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Behavioral compliance for dynamic versus static signs in an immersive virtual environment

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ABSTRACT

This study used an immersive virtual environment (IVE) to examine how dynamic features in signage affect behavioral compliance during a work-related task and an emergency egress. Ninety participants performed a work-related task followed by an emergency egress. Compliance with uncued and cued safety signs was assessed prior to an explosion/fire involving egress with exit signs. Although dynamic presentation produced the highest compliance, the difference between dynamic and static presentation was only statistically significant for uncued signs. Uncued signs, both static and dynamic, were effective in changing behavior compared to no/minimal signs. Findings are explained based on sign salience and on task differences. If signs must capture attention while individuals are attending to other tasks, salient (e.g., dynamic) signs are useful in benefiting compliance. This study demonstrates the potential for IVEs to serve as a useful tool in behavioral compliance research.

1. Introduction

Effective warnings are an essential tool of hazard control for products and environments. They can help to maintain safety, reduce injury and limit property damage. Warnings effectiveness as a construct can be conceived and assessed in diverse ways. According to most information processing models, warning processing is described as involving the stages of noticing, encoding, comprehending and behaviorally complying (see Rogers et al., 2000; Wogalter, 2006). Although the pre-compliance stages are critical for warning success, behavioral compliance, the last stage in the process, is often seen as the ultimate measure or "gold standard" of warning effectiveness.

However, from the point of view of conducting research, factors that influence compliance are difficult to investigate because of methodological difficulties and ethical constraints. One main limitation in conducting behavioral compliance studies is that research participants cannot be exposed to real hazards, but it is threat of injury or property damage for which warnings are used. Another difficulty is that producing realistic experimental settings that appear risky but have no actual risk is challenging and can be expensive in terms of money, time and effort (e.g., Wogalter et al., 1987). Consequently, even though there has been a substantial body of research on the topic of warnings, a relatively small proportion of studies have measured actual behavioral compliance (see e.g., Braun and Silver, 1995 for reviews of this literature; Kalsher and Williams, 2006).

Virtual reality (VR) could potentially change this situation by helping to overcome some of the main constraints, since it can simulate risky contexts for use in warnings research (Duarte et al., 2010b). High-quality immersive virtual environments (IVEs) can promote ecological validity while allowing good control over experimental conditions. However, such assumptions require further investigation.

To date, few studies have used VR in warnings research and the majority of them have mainly focused on exit signs (e.g., Glover and Wogalter, 1997; Shih et al., 2000; Tang et al., 2009). VR research on exit signs has demonstrated the ability for this kind of research to measure sign manipulations on compliance. Nonetheless, to fully explore the utility of VR in warning research, other types of signs (e.g., environmental safety warnings) should be tested.

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Furthermore, to increase the ecological validity, compliance with warnings should be tested with participants involved in other types of tasks (e.g., undertaking work-related tasks), which could involve the interaction with potentially hazardous products, as well as provide the opportunity to manipulate situational factors (e.g., emergency, mental workload).

In warning research literature, there are several behavioral compliance studies that demonstrate the effects of sign type (e.g., Wogalter et al., 1993; Wogalter and Young, 1991), and the presence (versus absence) of warnings (Wogalter et al., 1987). In a review of the behavioral compliance literature, Silver and Braun (1999) concluded that the presence of a warning had a positive effect on behavioral intentions and compliance. Several other studies lead to the same conclusion (e.g., Laughery et al., 1998; Wogalter et al., 1987, 1994). Another fairly strong finding is that dynamic presentations produce greater compliance than static presentations (e.g., Wogalter et al., 1993). One explanation for this finding, based on attention theory (e.g., Kahneman, 1973; Wickens and McCarley, 2008), is that dynamic presentations are more likely to be noticed than static ones because of its prominence (also known as salience and conspicuousness) calls attention to itself; more prominent stimuli are better able to switch attention and break into consciousness when attention had been focused on other tasks.

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, which allow them to be multimodal and customized. Recent articles suggest that technology-based warnings can be more effective than the traditional solutions (e.g., Smith-Jackson and Wogalter, 2004; Wogalter and Conzola, 2002; Wogalter and 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.

1.1. Study goals and rationale

This research was focused on determining whether VR, as a methodological tool, could provide capable means to measure behavioral compliance to warnings. VR's adequacy was determined by examining if it would be sufficiently sensitive to detect differences between manipulated warnings and do so in ways that resemble results found in actual field or in laboratory behavioral-compliance situations (Wogalter et al., 1989). Such finding would be important for warning research because it would give researchers the opportunity to avoid some main limitations of the field and laboratory approaches.

The specific objectives of this research can be summarized as follows: (1) to investigate the effect of warning design variables (sign type: static and dynamic) on compliance with posted safety signs during a work-related task, and with exit signs during an emergency egress; (2) to examine the effect of situational variables (uncued and cued safety signs) on compliance with posted safety signs during a work-related task; (3) to examine a gender effect on compliance.

In the present study, behavioral compliance to different signs was measured using an immersive realistic-appearing virtual environment (IVE). Signs were either static or dynamic or they were absent. A work-related task was designed for the simulation that was believable and allowed incidental exposure to signs as they conduct various parts of the task in the IVE. At several points in the task, participants are confronted with safety signs while taking the role of a security officer who moves through the building to shut down certain systems for the night and who is confronted with different signs as they perform the shutdown task while navigating through the IVE. Later, at a predetermined point, an unexpected emergency (simulated explosion followed by a fire) occurred. As participants try to find their way out of the building, there were static or dynamic exit signs or no signs. Thus, situations (e.g., the unexpected fire) were presented to participants that would be difficult to test in a live setting.

Additionally, the effect of uncued and cued signs was examined. The uncued and cued signs were similar in overall design. The main aspect that differed between them was the task. For the uncued signs, the signage and situation was not pre-cued by instructions given to participants. They were unexpected and they appeared in the VE as participants were attempting to carry out the security shutdown task. The cued signs, however, were pre-cued by being part of the tasks that participants were carrying out as per instructions. Lastly, the emergency exit signs, which were critical for the evacuation taking place later in the simulation, in a separate emergency fire phase.

Attention theory (e.g., Kahneman, 1973; Wickens and McCarley, 2008), suggests that dynamic signs should be more effective at being noticed when individuals are occupied on other tasks than static or no/minimal signs. To switch attention away from the main task, the more salient, dynamic signs would be better able to accomplish this. However, the cued signs might not benefit as much from the dynamic quality since participants were expecting and looking for the information. Thus compliance to cued expected signs ought to be high even when minimally salient. Dynamism might benefit exit signs because emergencies and stressful situations, such as exiting a building due to a fire, could reduce available attention to notice the less salient (static or no) signs. Dynamic exit signs could be better than static ones because in an emergency there is stress that might tie up part of attention capacity. Support for this pattern would be informative, if found.

It is worthwhile to mention that the dynamic signs used were multimodal (i.e., visual and auditory), including flashing lights around the backlit signboards and a tone/beep. The auditory modality has certain advantages, such as omnidirectionality, therefore not dependent from a particular viewpoint, and impossible to shut off. The reason for using a multimodal presentation instead of a unimodal one is it would be expected in presenting dynamic warnings, as most video recording and presentation does (see Cohen et al., 2006 for a review of multi-modal warnings).

Gender was included as a factor in the analysis of conditions, because some research suggests that females are slightly more likely to notice, read and comply with warnings than males (e.g., Glover and Wogalter, 1997; Godfrey et al., 1983; LaRue and Cohen, 1987; Laughery and Brelsford, 1991; Young et al., 1989).

2. Method

2.1. Participants

Data from 90 university students were analyzed. One hundred participated but due to data corruption or simulator sickness, 10 were dropped. The resultant sample was aged 18–35 years old ($M = 21.3$, SD $= 3.2$). The experiment was a between-subjects design with participants being assigned randomly to one of three experimental conditions (no/minimal sign, static, and dynamic), each with 30 individuals with the constraint that an equal number of females and males appeared in each condition. All participants completed a consent form. None of them reported prior experience with IVEs or having physical or mental conditions that they believed would prevent them from participating in a VR simulation. All reported having normal or corrected visual acuity. Congenital color vision deficiencies (i.e., total color blindness and strong and mild forms of both protan and deutan deficiencies) were screened through Ishihara Test (Ishihara, 1988). No participants were excluded due to color vision deficiencies.

2.2. Apparatus

All tasks were performed in an immersive virtual reality system – *ErgoVR* (Teixeira et al., 2010). The system's configuration comprised two magnetic motion trackers from Ascension-Tech®, model Flock of Birds, for monitoring head and hand movements; a joystick from Thrustmaster® as a locomotion device; a 2D Head-Mounted-Display (HMD) from Sony®, model PLM-S700E; wireless headphones from Sony®, model MDR-RF800RK; a Microsoft® Windows graphics workstation, equipped with an NVIDIA® QuadroFX4600 graphics card and an external monitor.

Participants were seated at a desk, inside of a dark and silent room (the sound level was below 50 dBA), during the entire experimental session. For the participants' safety, as well as for technical reasons, the researcher was present, inside the room, during the entire procedure. The experimental setup is shown in Fig. 1.

Participants' viewpoint of the VE was egocentric and the HMD provided 30° horizontal field of view, 18° vertical and 35° diagonal, operating at a resolution of pixels, at 32 bits of color depth. Participants could regulate their gait speed, by tilting the joystick, from stopped (centered at top) to an average walk pace (1.2 m/s), up to a maximum gait speed near 2.5 m/s. Accordingly to Bohannon (1997), these two velocities were the comfortable speed for older women (in their 70s) and the maximum speed for young men (in their 20 s), respectively. The lower speed approximates walking at a natural speed, and the higher speed is likened to walking as fast as possible, in a safe manner, without running.

The joystick controlled movements of the "virtual body" (the joystick being tilted forward/backward results in a correspondingly forward/backward movement, while being tilted to the left or to the right represents a rotation of the virtual body to the desired direction), but not the head movements (because of the motion tracker coupled to the HMD, whenever the head moved the viewpoint on the VE changed). This means that the participants could use their head movements to visually explore the VE but could not use them as an input for the direction they wanted to walk in the VE. Thus, the participants could move themselves toward a given direction even though they were looking to another direction. For example, they could be walking forward in a hallway because they wanted to go to a given room and, while walking, they could scan the side walls and doors (without needing to stop and rotate the body toward the door) to read the signage to identify a room. This method was considered less nauseogenic than others, in which the head movements are not tracked and the movement is achieved solely by hand-control devices (Simeonov et al., 2005).

A motion tracker, positioned on the participants' left wrist, allowed them to control a pointer (2D symbol with a shape of a hand) that was used to press buttons associated with the signs (for compliance assessment purposes). To accurately press a button, they had to position themselves no further than the length of an outstretched arm from the button.

The ErgoVR system automatically collected data (e.g., buttons pressed and paths taken by the participants), at a 60-Hz rate, for subsequent analysis.

Fig. 1. Positioning of the participant and apparatus.

2.3. Virtual environment (VE)

The base structure of the VE was initially designed using AutoCAD® 2009, and then modified by 3ds Max® 2009 (both from Autodesk, Inc.). The VE was then exported using OgreMax v1.6.23 into the ErgoVR system.

The VE was designed as a company headquarters divided in two major areas entitled "Rooms" (Area 1) and "Escape routes" (Area 2). The VE was relatively uncluttered in terms of visual and auditory complexity. Area 1 contained four rooms (meeting room, laboratory, cafeteria and warehouse), which were furnished and decorated, each sized m. Two symmetrical and perpendicular axes of corridors, 2 m wide, interconnected the rooms that were circumvented by another corridor with an exit leading to the escape routes area, as well as with several closed doors. Area 2 consisted of a sequence of six corridors in a T-shaped format. At the end of each corridor only one of the directions (right/left) provides access to the exit. The layout of the VE (floor plan) can be seen in Fig. 2.

The VE provided animation effects to enhance realism and fidelity level. The effects were visual (e.g., buttons changed their color after pressed; flames and smoke were visible after the explosion) and auditory (e.g., sounds associated with buttons; ambient background music; door's sliding noise; fan starting sound; blast sound; fire alarm siren; fire crackling noises). They were included in the IVE to provide feedback to actions. There was no haptic feedback (except joystick positioning). Signs were positioned in the main intersections or decision points. Images of the VE can be seen in Fig. 3.

2.4. Design

This was a two-way between-subjects design with sign-type and gender as independent variables. The three experimental conditions (i.e., no/minimal, static and dynamic signs) are depicted in Fig. 4 and are described below:

- *No/minimal signs*: VE without 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.
- *Static*: VE with color printed signs, consistent with the International Organization for Standardization's 3864-1 (ISO, 2002) standard.
- *Dynamic*: VE with the signs displayed in backlit panels, augmented with 5 flashing lights and an alarm sound (beep) activated or deactivated by proximity sensors. The flashing lights had 4 cm of diameter, orange colored and with a flash rate of 4 flashes per second, with equal intervals of on and off time.

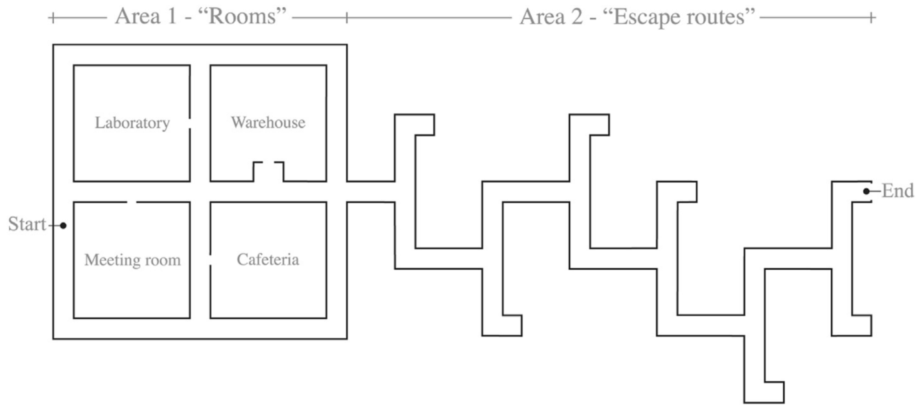

Fig. 2. The VE layout.

2.5. Stimulus material

The signs can be classified into 3 categories: (1) uncued signs, (2) cued signs and (3) exit signs. The ISO-type signboards had a size of 30 × 40 cm, had both a symbol and text, whereas the exit signs had a size of 30 × 15 cm.

(1) *Uncued signs:* These signs contained a hazard alert (i.e., yellow triangle with black symbol) and a mandatory (i.e., white image within a solid blue circular surround shape) panel configuration. The former was used to indicate a potentially hazardous situation that, if not avoided, may result in injury, and to alert people to areas that require caution (e.g., inhalation hazard to start air extractor before entering the room). The latter were used to convey actions that should be taken to avoid hazards and/or property damage, or to be in accordance with company's regulations (i.e., mandatory to disconnect the music before leaving the room, and to warn before entering the room). The uncued signs were the main targets of the behavioral compliance evaluation. These signs, and the scenario where they were embedded, were designed so that participants would have little or no expectation that they would be part of the VE, as they were not pre-cued by the previously given task instructions.

(2) *Cued signs:* These signs were similar to the uncued signs described above but played a different role in the scenario. They identified the location of safety equipment (e.g., a gas valve) and were supplemented by a text component. The cued signs were mentioned in the task instructions, given to the participants through the wallboards placed in various parts of the VE, which they were asked to perform along the simulation. In other words, the pre-cued signs' information was expected; participants were looking for the safety-related equipment as part of the tasks that they were carrying out in the IVE.

(3) *Exit signs*: These emergency signs, which were used to mark the routes of egress, were entirely symbol-based, containing an arrow and a running figure in a doorway.

Examples of uncued and cued signs and exit signs are displayed in Fig. 5.

Fig. 3. Screen shots of the VE.

Fig. 4. Screen shots from the VE showing the cued sign "energy" in (a) no/minimal signs, (b) static, and (c) dynamic conditions.

2.6. Measures

Behavioral compliance measures and performance during egress are the main dependent variables. Compliance was participants acting in conformity to the instructions given by the signs (uncued and cued) in Area 1, and exit signs in Area 2.

In the no/minimal signs condition, compliance refers to the safety behavior performed; this meant pressing the buttons for uncued and cued signs, and turning toward the exit for exit signs. It should be noted that in the no/minimal signs condition a text label (i.e., placed below the button) identified the device (e.g., siren, gas-valve), and providing the means to perform compliant behavior.

There were three composite compliance measures:

(1) *Uncued signs:* This was measured by the number of times the participants pressed the buttons (music; siren; extractor) as directed by the three warnings presented in the simulation (100% success = 3 pressed buttons);
(2) *Cued signs:* This was measured by the number of times the participants pressed the buttons (security system; gas; energy), as directed by the three signs presented in the simulation (100% success = 3 pressed buttons).
(3) *Exit signs:* This was measured by the number of times the participants went correctly in the direction indicated by the sign (in the conditions with signs) or toward the exit (control condition). In order to be considered a decision, the participant had to cross the square defined by the intersection (2×2 m). Small movements, in each left or right direction, were considered hesitations and were disregarded (100% success = 6 correct decisions).

Performance during the egress refers to three metrics automatically recorded by the ErgoVR system. This information was collected to examine the impact of the IVE in general and in specific locations, and between the experimental conditions. These measures were:

(4) *Time spent*: This measure encompassed the period of time (in seconds) participants spent in Area 2 (i.e., egress time). Once the participants crossed the door threshold dividing both areas, a time record was started and it ended when the participants reached the exit point or when the simulation was stopped (after 20 min).
(5) *Distance traveled*: This measure was the distance traveled (in meters) after crossing the trigger at the beginning of Area 2 until reaching the end point, or at the 20-min point.
(6) *Number of pauses*: This encompassed all the pauses recorded after the participants crossed the door at the beginning of Area 2, until the end point, or at the 20-min point. A pause is defined as the occurrence of the participant (its virtual body) being stationary for the minimum time interval of 2 s (Conroy, 2001). This lower limit for the time interval was adopted assuming that it would exclude most momentary hesitations (such as those caused by difficulties in using the joystick).

2.7. Procedure

The entire study including the content of all the signs as well as all instructions were communicated in the Portuguese language. English translations are given in this report.

Upon arrival to the laboratory, participants first completed a consent form. They were then tested for color vision deficiencies, and completed a questionnaire that inquired about their experience with VR and propensity for simulator sickness. This was followed by a demographic questionnaire collecting age, sex and so forth. After being introduced to the equipment, participants were provided with a description of the study. Note that participants were not told of the real objective of the research; they were instead told that they were evaluating new VR system. Participants completed a practice trial to familiarize themselves with the devices and the interaction in IVEs. In this practice trial, participants explored an IVE consisting of two rooms containing some obstacles (e.g., doors, corridors, pillars) that required some skill to be circumvented. The experiment began after participants reported they were comfortable with the VR system. After completing the practice trial, participants took part in one of the experimental conditions. For most participants the entire session lasted approximately 40 min.

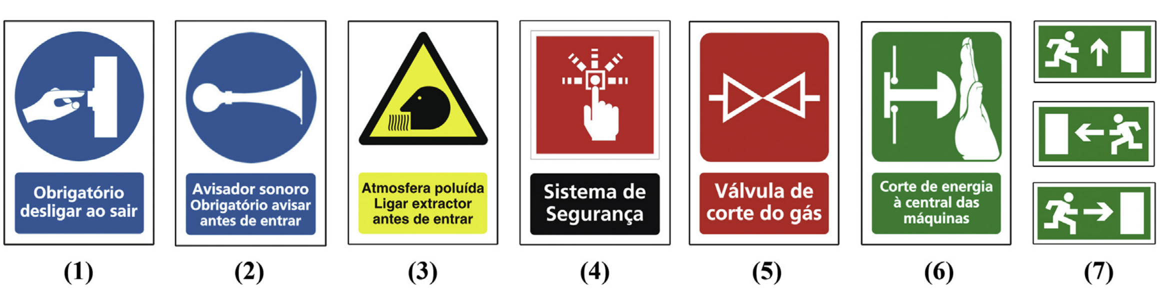

Fig. 5. Stimuli used in the experiment. Uncued signs (1–3): (1) music – mandatory to disconnect before leaving the room; (2) siren – mandatory to warn before entering; (3) air extractor – inhalation hazard, start air extractor before entering the room; cued signs (4–6): (4) security system; (5) gas valve; (6) cut-off energy to machinery room; and exit signs (7).

The given scenario was a series of end-of-day routine security checks that simulated a security officer closing up of a company's facility. Participants were told a cover story in which they were selected by their supervisor to substitute someone who had fallen sick, and were in a section of the building that was new to them. They were instructed to search for written instructions, present in every room (posted on black/white boards), that would guide them and let them known which were the specific goals they were supposed to accomplish.

The participants had to fulfill several tasks, involving entering into each one of the four rooms in the following order: meeting room, laboratory, cafeteria and warehouse. The safety signs were placed on the walls of the rooms and the exit signs placed in every hallway and passageway intersection. After entering the warehouse or 5 min 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, as well as flames and smoke could be seen blocking all the corridors leaving only the exit route clear. Participants were to leave the building as fast as they could.

As participants progressed through the T-shaped intersections, flames and smoke appeared to block (although not physically) access through the corridors behind them. When the participants reached the exit, or when the experiment reached the time limit of 20 min, the simulation was stopped. The time limit was established to avoid or reduce fatigue and/or simulator sickness. According to Bowman et al. (2002) an exposure greater than 30 min would be considered lengthy (but this likely depends on the specific VE).

3. Results

The participants' safety behavior was assessed in the two parts of the simulation (i.e., during the work-related task and during the emergency egress). The dependent variables were compliance with uncued, cued and exit signs, as well as egress performance metrics (i.e., time spent, distance covered, and number of pauses). Dependent variables were analyzed using non-parametric two-way ANOVAs (e.g., Zar, 1999) with sign type and gender as factors. This analysis is an extension of Kruskal–Wallis test and the test statistics have an approximate Chi-square distribution. The nonparametric version of two-way ANOVA was used because the dependent variables as regards to the compliance measures are quantitative discrete and the ones related to egress performance measures did not meet the ANOVA assumptions. When appropriate, nonparametric post-hoc analyses using Bonferroni–Dunn test were conducted to determine significant differences. A probability level of 0.05 was used for statistical significance.

3.1. Compliance with uncued and cued safety signs

The mean compliance values and standard deviation for uncued and cued signs are shown in Fig. 6.

3.1.1. Compliance with uncued signs

A non-parametric two-way ANOVA showed that the sign type produced a significant effect on compliance with uncued signs, X^2 $(2,N = 90) = 52.92$, $p < 0.001$. Post hoc analysis indicated that there were significant differences among all pairs of sign-type conditions: dynamic signs ($M = 2.70$; SD $= 0.54$) produced significantly higher compliance than the static signs ($M = 1.40$; SD $= 1.00$), $p < 0.001$, and the no/minimal signs conditions ($M = 0.60$; SD $= 0.50$), $p < 0.001$. The static signs condition also produced significantly higher values of compliance than the no/minimal signs condition, $p = 0.016$. Gender (X^2 $(1,N = 90) = 0.52$, $p = 0.473$) and interaction effects (X^2 $(2,N = 90) = 1.24$, $p = 0.537$) were nonsignificant.

3.1.2. Compliance with cued signs

No significant effect of sign type was found, X^2 $(2,N = 90) = 0.40$, $p = 0.821$ (dynamic: $M = 2.50$; SD $= 0.78$; static: $M = 2.40$; SD $= 0.77$; no/minimal: $M = 2.47$; SD $= 0.68$). There was also no effect of gender, X^2 $(1,N = 90) = 1.28$, $p = 0.258$, or interaction with sign type, X^2 $(2,N = 90) = 1.36$, $p = 0.506$.

3.2. Compliance with exit signs and performance measures during egress

3.2.1. Compliance with exit signs

Analysis revealed a significant effect of the experimental condition for compliance with exit signs, X^2 $(2,N = 90) = 39.89$, $p < 0.001$. Post hoc analysis indicated that there were significant differences among the no/minimal signs ($M = 2.90$; SD $= 1.40$) and both static ($M = 4.60$; SD $= 1.69$), $p < 0.001$, and dynamic conditions ($M = 5.23$; SD $= 1.38$), $p < 0.001$, but no significant difference was found for dynamic versus static signs ($p = 0.369$). There was no significant gender or interaction effect. Fig. 7 shows mean of correct directional choices for the experimental conditions.

3.2.2. Egress performance

For the three egress metrics, lower scores indicate better performance. The means for the egress time, distance covered, and pauses for the three sign conditions are shown in Fig. 8. Across all three graphs dynamic signs showed the best performance and the no/minimal signs the lowest, with static signs intermediate between the other two sign types. A significant effect of sign type was

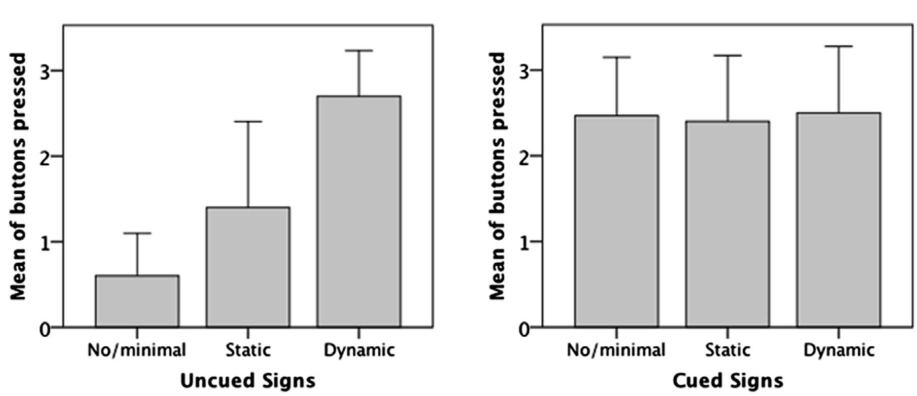

Fig. 6. Mean (SD) of buttons pressed for uncued signs (left) and cued signs (right), by experimental condition.

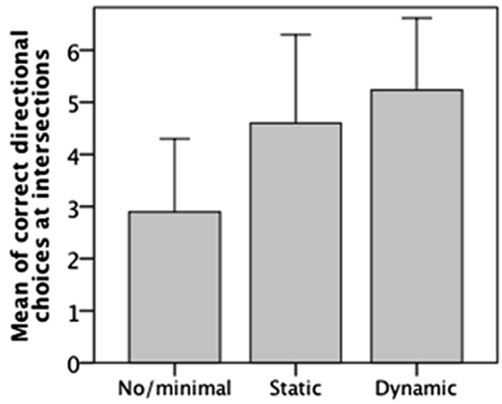

Fig. 7. Mean (SD) of correct directional choices at T-shape intersections, during egress, by experimental condition.

found for all metrics (Time: X^2 (2,N = 90) = 28.37, $p < 0.001$; Distance: X^2 (2,N = 90) = 18.79, $p < 0.001$; and Pauses: X^2 (2,N = 90) = 23.64, $p < 0.001$). Post hoc analysis showed that the no/minimal signs condition produced significantly worse egress performance compared to the other two sign conditions ($ps < 0.001$). Although dynamic egress signs appeared to produce lower egress scores than the static egress signs the difference was not statistically significant. No significant differences were found for gender and interaction effects.

4. Discussion

A simulation of two activities (a security officer task and emergency evacuation) was used to investigate the influence of dynamic or static signs on behavioral compliance to safety signs, uncued and cued, and exit signs. The safety behavior attained on the no/minimal signs condition was used as a baseline.

Results show that dynamic signs were better than static signs, and static signs were better than no/minimal signs for the uncued signs. There were no significant compliance differences due to sign type for the cued signs probably because compliance was very high (near ceiling), which may have prevented the showing of an improvement by the dynamic signs. The results confirm that signage can influence compliance behavior. Also, the pattern of findings are generally in accordance with previous live and VR research showing higher compliance to salient than less salient signs (e.g., Conzola and Wogalter, 1999; Glover and Wogalter, 1997; Wogalter et al., 1987, 1993; Wogalter and Young, 1991).

The reason that the finding of concordance between reality and simulation has some importance is that potentially simulation could create realistic appearing scenarios that could not be easily and safely conducted given the difficulties mentioned at the outset of this article (e.g., safety concerns, time, effort, money) involved in conducting behavioral compliance research. Simulation could play a useful role in compliance research and measurement.

Furthermore, these results support the notion that some signage is not as good as others. For the uncued signs, dynamic versions were better than static ones, but this difference between dynamic and static signs was not significantly for the cued signs and exit signs. Thus, at least for the uncued signs, dynamic properties improve compliance. Because generally, in real life, signage is uncued people are usually doing other tasks and do not typically search for warnings (Adams et al., 1998). Dynamic stimuli have a better capability to capture (or switch) attention toward it (Kahneman, 1973; Wickens and McCarley, 2008).

The cued signs showed no static versus dynamic differences. It is notable that compliance was quite high across conditions, so there is some inclination to giving a ceiling-effects explanation for these nonsignificant differences. It seems, however, situational demands may be the root cause: in the IVE, compliance was also high in the no/minimal signs conditions – as high as the dynamic condition. Thus, the situation and scenario apparently provided an effective context on what participants should be doing in the realistic IVE. Another potential reason for the cued signs findings is related to the one given above for the warnings results. For the uncued signs, salience (as in dynamic signs) mattered. With cued signs, salience did not matter and compliance was high across conditions. The reason relates to participants' task. They received instructions to carry out tasks and were searching for the cued signs. When searching for information, sign salience may be less important. This is not to say that salience is completely unimportant when people are specifically searching – it just has a smaller effect. A bigger effect is needed when the sign must call attention to itself while participants are doing other tasks, as with the warning signs.

Egress performance was worst in the no/minimal signs conditions. Although dynamic signs showed the best egress performance in terms of magnitude for all three egress metrics, the difference compared to the static signs condition failed to reach statistical significance. However improved performance reached significance in several other measures comparing dynamic signs with static signs (and no/minimal signs). Participants viewing dynamic signs had higher compliance rates, spent less time, covered shorter distances, and took fewer pauses in the egress phase. These results can also be explained by Attention theory. People under stress (desiring to escape a fire in the latter phase of the study) may need greater sign salience to direct them. This because stress acts like performing another concurrent task and uses attentional capacity. The emergency situation leads one's attention to be distracted to some extent, and a dynamic exit sign is better able to attract attention to itself than the static exit sign, which was in turn better than the no exit sign condition. However, the difference in performance between static and dynamic signs conditions was not statistically

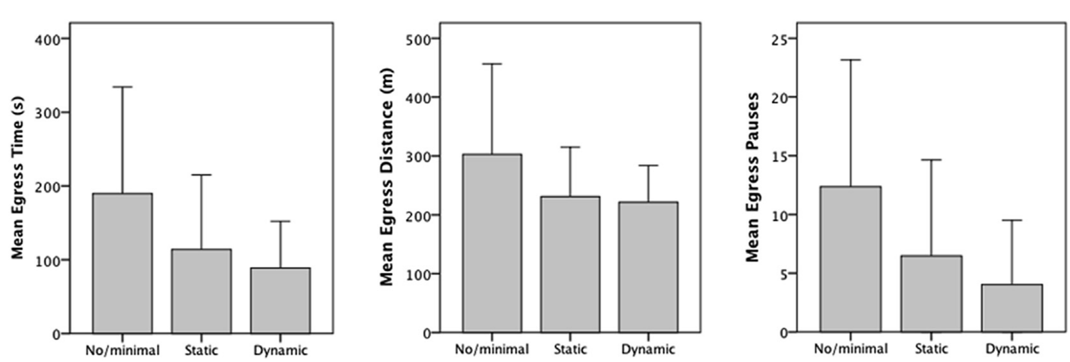

Fig. 8. Means (SD) of egress time (left), distance (center) and pauses (right), by experimental condition.

significant. Mantovani et al. (2001) also failed to show significant differences in egress performance between exit signs conditions. One potential explanation for a failure to find a difference between the two signs conditions is that a learning effect played a role due to the standard placement of the exit signs along the six T-shape intersections.

Most guidelines on warnings recommend inclusion of consequences information. However, the signs in this study did not contain this information. There are two main reasons. First, based on most previous research, the inclusion of consequences would raise the compliance levels. In the present study, we sought to keep levels of compliance at moderate levels so that differences between the manipulated conditions could be determined without having ceiling effects (very high levels near 100%) that would negate the display of differences between conditions. Second, most signs in the real world often do not contain consequences information. Thus, in an effort for realism and applicability to real-world context, the warnings in this study did not contain consequences information. Nevertheless, future research should examine the effect of added consequences information to warning signs in VR to measure the effects.

5. Conclusions

Users are, in most cases, engaged in some ongoing, more or less complex, activity when encountering warning signs. Is therefore necessary to consider the signs within the context of a broader situation, under the influence of diverse factors. Overall, the results of the current research lend support for the potential effectiveness of dynamic multimodal signs. Although promising, there are some implications regarding the implementation of these enhanced signs in real contexts (see Wogalter and Mayhorn, 2006 for a review of technology-based warnings).

Dynamic signs might be beneficial mostly for situations in which the warning is not applicable most of the time. For exposure over time the dynamic signs are less likely to induce habituation than their static counterparts. In this case, since sensor-based signs were used and assuming that they were properly programmed and maintained, they would be active only when necessary. Thus, when not flashing and or emitting a sound the signs could be disregarded. The inactivity of the sign can also be considered a message. A typical example is the fire-alarm in buildings. Also, when integrated in a system, these signs are not independent and will be activated according to specific chain of actions.

Other advantage is that these signs could be tailored to the situation or to the person. For example, the signs could display the appropriate degree of hazard. Variations in some design variables such as the color, the tone and/or the number and duration of exposures, could do this. A typical example is in-vehicles collision warnings and alarms in medical-devices. Furthermore, combinations of sensors with databases could recognize particular individuals or behaviors. For example, the system could differentiate between the presences of a visitor and a worker and decide the extent to which the users might be at risk.

The use of flat-panels displays, as a probable support for these signs, would be beneficial in cluttered or low-visibility environments (e.g., with smoke or dust) due to their increased bright and high contrast. Furthermore, these displays would also provide the means to communicate diverse types of information or instructions as needed (e.g., egress information during a fire), and to give perceptual and cognitive support to users with special needs (e.g., disabled persons).

However, a number of potential barriers exit and must be considered before implementation. Examples are the potential for intrusiveness and annoyance, increased financial cost as well as maintenance issues. Other potential problem is the reliance on automation, sometimes expressed as “complacency” (e.g., Singh et al., 1993) and the tunneling effect (e.g., Yeh and Wickens, 2001), which may generate greater risks than no warning being provided.

The question of how to evaluate warning signs effectiveness is an important one. This is a critical issue because any methodology always brings along limitations that can influence the study’s results. Behavioral compliance is sometimes known as the “gold standard” measure for warning effectiveness (e.g., Kalsher and Williams, 2006), but because of its difficulty, mostly due to the cost of effort, time, safety and ethical considerations, fewer studies have been conducted compared to other methods (e.g., Wogalter et al., 1987; Silver and Braun, 1999).

VR has been proposed as an alternative tool for investigating warning effectiveness, with good potential to overcome the constraints that have limited the conduct of prior compliance research (see Duarte et al., 2010b). This idea is gaining relevance given technology is rapidly improving and where Institutional Review Boards are increasingly limiting research studies that have avoidable risks. Most VR studies related to warnings use an emergency egress paradigm (e.g., Gamberini et al., 2003; Glover and Wogalter, 1997; Mantovani et al., 2001; Ren et al., 2008; Tang et al., 2009). The present study shows that there are other ways to measure compliance.

There are relatively few studies in the warnings literature that have measured actual compliance behavior, and none have done so outside of egress signage with VR-based methodologies. Thus, it becomes important to demonstrate the veracity of VR methodology in warning compliance research. The findings in the present research are in accordance with a live demonstration of dynamic warnings producing greater compliance than static presentation (e.g., Wogalter et al., 1993).

The use of IVE appears a natural direction for warning research toward so as to promote more behavioral compliance research on warnings that might otherwise be difficult or impossible to conduct in real world settings. Future VR research on warnings could examine other situational aspects: in this study, the dynamic warnings were displayed in a relatively uncluttered environment, without time pressure or multiple concurrent tasks and no other persons around. Given that these conditions are not common in many real-world situations, future studies could examine other environmental context (e.g., visual clutter, lighting, smoke), situational factors (e.g., time stress, cognitive workload), social factors (e.g., presence of avatars/embodied agents) and individual factors (e.g., age, previous experience). Additionally, VR can also be seen as a means to train workers on safety-related procedures, including opportunities for learning the meaning of certain warnings, particularly less-frequently presented ones, could serve as practice on the proper safety-behavior to engage in order to be safe. Thus, exposure to dynamic warning signs in the VR environment as a method of training could aid to make better decisions on what to do if these or similar warnings are received in real life emergency situations.

VR research will likely contribute knowledge about warning-related processing and to future development of more effective sign designs. Looking toward the future, and considering the many ways in which technology is changing (e.g., Mayhorn and Wogalter, 2003; Wogalter and Conzola, 2002), it is exciting to consider the possibilities.

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