

To investigate whether the participants got sick from viewing the virtual environment, cybersickness was measured with the Simulator Sickness Questionnaire (SSQ) developed by Kennedy et al. (1993). The questionnaire existed of three components: nausea, oculomotor effects and disorientation. The SSQ contained 16 items and each item was scored on a 4-point scale (0-‘doesn’t feel anything’, 1-‘a little’, 2-‘medium’, 3-‘a lot’). The total score of SSQ was an aggregate score of the three components and it ranged from 0 to 235.62.

3.3.4. Heart rate

It was expected that heart rate would go up if people were feeling anxious. To measure elicited fear responses in the virtual public speaking world, the physiological measurement of the heart rate of the participants was included. The heart rate was recorded with a Mobi8 system from TMSi with Xpod Oximeter. The participant inserted a finger into an adult articulated finger clip sensor. A baseline for the heart rate was obtained in a neutral environment. Heart rate mean changes between the virtual public speaking world and the neutral world were used to measure the participants’ fear response.

3.3.5. Stereoacuity test

To test whether the participants could actually see stereoscopy, the TNO stereoscopic vision test was used to measure their stereoacuity.

3.4. Procedure

Prior to the experiment, participants were provided with an information sheet, and the procedure was explained to them. They were then asked to sign an informed consent form.

Participants were then asked to fill in an information questionnaire, the simulator sickness questionnaire and the original PRCS questionnaire before they were immersed in the virtual environments. The TNO stereovision test was also done to measure the participants' stereovision acuity. To make the participants familiar with the virtual environment, they were first exposed to a neutral world without stereoscopic rendering. In the neutral world, the participants could look around, move forward or backward by pressing the up or down arrow keys on a keyboard, or watch TV showing a documentary about wildlife. An earlier study showed that this world was perceived as neutral as it provided comparable effects with the actual world setting (Busscher, et al., 2011). Participants were exposed for seven minutes to the neutral environment. During these seven minutes the heart beat was recorded and used later as the baseline for the physiological measurements in the public speaking world. Participants were also asked to score the presence and SSQ immediately after exposure to the virtual neutral world.

When the participants were made familiar with the virtual environment system, they were asked to give two talks of five minutes each. They were free to talk about anything they wanted to talk about, but they were not allowed to use any notes or visual aids. One of the talks was given with stereoscopic rendering and one without stereoscopic rendering. The order was counterbalanced across participants. The two presence questionnaires, the modified PRCS questionnaire and the SSQ were administered after each talk in the virtual environment. During the talk physiological data such as heart rate was also recorded. The content of the presentation was recorded using a web camera. The experimenter left the experimental room when the experiment was started. Afterwards there was a debriefing session, in which the experimenter discussed with the participants about their experiences and explained to them the full details of the experiment.

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4. Results

4.1. Presence

Means and standard deviations for SUS and the IPQ subscales are shown in figure 2. Although the sequence of stereoscopic and non-stereoscopic viewing was counter-balanced, we first conducted two Multivariate tests to check the order effect on the presence scores. The result showed neither a significant difference between different viewing orders for self-reported presence in the non-stereoscopic condition ($F(5,80) = 0.98$, $p = 0.44$; $\eta^2 = 0.058$), nor in the stereoscopic condition ($F(5,80) = 0.79$, $p = 0.56$; $\eta^2 = 0.047$). Hence, the results for the different viewing orders were grouped in the rest of the analysis.

To get a general idea of the presence level reported in this experiment, the IPQ presence subscales in the non-stereoscopic and stereoscopic viewing condition were compared to the online IPQ data set[3]. Presence in the non-stereoscopic virtual environment was compared with an independent-samples *t*-test to the online mono HMD data; no significant difference was found. Presence in the stereoscopic virtual environment was compared in a similar way to the online stereo HMD data; spatial presence ($t(121) = 2.01$, $p = 0.047$; $d = 0.40$), involvement ($t(121) = 3.01$, $p = 0.003$; $d = 0.59$) and realism ($t(121) = 3.26$, $p = 0.001$; $d = 0.64$) were all significantly higher than in the online IPQ data set.

This experiment had a doubly multivariate repeated measure design and all the participants were measured on several variables in multiple conditions (i.e., stereoscopic rendering and non-stereoscopic rendering). To test the overall effect of stereoscopic rendering on presence, a repeated-measures MANOVA was used (Stevens, 1996; Tabachnick & Fidell, 2006), with viewing condition (i.e., non-stereoscopy vs. stereoscopy) as independent within-subjects variable. The IPQ and SUS presence

[3] Downloaded on June 9th, 2011. For comparison data see http://www.igroup.org/pq/ipq/data.php

scores were used as the dependent variables. The general question of ‘the sense of being there’ was not included in the test due to its overlap with the spatial presence subscale (Schubert, et al., 2001). The results showed a significant effect of stereoscopy on presence ($F(4,82) = 2.86$, $p = 0.028$, $\eta^2 = 0.123$). Next, to run a priori comparisons, paired-samples *t*-tests were performed using the IPQ and SUS presence scores in both conditions as paired variables. A significant main effect of stereoscopy on spatial presence ($t(85) = 2.72$; $p = 0.008$; $d = 0.29$) and SUS presence ($t(85) = 2.23$; $p = 0.028$; $d = 0.24$) were found, but not on involvement ($t(85) = 1.78$; $p = 0.078$; $d = 0.19$) or realism ($t(85) = 0.77$; $p = 0.446$; $d = 0.08$). Note that as these were a priori comparisons, alpha was not adjusted for the paired-samples *t*-tests.

Since it might be possible that stereoscopy only had an effect on presence for people with good stereovision, a sub-group of participants with a threshold of 60 seconds of Arc as tested by the TNO stereo vision test (Evans, 2007) was selected. The paired-samples *t*-test for spatial presence between non-stereoscopic and stereoscopic viewing was repeated. It showed a significant difference in spatial presence ($t(51) = 2.17$, $p = 0.034$; $d = 0.30$) for the high stereoscopic vision group. However, the result was more or less comparable to the result across all the participants. No difference was found by stereoscopic rendering for either the involvement or realism subscale.

Task was suggested to be an important factor for presence (IJsselsteijn, de Ridder, Freeman, & Avons, 2000; Witmer & Singer, 1998). To further test the task effect on presence, a repeated-measures MANOVA analysis using viewing condition (i.e., non-stereoscopic neutral world versus non-stereoscopic public speaking world) as independent variable and presence score as dependent variable was done. The result showed a significant effect of task on presence ($F(4,82) = 4.05$; $p = 0.005$; $\eta^2 = 0.165$). The paired-samples *t*-tests on the IPQ subscales and SUS illustrated that only involvement was significantly higher ($t(85) = 3.13$, $p = 0.002$; $d = 0.34$) in the public speaking world than in the neutral environment. As the neutral world was designed and displayed with the same technology, the result indicated that task had an effect on presence in the virtual environment; the participants reported higher presence in the virtual environment that required a higher cognitive load.

"Figure [2] here"

4.2. Anxiety

Means and standard deviations of the scores of the anxiety measurement with the PRCS and the modified version of the PRCS (MPRCS) for the non-stereoscopic and stereoscopic viewing condition were M = 8.05, SD = 2.16; M = 3.93, SD = 3.02; M = 3.97, SD = 3.33 respectively. A paired-samples t-test did not find a significant difference between the non-stereoscopic and the stereoscopic condition ($t(85) = 0.14$, $p = 0.886$; $d = 0.02$). A series of correlation analyses were done to investigate the relationship between presence and anxiety. In the non-stereoscopic public speaking world, a significant correlation ($r = -0.23$, $p = 0.035$) between the self-reported anxiety and the level of involvement was found. Participants who were more involved showed less anxiety. In the stereoscopic environment, the correlation between SUS presence and self-reported anxiety ($r = -0.25$, $p = 0.019$) was significant. Also this result indicated that participants reported less anxiety when higher levels of presence were perceived.

A sign of pronounced feelings of presence would be that participants behaved similar in the virtual public speaking world as they would in the real-life situation (IJsselsteijn, 2004). To measure this presence response we calculated the correlation between the participants' anxiety in the virtual public speaking worlds (i.e. the post-measurement scores of the PRCS after each virtual reality exposure) and a real-life public speaking event (i.e. deduced from the PRCS scores before the virtual exposure). The result showed a significant correlation both for the non-stereoscopic world ($r = 0.22$, $p = 0.044$) and the stereoscopic world ($r = 0.26$, $p = 0.014$). This implies that in both rendering conditions people experienced similar feelings of anxiety in the virtual world as they would in the real world.

4.3. Simulator sickness

The SSQ score was obtained by subtracting the pre-measurement data for each viewing condition from the post-measurement data. The mean and standard deviation of the resulting SSQ scores in the non-stereoscopic and stereoscopic viewing condition were $M = -0.57$, $SD = 17.95$; $M = 2.4$, $SD = 13.04$ respectively. Note that the values ranged from -235.62 to 235.62. A paired-samples t-test with the SSQ scores paired between the non-stereoscopic and stereoscopic viewing condition showed no significant effect of stereoscopy on simulator sickness ($t(85) = 1.04$, $p = 0.3$; $d = 0.11$).

In addition, we found no significant correlation between the simulator sickness score and the level of presence. Also no significant correlation between the self-reported anxiety from the MPRCS and the simulator sickness was found.

4.4. Heart rate

Due to technical problems, heart-rate data for only 60 participants were obtained. Means and standard deviations of heart rate in the neutral environment, non-stereoscopic and stereoscopic viewing condition were $M = 71.04$, $SD = 6.96$; $M = 75.41$, $SD = 7.47$; $M = 75.14$, $SD = 7.18$ respectively. Heart rate increased significantly in both non-stereoscopic ($t(59) = 8.06$, $p < 0.001$; $d = 1.03$) and stereoscopic ($t(59) = 9.133$, $p < 0.001$; $d = 1.16$) public speaking world compared to heart rate in the neutral world. Results indicate that heart rate increased in the public speaking world which suggests that the virtual world is effective in eliciting a fear response.

Changes of heart rate between public speaking in both viewing conditions and the neutral world were obtained by subtracting heart rate mean in the neutral world from the one in the public speaking world. A paired-samples *t*-test was done using the heart rate change for both viewing conditions as paired variable. The result showed no significant difference between non-stereoscopic and stereoscopic viewing ($t(59) = 0.26$, $p = 0.799$; $d = 0.03$).

A series of correlation analyses was done to investigate the relationship between heart rate, anxiety and presence. A significant correlation between the IPQ realism subscale and the heart rate measurements was only found in the stereoscopic viewing condition ($r = -0.25$; $p = 0.048$). Participants experienced less anxiety when they felt more presence in the virtual public speaking world. This result is in accordance with the MPRCS measurement.

5. Discussion

Rendering stereoscopy into the HMD significantly improved presence as shown by the IPQ subscale spatial presence and the SUS presence. However, no significant improvement in IPQ involvement and realism were found. In addition, no difference in heart rate or in reported anxiety and cybersickness was found. Furthermore, with an effect size of $d = 0.29$, the difference found on the IPQ subscale spatial presence between non-stereoscopic and stereoscopic viewing was statistically small when considering Cohen’s classification (Cohen, 1992). Still in theory a small statistical effect can be of large practical relevance. Nevertheless, when setting this effect size against presence differences reported for other comparisons of display technologies used for other disorders it seems relatively small. Take for example Krijn et al. (2004) and Juan & Perez (2009) who studied the presence difference between HMD and CAVE for treatment of acrophobia. Krijn et al. reported effect sizes ranging from $d = 0.95$ to $d = 1.2$, while Juan & Perez reported an effect size of $d = 0.68$. Also, for the treatment of anger an effect size of $d = 0.55$ was found for the difference between HMD and a flat screen (Miyahira, et al., 2010). These effects are around two to four times larger than the effect size found in this study.

It might be hypothesized that the virtual world in this experiment did not yield enough presence to make the difference between non-stereoscopic and stereoscopic more apparent. However, presence was scored in the middle of the scale, and there was no reason to suspect floor effects. Furthermore our presence ratings were comparable to or higher than the online IPQ dataset. Presence responses and increased heart rate were also found in both viewing conditions. These results suggest that the virtual public speaking world did successfully evoke high presence in the participants.

Maybe the task of speaking in public has drawn away participants' attention from the actual stereoscopic or non-stereoscopic rendering. Task is known to be able to have a significant effect on presence. Especially, tasks with a high cognitive load may attract more attention and can easily transfer participants' consciousness into virtual reality. For example, Hoffman et al. (1998) found that presence can be significantly improved when a virtual chess is put in a meaningful way for experienced chess players. However, Riley (2001) found that task complexity can also have a significant negative effect on presence. In this study, the task of giving a talk in the virtual public speaking world resulted in a significant improvement of the level of Involvement in the non-stereoscopic environment compared to the neutral environment. Hence, participants may have focused more on their task rather than on the actual representation of the virtual environment.

The question can be raised whether the avatars were rendered too far away from the participants which may have resulted in a weak stereoscopic perception. However, according to the research on stereoacuity, the distance between the avatars and the back wall was within the limit under which the stereoscopic effect was detectable. Stereoacuity[4] is a measure of ability to detect the depth of a test stimulus with respect to a comparison stimulus that is in the plane of zero disparity (Howard & Rogers,

[4] The angular measure of stereoacuity (η) and the depth difference (Δd) are related by $\eta = \frac{a\Delta d}{d^2}$ in radians . Where a is the interpupillary distance (Howard & Rogers, 2002).

2002). Typical stereoacuity as measured, for example, by the TNO stereotest is less than 1 minute of arc. For an average interocular distance of 6.3cm, a target distance of 3.66 meters with a stereoacuity of 1 arcmin, the just detectable depth interval is 6cm. For a target at 6.8 meters, the just detectable depth interval is 21cm. Since the virtual distance between the avatars and the back wall was around 4 meters, the disparities were such that the depth could be detected easily. Therefore, in this experiment the lack of large effects of stereoscopic rendering on variables other than spatial presence, was not mainly due to the fact that the binocular disparities were too small to be seen as stereoscopic depth. However, in a more intimate environment including fewer avatars sitting closer by, stereoscopy might evoke significantly higher presence, cybersickness and social anxiety in participants than monoscopic rendering. It might for example be that when avatars are closer by, they command more attention towards them away from the task in the virtual environment. For example, Herblin (2005) reported that participants' eye contact and the subjective expression of having addressed everybody were higher in a group at a close distance (including 1-2 avatars) than in a group at an average distance (including 3 avatars) and far distance (including 4-5 avatars). Furthermore, as the target comes closer, the just detectable interval gets smaller and participants are more sensitive to depth cues. Whether our results can be generalized to other more intimate social environments needs to be further studied.

Another reason for the relative small difference caused by stereoscopic rendering may be due to the existence of motion parallax provided by the motion tracker in the HMD. There are several depth cues other than binocular disparity to give humans depth information. Examples are motion parallax, occlusion and linear perspective. Studies in literature already proofed that motion parallax may give a stronger depth sensation than stereoscopy. For example, Schooten et al. (2010) found that stereoscopy had no added value in perceived depth when motion was present. Barfield et al. (1999) suggested that, given a desktop display, motion parallax cues might be of greater benefit in sparse visual scenes than binocular disparity cues. In the current study, no significant improvement of involvement and realism with the introduction of stereoscopy was found, which might indicate that motion parallax engendered so much depth impression in people, that stereoscopy did not add value.

Considering visual discomfort caused by stereoscopic viewing (Lambooij, et al., 2010), it was hypothesized that people may report more cybersickness in the stereoscopic viewing condition. However, no difference in the virtual public speaking world was found by manipulating stereoscopic rendering. The result is in line with the report by IJsselsteijn et al. (2001). They also did not find a significant effect of stereoscopy on cybersickness in a virtual rally car world.

Participants did not report more anxiety in the stereoscopic viewing condition. They did not have a higher heart rate increase either. Although some correlations between, on one hand, self-reported presence and, on the other hand, anxiety and heart rate were found, the improvement of reported presence went together with less anxiety and reduced heart rate in the participants. This seems to agree with the study of (Busscher, et al., 2011), who showed that non-phobic individuals reported higher presence score than phobic individuals.

No significant correlation between anxiety (PRCS) and heart rate change was found. There was, however, a significant negative correlation between heart rate increase and realism; a similar tendency was previously reported by Wiederhold et al. (2001). Besides fear and anxiety, heart rate is also affected by reactions to unexpected stimuli. It is reported that heart rate deceleration has been correlated with the orienting response to novelty and accelerations with defensive responses such as fear and anxiety (B. K. Wiederhold & M. D. Wiederhold, 1999). The immersed participants who had no fear in the virtual public speaking world may have reacted to the virtual world as an unexpected, novel stimulus.

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6. Conclusions

When using stereoscopy in a virtual public speaking world displayed in a motion-tracked HMD, only an improvement in perceived spatial presence was found. Feelings of involvement and realism was not found to be affected by the rendered stereoscopy, neither was simulation sickness scores, heart rate or elicited anxiety. In addition, the effect of stereoscopy on spatial presence seems small compared to reports of the effect of other display technologies on presence. Therefore, in the case of public speaking, adding stereoscopy to a motion-tracked HMD based VRET system seems unlikely to result in a large presence improvement. Considering that the essential social element of public speaking is talking to people in public spaces, and with that raising anxiety for embarrassment and for being judged by others, the result may likely be generalized to other virtual applications in the social domain, in which individuals are exposed to social scenes with public at a moderate distance. Further studies need to be done to test whether our results can also be generalized to social situations in which other people are at a shorter distance from the participant. Given the fact that motion parallax present in the HMD might have played a substantial role in the results, it is less clear whether our conclusions can be generalized to e.g. the comparison of stereoscopic and non-stereoscopic rendering on flat displays. Despite the need for further research, our results clearly question the practical relevance of stereoscopic rendering in motion-tracked HMDs for VRET in the public speaking domain.

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Figure 1A: Individual wearing head mounted display and physiological measurement equipment in the experiment. Figure 1A should be reproduced at one column width.

Figure 1B: Virtual public speaking world. Figure 1B should be reproduced at one column width.

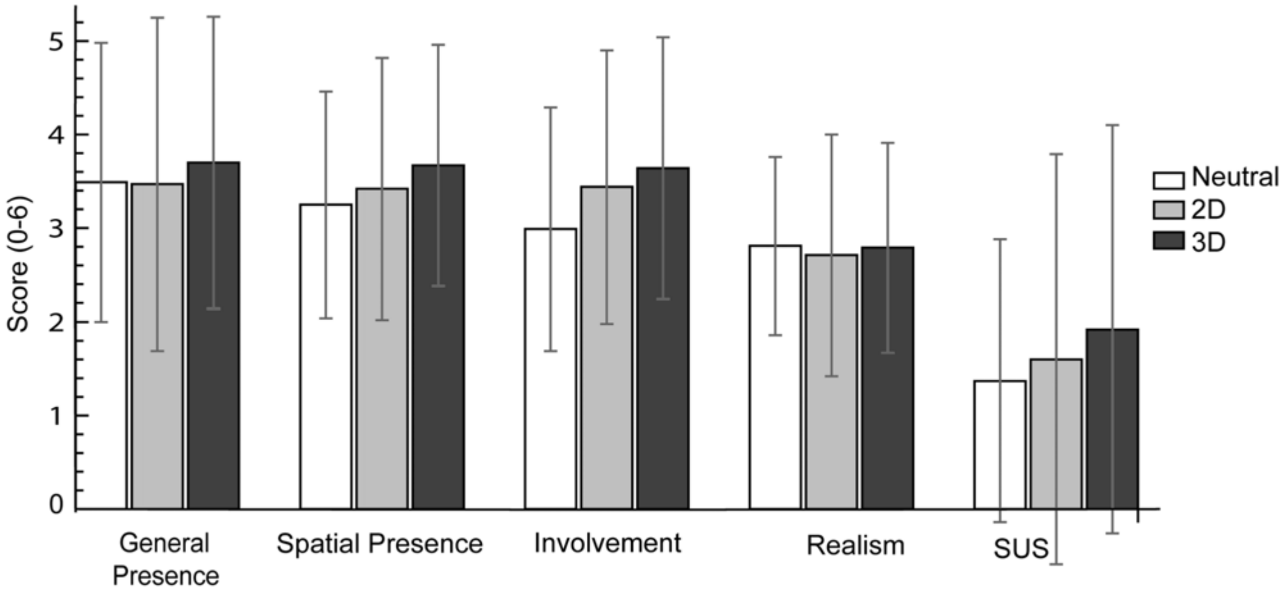

Figure 2: Means and standard deviations for the SUS and IPQ subscales for three different environments. Figure 2 should be reproduced at two-column width.