A Pilot Study Using Virtual Reality to Investigate the Effects of Emergency Egress Signs Competing with Environmental Variables on Route Choices

Elisângela Vilar[1], Emília Duarte[2], Francisco Rebelo[1,3], Paulo Noriega[1,3], and Ernesto Filgueiras Vilar[4]

[1] Centre for Architecture, Urban Planning and Design (CIAUD), Rua Sá Nogueira, Pólo Universitário, Alto da Ajuda, 1349-055 Lisboa
elipessoa@gmail.com, {frebelo,pnoriega]@fmh.ulisboa.pt
[2] Unidcom, IADE – Creative University. Av. D. Carlos I, 4, 1200-649 Lisbon, Portugal
emilia.duarte@iade.pt
[3] Ergonomics Laboratory, Universidade de Lisboa, Alameda da Universidade, 1649-004 Lisboa
{frebelo,pnoriega}@fmh.ulisboa.pt
[4] Beira Interior University – Communication and Arts Department, Rua Marquês d'Ávila e Bolama 6200-001 Covilhã, Portugal
ernestovf@gmail.com

Abstract. Emergencies (e.g., fire egress) into complex buildings are stressful situations which can provoke unexpected, undesired and sometimes unsafety behaviors in the users. Thus, the main objective of this pilot study was to investigate the relative influence of new technology-based exit signs, when compared to the conventional static ISO-type counterparts, in the users' wayfinding behavior during an emergency egress. A critical situation was designed in which the environmental variables and exit signs, at the 12 decision points, were giving conflicting directional information. Thirty participants were randomly assigned to the two groups (i.e., Static signs and dynamic signs), and their route-choices in the 12 decision points displaced along a route into a virtual hotel were collected using a Virtual Reality-based methodology. Findings suggest that for the group exposed to static ISO-type exit signs, the reliance on environmental variables decreased along the egress route, and for the first intersection about 73% of participants preferred to follow by the direction which was the opposite of that posted on the egress sign. However, when technology-based signs were used, the influence of the environmental variables was weak from the first decision point to the end, as suggested by a compliance rate with the exit signs reaching almost 98% along the entire route.

Keywords: Emergency egress, wayfinding, virtual reality, technology-based signs, exit signs.

1 Introduction

Emergencies (e.g., fire egress) into complex buildings are stressful situations which can provoke unexpected, undesired and sometimes unsafety behaviors in the users.

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Examples are the wrong decisions in following the marked emergency routes, increasing the egress time over the limit or even trapping the users inside the building. Such problem can be aggravated when the environmental variables (e.g., light, corridors' width), acting as "attractors", are communicating contradictory information to the users. In such cases, the conflicting cues can increase the users' uncertainty regarding the route decision and lead to an escalation in the number of victims.

Previous studies [e.g., 1, 2] verified that some environmental variables can be considered affordances that, somehow, attract the users toward them in a route-choice decision. In a previous study [i.e., 3] was also found that when such environmental variables are competing with ISO-type conventional static emergency exit signs, the users' wayfinding behavior at the beginning of the egress route was not the intended (i.e., at the first route-decision, most of the participant did not comply with the exit sign, and took the opposite corridor). The results reveal worrying low rates of compliance (about 70%) for the first three decision points, with an increment of the compliance along the route.

Considering this, the main objective of this pilot study was to investigate the relative influence of new technology-based exit signs, when compared to the conventional static ISO-type counterparts, in the users' wayfinding behavior during an emergency egress. A critical situation was designed in which the environmental variables and exit signs, at decision points, were giving conflicting directional information (i.e., in a two ways intersection, one of the available paths was brighter and wider than the other, attracting participants' to it. However, an exit sign was placed pointing to the opposite direction, a darker and narrower corridor).

To conduct the study, a virtual building was designed and a Virtual Reality (VR)-based methodology was used to facilitate the manipulation and control of the variables, as well as to allow the exposition of participants to a stressful emergency situation without submitting them to a real hazard. The use of VR to study behavior during emergency situations has been studied by Gamberini and colleagues [4]. These authors used VR to examine how people respond during a fire in a public library by manipulating variables such fire intensity and the initial distance to the emergency egress. Their results suggest that users seemed to recognize a dangerous situation within the context of a simulation and readily produced adaptive responses, thereby indicating that VR is a suitable venue for emergency simulations.

2 Experiment

2.1 Design of the Experiment

The study used a between-subjects design. The dependent variable was the participant route-choice at pre-defined decision points (i.e., 12 corridor intersections). Two experimental conditions were considered:

- Static – With an emergency directional system composed by conventional static ISO-type emergency exit signs;

- Dynamic – With an emergency directional system composed by new technology-based emergency exit signs.

2.2 Participants

Thirty university students, 15 females and 15 males, aged between 18 and 35 years (M = 21.67, SD = 3.809) participated in the study. They were randomly distributed across three experimental conditions:

- Static: Fifteen participants, 8 females and 7 males, aged between 19 and 35 years (M = 22.20, SD = 4.828);
- Dynamic: Fifteen participants, 7 females and 8 males, aged between 18 and 28 years (M = 21.13, SD = 2.475).

All participants had normal sight or had corrective lenses, as well as normal color vision, screened with Ishihara, 1988 [5]. They also reported no physical or mental conditions that would prevent them from participating in a VR simulation. All participants were asked to sign an informed consent form.

2.3 Experimental Task

Critical situation. The critical situation was created taking into account the existence of contradictory information that was manipulated by inserting posted static emergency signs or technology-based emergency signs pointing to the opposite direction of the corridors that were the most chosen by participants. The most chosen corridors were selected from a previous study carried out by Vilar and colleagues [2] about navigational choice preferences associated with environmental variables (i.e., corridor width and brightness). For the current study, only twelve corridors intersections (Fig. 1) of fifty-seven different situations studied earlier [2] were selected. Corridor selection followed the criteria: i) the most chosen corridors considering the available alternative corridors (i.e., left vs. right, front vs. left, and front vs. right) for each situation (i.e., only corridor width, brightness enhanced in the wider corridor and brightness enhanced in the narrower corridor), ii) the intersection type (i.e., "T-type" and "F-type"), and iii) the narrower corridor when the difference across the percentage of choices was less or equal to 1%.

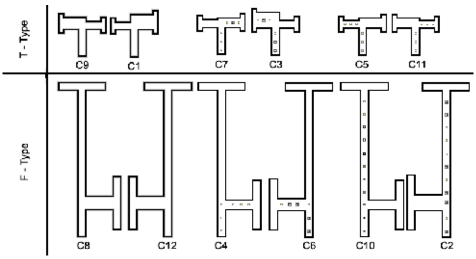

Fig. 1. The twelve "T-type" and "F-type" corridor intersections selected from the study of Vilar and colleagues [6]

The factors of attraction (i.e., corridor width, brightness enhanced in wider corridor, and brightness), attractors direction (i.e., left, right and front) and percentages of choices toward the attractor attained by Vilar and colleagues [2] for the twelve selected corridor intersections can be seen on Table 1.

Table 1. Percentages of choice for the twelve most chosen corridor intersections from Vilar and colleagues [6] used as the basis for the design of the virtual building and signs placement

Corridor intersection	Variable (attractor)	Direction	% of choices towards the attractor
C1	Width	Right	72.05
C2	Brightness	Front	75.83
C3	Brightness and width	Left	87.87
C4	Brightness and width	Right	89.58
C5	Brightness	Left	81.67
C6	Brightness and width	Left	91.25
C7	Brightness and width	Right	89.58
C8	Width	Right	63.75
C9	Width	Left	72.92
C10	Brightness	Front	78.33
C11	Brightness	Right	83.68
C12	Width	Left	57.50

Virtual Environment (VE) - The Hotel. For the design of the hotel building used in the present study, twelve corridor intersections previously selected (Table 1) from Vilar and colleagues [2] were used. These twelve corridor intersections were mixed and then randomly divided into three groups of four corridors each that comprise three sections of the building floor plan. Each section was designed to have the same travel distance, regardless of participants' directional choice at each choice point (Fig. 2).

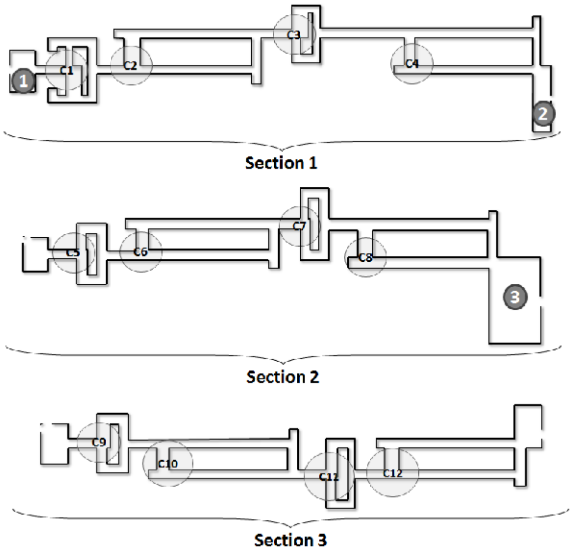

Fig. 2. Top view of the floor plan with the three sections and with the location of the 12 selected corridor intersections. Numbers 1, 2 and 3 show where the wayfinding instructions were delivered to the participants

The virtual hotel was generated based on requirements operationalized during systematic meetings involving experts in Ergonomics, Architecture, Psychology, Design and Computer Engineering. Requirements were mainly related to the context, the building's design aspects, the wayfinding tasks that participants have to perform, the navigational aspects and the strategies to enhance the sense of presence and involvement.

The experimental conditions were created considering two emergency directional system composed by conventional static ISO-type exit signs (Static condition) and by new technology-based exit signs (Dynamic condition).

Static ISO-type exit signs are symbol-based and consistent with the International Organization for Standardization (ISO) standard [7]. ISO standard exit signs are required by law to illustrate an arrow and running figure in a doorway (Fig. 3).

Fig. 3. Static ISO-type emergency exit signs used for the Static condition

Technology-based emergency exit signs used for the Dynamic condition were developed by a design team considering the User-Centered Design methodology. A behavioral intention test was also performed with thirty university students. For this, an animation with the designed technology-based emergency exit sign was presented to the participants and they had to ask two questions: i) what is this sign? ii) What would you do if you see this sign? Most of the participants (67.2%) considered the sign an emergency exit sign. Most of them (76.6%) also reported that if they saw the sign they would follow its direction through an emergency egress.

Screenshots of the static ISO-type and the technology-based exit signs used for Static and Dynamic experimental conditions can be seen on Fig. 4.

To create the critical situations, the signs were always positioned to point to the directions opposite to those that were considered the most probable choice (see Table 1) according to the results of the study conducted by Vilar and colleagues [2].

Fig. 4. Screenshots from the Dynamic and Static conditions

Scenario and Wayfinding Task. To increase participant involvement, a scenario was created. At the beginning of the experimental session a cover story was given to the participants. The cover story created was that the participant had to give a lecture in an important conference at a hotel and conference center, however he/she was late and still had to talk to the receptionist to complete his/her conference registration and to know the location where the presentation would be made. When the participant reached the second floor, where the presentation would occur, he/she was informed that a fire has been detected on the premises. Participants were also told that they should behave as they would in a real-life situation. Fig. 5 shows screenshots of some fire locations within the building.

Fig. 5. Examples of fire with smoke in the second floor of the VE during the emergency

It was considered a controlled navigation approach because the corridors already passed by the participant were closed by doors during everyday wayfinding and by fire and smoke in the emergency situation. Thus, for each choice point, when participants chose one of the two alternative corridors, the corridor of the path that was not chosen was closed by a door (or fire), forcing them to continue along their initial selected path. At the beginning of each section, there was a room which was used to deliver the wayfinding task via virtual characters and to calculate the participants' partial performance.

2.4 Experimental Settings

The VE was projected onto a screen using a stereoscopic projector (i.e., Lightspeed DepthQ 3D) and visualized by the participants through active shutter glasses (i.e., MacNaughton Inc.'s APG6000). The projected image size was 1.72 m (59.7º of horizontal field-of-view - FOV) by 0.95 m (35.2º of vertical FOV) with an aspect ratio of 16:9. The observation distance (i.e., the distance between the observers' eyes and the screen) was 1.50 m.

A Logitech®Attack™ 3 joystick was used as an input device to collect the participants' answers. The movement's speed gradually increased from stop (0 m/s) to a maximum speed (3 m/s). Wireless headphones (i.e., Sony® MDR-RF800RK), allowed the participants to listen to instrumental ambient music, the wayfinding task instructions given orally by the virtual characters, and the sounds of a fire siren and fire.

2.5 Procedure

Before starting the experimental session, all participants were asked to sign a consent form and advised that they could stop participation at any time. The average duration of the entire experimental session was approximately 30 minutes, divided into a training session and a VR-based component. Participants were told that they ought to fulfil the given tasks as accurately and as quickly as possible.

The training session had the following main objectives: i) to familiarize participants with the simulation setup; ii) to allow them to practice the use of navigation and visualization devices, to bring their virtual movements closer to their realistic/natural actions; iii) to homogenize differences in the participant's performance using joystick; and iv) to make a preliminary check for symptoms of simulator sickness (participants were asked to report whether they felt any discomfort). For this, participants were encouraged to explore freely and navigate into a training VE, as quickly and efficiently as they could, without time restrictions. The researcher monitored participants' control of the navigation device by verifying their accuracy in executing some tasks, such as circumnavigating a pillar placed in the middle of a room without bumping into this element and walking through a zigzag corridor without touching the walls. Participants were also instructed to inform the experimenter when they felt relaxed and comfortable with the equipment. Only after verifying some of these equipment-related skills did the researcher permit the participant to start the VR-based component. No dialogue between the participant and the researcher was allowed after the simulation started.

The interaction started in the ground floor of a hotel and convention centre where participants received three wayfinding tasks (i.e., find three different locations in the building) from virtual characters present in the VE. The last task sent the participants to the second floor of the building via an elevator. Once they exited the elevator, an auditory alarm sounded and they were prevented from further elevator use. Thus, participants were faced with finding an emergency egress point by navigating through the second floor to escape from the fire.

If the participants reached a time limit of 20 minutes inside the simulation, the experiment was stopped to prevent eye fatigue, or simulation sickness, or both. Simulator sickness was mainly evaluated through participants' verbalizations. However, the researcher also monitored them during the interaction for symptoms such as redness of face, nausea, dizziness, and sweating [8, 9].

At the end of the VR-based component, a post task questionnaire was used to collect demographic information such as age, gender, occupation and dominant hand.

3 Results

Criteria for presenting results are related to the choices favoring the direction pointed by the signs considering the experimental conditions (i.e., Static and Dynamic). Participants' route performance considers the directional choices recorded for the entire route (12 corridor intersections). Table 2 summarizes the results obtained for all conditions. The corridors are presented according to their disposition on the building's plan. All statistical analyses were conducted using IBM SPSS v.20. The statistical significance level was set at 5%.

Table 2. Results considering the predicted directions from previous study [2], participants' route performance, percentages of choices contrary to and favouring the posted emmergency signs in static and dynamic conditions. Corridors were arranged according to their disposition on the building's plan.

Corridor (intersection type)	Variable (predicted attractor)*	Variable Direction*	% of choices contrary to the environmental variable*	Experimental conditions			
				Static		Dynamic	
				% choice contrary to sign direction (N)	% choice favoring sign direction (N)	% choice contrary to sign direction	% choice favoring sign direction
C1 (T)	Width	Right	72.0	73.3 (11)	26.7 (4)	6.7 (1)	93.3 (14)
C2 (F)	Brightness	Front	75.8	26.7 (4)	73.3 (11)	6.7 (1)	93.3 (14)
C3 (T)	Brightness and width	Left	87.9	26.7 (4)	73.3 (11)	- (0)	100 (15)
C4 (F)	Brightness and width	Right	89.6	- (0)	100 (15)	- (0)	100 (15)
C5 (T)	Brightness	Left	81.7	13.3 (2)	86.7 (13)	- (0)	100 (15)
C6 (F)	Brightness and width	Left	91.2	6.7 (1)	93.3 (14)	6.7 (1)	93.3 (14)
C7 (T)	Brightness and width	Right	89.6	13.3 (2)	86.7 (13)	6.7 (1)	93.3 (14)
C8 (F)	Width	Right	63.7	6.7 (1)	93.3 (14)	- (0)	100 (15)
C9 (T)	Width	Left	72.9	6.7 (1)	93.3 (14)	- (0)	100 (15)
C10 (F)	Brightness	Front	78.3	- (0)	100 (15)	- (0)	100 (15)
C11 (T)	Brightness	Right	83.7	6.7 (1)	93.3 (14)	- (0)	100 (15)
C12 (F)	Width	Left	57.5	6.7 (1)	93.3 (14)	- (0)	100 (15)
Participants Route Performance (%)				**15.6**	**84.4**	**2.2**	**97.8**
SD				20.2	20.2	3.3	3.3

Predicted results were attained from Vilar and colleagues (2013)* study.

A chi-square test of independence was performed to examine the relation between participants' route-choices favoring the direction posted by the sign and the emergency sign type for the 12 corridor intersections. The relation between these variables was significant only for the corridor intersection C1 ($X^2(1) = 13.889$, $p < .01$) and C3 ($X^2(1) = 4.615$, $p < .01$). However, differences were not statistically verified for the others analyzed corridor intersections ($p > .05$). Thus, technology-based emergency exit signs were more likely to be followed by the participants when seen for the first and third times than static ISO-type emergency exit signs.

4 Discussion and Conclusion

Preliminary data attained in this pilot study provide insights about the importance of verifying effectiveness of emergency exit signs considering users' wayfinding behavioral while interacting with a simulated emergency situation. The main objective of this pilot study was to investigate the relative influence of new technology-based exit signs, when compared to the conventional static ISO-type counterparts, in the users' wayfinding behavior during an emergency egress. A critical situation was considered (i.e., environmental variables and direction posted in the signs present conflicting information, for instance, in a two ways intersection, one of the available paths was brighter and wider than the other, attracting participants' to it and an exit sign was placed pointing to the opposite direction, a darker and narrower corridor).

Main results shown that high percentages of participants in an emergency and stressful condition chose not to follow the direction posted in static ISO-type emergency exit signs when the sign was available for the first time (C1). Considering that missing the right direction in the first available exit sign could foreseeably make people walk greater distances and spend more time than necessary to escape from a hazardous situation and could potentially increase the likelihood of injury or death, this result is disturbing. When technology-based emergency exit signs were considered, higher percentages of participants preferred to follow the direction indicated in the sign since its first appearance.

Main limitation of this study was the reduced number of participants. A large sample could represent different results, mainly related with the differences in the percentages of choices for the following corridor intersections. Considering other dependent variables than participants' directional choices, such as partial and total egress times and travelled distance, could also reinforce the need of new alternatives for the emergency exit signs generally used for emergency indoor signage.

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