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Research on workplace safety sign compliance: Validation of a virtual environment prototype

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Abstract

Recent studies have highlighted Virtual Environments (VEs) as feasible tools for conducting safety sign research. Conversely, guidelines on how to conduct such studies with workplace safety signs and older workers, is scarce. The nature of this study is justified by the fact that, as workers grow older, their ability to comply with such signs is adversely affected by age-related deficits. Therefore, the present pilot study sought to assess the quality of a VE prototype that was specifically designed to conduct safety sign research with middle-aged working adults (50-65 yrs). Using a work-related context, and a sample of twelve workers, the study consisted of two key moments: 1) to examine the workers' interaction, by evaluating their behavioral compliance; and 2) to analyze their overall user experience, by assessing their subjective perceptions. In order to undergo such an evaluation, the following VE interaction issues were addressed: simulator sickness, sense of presence, level of engagement and hazard perception. Both behavioral and subjective data were gathered from three sources: observation, post-hoc questionnaires, and semi-structured interviews. Results reveal that: 1) the VE's workplace safety signs were ineffective in promoting behavioral compliance; and 2) despite the occurrence of some simulator sickness, overall, participants had high levels of presence and engagement, as well as correctly perceived the VE's hazard. In conclusion, the VE prototype proved to be adequate for the study's purpose.

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Keywords: Virtual environments; Safety sign research; Behavioral compliance; Interaction; Aging; Usability; User experience.

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1. Introduction

Safety signs play a vital role in work environments. However, despite their importance, they are not always effective [1], that is, they don't always provide workers with the necessary information so that behavioral compliance decisions are made rationally/wisely. The effectiveness of safety signs depends on three main factors, namely their ability to: attract attention; provide knowledge; and promote compliance [2]. According to most information processing models [e.g., 3,4], behavioral compliance is considered to be the most important measure for assessing the effectiveness of safety signs. Research on this matter has identified a number of issues that influence the success of behavioral compliance (for example: location, typography, size, format/layout color, contrast; as well as target audience issues, i.e., gender, age, cultural background, familiarity) [4].

Regarding the age parameter, several studies [e.g., 5–7] alert to the fact that there are important differences between generations, i.e., older populations have a number of age-related deficits which clearly puts them at a disadvantage in hazardous situations. This is, their ability to notice, encode, comprehend and comply with safety signs are adversely affected by declines in the visual, auditory and cognitive capacities. Consequently, safety for older workers is of great concern, since inadequately designed working environments and ineffective safety signs, conjointly with such deficits, may not only jeopardize their ability to work, but also degrade their quality of life. In light of that fact, there is an urgent need to enhance safety sign research, and the design of new/more effective signs, especially when the workforce population is increasingly ageing [8]. Conversely, research regarding the effectiveness of safety signs for older working populations is limited by several methodological, economical and ethical constraints, for example: 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).

However, due to contemporary technological advances, a few current studies have highlighted the use of Virtual Environments (VEs) as feasible tools for surpassing these limitations, as well as for conducting such types of studies [e.g., 9]. When compared to conventional evaluation methods, the advantages of using such tools for safety sign research are manifold: the ability to create low-cost experimental, interactive and quasi-real environments (in which hazardously simulated situations can be studied in a safely manner) with an enhanced control of the variables, as well as ecological validity over the experimental conditions.

1.1. Current study

Although the use of VEs in various scientific domains are considerable, in the field of Safety Communications and Warning Signs, VE usability knowledge on how to conduct behavioral compliance studies regarding workplace safety signs and their effectiveness for older workers is scarce and very much in its infancy. The current body of VE safety sign research raises some concerns when generalizing/applying their usability principles to real-world problems, since the majority of the performed studies used either younger subjects [e.g., 10,11] or much older age groups [e.g., 14,15], and/or mainly focused on way-finding/exit/emergency egress signs [e.g., 16–18]. In this context, the present paper presents the definition and results of a pilot study which used an experimental VE prototype that was specifically designed for conducting studies on behavioral compliance with middle-aged working adults (50-65 yrs). Such a study was developed within the scope of a larger and ongoing research project which proposes to design more effective and inclusive technology-based safety signs for older workers, by comparing two groups of workers, i.e., younger (20-35 yrs) vs. middle-aged adults (50-65 yrs). Consequently, in light of this larger project, the current pilot study's main objective was to validate the proposed VE prototype's first draft design; hence, it aimed to assess its feasibility (i.e., protocol, content, equipment, data system) for conducting safety sign research. Using a generic work-related context (which consisted of a hazardous situation), the study comprised of two key moments to undergo the referred evaluation: 1) to examine the study's subjects' interaction inside the VE, by evaluating behavioral compliance; and 2) to analyze their overall user experience with the prototype, by assessing their subjective perceptions about their interaction. Consequently, this paper addresses the following VE interaction topics: simulator sickness, sense of presence, level of engagement, and hazard perception. Such topics are considered to be the underlying principles key to VE behavioral compliance studies with safety signs.

2. Method

2.1. Participants

The study used a sample of twelve working adult volunteers (with diverse occupational professions), aged between 20 to 65 years old (Mean Age = 42.6, SD = 15.3). 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 asked to fill in a consent form and demographic questionnaire, as well as were screened for color vision deficiencies, using the Ishihara Color Vision Test [17]. In sum, none of the participants reported mental/physical conditions or hearing/vision limitations (they all had a corrected, and/or 20/20 vision).

2.2. Apparatus and system set-up

An immersive Virtual Reality (VR) system set-up was used to evaluate the proposed VE prototype, and to automatically collect data regarding the participants' interaction. Such a system comprised of the following devices: 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, which was used to run the experiment. The VE prototype's scenery/setting was designed in 3D, using the Sketchup Pro software, and then exported to the Unity3D game engine, where the simulation was defined. In order to collect quantitative data (i.e., time spent and path trajectory), a log system which automatically recorded the participants' interaction in real-time was used. The camera representing the participants' viewpoint was set at eye-height (which was assumed to be 1.53m above the ground [18]) and its Field-of-View (FOV) definition was left with the software's standard default settings. The velocity at which the participants moved/navigated inside the VE was controlled in order to simulate a more natural/life-like walking pace [19] (i.e., 1.26m/s to 1.35m/s). The velocity at which the participants' directed their head movements was reduced in order to match real-life head movements. The simulation's image frame rate, i.e., number of rendered frames per second (FPS), was also regulated (i.e., they were to above 70Hz per second) avoid lag effects and to provide the participants with an optimized VE experience.

2.3. Virtual Environment (VE)

The VE was designed to represent part of a stereotypical, yet realistic factory (see figure 1). Such a scenario was chosen with the intention of depicting a work-related and hazardous situation, where safety signs could be placed and behavioral compliance could be analyzed. Its 3D model consisted of two large (30m x 17m) rectangular-shaped modules (Module 0 and 1), which were linked together via a smaller (17m x 15m) open space. Module 0 was free of any hazards, it contained a number of factory objects, whereas Module 1 depicts an overhead hazard (represented by the crane and container). The space linking the main modules represents the factory's entrance/exit points. The visual and auditory level of clutter was strategically and coherently placed, in an intricate manner, in order to provide the participants with an engaging experience, and to enhance the VE's realism. Inside the VE, a number of safety signs and markings were placed on the module's architectural elements (façades, walls, columns and floor). However, in this particular pilot study, behavioral compliance was only assessed with respect to the safety signs placed in Module 1, which were deliberately and antecedently located before the hazard, namely on the module's columns (to the right of the VE). The safety signs were: static ISO-type signs; 60cm x 42cm in size (in accordance with ISO 3864-1:2011 [20]); and mounted between 1.2m to 1.8m above the ground (as defined by the ISO 16069:2004 [21]).

2.4. Simulation design: strategy and task

The study's simulation was divided into two main phases. In the first moment, participants were provided with the VE's contextual narrative/cover story in which they were asked to imagine the following situation: it is the end

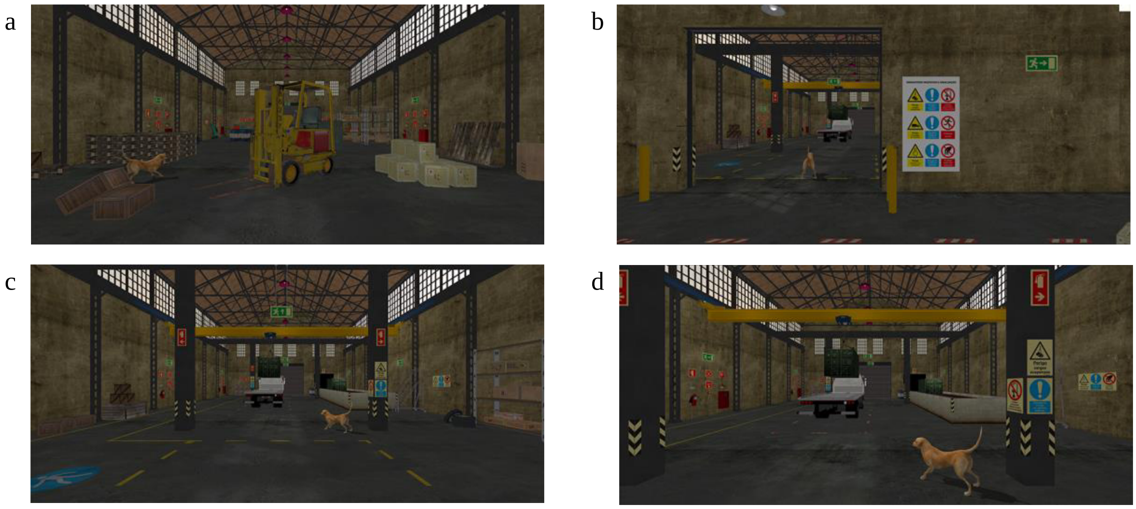

Fig. 1 (a) Inside Module 0; (b) Module 1's entrance; (c) Inside Module 1; (d) Details of Module's columns.

of the afternoon, upon arrival to your home, you take your dog for a walk; when passing by the industrial area, the dog is startled by a cat and enthusiastically runs after it into a factory; the security guard at the factory's entrance gate, who witnessed what happened, lets you enter the factory to find/retrieve your dog, but alerts you to the fact that, although the factory is abandoned at the moment (i.e., the workers are changing shifts), it continues to labor, thereby exposing you to a number of hazardous situations of which you are advised to be cautious. In the second phase of the simulation, and in light of the context above, the participants were then required to perform the experiment's task, i.e., to catch the dog. To engage the participants and enhance excitement, the dog barks every 15 seconds and runs away as soon as the participants almost reached it. However, in order to avoid situations in which the participants could possibly get lost in the VE and/or not see the safety signs, the dog circulated/waited for the participant at strategic points of interest in the VE, for example: it ran around the column precisely where the safety signs were placed, as well as stopped right by it. As participants followed the dog's path, they were confronted with an overhead hazard, as referred to above. When entering the module, the participants were forced to decide (i.e., evaluate the cost of compliance) between two paths: 1) to follow the dog's path, i.e., the hazardous/dangerous path (beneath the crane/under the container); or 2) follow the safety path, on the opposite side of the module (on the left), as indicated by the safety signs and floor markings. In order to enhance the hazard's realism and saliency, as well as to entice excitement, as soon as the participants passed the first set of columns, the overhead crane would start moving (initiated by a sound), and the container began to move to the right.

2.5. Measures

Two usability test beds were conducted, which gathered both behavioral and subjective measures. The first test bed's main objective was to examine the participants' performance/interaction inside the VE (in Module 1), by assessing behavioral compliance (i.e., the extent to which the participants adhered to the VE's safety signs, placed on the module's columns). Such variable was measured by a set of actions and path trajectories that the participants took (for example, whether the participants followed the hazardous/dangerous path or the safety path), via the system set-up's log system, as well as through observation. For technical and methodological reasons, the first author was present and close to the participant, during the entire experiment's procedure. Such a methodological set-up provided the evaluator with the means to observe the participants' interaction and gather real-time reactions.

The second test bed sought to analyze the participants' overall user experience/satisfaction with the prototype, by assessing their subjective perceptions about their interaction with the VE. In order to undergo such an evaluation, the following methods and questionnaires were applied. The *Simulator Sickness Questionnaire (SSQ)*: in order to evaluate to what extent the VE prototype could be satisfactorily used by the participants (i.e., comfortably and free of any pain or sickness) and the occurrence of any Virtual Reality Induced Symptoms and Effects (VRISE), this questionnaire (based on [22,23]) was applied twice: one after a pre-experimental training session, and another at the end of the experimental session. Participants were asked to score 23 symptoms (e.g., general body symptoms; and eye-related symptoms) on a four-point scale. The *Presence Questionnaire (PQ)*: this questionnaire (adapted from [24–26]), which was applied at the end of the simulation, intended to evaluate to what extent the participants felt present inside the VE. Participants were asked to score the quality of their VE experience according to their sense of presence, and a number of factors pertaining to the VE's characteristics/system set-up, namely: sensory factors; level of realism; interaction factors; distraction factors; and display image quality. Each question was ranked using a 7-point scale, where participants indicated the strength of their agreement with the questions' statements. *Interview and Self-reporting Protocol*: at the end of the experimental session, in a semi-structured interview, participants were encouraged to talk about their actions, goals and thoughts regarding the study's design and were asked to verbalize/articulate their opinions/insights on how they viewed/visualized, felt, behaved and interacted with the VE prototype, as well as report any difficulties they encountered. During this interview, the following questionnaires were applied and discussed. The *Hazard Perception Questionnaire (HPQ):* in order to understand to what extent the hazard present in the VE was taken seriously, i.e., if the participants perceived it as real/dangerous, this questionnaire (adapted from [27]) was applied while participants were confronted with a video of their performance. Participants were asked to rank their level of hazard perception according to the following categories: hazard awareness; hazard-risk level; likelihood of injury; severity of injury; cautious intent; familiarity; control; hazard saliency; and hazard realism/stimulus influence. Such questions were scored according to a 9-point scale in which, once again, the participants ranked the strength of their agreement with the questions' statements. The *Safety Signs Questionnaire (SFSQ):* in order to evaluate to what extent the safety signs had an effect on the participants' behavioral interaction, in this questionnaire (adapted from the previous questionnaire), participants were asked to state whether the safety signs had influenced, or not, their behavior, according to the following categories: safety signs' awareness; attention capture; attention maintenance; and visibility. Such questions were ranked using the same 9-point scale above. The *Overall Usability Questionnaire (OUQ):* in order to validate the VE´s overall design characteristics/features, and the simulation's game strategy, this questionnaire (adapted from [28]) was applied at the end of the interview. Taking into consideration everything that had been discussed throughout the experimental session, in this questionnaire participants were asked to score the quality of their VE experience according to the following categories: contextual narrative coherency; task entertainment; task difficulty; visual and auditory stimulus coherency; simulation duration; clutter level; and clutter level interference. Each question was ranked using the same 7-point scale, as previously described.

2.6. Procedure

The study's experiment was divided into four main stages: 1) introduction to the study; 2) pre-experimental training session; 3) experimental session; and 4) follow-up questionnaires and semi-structured interview. The whole procedure lasted approximately 60min in total.

1) After signing a consent form, the participants filled out the demographic questionnaire and were screened for color vision deficiencies. They were then introduced to the study's purpose and equipment/devices. In order not to influence their behavior/performance, they were unaware of the study's main objective. Participants sat at a desk for comfort/security reasons. 2) In the pre-experimental training phase, participants interacted with a different VE, specifically designed for training purposes, so that they could familiarize themselves with the devices and learn how to interact within the VE. Participants were asked to explore this VE freely, with no time restrictions. Once the participants verbally declared that they felt at ease to continue, the training session ended, and they then filled out the first *SSQ*, to check for any preliminary indications of VRISE. Overall, this pre-experimental training phase lasted approximately 5min. 3) After a 5min break, the experimental session began. As previously described, their

task was to catch the dog. This simulation also had no time restrictions. Such performances were video/audio recorded for later analysis. 4) Following the completion of the simulation, participants filled out the second/last *SSQ* (to assess if there was an increase in VRISE over a time period of approximately 10min in total), and then the *PQ*. After another 5min break, the semi-structured interview took place. In this interview, the participants were confronted with a video of their interaction within the VE. When analyzing the video, they were asked to explain their actions (i.e., the reason behind the actions/paths they took), and simultaneously fill in the rest of the questionnaires (as referred to above), in the following order: *HPQ*; *SFSQ*; and finally the *OUQ*.

3. Results and discussion

The data obtained for behavioral compliance measures reveal that 83.4% of the participants followed the dog's path (i.e., the hazardous/dangerous path, beneath the overhead hazard), whereas merely 16.7% followed the safety path (only after the container started to move). In addition, it was interesting to see that among these, 66.7% of the participants stopped/waited for the container to pass first, before moving forward. Such results reveal that the hazard's level of saliency (i.e., the fact that it started to move) had an effect on the participants' actions. However, such effect did not influence/alter their decision about their path trajectory. With such data, one can infer that the VE's situational/environmental characteristics (i.e., the hazard's and safety signs' saliency) were ineffective in promoting behavioral compliance.

As for the *SSQ's*, the data gathered exposes the occurrence of a number of VRISE. The most recurring general body symptoms were: overall discomfort (25%); increased salivation (25%); sweating (42%); nausea (33%); vertigo (33%); and stomach awareness (33%). The most recurrent eye-related symptoms included: tired eyes (25%); difficulty in focusing (33%); blurred vision (42%); dry eyes (25%); and overall visual discomfort (33%). When taking into consideration the total amount of time the participants were exposed to a VE (i.e., in the pre-experimental training session and the final experimental session), one can infer that after a short (approximately 10min in total) exposure, the pre-retirement workers' overall well-being was affected, and as a result, may have impacted their interaction inside the VE.

In what concerns the *PQ*, the data gathered reveals that: 1) the participants felt highly present (Mean = 5.5, SD = 1.2), as well as engaged inside the VE, to the point that they lost track of time; 2) the VE's sensory factors were very compelling (Mean = 5.6, SD = 1.0), i.e., one can infer that the participants felt that their visual and auditory senses, as well as their notion that objects inside the VE were in motion, was very engaging; 3) the VE's overall realism was also high (Mean = 5.7, SD = 1.3), i.e., that it consistently and coherently matched/portrayed a real-life situation; 4) the VE's interaction factors were fairly good (Mean = 5.2, SD = 1.1), i.e., one can infer that the participants believed to have had a satisfactory experience with the VE, and that they were able to control their movement (body and head) with ease; 5) overall, the participants were not distracted by the system set-up's devices (Mean = 5.0, SD = 1.6) and could easily concentrate on the task, however, they were more aware of the control device; and 6) the participants felt that the visual display's image quality (i.e., resolution) was average/moderate (Mean = 4.6, SD = 1.8), and that it interfered, to a certain extent, with their capacity to view/see details inside the VE.

In the *HPQ* this questionnaire, the attained data indicate that, overall the participants: 1) were more than aware that there was a hazard present in the module (Mean = 5.0, SD = 2.5), i.e., they immediately identified the overhead crane/container as the hazard; 2) considered it to be more than dangerous (Mean = 4.9, SD = 2.8); 3) were more than likely to be injured by it if it fell on top of them (Mean = 4.8, SD = 2.0); 4) considered the injury to be extremely severe (Mean = 7.5, SD = 1.1); 5) in their opinion, were cautious when passing through the module (Mean value = 4.5, SD = 1.8), because they waited for the container to pass over; 6) they were more than familiar with the situation (Mean = 5.3, SD = 2.2), i.e., they had seen similar situations to this one before; 7) they were in control of the situation (Mean = 4.7, SD = 2.6), i.e., in their opinion, they took precautionary actions; 8) thought that the hazard was very salient (Mean = 5.8, SD = 1.8); and 9) stated that the hazard's characteristics (its visual and auditory cues/stimulus) had highly influenced their behavior (Mean = 5.8, SD = 2.1), i.e., the fact that it started to move made them realize that they had to be careful when passing through the module and finding/retrieving the dog.

As for the *SFSQ*, the results gathered in indicate that, overall: 1) the participants were, to a certain extent, unaware of the safety signs (Mean = 3.4, SD = 3.2), i.e., the participants stated that they realized that there were visual placards placed on the VE's architectural elements, but not safety signs; 2) the safety signs did not capture the participants' attention (Mean = 3.1, SD = 3.3); and therefore, 3) they did not view and/or read its contents/information (Mean = 0.9, SD = 2.2). However, when looking back at their interaction in the video, the participants realized that the safety signs were actually quite visible (Mean = 4.7, SD = 2.4); however, they were more focused on completing the task of catching the dog. In addition, a few participants declared that they were more worried about losing the dog, and for that reason were more concerned with its safety than that of their own.

In what concerns the *OUQ*, the attained data reveals that the participants rated the VE's overall experience as 'very good' (Mean = 5.7, SD = 1.2). In other words, one can conclude that they: 1) found the VE's context and narrative to be very coherent with each other (Mean = 6.0, SD = 1.2); 2) felt that the task was fairly entertaining (Mean = 5.2, SD = 1.7); 3) thought the task was very easy to execute (Mean = 6.0, SD = 1.0); 4) found the visual and auditory cues/stimulus very coherent and engaging, especially the sound effects (Mean = 5.8, SD = 1.3); 5) felt that the task was fairly short (Mean = 5.4, SD = 1.3), i.e., they wanted it to continue because they found it engaging and amusing; 6) didn't find the VE to be visually/auditorily cluttered (Mean = 5.7, SD = 1.2); and 7) found that such level did not interfere with their performance (Mean = 5.8, SD = 1.1). However, one recurring commentary that was made during the interview was related to the velocity at which the participants could move/navigate inside the VE, i.e., all participants felt that the walking pace (set for the control device) was a little bit slow, and that given the situation and task (find/retrieve the dog in safety), they felt the need to run or walk a little bit faster.

4. Conclusions

This paper's main contribution was to present the structure and findings of a pilot study which aimed to validate a VE prototype that was specifically designed for conducting studies on behavioral compliance with middle-aged working adults (50-65 yrs). Using a generic work-related context (which consisted of a hazardous situation), the study gathered both behavioral and subjective measures in order to assess the VE's quality for safety sign research. By analyzing the study's results regarding the first test bed, which pursued to evaluate the participants' behavioral compliance, one can conclude that the VE's safety signs were ineffective in promoting behavioral compliance. However, the hazard's level of saliency (i.e., its visual and auditory cues/stimulus) had influenced, to a certain extent, their behavior. Regardless, it did not impact their decision about their path trajectory. In addition, when comparing this data with the second test bed's (which sought to gather subjective perceptions about the VE experience) findings, one can conclude that, in general, participants had high levels of presence and engagement, as well as correctly perceived the hazard present in the VE (i.e., they understood the magnitude of its danger). In other words, the participants interacted with the VE in a realistic and natural manner; thereby validating the set of actions and path trajectories they took. The reasons behind their non-compliance are unclear. Such a result may be justified by the fact that the safety signs were not salient enough to attract the participants' attention, and therefore, they were unaware of the VE's safety signs, and/or were more preoccupied/focused with the task at hand. When analyzing the data obtained regarding the VE's overall usability, one can infer that such behaviors were not a result of the prototype's design (i.e., visual and auditory characteristics/features and game strategy). On the contrary, participants found the VE to be consistently, coherently and realistically designed. However, since a number of VRISE were accounted for, some adjustments to this first draft will need to be made, as well as more studies will need to be carried out in order to assess the extent to which the VE prototype's features (i.e., the system set-up and/or methodological procedure) affected the participants' overall well-being, and as a result impacted their behavioral compliance. In conclusion, such a study demonstrated that the VE prototype is adequate for behavioral compliance studies with older working populations, as well as highlighted the urgent need to enhance safety sign research, and the design of new/more effective signs for an increasingly ageing workforce population.

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