Exploring Hazard Perception and Compliance: A Pilot Study on the Influence of Safety Signs in a Non-conspicuous Hazard Situation

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Abstract. This pilot study aimed to evaluate the impact of conventional ISO type safety signs on enhancing hazard-risk behaviours and prompting behavioural compliance, in a non-conspicuous hazardous situation (i.e., a Conveyor belt hazard, void of any visual and/or auditory cues). Using a work-related (i.e., a stereotypical, yet realistic factory setting) virtual reality-based experimental set-up, and a sample of twelve workers (20–65 yrs), the study´s objectives were to assess to what extent the printed static safety signs were effective in prompting compliant behaviours in the given situation, as well as to collect the participants' hazard-risk perceptions regarding such a context. The study, therefore, addresses topics under the Virtual-reality domain such as: simulator sickness; level of presence; overall virtual environment design; as well as hazard-risk and safety sign perception. Results reveal that in this non-conspicuous hazardous situation, the participants adequately perceived the hazard and adopted safe behaviours, despite being unaware of the presence of such safety signs in the environment.

Keywords: Virtual environments · Workplace Safety Sign Research · Ageing · Augmented Reality · Behavioral compliance · Hazard Saliency · Hazard-risk perception · Interaction · User Experience

1 Introduction

One approach to enhancing workplace safety includes the development and strategic use of environmental safety signs as a means of communicating safety-related information to workers. Such mediums, usually in the format of static plates, play a vital role in alerting/informing workers to potential hazards in the environment [1]. However, despite their importance, research findings suggest that the conventional ISO type safety signs are not always effective [2], as they often fail to attract attention, provide knowledge and prompt compliant (safe) behaviours [3]. The latter being, according to most cognitive models [4, 5], the most significant variable when determining the success of such signs. Regrettably, given the high number of debilitating injuries and fatalities (approximately 9.7 deaths per 100 000 working persons) reported by work databases [6], such facts

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highlight the critical need for innovation in workplace safety signs, especially with the rise of older working adults.

With the worldwide gradual increase of life longevity, and consequently, the extension of the retirement age to 65 + years [7], the workforce population has been hit by a global "silver wave/tsunami" which has inevitably increased, over the years, the number of working older adults (55–65 years old). According to the European Labour Force survey (EU-28), the number of workers aged 55 + increased from 12.1% to 19.7% between 2003 and 2018, accounting for almost one fifth of the entire workforce (90.5 million persons from a total of 230.4 million) [6]. In the US, similar data can be found with such a population representing 22.4% (35.7 million) of the labour force [8]. Consequently, this demographic shift has raised several concerns regarding workplace safety, because with old age, job performance can be adversely affected by the natural deterioration of the physical and mental capacities which, subsequently, can make older workers more susceptible to accidents.

Over the years, studies on the effectiveness of safety signs claim that with old age, the visual, auditory and cognitive capacities decline, which thereby place older workers at a disadvantage in hazardous situations [9, 10]. Fortunately, research has suggested that Augmented Reality-based safety signs (as an interactive computer generated medium which displays digital imagery/graphics over a view of the actual physical world in real-time) may be more effective in communicating safety-related information to older workers, thanks to their dynamic and conspicuous/multimodal properties [11]. In the transportation domain (where Advanced Driver Assistance Systems and Enhanced Vision Systems are used), the current body of research has emphasized that AR contributes to enhancing safety. Such studies report that such technology not only has the ability to detect (in real-time) the presence of a hazard and punctually alert the person [12, 13], but may also provide users with appropriate cognitive support, thereby enhance their sensory perception [14]. In a previous study [15], where a complex work-related virtual environment (that consisted of two different types of hazardous situations, with distinct levels of saliency) was used to assess the effectiveness of an AR safety system that was specifically designed for such a purpose, researchers concluded that the system was successful in prompting more cautious (safe and compliant) behaviours. However, in this specific study, data was unclear about whether such safety signs enhanced the workers' sensory/hazard perception of their surroundings, especially regarding a particular situation in which the danger/hazard was non-conspicuous/salient (i.e., void of any visual and auditory cues). Researchers appoint to the fact that there was a significant decrease in the participants' hazard-risk awareness levels.

It is within this context that this paper seeks to discuss the preliminary findings of a pilot study that was designed to assess whether, in the same situation, such a phenomenon would also occur regarding traditional workplace ISO-type safety signs. In other words, the present study sought to understand if the type of safety sign (in this case the conventional ISO static printed placards) to which the participants are exposed to influences/impacts their hazard-risk awareness levels in a non-conspicuous hazardous situation. Such a study is part of an ongoing research project that is focused on improving workplace safety for an ageing workforce through the use and design of more effective safety signs. Such a project is driven by the premise (hypothesis) that, due to their saliency/conspicuity, AR safety signs are more effective than the conventional ISO-type counterparts in promoting safety among workers.

In light of this larger research project, the present pilot study used the same Virtual Reality-based (VR) experimental set-up and overall interaction framework to that of a previous study [16], in order to circumvent the methodological, economical and ethical constraints that limit this type of research, namely: the inability to intentionally/ethically expose research subjects to real hazards; the rarity/unpredictability of hazardous events; and the challenge/difficulty behind producing experimental settings which mimic real-life settings (i.e., hazards which have distinct levels of saliency) [17]. Therefore, by using the same workplace context, the study comprised of three key moments: (1) to examine whether the ISO-type warnings were effective in enhancing the participants' behavioural compliance when confronted with the given non-conspicuous hazard (i.e., stationary and soundless); (2) to understand whether the hazard's level of salience would have an effect on the participants' behaviours; and (3) to analyze the participants' hazard-risk perceptions regarding this particular situation. In order to undergo such an evaluation, this study's results will be compared to those of a previous study [16], in which data was collected under the same safety sign conditions regarding a conspicuous hazard (i.e., with visual and auditory cues). Consequently, this paper addresses the following topics under the VR domain: simulator sickness, level of presence, overall virtual environment design, as well as hazard-risk and safety sign perception.

2 Method

2.1 Participants

A sample of 12 adult workers aged between 20 to 65 years old (Mean Age = 42.6, SD = 15.2), with varying professional experiences, volunteered to participate in this study. Of these, six were men (Mean age = 42.0, SD = 13.4) and six were women (Mean age = 43.2, SD = 17.0). Before beginning the experiment, participants were required to sign a consent form and complete a demographic questionnaire; as well as were screened for color deficiencies (using the Ishihara Color Vision Test [18]) and cognitive impairment (by applying the Mini-Mental State Examination [19, 20]). In sum, participants reported to be absent of any have visual/physical/mental conditions that could impact/influence their performance during the experiment. Moreover, they stated to have no prior experience with any VR-based system set-up and/or simulation.

2.2 System Set-Up

An immersive VR system set-up (based on [16]) was used to conduct the study, as well as automatically collect data regarding the participants' interaction. The following devices were used: (1) the Oculus Rift Development Kit2 Head-Mounted Display (HMD), which was used to visualize the VE; (2) the Xbox 360 wireless gamepad, i.e., a control device used to interact with the VE; (3) wireless Sony headphones, model MDR-RF800RK, which transmitted the VE's sounds; and (4) a Dell Alienware M18x laptop - with an Intel Core i7-3610QM processor, 16GB of memory, and a Dual 2GB GDDR5 Nvidia

GTX 675M SLI graphics card - which was used to run the simulation. In order to collect quantitative data, an event log system (based on scripts and triggers that were specifically programmed for this study) was adapted and used to automatically record the participants' interaction in real-time.

The VE's 3D models (scenes and assets) were designed using the Sketchup Pro software, and then exported to the Unity3D game engine (version 4.6.3f1) in order to fine tweak its ambiance (lights, textures and sounds) and define the simulation's mechanics (animations and gameplay). To prevent possible simulator sickness, the following features were considered/applied: (1) the participants' viewpoint was set at eye-height (1.53m above the ground), and their Field-of-View was set using the software's standard default settings; (2) the velocity at which the participants could rotate their viewpoints was reduced to match real-life head movements; and (3) their travel/navigational speed (which gradually increased from 1.26m/s to a maximum of 1.35m/s) was controlled in order to simulate a more natural/life-like walking pace; and (4) the 3D model was optimized to maintain an average image frame rate above 75Hz per second throughout the simulation, in order to avoid any lag effects that could impact the participants´ overall experience.

2.3 Virtual Environment (VE)

3D Model. For this pilot study, the same work-related environment used in the previous study [15] was applied: a section of a factory comprising of two different types of hazardous situations (an Overhead hazard and Conveyor hazard), each one with a distinct level of saliency (conspicuous vs. non-conspicuous). Therefore, the 3D model consisted of two large (30m x 17m) rectangular-shaped modules, linked together via smaller (17m x 15m) open spaces, which represented the factory's entrance/exit points.

Environmental Cues. The same situational characteristics (visual and auditory cues), for each type of hazardous situation, was maintained: (1) in the conspicuous Overhead hazard, in Module 1, the crane/container was accompanied by sound (an alarm) and motion (the crane began to move); (2) whereas in the non-conspicuous Conveyor hazard, in Module 2, the conveyor belt remained stationary and soundless.

Safety Signs. All modules contained a series of conventional/static safety signs and markings throughout the various sections and architectural elements (namely façades, walls, columns and floor). However, for this particular pilot study, behavioural compliance was assessed regarding the ISO-type safety signs in Module 2 (i.e., the Conveyor belt situation), which were purposely placed before the hazard, on the module´s main entrance columns (to the left of the VE - see Fig. 1). Similarly to a previous prototype [16], such safety signs were 60cm x 42cm in size (in accordance with ISO 3864–1 [21]) and mounted between 1.2m and 1.8m above the ground (as defined by ISO 16069 [22]).

2.4 Strategy to Assess Behavioural Compliance

As in the previous studies, in order to perform the experiment's task, participants had to search for and detect the dog (as it ran across the factory's modules), as well as retrieve

Fig. 1. Screenshot of the entrance to Module 2 - Conveyor Belt Hazard.

it. As the participants followed the dog's into the module, they were not only confronted with a set of ISO-type warnings (as referred to above), but also the conveyor belt hazard itself. In this precise moment, participants were forced to decide between two pathways: (1) to follow the dog's path, crossing over the conveyor belt; or (2) to take the safety path, on the opposite side of the module (on the right), as indicated by the safety signs and floor markings. If participants chose not to comply with the safety signs and instead decided to follow the dog's path, the study inferred that such signs were not effective.

2.5 Measures

To prove the study's hypothesis, two usability test-beds were conducted in order to collect both objective and subjective measures. The first test-bed sought to assess to what extent the ISO-type safety signs prompted compliant behaviours in the non conspicuous hazardous situation (Conveyor hazard); this data was collected by observing the participants' actions and path trajectories, namely if they followed the dog across the dangerous route (i.e., over the conveyor belt) or they took the safety path alongside the module, as indicated by the safety signs and markings. The study's hypotheses regarding this particular assessment was two-folded: firstly, the ISO-type safety signs would be ineffective (due to their lack of salience) in promoting the compliant behaviour of circulating on the safety path; secondly, participants would fail to adopt safe behaviours due to the hazard's inconspicuous characteristics.

The second test-bed aimed to collect data regarding the participants' overall user experience, mainly their subjective hazard-risk perceptions regarding their interaction when confronted by the hazard. Due to the hazard's passive state (motionless and soundless), it was hypothesized that the participants' hazard perception levels would decrease, similarly to the results attained in a previous study [15]. In other words, they would fail to recognize and perceive the hazard's severity. In order to collect such data, a number of post-hoc questionnaires (using 4 to 9-point scales, adapted from [15]) were applied to assess issues related to the participants' hazard-risk awareness levels and their perception of the safety signs, as well as matters concerning their interaction and experience with the VE such as simulator sickness, level of presence/engagement and overall design.

2.6 Procedure

For this pilot study, the same methodological procedure was applied, thereby dividing the experiment into five main stages: (1) introduction to the study; (2) pre experimental training session which was divided into two different moments for interaction and perceptual assessments; (3) experimental session; and (4) follow-up questionnaires. The whole procedure lasted approximately 60 min in total. For security reasons, participants sat a desk throughout the duration of the experiment, as well as were accompanied by the researcher's presence in order to observe and monitor the participants' interaction inside the VE.

3 Results

3.1 Behavioural Data

Data from the 1st test-bed reveals that only 33.3% of the participants followed the dog's path across the Conveyor belt (i.e., the hazardous route), meaning that 58.3% of the participants opted to take the safety path. When comparing these results with a previous study's findings [16], in which the same measures were addressed regarding the static/conventional ISO-type safety signs' effectiveness in the Overheard hazardous situation (see Table 1 below), data discloses a 41.6%p.p. increase in compliance between both situations.

Table 1. Descriptive statistics (Percentage values) for behavioural compliance measures.

Participants' trajectories	Module 1: Overhead hazard	Module 2: Conveyor hazard
Followed the safety path	16.7%	58.3%
Followed the dog across the hazard	83.4%	33.3%

3.2 Subjective Data

Simulator sickness Questionnaire (SSQ): data obtained from the SSQs, which were applied twice during throughout the procedure (namely at the end of the pre experimental training session, as well as the experimental session), exposes the incident of slight simulator sickness (25%). The most recurring general body symptoms accounted for were: sweating (42%); nausea (33%); and blurred vision (42%). With these results, one can infer that after a short (approximately 10 min in total) VR exposure, the participants' overall well-being was affected, and thereby may have impacted their experience and interaction inside the VE.

Presence Questionnaire (PQ): In what concerns the participants' level of presence inside the VE, results reveal: that the participants felt highly immersed (Mean = 5.5, SD = 1.2) and the VE to be sensorially engaging and realistic (Mean = 5.6, SD =

1.2); and that they were able to interact with the system set-up with ease and that the control devices didn't interfere with their interaction (Mean = 5.1, SD = 1.4). The only factor that may have impacted their experience was the visual display's resolution, as participants reported to have had some difficulty in clearly seeing the VE's details (Mean = 4.6, SD = 1.8).

VE Design Questionnaire (VDQ): Regarding the VDQ, the attained data reveals that the participants found the experience to have been well-designed and entertaining (Mean 5.7, SD = 1.3), as well as the visual and auditory stimuli were very coherent with the given context and setting, therefore engaging and realistic (Mean = 5.8, SD = 1.2).

Hazard-risk Perception Questionnaire (HPQ): Data obtained for the HPQ indicate that in this particular situation, in which the hazard was inconspicuous (stationary and soundless), participants were very much aware of its presence in the module (Mean = 7.0, S.D = 1.2) and considered it to be very dangerous (Mean = 6.0, SD = 1.8). When comparing such findings with those attained in a previous study [16], regarding the participants' overall impressions on the Overheard hazard (characterized as the conspicuous hazard, due to its visual and auditory cues), data reveals a significant increase across all hazard-risk variables (see Table 2). However, it is to be noted that in this pilot study's non-conspicuous hazardous situation (i.e., Conveyor belt hazard), participants found the severity of the injury only to be fairly high (Mean = 5.3, SD = 2.0), meaning therefore, that there was a 2.2 decrease in value when compared to the conspicuous hazard counterpart.

Table 2. Descriptive statistics (Mean and Standard Deviation values) regarding the Hazard-risk Perception Questionnaire (HPQ).

Module 1: Overhead			Module 2: Conveyor	
Measures	*Mean*	*SD*	*Mean*	*SD*
Hazard awareness	5.0	2.5	7.0	1.2
Hazard-risk level	4.9	2.8	6.2	1.8
Likelihood of injury	4.8	2.0	5.5	2.1
Severity of injury	7.5	1.1	5.3	2.0
Cautious intent	4.5	1.8	6.2	2.1
Familiarity	5.3	2.2	4.2	2.4
Control	4.7	2.6	6.6	2.1
Hazard saliency	5.8	1.8	5.6	1.8
Hazard stimulus influence	5.8	2.1	6.6	1.4

Safety Signs Perception Questionnaire (SPQ): In what concerns the participants' impressions about the study's ISO-type safety signs, similar results to the previous study were also found, namely: that the participants were fairly unaware of such signs (Mean

= 3.4; SD = 3.3); that such signs did not totally capture their attention (Mean = 3.4, SD = 3.1); and consequently, they did not read their warning (Mean = 0.9, SD = 2.2).

4 Conclusion

This paper presents and discusses the preliminary findings of a pilot study that was carried out to assess the effectiveness of ISO-type safety signs in non-conspicuous situations, namely, a Conveyor belt hazard void of any visual and/or auditory cues. It's main goal was to compare such findings with a previous study [16], in order to understand and analyze two variables: (1) the signs' ability to invoke behavioural compliance in the given situation; and (2) the participants' ability to adequately perceive the hazard. Using the same VR-based experimental set-up as the previous studies (a stereotypical, yet realistic factory), two test-beds were applied to obtain both behavioural and subjective data respectfully.

By analyzing the first test-bed, whose main objective was to observe the participants' path choices, results indicate that more than 58% of the participants followed the safety path as indicated by the safety signs and floor markings. Unfortunately, for the study's first hypothesis, such data does not disclose whether or not the signs contributed to such actions, as the SFQ reveals that participants were unaware, to a certain extent, of such signs' existence. However, when comparing such data with the previous study (i.e., Overhead hazard, conspicuous hazard), one can infer that in this particular situation, participants were more able to identify, as well as understand what type of hazard the Conveyor belt consisted of. Subsequently, the study's second hypothesis regarding the effect of the hazard's level of salience, on the participants' behavioural compliance, was refuted.

As for the study's third hypothesis regarding the participants' hazard-risk behaviours, one can infer that, when confronted with the hazard, the Conveyor belt's lack of salience (absence of sound and movement) had a significant influence on the participants' behaviours, thereby disconfirming such a premise. However, although participants adequately perceived the hazard, data from the HPQ reveals that participants only classified the situation as fairly dangerous, which raises questions as to the reasons behind such an increase in behavioural compliance.

Subsequently, since such findings are inconclusive due to the lack significant data across the experimental conditions. In light of the larger research project, which aims to design more effective safety signs for an ageing workforce, further testing with a larger sample, will have to be carried out in order to verify whether the type of safety sign impacts the participants' hazard-risk perceptions, in both conspicuous and non conspicuous hazard situations.

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