# Virtual Reality in the Study of Warnings Effectiveness

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**Abstract.** Warnings are a very important method to control hazards and to promote safety. Despite its importance, warnings have important gaps that limit their validity and make its design so difficult. In this sense, warnings effectiveness evaluation is crucial to guarantee effective people safety. However, warnings traditional evaluation methodologies have several limitations. To this extent, the main purpose of this work is to determine Virtual Reality (VR) ecological validity as a warnings evaluation technique. We describe a methodology that uses VR as a technique to evaluate safety signs. The main advantages of VR use, associated with the interaction level, are discussed.

**Keywords:** Warnings, Behaviour, Effectiveness, Virtual Reality, Interaction.

## 1 Introduction

Warnings research basic goal is to develop an effective method for designing good warnings and to assess their effectiveness. This is an important matter because information transmitted by warnings is critical to avoid accidents, injuries and material losses. Especially when we know that, despite its importance, warnings have serious limitations. However, despite knowing that warnings could fail their purpose of promoting safe behaviours, they are used in a great number of situations. Among the most popular types of warnings are signs, labels, instructions and many others. Generally warnings are static and visual, and most of them contenting text, pictograms and colour-form code components. Visual warnings are very popular but they require user to direct its attention towards them, otherwise they will be undetected. This does not happen with auditory warnings, because they are omnidirectional. Research has shown greater levels of compliance for multimodal warnings [1-3]. Besides the warning displaying method [4], warnings effectiveness is affected by several other variables such as warning design characteristics [5] and warnings content [6].

Warnings effectiveness can be assessed through the evaluation of several factors, such as the ability to switch and maintain the attention, the understanding easiness, the memorized/evoked intensity, its adjustment to users beliefs and attitudes, the

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motivation strengths and, the ability to change the receivers behaviour. These factors are organized in stages, as described in "Communication-Human Information Processing" (C-HIP) model [7]. According to this model, the information processing sequence begins with the source and goes trough several stages, specifically related to receiver, as attention, comprehension / memory, attitudes / believes, motivation and behaviour. The literature reveals that, each stage is influenced by different variables and works as a bottleneck to warnings success. Despite the processing appearing like a lineal sequence, actually, feedbacks exist between stages and it does not exist a fixed sequence processing. We can summarize this process in 3 major moments that can also be used as warnings criteria of quality: 1) noticing the warning; 2) comprehending the information and 3) complying with the warning.

We can use several methodologies to evaluate warnings but, the main problem is the ecological validity that such methodologies possess. The literature reveals that the success scores are affected by methodological variables such as the used test technique and the exhibition context method. This influence was also verified in the comprehension test, previously accomplish by us, with the intent of evaluate ISO type signs [8]. It was possible to confirm the pictures great influence, when used to supply context information. We concluded that people try to acquire cues, from the images, that may help them to understand the signs [9].

Comprehension test is frequently used because message understanding is a very important indicator of its quality and also because this is also a much simpler procedure than the one that is necessary to evaluate the user's real behaviour. However, with the comprehension test is only possible to check the declared behavioural intentions, but not the real behaviour. These findings motivated us to look for a methodology that could avoid this problem but, at same time, with good ecological validity. Consequently, with this study we intend to propose the VR use as context displaying technique. We start from the assumption that VR, as technique for warnings evaluation, possesses high ecological validity and that it is a valid alternative to other traditional techniques. With VR the exhibited context can be dynamic, realist, rich in details and it can allow great interactivity with users, resembling the real world. An advantage of this technique is the possibility to evaluate the warnings effectiveness in a complete way. We could, for instance, know if the signal was detected, if it was understood and if the adopted behaviour was the correct one.

## 2 Assessing Warning Effectiveness Methodologies

*Behaviour evaluation:* Behavioural consonance is considered the gold standard measure of warnings effectiveness. In practice, what really interest is if the instructions, contained in the warning message, are followed. However, from the research point of view, the behaviour analysis is the most difficult evaluation of all. This is due to several reasons: a) we cannot expose people to dangerous or potential traumatic situations, because of ethical and safety reasons; b) during the extent of the observation period, the probability of occurring dangerous situations is very low; c) for a simulated situation be credible, it should look realistically dangerous but, at the same time, be safe for the participants; d) this kind of research is time consuming, expensive and difficult to carry out. The behaviour evaluation has been investigated, most of the time, in laboratory because it is difficult to observe real users dealing with warnings in a real context. To be more effective, this evaluation should be incidental exposure type, in which participants ignore experiment true purpose. Due to the above mentioned difficulties, when a field study is carried out, it is almost always performed using questionnaires to collect data about risk level perception, message understanding, warnings evocation and behavioural declared intentions assessment.

*Comprehension evaluation:* The comprehension is, next to the behaviour evaluation, the best indicator used to check signs success, being also relatively easy to implement. The most recommended method for evaluation comprehension is the structured interview with open-end and oral answers accompanied with the context, exhibited through pictures. Although this method is not the most frequent, it is what presents larger ecological validity. The most frequent method is the multiple choices questionnaire, which is faster to apply and easier to deal with data. In ANSI Z 535.1.5 [10], both tests are accepted, regardless of preference given to open-end oral tests. The multiple choice procedures should be avoided also because the inappropriate inflation of comprehension scores that result of the comprehension influence imposed by the distractive answers [11]. A multiple choice procedure does not reflects usual signs processing. In the real world there are no similar situations, where individuals have to choose an answer from a group of juxtaposed alternatives. Wogalter, Brantley, Laughery, & Lovvoll [12] suggest that the open-end answer method is the most suitable for comprehension tests accomplished, accordingly to ISO 9186 [13]. The open-end answer procedure can be filled writing or verbalizing the answers. However, the obtained results in both procedures are not the same. According to Brantley & Wogalter [14] the written answers can supply such brief answers, that they can fail in the transmission of the participants true knowledge. The incomplete answers can contribute to lower comprehension scores. Further more, the oral answers will allow the interaction of the investigator with the respondents, through the accomplishment of follow-up questions. This could help to gather more information from participants increasing the success without biasing the answers [14].

*Context supply:* About context supply Wolff and Wogalter [15] state that, in the real world the signs exist inserted in a context that necessarily affects its understanding. Without the existence of contextual cues the obtained results can be false. Therefore, independently of the adopted method, to guarantee the ecological validity of the evaluation, the warnings should always be inserted in a context. This context should be the real, with all the associated problems that were mentioned before, or it can be simulated at laboratory. The simulated context, that it is the most viable option, can be supplied through several processes: realistic physical sceneries built in a studio; virtual reality; video; picture and text. All these context supplying types have important differences among them: at the realism level; at the amount of information transmitted; at the immersion level and at the level of allowed interaction. The use of pictures is a good method to supply context indications. However, accordingly to the literature we need to take some precautions with the pictures we present because, it can affect interpretations, once images can emphasize certain objects or behaviours. Thus, an elucidating picture of the context should show the environment, instead of people. If, eventually, the picture illustrates people, then it should not show those people involved in a forbidden or undesirable behaviour, because that could distort the answer.

## 3 Some Considerations About VR in Warnings Research

Nowadays, thanks to technological evolution, VR is used in different areas such as medicine, aviation, military training, education and ergonomics. In warnings issues VR is becoming an alternative research technique. Glover and Wogalter [16] have developed a virtual coal mine to evaluate warnings effectiveness. They compared the workers exit behaviour during an emergency situation, with the behaviour during a normal lunch exit. The obtained results, although limited, have revealed that this is a promising technique.

Some of the advantages associated to the use of VR are high level of variables control; the rigor of behaviour observation during tasks implementation; the richness of the contexts; the easiness of variables manipulation; the possibility to evaluate behaviour during dangerous simulated situations. VR difficulty of construction and implementation is related with the fact that it is an interactive system. Interactivity implies hardware and software combination in order to trade inputs/outputs between them so that human operator can carry out certain task. This interaction can happen with several immersion levels, precision and efficiency.

Considering that a VR application should contain a wide variety of objects, behaviours, interactions and communications, with different complexity degrees, its project is complex and requests robust methodologies. We think that the methodology to conceive VR application should be based in a user centred design process, as proposed in ISO:13407 [17]. This approach will complement the chosen methodology. To ensure that VR usability is guaranteed, the conception procedure should also be multidisciplinary, incorporating human factors and ergonomics knowledge and techniques.

## 4 Related Work

Just as mentioned, the present study was motivated by the methodological difficulties felt during the accomplishment of a previous comprehension test. Such test was accomplished to evaluate the effectiveness of 17 safety signs, ISO type, in use in Portugal. To carry out that evaluation we have performed a comprehension test with potentials users. The purpose was to obtain comprehension scores, for the selected signs, using the methodologies recommended in the literature. The whole procedure is concisely described below.

- *Procedure*

*Signs selection:* given the great diversity of available safety signs, it was necessary to find a process to reduce the variety. The selection was accomplished in two stages. The first stage consisted of a Heuristics Based Preliminary Evaluation, performed with a sample of 6 individuals, both genders, whose ages ranged from 24 to 57 years old. These individuals did not participate in other subsequent tests. The accomplishment of preliminary tests helps to save time and money by rejecting inadequate signs, in an early stage of the design process, and promoting more detailed tests only with signs that are potentially effective. Researches refer that 80% of problems can be identified with only 5 respondents [18]. The purpose of this preliminary test was to choose those signs that were considered the most difficult to comprehend by the users population. This procedure allowed the selection of 30 signs from dozens available in specialty catalogs. Some signs, considered easy to understand, were also chose in order to have a comparison term in the obtained data. In a second step, the 30 selected signs were tested a second turn with a procedure designated as Judged Comprehensibility. This procedure, proposed by ISO 9186 (2001) [13] standard allows to identify the signs variants that reach higher understanding values and that are worth more study. The purpose of this procedure is to esteem the understanding value, in a fast and cheap way, before the use of other costlier methods. The judged comprehensibility could also be useful to compare comprehension levels of same referent variations [19]. According to Zwaga [20], the results from this estimation test could help to preview the final comprehension test scores, with a 20% of margin error. To carry out this test a table was built, in Excel® software, where the selected signs from the preliminary test were inserted together with referent description, intended meaning and context of use. At the bottom, it was included a small demographic questionnaire: age, gender, education level, studies subject and occupation. The file containing the test was sent by e-mail with brief explanations about test purpose and filling instructions. The sample consisted of 90 individuals, with ages ranging between 18 and 62 years-old, with an average age of 28 year-old and 10,32 standard deviation, males and females. These individuals did not participate in any other test. The participants filled out the table and they returned the file also by e-mail. The selection of the 17 final signs, which will follow to next phase, was supported by the achieved mean values.

*Comprehension evaluation:* the comprehension was evaluated using a method designated by Comprehension Test. This method consists of a structured interview, accomplished individually. The answers are open-end and supplied vocally. The whole procedure is videotaped. The studied signs were printed in an A4 sheet of paper, on their real colour together with a picture (context). The approach to the participants began with a generic explanation of the present study purposes complemented with instructions, together with an example about the requested task. The individuals answered the following questions: What does mean this sign? Which is the certainty degree on the attributed meaning? Did you already know the sign? Where do you usually find it? What should be done when sighting this sign? Along the whole procedure, some follow-up questions were putted: What else can you say about this sign? What do you identify from the drawing of the pictogram? There was no time restriction. The sample consisted of 90 participants, both gender, 30 working adults with active life, 30 young graduation students and 30 people with cerebral palsy.

*Obtained results:* The comprehension of the sign meaning was divided in two aspects: the comprehension of the pictogram meaning and the comprehension of sign colour-shape code meaning. The answers were classified in 5 categories accordingly to the recommendations of ISO 9186: (1) Correct or almost correct answer; (2) Much probable correct answer; (3) Probable correct answer; (4) The given answer is wrong or is “I don’t know”; (5) The given answer is opposite to the intended one (critical). To reduce the level of subjectivity the answers were evaluated by a jury of 3 elements. To obtain the signs final score, designated by rate of successes (of comprehension and of behavioural adequacy), it was attributed a value to each one of the answer categories. Like this, the frequency values, relative to each answer categories, was multiplied by the following values and after transformed in to percentage: a) answers belonging to category one: x 1; b) answers belonging to category two: x 0,75; c) answers belonging to category 3: x 0,5; d) answers belonging to category four: = 0; e) answers belonging to category five: x -1. The value obtained by the addition of all values is the final score of the sign.

The accomplishment of statistical inference (test of Mann-Whitney and Kruskal-Wallis) allowed the determination of the existence of eventual statistically relevant relationships among the independent variables (e.g. gender, age, education, specialization area, occupation, usual mean of transportation; ATM’S use; Internet use; sample; etc.) and the dependent variables (meaning comprehension; behavioural intentions adequacy).

This test allowed checking hypotheses as: a) are the studied signs understood, in a satisfactory way, by the users? Do users know the correct behaviour they should adopt in face of the signs? Where the signs already known by the users? Are signs comprehension success and behavioural adequacy related to the independent, intrinsic and extrinsic signs variables?

## 5 Methodology with VR

The present study will be laboratorial and incidental exposure type. The main purpose is to observe the participants' real behaviour during the interaction with signs. The context method of exhibition will be VR. The participants will interact with VR using a head-mounted display, with sound stereo and a joystick. During that interaction participants will be confronted with different sceneries, containing signs, where they must accomplish predefined tasks. The signs will transmit the necessary information for adopting the adequate behaviour. The behaviour quality, speed reaching goals and accuracy of the decisions will be important indicators to register. The adopted methodology is divided in 4 major phases: (1) Definition; (2) Modelling; (3) Data collect; (4) Results and conclusions.

*Definition:* To begin with VR application design process it is necessary a previous definition of the work context (physical and organizational environment; products and machineries; displayed environmental signs; types existing dangers) that will be simulated. To achieve it, a brainstorming meeting will be accomplished among the research team members. Following, will be defined the activity/task to carry out (type task(s); danger level; mental work load; duration; sequences; etc), based on heuristics and field analyses. The signs type to include will also be chosen. One of the most important stages, in this phase, is the definition of the variables to study (independent and dependent), as well as, the values types to be monitored, the measurement and registration processes. This moment ends with the VR system verbal/graphic (tree diagram) description and its decomposition in sub-components to design those which are conceptually distinct and easier to achieve. Each one of these components is a VR interface component.

*Modelling:* The modelling process will be iterative, top-down type and turning around a cycle composed by high-level and low-level design phases. High-level design means a moment where the VR application design and architecture are specified with high level of abstraction. To obtain that interface generic description we just need to have its functional description. Low-level design phase means a phase with high detailed and concrete definition of the interface. The high-level design phase will consist in a storyboard followed by a paper prototyping. The storyboard, where the activity to be simulated will be illustrated, is based upon the data collected in the previous phase. This document will be created using the drawing cartoons techniques and will be useful as a visual and written guidebook for modelling procedures. As soon as the storyboard is finished and considered appropriate, we could begin to elaborate the paper prototype with the sceneries development. The paper prototype will consist of boards, A3 format, that will illustrate two-dimensional sceneries views (floor plans and cross section drawings), with rigorous proportions. The purpose of this prototype will be the rigorous definition of all the variables to model indicating, for instance, entrance places, routes, equipments, signs location, among other modelling relevant aspects. With paper prototype we can accomplished a prior test with specialists, to analyse the proposal adequacy to the defined purposes. This analysis will involve 5 specialists. After dealing with all data, it will be possible to initiate the VR digital modeling at a low-level design phase. Consequently, low-level design begins with the elaboration of a digital prototype that should respect all previous obtained conclusions and it finishes with the VR application final design. The digital prototype will be elaborated using a software considered appropriate, like 3DStudio Max®, or similar, that will allow the visualization of the VR sceneries that already should resemble, as most as possible, in detail and quality, to the final proposal. This digital prototype will be subject the prior tests also with 5 potentials users. This design process is characterized by a great iteractivity, being accomplished in design-evaluation cycles until reaching a refined solution. This will allow to evaluate VR usability and to correct all detected deficiencies. After having concluded the process of prior tests, having all emends and modelling optimized, the elaboration of the VR final version will begin using *Unreal* platform and chosen hardware. This moment will finish with the final design of VR application, which should be ready to collect data. It will be still accomplished the synchronization between the simulation and the chosen peripherals (glasses, headphones, joystick). The great advantage of this methodology is to allow an easy understanding and the systematic analysis of what is inherent to the interface design, in other words, the several human-computer interaction types, the objects, the behaviours and the communications, needed to interact.

*Data collection:* A sample of 50 signs potentials users will be recruited to participate in this phase. The interaction with VR begins with the accomplishment of a trial test, to determine the participant ability to interact with VR (to detect the presence of simulators sickness, phobias, etc). This moment serves also to familiarize the participant with the simulator commands, navigation procedures and to understand the kind of task she/he is ask to carry out. Following, the participant will fill out a small demographic inquiry and sign a declaration as she/he has consciousness about the test type in which she/he will be involved and their purposes, as well as giving consent to use data and collected images during the test. After this, the participant is randomly distributed for 2 test conditions: 1) sceneries containing static signs; 2) sceneries containing dynamic signs. Next, the participant receives the equipment that she/he should put with investigator's help. Specific instructions about the following tasks purposes and progress process are given. The interaction begins. The participant will have to fulfil a task, established at the beginning of the interaction, in which, the reading of the signs is fundamental. Completing the task presupposes reaching stipulated parallel goals as, for instance, to perform a calculation task, to press a certain command, to read a written message, to hear auditory instructions, to memorize environmental characteristics, etc. During the displaying sequence of sceneries the mental workload and the risk level will increase, until it reaches an emergency (a fire) situation. To reach interaction success, or in other words, to reach the established goals, the information transmitted by the signs is fundamental. The whole procedure will be digitally videotaped. During the interaction it will be collected data related to: a) ocular movements (visual sceneries exploration; signs detection); b) stimulus response time; c) adopted behaviour. At the end, after exposure, other subjective and objective data will be gathered through questionnaires, similar to those described in related works item of this paper. Other aspects related to communication human-information processing will be assessed in this questionnaire: 1) *Attention:* did the participants see the signs? Are the signs sufficiently conspicuous? Are the signs readable? 2) *Comprehension:* What message does the sign transmit? Do the signs transmit useful messages to avoid danger? Do the signs transmit information about the potentials consequences associated to a non consonant behaviour? Do the participants have knowledge about the potential danger associated to the sign, and about the severity of the potentials consequences related to an inadequate behaviour? 3) *Knowledge:* Which was your previous experience with the situation, the activities and/or tasks? Which was the subjective notion of danger level associated to the signs? Which was the participant's familiarity with the situation and the signs? 4) *Motivation:* Which is the cost-benefit rate associated to the signs? Was there any social influence? Which was the work load influence? The questionnaire will also evaluate the participant's opinion about sceneries, about the tasks, about the signs and about immersion level. The adopted behaviour will be analyzed through the analysis of the monitored performance. It will be accomplished a subsequent statistical analysis to find out the existence of eventual statically significant relationships among independent and dependent variables.

## 6 Conclusions

During the accomplishment of previous safety signs comprehension test, using pictures as a technique to display context, was possible to observe that pictures have huge influence on participant's answers. The weight of the context increases in function of the sign pictograms abstraction degree. This behaviour was expectable as we know that human perception is characterized by a simultaneously direct and indirect processing. The quality and the perception speed will be larger and better, when the available information is also larger. Therefore, the choice of the context displaying method can not be made by chance. In our opinion, a way to run away from the potential bias, provoked by the context displayed by pictures, will be the use of dynamic contexts with larger ecological validity. The video is a possibility but, that technique implicates the access to a real context to gather the images. This would create an extreme difficulty to the research because, except if there was sceneries constructed in a studio, which would be very costly, it would be very difficult to have the absolute control of those variables. In this sense, VR is figured as an alternative, with ecological validity. This technique allows, not only, a realistic and dynamic context but, also, the possibility to manipulate and to control countless variables in a simpler way than in other procedures. The VR related difficulties do not overcome the associated advantages once, not all analyses will request high realism, detail, immersion and interactivity levels. The behaviour can be directly observed in VR, in different mental load and risk level situations. VR allows observing the signs displayed in very unfavourable situations to the user. The signs design should be focused for extreme situations, which are those when the users belong to lower abilities and capabilities group, where the environmental and physics variables are the most extreme and unfavourable to the accomplishment of the task, where the work load is high and where the risk is very high. If a sign reaches acceptable effectiveness levels in these conditions, then it will have a very high probability of success in most situations.

Unfortunately, the actual reality tells us that many signs are badly designed and are being used without any validation process. This reality can reflect the absence of design and validation methodologies easy to implement, or, methodologies with significant functional limitations that capture biased data. Therefore, the Virtual Reality comes as a technique with potential to allow the interaction investigation as an open system and in constant movement, but, without losing the demanded realism. Through the simulation with virtual environments, it can be easier to understand which fault has leaded to sign failure and in which process step it occurred.

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