Verification of workplace design guidelines for the control room: Can virtual reality replace the physical mock-up?

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Early identification of potential human factors guideline-violations and corrective input into the design process is desired for efficient and cost-effective control room design. Virtual Reality (VR) technology makes it possible to perform evaluation of the design of the control room at an early stage of the design process, but can we trust the results from such evaluations? This paper describes an experimental validation of a VR model against the real world in five different tasks of guideline verification. Preliminary results indicate that guideline verification in the VR model can be done with satisfactory accuracy for a number of evaluations. However, some categories of guidelines require further development of measurement tools and use of higher model resolution than the model used in this study.

INTRODUCTION

The importance of a well-designed human-system interface to reliable human performance and process plant safety is widely acknowledged. Review of the control room design plays a significant role in supporting plant safety, and designers rely on the use of human factors engineering guidelines to support the identification of potential safety issues. Criticism is often aimed at the human factors techniques for being unable to give fast and reliable feedback in early stages of the design process. Efficient verification and validation techniques of control room design are therefore in high demand. Today, this is done either through a pen and paper verification or verification of a physical mock-up of the proposed control room. In the first case, the verification will usually use the results from analysis performed during the design process, which may be imperfect. For example, the result of a task analysis may be used as a criterion in verifying that all required controls and displays are provided to support human functions (NUREG-0711, 1994). In the second case, the use of a physical mock-up is expensive in terms of physical infrastructure, in addition to being time- and personnel demanding.

VR technology has proved to be a promising, powerful, and cost effective tool in control room design-work. It enables designers to spend more time evaluating creative new ideas, helping them to identify and eliminate potential problems early in the design process, and enables end-users to actively participate in the design process. However, more knowledge should be obtained about the quality of results from utilisation of VR technology in guideline verification.

CAN VIRTUAL REALITY REPLACE THE MOCK-UP?

Considering how human beings judge their surroundings, how they perform movement, and problem solving in virtual environments raises a number of questions. The number one question raised in literature describing virtual environments is the question of *presence*. Witmer and Singer (1998) described presence as "the subjective experience of being in one place, even when one is physically situated in another". The perceived meaningfulness of the virtual environment is believed to influence the sense of presence. Hoffman, Prothero, Wells & Groen (1998) found that chess players felt a higher sense of presence when viewing meaningful chess positions than when viewing meaningless positions. Witmere and Singer (1998) argue that presence requires the ability to focus on meaningfully coherent set of stimuli. On basis of the literature, it is therefore believed that the verification can not give dependable results if the virtual environment is not of high enough quality to provide sense of presence.

For this paper, presenting preliminary results, little room is found for the theoretical considerations, leaving the question of validity out of the discussion, focus is merely on the more practical question: "Can sufficient information be provided in the virtual environment so the evaluator of guidelines can solve the task of verification with satisfactory results?" For the broader discussion of these topics, the

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reader is referred to the OECD Halden Reactor Project work report series (Drøivoldsmo, Nystad and Helgar, 2000).

To test whether results from use of VR technology are dependable, an experiment was performed. The purpose was to compare the results from guideline verification in a real control room with the results from verification in a VR model of the same control room.

METHOD

Twelve participants were drawn from the population of potential practitioners of control room verification and validation systems at the Halden Project, i.e. the staff from the Man Machine Systems Research division and the Control Room Systems division. Each of twelve subjects performed guideline verification in the Halden Boiling Water Reactor control room (HBWR condition) and in a VR model of the same control room (VR condition). They were instructed to verify a set of 50 randomly chosen guidelines from five relevant sections of chapter seven in (1996a).

The design was counter-balanced by letting half of the subjects perform the HBWR control room guideline verification first, while the other half performed the VR model verification first. To prevent learning effects, the second guideline verification took place approximately two months after the first.

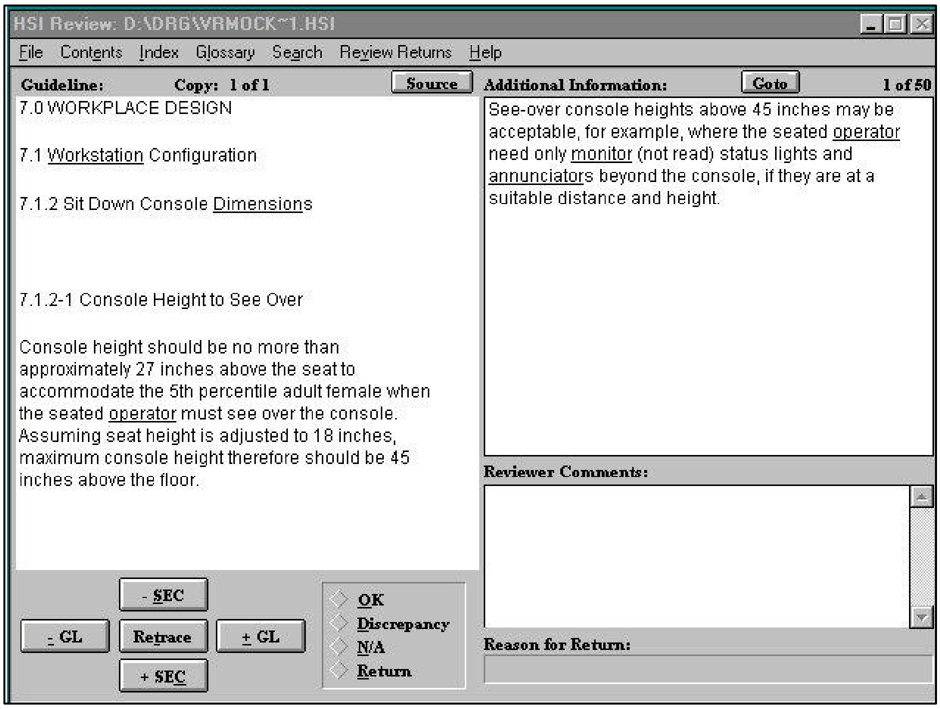

Figure 1. Example of a guideline as presented to the subjects with the NUREG-0700 software tool.

The 50 guidelines were presented to the subjects on a laptop PC running a software version of NUREG-0700 guidelines (NUREG-0700, 1996b) as shown in
Figure 1. The same laptop and software were used in both the HBWR and the VR condition to record how well the control room conformed to each guideline.

In the HBWR condition, subjects performed measurements and evaluations in the actual HBWR control room. They used a laser range finder and a standard tape measure to measure distances. In the VR condition, subjects used a VR application where they could navigate in a VR model of the HBWR control room using a mouse and keyboard. Distances were measured by selecting two points in the model using the mouse. A fixed angle view tool and a model of a control room operator were available in the VR model to view the operator's field of view. The VR application was presented using a projector on a screen 2,6 m from the subject, showing a picture of size 3,0 m X 2,3 m (as shown in Figure 2).

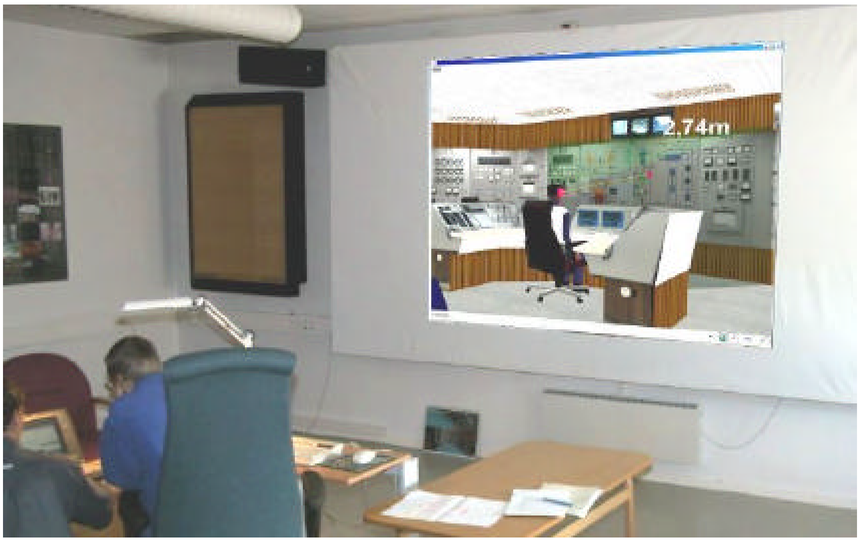

Figure 2. Experimental set-up in the VR condition, showing the subject in front of the screen used for displaying the model.

Participants were tested one by one. After instruction and a short practice period, each participant completed the five verification tasks without any rest or interruption. The natural order of the guidelines from NUREG-0700 was kept and all subjects performed the tasks in the same order. Each run took about 1 hour to complete.

Subjects rated the control room guidelines using one of four categories: If the control room conformed to the guideline, it was rated 'OK'. If it did not conform, it was rated 'Discrepancy', and subjects commented on the discrepancy. If the guideline was not applicable to the control room, it was rated 'N/A', and if it could be rated only if the subject received additional information or other measurement instruments, the subject used the category 'Return'. If the subject chose 'Return' then the most appropriate of the following reasons had to be chosen: 'Need operator input', 'Need plant management input', 'Requires measurement instrument', 'Requires additional documentation' or 'Other requirement'.

RESULTS AND DISCUSSION

Subjects ratings were compared to a instructor's copy based on detailed measurements from the HBWR control room. In the preliminary results presented here, the reason for 'Return' is not taken into consideration. The five sub-categories based on the classification used for the NUREG-0700 chapter sections are described in Table 1.

Table 1. The categories of guidelines making up the five tasks

Task #	Categories of guidelines
1	Workstation console and desk , covering sit down console and desk dimensions (15 guidelines)
2	Workstation chair (5 guidelines)
3	Control room configuration including ambience and comfort (13 guidelines)
4	Panel layout (5 guidelines)
5	Panel labelling (12 guidelines)

The current preliminary status of results does not allow any presentation of statistics, but as shown in Figure 3, the trends in the data indicate better performance in the HBWR condition in tasks 2, 3 and 5. In task one, the performance scores seem equal in the two conditions, and in task four, both conditions are not much above chance.

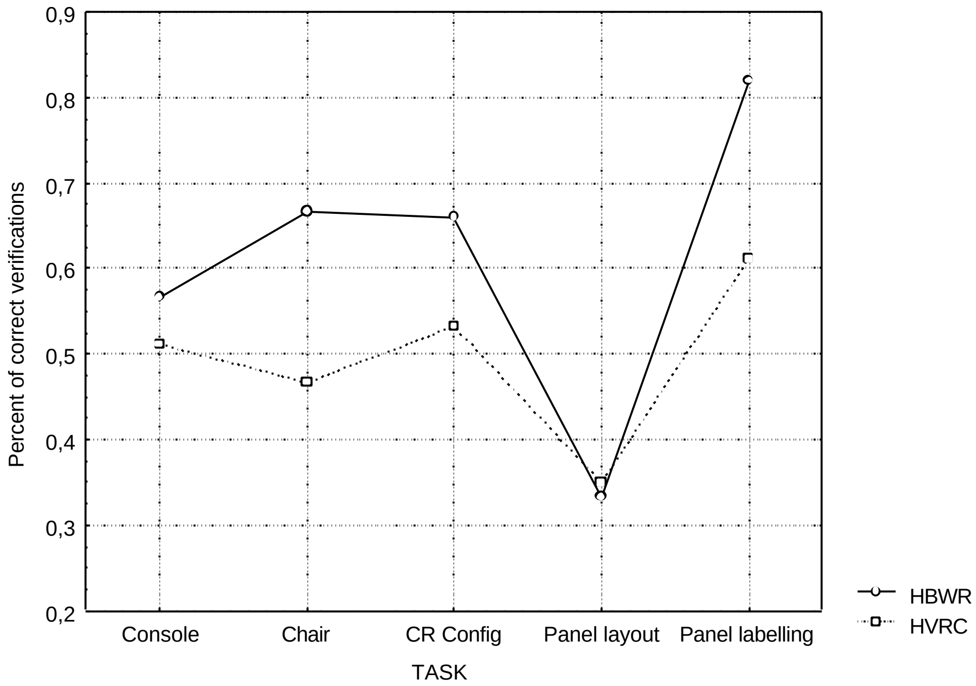

Figure 3. Mean score of correct verification as a function of task and experimental condition

Task number one included a high number of detailed measurements. The VR environment provided special measurement tools, designed for measurement on the accuracy level needed for solving this task, and these tools seem to have been sufficient with respect to usability and accuracy. A more detailed analysis is required for comparison of the different tools used within the task.

For tasks two and five, the guideline verification of the control room chairs and panel layout, the seemingly better performance in the HBWR condition was expected. The simulation of the chairs did not provide the functionality needed for proper evaluation, i.e., turning and rolling of the chairs. The panel labelling task included a number of guidelines where font sizes, space between letters etc, needed to be verified. The resolution of the VR environment used in the experiment made it impossible to judge single letters.

For the control room configuration task, the reason for better performance in the HBWR condition is unclear. Several of the participants reported feeling unwell during the session in the VR environment. According to Witmer and Singer (1998) simulator sickness is negatively correlated with sense of presence, probably because the symptoms of simulator sickness draw attention away from the virtual environment. However, more detailed records of the sickness problem must be analysed before concluding.

The nature of this task implies a need for an overview of the control room. Screen-based projection has been found to produce a greater sense of presence in inexperienced users than monitors (Deisinger et. al 1997, cited in Stanney and Salvendy 1998). The use of a large screen in this experiment should give good performance conditions in the VR environment. What remains unexplored are the navigation tools and effects of fatigue. Stanney and Salvendy (1998) have described drowsiness and lowered arousal or mood during exposure to virtual environments. The fact that the control-room configuration task on average was after about half an hour of exposure to VR could have had a negative effect.

CONCLUSION

On the basis of the data analysed so far, the results indicate that satisfactory results can be found if the VR environment provides good support for the evaluator. An unexpected difference found in performance between the two experimental conditions in the control room configuration task, indicates a need for a greater sense of presence in the VR model. Even if overall performance seems higher in the real control room, much of this difference is due to the resolution of the model in this experiment.

One should also bear in mind that the situation facing the evaluator in a design mock-up never could be as good as in the real control room condition used in this experiment.

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