Behavioral Compliance in Virtual Reality: Effects of Warning Type

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ABSTRACT

Virtual Reality (VR) is used to examine the effect of different warnings on behavioral compliance. Sixty university students performed a virtual end-of-day routine security check and interacted with four workplace ISO type warnings and three posted signs. The scenario was designed so that warning presentation was not pre-cued or expected. Other signs, however, were pre-cued; these were expected because they were part of the instructed tasks that were carried out. Participants were randomly to static vs. dynamic conditions. Behavioral compliance was measured according to whether participants followed the directive to press particular panel buttons. Data demonstrate that dynamic warnings produce higher behavioral compliance than static ones, but there were no dynamic vs. static differences for the pre-cued posted signs. Implications arising from the use of this technique and resultant findings are discussed.

Keywords: Safety warnings and signs; behavioral compliance; virtual reality

INTRODUCTION

Safety-sign and warning effectiveness depends on a series of events. Several cognitive models have been proposed to explain how the processes occur (e.g., Lehto and Miller, 1986; Rogers, Lamson, & Rousseau, 2000; Wogalter, DeJoy, & Laughery, 1999; Wogalter, 2006). Three main stages of warning processing that most models include are noticing, comprehending and complying. Compliance is considered the ultimate outcome measure of warning success since for compliance all or most of the stages will have been successfully processed. But from the point of view in conducting research, compliance is difficult to investigate because it is limited by methodological difficulties and ethical constraints. One main difficulty is that research participants cannot be exposed to real hazards. Another difficulty is that producing a realistic scenario that has no actual risk is expensive in terms of money, time and effort. Consequently, even though there has been a substantial body of research on the topic of warnings, relatively few studies have measure actual behavioral compliance.

Fortunately, new technology and techniques have become available that could change the situation with respect to warning compliance research. Virtual Reality (VR) may help to overcome some of the main constraints since it can simulate adequate, but safe, contexts of Virtual Environments (VE) for use in warnings research. High quality VEs can promote ecological validity, while allowing good control over experimental conditions. Thus VR combines the best aspects of laboratory and field research, and allow the simulation of hazard-associated emergency situations while keeping the participants safe from actual harm.

To date, few studies have used VR in warnings research and the majority of them have mainly focused on exit signs (e.g., Glover & Wogalter 1997, Shih, Lin, & Yang, 2000; Tang, Wu, & Lin, 2009). Research on exit signs has provided valuable information, and in particular, has demonstrated the ability to measure sign manipulations on compliance. However, to fully explore the utility of VR in warning research, other types of signs should be tested. There are two main reasons for this need. One is to determine if VR as a method would provide a means to measure behavioral compliance to warnings. The second reason is to determine if the method would be adequately sensitive to pick up differences between manipulated warnings and resemble results similar to those recorded in real behavioral-compliance situations.

In the present research, the VE was a company headquarters and the scenario was an end-of-day routine security check. In order to carry out the required tasks (including the behavioral compliance aspects), participants had to press buttons associated with the warnings and posted signs shown in the VE.

In warning research literature, there are several behavioral compliance studies showing effects of sign type (e.g., Wogalter & Young, 1991, Wogalter, Kalsher, & Racicot, 1993). One fairly strong and consistent finding is that dynamic presentation produces greater compliance than static presentations (e.g., Wogalter et al., 1993).

Static signs are traditionally made of paper, metal or plastic, and generally, the method of communication is passive. In contrast, dynamic signs usually use more advanced technology that can be multimodal and customized. Recent articles suggest that technology-based warnings can be more effective than the traditional solutions (e.g., Wogalter & Conzola, 2002; Mayhorn & Wogalter, 2003; Smith-Jackson & Wogalter, 2004; Wogalter & Mayhorn, 2005) since they have features that can enhance the warnings in a number of ways, such as making them more noticeable and more resistant to habituation. As a result, dynamic warnings raise levels of compliance over warnings without dynamic properties, i.e., static.

The safety warnings and signs used in the present research are symbol-based type signs consistent with the International Organization for Standardization's (ISO) 3864-1 (ISO, 2002) standard. The signs had both a symbol and text. Accordingly to ISO 9186 (2001) standard, a safety sign is “a general safety message obtained by a combination of color and geometric shape and which, by the addition of a graphical symbol, gives a particular message” (ISO, 2001). Traditionally, a symbol alone format of ISO 3864-1 is used, without text, due to multilingual considerations. Recent efforts have been taken to harmonize with American National Standards Institute (ANSI) Z535 (2002) standards, and now ISO signs can be used together with text panels.

In the present study, there were two kinds of visual displays in the VE: they were designated as "Warnings" and "Posted Signs." Warnings contained an explicit safety message communicating information about a hazard, the hazard’s consequences and also providing guidance on how to avoid the hazard. The warnings were the main target of behavioral compliance evaluation. The warnings and scenario that they were embedded were designed so they would not be expected by participants, as they were not pre-cued ahead of time by the task instructions that participants carried out. Nevertheless they were placed coherently within the VR scenario. The second type of visual display were posted signs. These posted signs had a different role than warnings. First they looked different (as will be described later) and they identified a safety device (e.g., a gas valve). Also, the content of the posted signs was mentioned within the instructions given to participants on the tasks they were to perform, and thus, the contents were pre-cued or expected prior to them being viewed in the VE.

METHOD

PARTICIPANTS

Sixty university students, 30 male and 30 female, aged 18 to 35 years old (mean age= 21.15, SD = 3.107) participated. They had no previous experience with navigation in VEs. Participants had normal sight or had corrective lenses and no color vision deficiencies. They reported no physical or mental conditions that would prevent them from participating in a VR simulation. All participants completed an informed consent form. Participants were randomly assigned to one of two experimental conditions (static vs. dynamic) each comprised of 30 individuals with an equal number of males and females in each condition.

APPARATUS

The used apparatus comprised 2 magnetic motion trackers from Ascension-Tech, model Flock of Birds for monitoring head and left hand movements; a joystick from Thrustmaster as a locomotion device; a Head-Mounted-Display (HMD) from Sony, model PLM-S700E; a Monocular Laptop HMD Mountable eye-tracking system from Arrington Research (Part Number MAE06); wireless headphones and a graphics workstation.

The VE was presented at a resolution of 800 x 600 pixels, at 32 bits, with a FOV 30°H, 18°V and 35° diagonal. The speed of movement gradually increases from stopped, to an average walk pace (1.2 meters per second) to a maximum speed around 2.5 m/s. The participants' viewpoint was egocentric. Participants were seated at a desk for the duration of the session. An example participant during an experimental session is shown in Figure 1. All participant sessions were videotaped. The VE displayed in the HMD was also simultaneously displayed in a second monitor. Thus, the researcher could see the same image as the participants did but also saw it superimposed with information on gaze and fixation time.

THE VIRTUAL ENVIRONMENT

The VE consisted of a company headquarters, with 4 rooms (meeting room, laboratory, coffee-shop and warehouse), each measuring 12 x 12 meters in size. The rooms were interconnected by 2 symmetrical axes of corridors, 2 meters wide, and circumvented by another corridor with an exit. The layout can be seen in Figure 2. In terms of visual and auditory complexity or pollution, the VE can be roughly classified as being uncluttered.

The base structure of the VE was designed using AutoCAD® 2009, and then it was imported into 3D Studio Max® (both from Autodesk, Inc.). The scenario was then exported using a free plug-in called OgreMax, to be used by the ErgoVR system (developed by the Ergonomics Laboratory of the FMH / Technical University of Lisbon).

Figure 1. Participant during the simulation

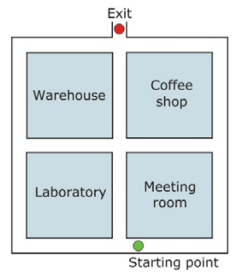

Figure 2. The VE floor plan

DESIGN OF THE STUDY

The experiment used a between-subjects design with two experimental conditions: (1) Static, and (2) Dynamic.

(1) Static: VE with color ISO type warnings and posted signs with a size of 30 x 40 cm, without abrasion marks.

(2) Dynamic: VE with color ISO type warnings and posted signs displayed in illuminated panels, with a size of 30 x 40 cm, augmented with 5 flashing lights and an alarm sound activated or deactivated by proximity sensors. The flashing lights, 3 on the top and 2 on the bottom, were 4 cm diameter, orange colored and with a flash rate of 4 flashes per second, with equal intervals of on and off time (Sanders & McCormick, 1993). The flash was twice as bright as the background. The sound was an alarm beep. An example of a sign in both dynamic and static versions can be seen in Figure 3.

Figure 3. VE images showing the “Inhalation hazard" warning in the (1) static condition on the left and the (2) dynamic condition on the right.

PROCEDURE

The procedure was divided in three major steps: pre-experimental training, experimental session, and post-hoc questionnaire.

In the pre-experimental training, participants were given a brief explanation about the study and were introduced to the equipment. They were unaware of the real objective of the research by being invited to evaluate new software for VR simulation. At the outset, they were asked to sign a consent form and were advised they could stop the simulation at any time. The Ishihara Test (Ishihara, 1988) was used to detect color vision deficiencies. Participants were shown a practice VE using the same equipment used in the experimental session. The practice VE consisted of 2 rooms containing some obstacles (e.g., doors, narrow corridors, pillars, etc.), requiring some skill to be circumvented. The purpose of this practice trial was to get the participants acquainted with the setup and to make a preliminary check for any initial indications of simulator sickness. In this practice trial, participants were told to freely explore and navigate the virtual room as quickly and efficiently as they could. They were told that when they felt that they were able to control the navigation devices and felt comfortable with the equipment that they should say so aloud. When they did, the experimental session started shortly thereafter.

Participants took part in one of two experimental conditions. The given scenario was a series of end-of-day routine security checks that simulated the closing up of a company's facility at the end of a workday. In the VR simulation, participants were to fulfill several tasks inside the VE, involving entering into each one of the main four rooms in the following order: Meeting room, Laboratory, Coffee Shop and Warehouse. In the VE, several warnings and posted signs were placed on walls of the rooms. The entire experiment and the content of the warnings and posted signs as well as all experimental instructions (print and oral) were communicated in Portuguese language. The English translations are given for the purposes of communicating this report. The warnings and posted signs are displayed in Figures 4 and 5.

(1) Mandatory to disconnect before leaving the room (blue)

(2) Caution, laser in operation, do not enter before turning it off (yellow)

(3) Sound warning, mandatory to warn before entering (blue)

(4) Inhalation hazard, start air extractor before entering the room (yellow)

Figure 4. Static version of ISO type warnings. Note that the warnings were not pre-cued by task instructions prior to being exposed in the VE.

(5) Security system (red)

(6) Gas valve (red)

(7) Cut-off energy to machine room (green)

Figure 5. Static version of ISO type posted signs. Note that the contents of the posted signs were pre-cued by the task instructions.

The written instructions were posted in a projection screen and whiteboards placed inside the rooms in the VE. Once the simulation started, no dialogue between participants and the researcher occurred.

Participants were told they should start the procedure by getting to the Meeting Room. Inside the Meeting Room, the following instructions were displayed: "Check for water cups on the top of the tables. If you find any, please leave a message in the Coffee Shop. Then go to the Laboratory room and turn on the security system." Near the exit door, above an ambient music button switch on a wall was Warning 1 – "Mandatory to disconnect before leaving the room."

Outside the Laboratory, close to the entrance door and above a button switch was Warning 2, which stated "Caution, laser in operation, do not enter before turning it off." However, an "out of order" label was stuck on the button. Inside the Laboratory, Sign 5 was present – "Security system." The instruction displayed inside this room was: "Now, go to the Coffee Shop and turn the gas off."

Outside the Coffee Shop, close to the entrance door was Warning 3, which stated "Sound warning, mandatory to warn before entering" was displayed. Inside the Coffee Shop, Sign 6 – "Shut-off gas" was present together with a button switch. The instruction given was "After the gas is shut-off, go to the Warehouse and cut the energy to the machine room."

Outside the Warehouse, whose door was closed, was Warning 4, which stated "Danger, inhalation hazard, start air extractor before entering the room." There was only one way to open the door, which was by pressing the button adjacent to the warning. Inside the Warehouse was a button switch adjacent to Sign 7, which stated "Cut energy to machine room." Since this was the last room, no further instructions were given here. After entering the warehouse, or following 5 minutes after entering the corridors leading to the warehouse, an explosion occurred, followed by a fire in the Warehouse and in the adjacent corridors. A fire alarm could be heard and flames and smoke blocked all the corridors leaving only the exit route clear. The simulation ended when the participants reached the exit.

After completing the simulation, participants answered a questionnaire concerning their experience in the simulation. These post-hoc data are not described in this article.

RESULTS

The main dependent variable was behavioral compliance, which was defined as the extent to which the participant adhered to the warnings and signs and was measured by the times participants pressed the buttons as directed by the warnings.

Table 1. Frequency of pressing buttons (behavioral compliance) as a function of warnings and posted signs by (1) static vs. (2) dynamic conditions.

	(1) Static		(2) Dynamic	
Warnings (1-4) and posted signs (5-7)	**freq**	**%**	**freq**	**%**
(1) Mandatory to turn off before leaving the room	12	40.00	29	96.70
(2) Caution, laser in operation, do not enter before turning it off	1	3.33	14	46.70
(3) Sound warning, mandatory to warn before entering	7	23.33	22	73.33
(4) Inhalation hazard, start air extractor before entering the room	23	76.67	30	100.00
(5) Security system	21	70.00	23	76.70
(6) Gas valve	30	100.00	29	96.67
(7) Cut-off energy to machine room	21	70.00	23	76.70

The influence of sign type (static vs. dynamic) on behavioral compliance (number of button pressed associated with warnings and posted signs) was evaluated at a significance level of .05 using *t*-tests. The analysis showed a significant effect of warning type (static vs. dynamic) on behavioral compliance to warnings ($p < 0.001$) but no effect was found for the posted signs ($p = 0.17$).

The Binomial Test was used to compare the two experimental conditions for each warning. The test assessed whether the proportion of participants who pressed the buttons in the two experimental conditions was equal. The analysis revealed that were significant differences between the static and dynamic conditions for the warnings 1, 2, 3, and 4 ($p < 0.01$) but not significant for the posted signs 5, 6, and 7 ($p > 0.10$). Compliance was higher dynamic warnings than static warnings.

CONCLUSIONS

Virtual Reality was used to simulate an interaction context with warnings signs with the purpose of evaluating behavioral compliance. University students performed an immersive virtual end-of-day routine security check and interacted with ISO type warnings and signs. Previous research indicated that dynamic warnings produce greater compliance behavior than static warnings. In the present study, the dynamic warnings and posted signs had simulated flashing lights whereas the static warnings and posted signs did not, and behavioral compliance was measured (pressing buttons associated with the directives of the signs). The results showed that dynamic warnings produced greater compliance than static ones. This result corresponds with actual behavioral compliance research with warnings that has found that dynamic warnings produced higher compliance than similar static ones. The dynamic features presumably make them more salient and increasing the likelihood that they be noticed and heed to them given, which resulted in the increased compliance compared to static (less salient) ones. But such effects were significant only in the cases of warnings. Warnings in this study were not pre-cued by the task instructions. They just appeared in the course of performing the tasks within the simulation. This was not the case for the posted signs. The posted signs were directly tied to the instructions and were "expected" postings at places participants were specifically instructed to go to. When the posted signs were targets of specific tasks then there was no difference between the two experimental conditions. The pre-cued posted signs did not need to be salient to be noticed. Also note that performance was relatively high in the posted sign conditions probably because their presence and information content were pre-cued. The high level of performance may have produced a ceiling effect that also prevented finding significant improvement for the dynamic posted signs over the static ones without more participants in conditions. Future data analysis such as time spent, paths taken and diverse subjective ratings could reveal other differences between conditions.

Further research is needed on the impact of other aspects of VR such as navigation devices and interaction. In this study, participants “flew” through the VE, since they were actually seated at a desk, moving by the means of a joystick. Also, participants had a rather limited ability to interact with the VE, since they could not manipulate objects as one does in the real world (e.g., to open doors and operate different kinds of machine controls).

The present research has implications for the use of VR to study the effectiveness of warnings in different settings and tasks. This kind of use is in its infant stages. This study affirms that there is good potential for it to serve as a technique to investigate warning effectiveness, particularly behavioral compliance. VR offers a way to overcome several key constraints that have thus far limited warning compliance research.

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