Sense of Presence in a VR-Based Study on Behavioral Compliance with Warnings

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Abstract. Recent researches suggest that Virtual Reality (VR) is amongst the best tools for examining behavioral compliance with warnings, therefore overcoming some ethical and methodological constrains that have been limiting this type of research. Yet, such evaluation using VR requires both usable and engaging virtual environments (VEs). This study examines the sense of presence experienced by the participants after having been immersed in a VE designed for evaluating the effect of sign type (static vs. dynamic) on compliance. The VR simulation tested here allowed participants to perform a realistic work-related task and an emergency egress, during which they were supposed to interact with warnings and exit signs. A neutral condition (i.e., no/minimal signs) was used as a control condition. Subjective and objective data were gathered from two sources, respectively, i.e., a post-hoc questionnaire administered to the participants, and a video analysis of the participants' interaction behavior during the VR simulation. Results reveal high levels of presence across the three experimental conditions.

Keywords: Virtual Reality, Presence, Behavioral Compliance, Warnings.

1 Introduction

Behavioral compliance with warnings generally requires that people take some sort of action. Thus, evaluating compliance involves observing what people do, i.e., if individuals carry out the warning-directed behavior. Although behavior is considered one of the most important measures of warning effectiveness, it is usually quite difficult to conduct behavioral tests [1]. The reasons include, among others: ethical and safety concerns (research participants cannot be intentionally exposed to real hazards), rarity and unpredictability of the hazardous events, difficulty of creating scenarios that mimic real-life situations which appear to be risky yet are safe, and the costs in terms

A. Marcus (Ed.): DUXU/HCII 2013, Part III, LNCS 8014, pp. 362–371, 2013.

of time and money to conduct such type of research. However, nowadays, the traditional way of conducting research on compliance with warnings is changing thanks to recent advances in technology and computer graphics. Consequently, Virtual Reality (VR) has been suggested as a promising tool to overcome such limitations [2]. Yet, such evaluation using VR requires both usable and engaging Virtual Environments (VEs) which enable users to feel as if they are there (sense of presence). Presence can be defined either as the sense of being there, in a mediated environment (e.g., VE), even when one is physically present in another [3, 4] or as a "perceptual illusion of nonmediation" [5], that is, when the person fails to acknowledge the existence of the display medium. Also, VEs that prompt a high degree of presence are usually considered as more enjoyable by participants, which can result in more effective VEs [6].

In this context, in this paper we present the results from an experiment that aimed to investigate participants' sense of presence by examining their interaction behavior and subjective perceptions in a two-part VR simulation (i.e., work-related situation and emergency egress), with tasks involving navigation, visual search, activation/deactivation of devices (i.e., compliance with warnings) and escaping from a fire. We specifically compare the users' responses, for the same tasks, across three experimental conditions resulting from manipulations made to the warnings and signs (i.e., static printed vs. dynamic multimodal) and a no/minimal-sign control condition. This study, which was part of a larger study about behavioral compliance with warnings [7], is grounded on the idea that VEs are a promising option for research on compliance with warnings.

To determine the extent to which the users felt they were present in the VE, we examined two types of measures commonly used for evaluating presence [8]: behavioral measures and subjective measures. Behavioral measures refer to interaction, that is, actions or postural responses in reaction to the events in the VE, such as startled reactions in reaction to an explosion or attempts to use firefighting equipment to extinguish the subsequent fire. Interaction is acknowledged, by several authors [e.g., 9, 10, 11], as one of the key reasons of presence in VEs. The interaction is closely related to functionality, concept that is considered to be more important for the ecological validity of the VE than its appearance [12]. Subjective measures refer to factors thought to underline the sense of presence. According to Insko [8], these factors can be grouped into four categories: control, sensory, distraction and realism. Usually these reported perceptions are gathered through post-immersion questionnaires. There are several well-established questionnaires for measuring presence, which usually have participants rating their experience on several questions across a numerical scale; e.g., Witmer-Singer [3], Slater-Usoh-Steed [13], ITC-SOPI [14].

2 Method

2.1 Apparatus

The study was conducted using the ErgoVR system [15], created by the Ergonomics Unit of the Technical University of Lisbon (http://www.fmh.utl.pt/ergovr/). For this study, the ErgoVR was an immersive VR system. The participants could see the VE through a Sony® PLM-S700E HMD, with 800 × 600 pixels resolution, at 32 bits, a FOV of 30°H, 22.5°V and 38°D, and an egocentric viewpoint, as well as were able to interact with the VE using a joystick. Two magnetic motion trackers from Ascension-Tech®, model Flock of Birds, were used for monitoring head and left hand movements. Wireless Sony® stereo headphones, model MDR-RF800RK, allowed participants to hear the sounds present in the VE. Figure 1 depicts the experimental setup. For a more comprehensive description of the software and hardware used see Duarte et al. [16].

Fig. 1. Positioning of the participant and the apparatus

2.2 Participants

A total of 100 university students participated in the study. A group of 10 participants (10%) were "experimental deaths", i.e., they underwent the procedure as a whole, or only part of it, but were excluded from the final sample due to simulator sickness or data corruption. Therefore, the study's sample consisted of 90 individuals, 45 males and 45 females, aged 18 to 35 years old (mean age = 21.3, SD = 3.2 years). They had normal sight or corrective lenses, as well as no color vision deficiencies. Participants were randomly assigned to conditions. Each condition contained 30 participants, equally distributed by gender.

2.3 Virtual Environment and Scenario

A virtual company's facilities, with four main rooms (i.e., meeting room, laboratory, cafeteria and warehouse) and six T-shaped escape routes, was developed for a simulating an end-of-day safety inspection routine task (experimental scenario) that was suddenly disturbed by an explosion, followed by a fire. Screen shots of the VE are depicted in Figure 2. Both parts of the simulation (routine and emergency) required participants to carry out safety related actions (i.e., press buttons to activate/deactivate safety-related devices and select egress routes). Posted warnings and signs gave the safety-related information. In the no-warning/sign condition, text-only labels positioned below the buttons identified the safety devices. In Figure 3, the foreseen sequence of tasks that the participants were asked to fulfill is depicted and marked on the VE floor plan. For a more comprehensive description of the VE used see Duarte et al. [16].

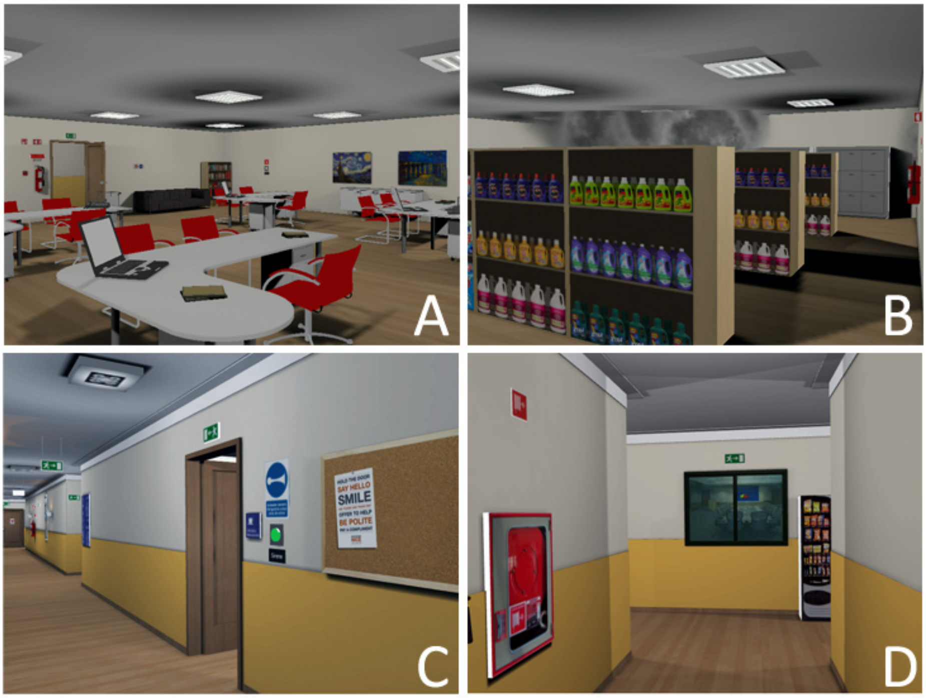

Fig. 2. Screen shots of the VE (A – Inside the Laboratory; B – Inside the Warehouse with fire and smoke after the explosion; C – Outside the Cafeteria showing the siren warning (ST) and button; D – At one of the T-shaped intersections showing the exit sign on top of the window).

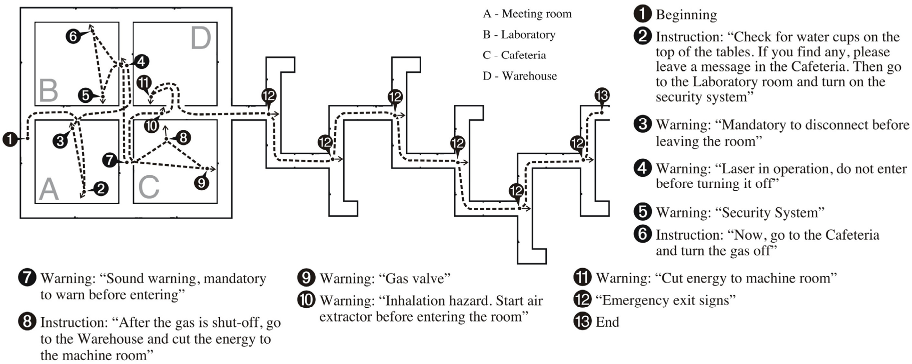

Fig. 3. Floor plan of the VE, showing the participants' foreseen sequence and the location of the instructions, warnings and signs

2.4 Design

This study used a between-subjects design. One experimental factor was manipulated: warning/sign type (i.e., static and dynamic), resulting into two experimental conditions. A third condition with no warning/sign posted on the environment served as control. The three experimental conditions are described below.

- ST (static warnings/signs);
- DY (dynamic warnings/signs);
- NE (neutral, no/minimal-sign).

The warnings and signs differ on modality and state according to the experimental condition. Regarding modality, the static warnings/signs were only visual, whereas the dynamic warnings/signs were multimodal (visual plus auditory), backlit, augmented with five flashing lights and supplemented by a tone. Regarding state, dynamic warning/signs had two states, activated or deactivated, triggered by proximity sensors (invisible triggers). For the control condition (NE) the VE had no posted warning and signs (except for the buttons' labels, which were essential for identifying the buttons' functions). This condition provides a baseline with which to assess the impact of the presence of signs on compliance.

2.5 Procedure

Participants were welcomed by the researcher and, after briefed about the study, were asked to sign an informed consent form. They were also advised that they could stop the simulation at any time without suffering any consequences or prejudice. The procedure started with a practice period. After the participants had finished the practice trial, they were told a cover story that intended to introduce them to the scenario (including the task). Participants were unaware of the real objective of the research. The task was to explore each room, according to the given instructions, and look for safety-related devices that should have been connected or disconnected during the night. At a given moment in the simulation (i.e., when they entered the warehouse) an unexpected explosion occurred, followed by a fire.

At the end of the VR simulation, they were given a follow-up questionnaire. The experimental session, in the VE, was intended to last approximately 15 minutes. The whole procedure lasted about 45 minutes, including training session, VR simulation and follow-up questionnaire.

2.6 Measures

For this study, the dependent variables can be grouped in two sets: (a) Behavioral measures, i.e., interaction with: fire extinguisher cylinders, fire alarm buttons, fire hose reels, electric switchboards, door handles; and (b) Subjective measures, i.e., quality of the sensorial experience, quality of the interaction with the VE, distraction factors, realism level, and notion of time.

The researcher collected data regarding participants' behavior through a free video analysis, while a multipart questionnaire, with 7 point Likert-type items, was used to measure participants' perceptions. Some items in the questionnaire were adapted from the Witmer and Singer Presence Questionnaire [3], and others were created in this study. All the items were communicated in Portuguese. English translations are given in this paper (see Table 1).

Table 1. Presence questionnaire items

	Item	Score
1.	How would you classify the overall level of sensory stimulation experienced during the simulation (e.g., involvement of your senses in the virtual experience)?	QSE
2.	To what extent did the visual stimuli make you feel "inside" the VE?	QSE
3.	To what extent did the auditory stimuli make you feel "inside" the VE?	QSE
4.	To what extent could you identify the sounds present in the VE?	QSE
5.	To what extent could you locate the sounds in the VE?	QSE
6.	To what extent could you visually explore the VE?	QSE
7.	To what degree was it easy to dislocate through the VE, by using the joystick (e.g., how easy was it for you to get to a certain point in the VE)?	QI
8.	To what degree could you control your displacement by using the joystick (e.g., how accurately could you position/stop yourself at the desired place)?	QI
9.	How quickly did you manage to adapt to the displacement, by using the joystick?	QI
10.	At the end of the simulation, how do you classify your displacement performance in the VE, by using the joystick?	QI
11.	To what degree was the looking behavior, offered by the system, natural (e.g., when you wanted to see something, in the VE, you moved your head in that direction)?	QI
12.	To what degree could you control the looking behavior (e.g., the capacity to direct your head, with precision, to a certain direction)?	QI
13.	To what degree was the execution of the virtual hand movements natural (e.g., when you wanted to touch the buttons, in the VE, did you move your hand in that direction)?	QI
14.	To what degree did you have control over the movements of the virtual hand (e.g., the ability to operate, accurately, the buttons in the VE)?	QI
15.	To what extent were you conscious of the HMD's presence during simulation?	DF
16.	To what extent did the form of navigation (joystick) cause distraction in the performance of the required tasks?	DF
17.	To what extent did the quality of the image displayed of the VE affect the performance of the required tasks?	DF
18.	To what extent, during the simulation, were you aware of what was happening around you, in the real world (e.g., be aware of sounds from the real world)?	DF
19.	To what degree is the simulation, you have just experienced, real?	RL
20.	To what extent do you consider your experience in the VE to be different from your experience in the real world?	RL
21.	Were you involved in the simulation to the extent that you lost track of time?	NT

Note: QSE = Quality of Sensorial Experience; QI = Quality of Interaction; DF = Distraction Factors; RL = Realism Level; NT = Notion of time; ENJ = Enjoyment.

3 Results

3.1 Behavioral Measures

Descriptive statistics for the behavioral measures across experimental conditions, as well as grouped altogether, are depicted in Table 2.

Table 2. Descriptive statistics (percentage and frequency of interactions) for behavioral measures across the three experimental conditions (30 in each condition) and total ($N = 90$)

	Experimental conditions			
Interaction with:	ST	DY	NE	Total
Fire extinguisher cylinders	57% (17)	43% (13)	53% (16)	51% (46)
Fire alarm buttons	67% (20)	57% (17)	73% (22)	66% (59)
Door handles	63% (19)	23% (7)	93% (28)	60% (54)
Fire hose reels	3% (1)	7% (2)	17% (5)	9 % (8)
Electric switchboards	3% (1)	3% (1)	0% (0)	2% (2)

To ascertain whether there were significant differences in interaction behaviors between the three experimental conditions, Pearson chi-square tests for homogeneity were conducted. No significant differences between the three experimental conditions were found on the participants' interaction behavior with fire extinguisher cylinders ($\chi^2(2, N = 90) = 1.156, p = .646$), fire alarm buttons ($\chi^2(2, N = 90) = 1.870, p = .433$), fire hose reels ($\chi^2(2, N = 90) = 3.567, p = .263$), and electric switchboards ($\chi^2(2, N = 90) = 1.023, p = 1.000$). Besides such differences, as demonstrated in Table 2, very few participants tried to interact with fire hose reels and electric switchboards, unlike the fire extinguisher cylinders and fire alarm buttons. Significant differences were found only on the participants' interaction behavior with door handles ($\chi^2(2, N = 90) = 30.833, p < .001$); $\phi_C = .585$, high effect). In what concerns the interaction with door handles, the NE condition exhibit higher percentages, and the DY condition present lower percentages of interactions, when compared with the ST condition.

3.2 Subjective Measures

The questions posed to the participants were thought to assess their perceptions regarding the major factors that contribute to the sense of presence. Descriptive statistics for the subjective measures, by each group of questions, across experimental conditions and in total are depicted in Table 3.

Table 3. Descriptive statistics, median (Mdn) and interquartile range (IQR), for the subjective measures of presence and enjoyment, across the three experimental conditions and altogether.

	Experimental conditions			
	ST	DY	NE	Total
QSE	5.08 (1.17)	5.50 (0.92)	5.50 (0.88)	5.33 (1.00)
QI	4.56 (1.09)	4.88 (0.91)	5.13 (1.31)	4.88 (1.25)
DF*	2.63 (1.63)	3.00 (1.13)	2.75 (2.00)	2.75 (1.75)
RL	3.88 (1.56)	3.50 (1.75)	3.88 (2.06)	3.75 (1.75)
NT	4.00 (3.00)	5.00 (2.50)	4.50 (2.25)	4.00 (3.00)

* Lower values are better

Overall, as indicated by the total values in Table 3, the median values of presence in the VE ranged from 3.75 to 5.33, according to a 7-point Likert scale with 7 indicating the highest level of presence.

To ascertain whether there were significant differences, among the three experimental conditions, in the participants' perceptions, Kruskal-Wallis tests were conducted. Results revealed statistically significant differences among the experimental conditions only for the participants' perceptions about the sensorial experience ($\chi^2_{KW}(2, N = 90) = 6.60$, $p = .037$). Nonparametric post-hoc multiple comparisons (Fisher's LSD method performed on ranks) showed that there were only marginally significant differences between ST and DY ($p = .055$), and ST and NE ($p = .073$). The boxplots for the quality of the sensorial experience by experimental condition, presented in Figure 4, illustrate these differences.

No statistically significant differences were found regarding the quality of the interaction ($\chi^2_{KW}(2, N = 90) = 3.86$, $p = .145$), distraction factors ($\chi^2_{KW}(2, N = 90) = .814$, $p = .666$), realism level ($\chi^2_{KW}(2, N = 90) = 1.55$, $p = .460$) and notion of time ($\chi^2_{KW}(2, N = 90) = .76$, $p = .683$).

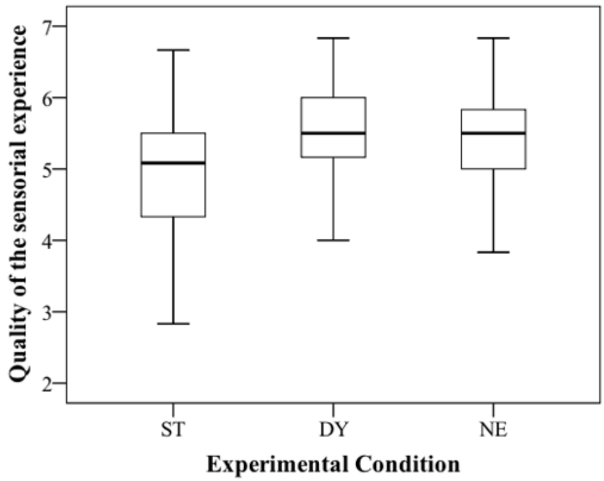

Fig. 4. Boxplots for Quality of the sensorial experience by experimental condition

4 Conclusions

The main contribution of this paper is to evaluate participants' sense of presence in a VE conceived for research on compliance with warnings. We have assessed presence by measuring both subjective and behavioral measures of presence. High levels of presence were considered important for our research on compliance with warnings, due to their potential influence on the study's ecological validity. Furthermore, consistency on the values of presence across the three experimental conditions was critical for the study because of its possible influence on the participants' behavior.

Overall, our data indicates that participants experienced a medium-high sense of presence across all the experimental conditions, as supported by both subjective and behavioral measures. In what concerns subjective measures, significant differences between the three experimental conditions were found only for the quality of the sensorial experience. To some extent this is an expected finding, since the VEs strongly differed visually, according to the manipulations made to the displayed warnings and signs.

We conclude that this VE was able to produce relatively high levels of presence that were consistent across the experimental conditions. Thus, it can be stated that VR did in fact allow the reproduction of a work-related task, and an emergency egress, while ensuring an engaging experience. Therefore, we conclude that there are positive indications about the use of VEs for research on behavioral compliance with warnings.

A second stage of this validation procedure is going on and involves studying participants' perceptions collected after exposed to other experimental conditions, as well as the examination of other variables such as previous experience with computer systems, gender, and degree of enjoyment.

Acknowledgements. A PhD scholarship from Portuguese Science Foundation (FCT) supported this study (SFRH/BD/21662/2005), which was developed in the scope of a Research Project financed by FCT (PTDC/PSI- PCO/100148/2008).

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