

The Application of Virtual Reality for Hazard Identification Training in the Context of Machinery Safety: A Preliminary Study

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In order to successfully acquire knowledge in area of machinery safety for engineering students it is necessary to adopt elementary principles associated with risk assessment. Identification of possible hazards is an important part of risk assessment and engineering students need to take part also in hands-on training to supplement their learning process. It is clear that one major obstacle to improve safety training is the problem of allowing learners to work directly with hazardous equipment. Traditional approach is based on the use of slide show presentations enhanced by animations or videos. This training method is passive in nature and does not allow for an actual realization of consequences resulting from ignoring safety practices during interaction between the student and the machine. In order to improve the educational practice in this context, the Virtual Reality (VR) technologies could be used. The purpose of this study was to conduct a preliminary investigation to determine whether training through VR simulator is comparable to traditional training in developing the skills necessary for performing identification of possible hazards related to lathe operation. The results of this preliminary study suggest that VR based training has the potential to constitute a valid alternative to the traditional training approach.

Keywords: Virtual Reality, Machinery Safety, Training

1 Introduction

Risk assessment is a series of logical steps to enable, in a systematic way, the analysis and evaluation of the risks associated with machinery [1]. Hazard identification is the most important step in any risk assessment. The objective of hazard identification is to produce a list of hazards, hazardous situations and hazardous events that allow possible accident scenarios to be described in terms of how and when a hazardous situation can lead to harm [2]. To accomplish this hazard identification, it is necessary to identify the operations to be performed by the machinery and the tasks to be performed by persons who interact with it, taking into account the different parts, mechanisms or functions of the machine, the materials to be processed, if any, and the environment in which the machine can be used [1]. Only when a hazard has been identified, it is possible to take action to reduce the risks associated with it. It is therefore vitally important to ensure that hazard identification is as systematic and comprehensive as possible, taking into account the relevant aspects described in [1]. Several methods are available for the systematic identification of hazards. In general, the majority follows one of the two approaches described further. A top-down approach is one that takes a check-list of potential consequences (e.g. cutting, crushing, hearing loss) as its starting point and establishes what could cause harm (working back from the hazardous event, to the hazardous situation and thence the hazard itself). The bottom-up approach starts by examining all the hazards and considering all possible ways that something can go wrong in a defined hazardous situation (e.g. failure of component, human error, malfunction or unexpected action of the machinery) and how this can lead to

harm. The bottom-up approach can be more comprehensive and thorough than the top-down approach but can also be prohibitively time-consuming [2]. International standard [3] specifies the requirements and/or measures to eliminate the hazards or reduce the risks for turning machines.

At present, most of the courses related to hazard identification in the area of machinery safety for engineering students are based on traditional approach that uses slide show presentations enhanced by animations or videos. Although this approach can assist students in visualizing specific type of hazards, the students play only passive role in this type of training. In order to improve the educational practice in this context, Virtual Reality (VR) technologies can be used. The use of Virtual Reality (VR) systems for training purposes has been extensively investigated in literature. The motivation for using VR in education is that it can expose learners to challenging or educational situations and allow them to repeatedly practice new skills in an environment that enables correction and non-dangerous failure. At first sight, these affordances seem ideal for teaching almost any skill, and immersion offered by VR technology seems well suited for successful educational approaches and theories such as constructivism, active learning, or simulation-based learning [4]. Based on the fact that presence enhances learning performance, there have been efforts to use VR in supporting different forms of training [5]. Apart from traditional areas such as military, aviation, medicine or nuclear security these applications include training for construction [6–10], mining [11–14], power systems [15–16], oil and gas industry [17–18], firefighter services [19] and manufacturing [20–22].

Many VR based simulators for acquiring skills to operate lathe have been already developed and studied. Kalwasiński et al. [23] proposed virtual environment to implement a computer-based tool for interactive simulation of lathe operation. The environment created in Quest software made it possible to undertake a number of actions related to the environment development, in order to enable an interaction between its individual elements and to interface a number of pieces of peripheral equipment to the tool. Chang [24] used EON Studio software to integrate virtual reality technology with the application of 3D solid model to simulate a virtual operation of the various operating steps and virtual machining of lathe works during practical operation of lathe machine. Hou and Watanuki [25] performed the measurement of brain activation response during lathe operation in a VR lathe environment and an actual lathe environment by near-infrared spectroscopy. The results show that brain activation response during lathe operation in the VR environment is very similar to the results obtained during lathe operation in the actual environment, thereby indicating that training in such a VR environment will be effective and useful. The results also revealed that the brain is more highly activated by operating the lathe than by watching the lathe being operated by another person. El-Tamimi et al. [26] developed a semi-immersive interactive virtual environment for machine training. Virtualis stereo-server is used to achieve interactive functionality, real-time visualization and integration of various VR devices. Present platform includes a virtual model of a conventional lathe machine. The results of initial study showed that the students feel that the interaction using tracking system and immersion gives them a sense of presence in the digital world that is helpful in acquiring skills and makes learning easy. Hashimoto et al. [27] developed and tested a simulator for training workpiece centering operation on the lathe. Simulator is composed of the working platform with the clamp-force-adjustment device and impulse hammer. A trainee can check eccentricity of the workpiece by using the test indicator and reduce it by adjusting the clamp force and hammering. Results of skill training examinations confirm the effectiveness of the simulator.

According to our knowledge, there is no systematic empirical research addressing the question of how hazard recognition skill can be improved through training in the area of machinery safety. The purpose of this study was to conduct a preliminary investigation to determine whether training through VR simulator is comparable to traditional training in developing the skills necessary for identifying possible hazards related to lathe operation.

2 Materials and Methods

2.1 Subjects

Twenty-two engineering students (19 males and 3 females) from the Technical University in Zvolen with ages ranging from 21 to 24 years participated in this experiment. Based on space limitation, simulator availability, and time restrictions, nine of these students were randomly selected to engage in VR training (simulator group: seven males/two females) in addition to the standard 8 hours of traditional course alongside the control

students.

2.2 VR simulator

Full immersive VR system was provided as a training method in the experiment. In order to carry out hazard recognition training we used the free application Lathe Safety Simulator [28]. The HTC Vive setup consisted of the headset and two controllers with SteamVR Tracking system. Training was performed on a desktop PC running on Windows 10 and Intel-I7-4790 Quad core processor (3.60 GHz, 16GB RAM) with graphical card (model NVIDIA GTX-970).

2.3 Procedure

All twenty-two students participated in the traditional education together. This consisted of in-class lectures based on slide show presentations enhanced by animations and videos. Students who were assigned to the simulator group received additional 60 minutes of training using VR simulator. They were invited to wear the headset and explore the virtual environment. For the purposes of this study, participants were directed to use two levels of simulator: lathe overview and lathe safety (see Fig.1). These levels were designed to allow participants to become familiar with operation of an industrial lathe by guided tour, including identification of different lathe parts and related tools as well as with main hazard zones of lathe.

2.4 Performance evaluation test

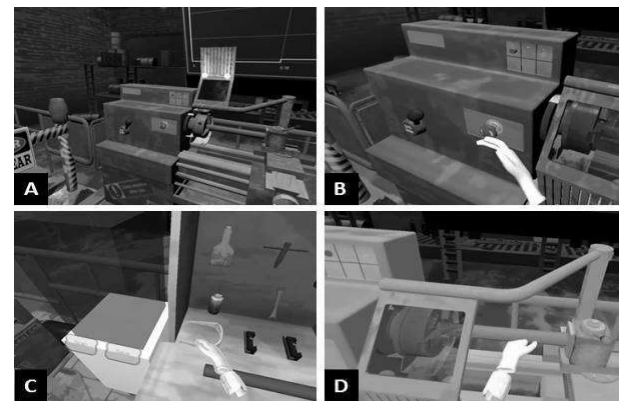


Fig. 1 Examples of hazard recognition training with Lathe Safety Simulator: A – exposed chuck, B – use of emergency button, C – wearing safety glasses, D – unintended contact with rotating workpiece

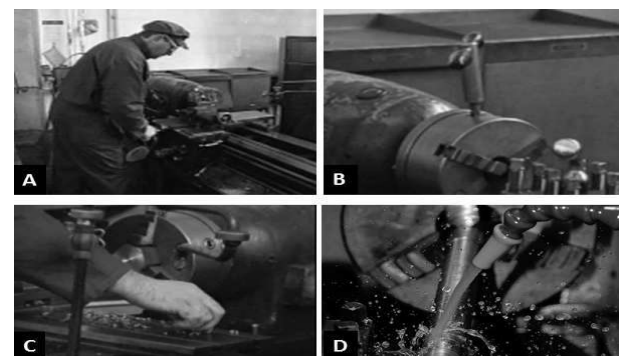


Fig. 2 Screenshots from video taken at the machine shop: A – unsuitable working posture, B – chuck key left in chuck, C – removing swarf with hand, D – cutting fluid aerosol

In this test, each subject was asked to examine 5 minutes of video footage taken at a machine shop. Video recorded for this purpose covered selected hazardous situations associated with lathe operations (see Fig. 2 and Tab. 1). Participants were asked to prepare a list of all the

hazards they could identify. For each subject we calculated the number of hazards identified and the number of correct hazards identified compared to a predefined list of hazards that could be identified on video. We used one-way ANOVA test to compare performance in different groups.

Tab. 1 List of hazards and hazardous situations presented to participants in performance evaluation test

Hazard and hazardous situation	Possible consequences
Chuck key left in chuck	Struck by the key when projected from the lathe.
Exposed chuck	Entanglement on uneven surface of chuck or workpiece when spinning.
Falling of heavy workpiece	Crushing foot or fingers.
Improperly mounted workpiece	Struck by workpiece.
Removing swarf with bare hand	Unprotected handling of swarf can result in laceration.
Flying chips	Hitting unprotected part of body.
Sharp edge of tool	Unintended contact with tool can results in cutting of fingers.
Noise	Excessive exposure can cause hearing loss or annoyance.
Cutting fluid aerosol	Excessive exposure can cause respiratory and dermatology diseases.
Unsuitable working posture	Excessive exposure can cause musculoskeletal disorder.

3 Results

Table 2 presents results from testing the hazard recognition performance. The results of one-way ANOVA in-

dicated that there were no statistically significant differences between the simulator and control group for number of hazards identified [$F(1, 20)=0.04$, $p=0.84$] and the number of correct hazards identified [$F(1, 20)=0.39$, $p=0.53$].

Tab. 2 Results of performance evaluation test

Subjects	Mean number of hazards identified	Minimum-maximum	Mean number of correct hazards identified	Minimum-maximum
Simulator Group n=9	10.7 (1.5)*	8-12	8.1 (1.45)	5-10
Control Group n=13	10.5 (1.45)	8-12	7.7 (1.38)	5-10

*Numbers at parentheses are standard deviations of the mean.

As can be seen from the data presented in Fig. 3, all participants were able to identify removing swarf with bare hand as a hazard. Other hazards with relatively high rate of recognisability in both groups included exposed chuck, improperly mounted workpiece, sharp edge of tool and noise. On the contrary, cutting fluid aerosol remained

unrecognized hazard for almost 60% of participants in both groups. The most significant difference between simulator and control group in terms of rates of success in hazard identification was recorded for unsuitable working posture.

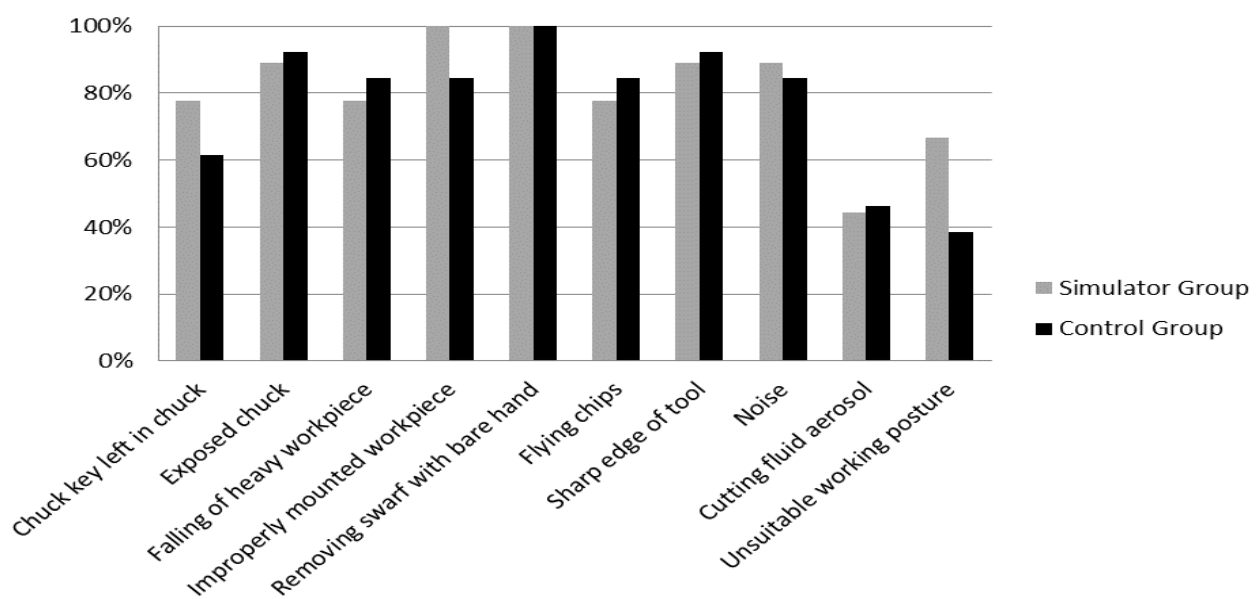


Fig. 3 Rates of success in hazard identification

4 Discussion and Conclusion

Improper lathe operation can cause serious injury [29-30]. The head mounted display (HMD)-based training systems are increasingly investigated for machine safety training. In HMD-based training systems, trainees can feel full immersion and interact with the virtual environment and equipment naturally and intuitively [14]. However, there are some known problems about HMDs. Firstly, many users have been reporting discomfort symptoms, such as nausea, sickness, and headaches, among others. Secondly, at the moment, HMD is not suited for collaborative work. This preliminary study aims to determine whether there is improved performance in hazards identification related to lathe operation after training using a VR simulator as a teaching aid compared with traditional training approach. As expected, the simulator group of engineering students did not identify significantly fewer hazards than subjects in control group. This result is in line with other research [31-33] on the effect of VR simulation in the training of hazard recognition skill.

Various limitations to this study need to be considered. Firstly, we used software application that is not primarily intended for hazard identification training. Therefore, there are some restrictions concerning the absence of electrical, thermal and other hazards. Secondly, the number of participants was relatively small. Although we successfully demonstrated that the training through VR simulator is comparable to traditional training in developing the skills necessary for performing identification of possible hazards related to lathe operation in our present study, the statistical significance for analyses regarding the indicators derived from the measurements of hazard recognition performance seems to be insufficient due to the small number of subjects. Therefore, we are not able to conclude that the increase of hazard recognition performance was greater than in the control conditions.

In this paper we have presented an ongoing study about application of immersive VR system for hazard identification training in the context of machinery safety. The results of this preliminary study are so promising to lead us to believe that VR based training has the potential to constitute a valid alternative to traditional training approach. Our further research efforts will be focused on the development of VR simulation model for identification of hazards associated with woodworking machine use.

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