ICCEPM 2022
The 9th International Conference on Construction Engineering and Project Management
Jun. 20-23, 2022, Las Vegas, NV, USA

Hazard Recognition and Construction Safety Training Efficacy using Interactive Virtual Reality (VR)

Meeranali Saiyad[1]*, Zofia K. Rybkowski[2], Patrick Suermann[3], Manish Dixit[4], Gregory Luhan[5], Hamzah Shanbari[6]

[1] *Department of Construction Science, Texas A&M University, 3137 TAMU, College Station, TX 77843, USA,* E-mail address: mms9338@tamu.edu
[2] *Department of Construction Science, Texas A&M University, 3137 TAMU, College Station, TX* 77843, USA, E-mail address: zrybkowski@arch.tamu.edu
[3] *Department of Construction Science, Texas A&M University, 3137 TAMU, College Station, TX* 77843, USA, E-mail address: suermann@tamu.edu
[4] *Department of Construction Science, Texas A&M University, 3137 TAMU, College Station, TX* 77843, USA, E-mail address: mdixit@arch.tamu.edu
[5] *Department of Architecture, Texas A&M University, 3137 TAMU, College Station, TX* 77843, USA, E-mail address: gregory.luhan@tamu.edu
[6] *The Haskell Company, 111 Riverside Ave, Jacksonville, FL 322502, USA,* E-mail address: hamzah.shanbari@haskell.com

Abstract: The majority of construction site incidents occur due to a lack of hazard awareness among workers on job sites. This lack of awareness is despite mandatory construction safety training, typically in the form of written content (safety manuals) or of images depicting hazards. To reduce job-site injuries and fatalities, general contractors have started adopting Virtual Reality (VR) to impart safety training to job site personnel. VR safety training can take the form of an immersive simulation comprising potential safety hazards intentionally embedded into a virtual job site; users are required to identify these hazards within a specified time frame with the expectation that they will be more adept at recognizing hazards on an actual job-site, resulting in fewer accidents. This research study seeks to identify the actual impacts of VR on construction safety awareness among participants. The research addresses the following question: Does VR improve hazard recognition awareness? The primary objective is to evaluate participants' performance of past construction safety awareness against present construction safety awareness after receiving VR training. Participants were asked to complete a multiple-choice Qualtrics™ questionnaire. The results of the study showed a statistically significant knowledge gain advantage with respect to hazard recognition and construction safety awareness with the use of interactive, immersive VR over a more conventional and passive safety training method.

Key words: immersive virtual reality, simulation, construction safety, hazard recognition

1. LITERATURE REVIEW

In the construction sector, virtual reality simulations have been reported to offer efficient safety instruction. A virtual reality (VR) based safety-training program offers an interactive training experience wherein users engage with an immersive virtual 3D environment. This interactive training allows users to strengthen their cognitive skills and awareness, which can in turn improve their understanding of the training content. It may also help to foster a safety culture that encourages construction workers to follow safe work practices. Because of the ability to rapidily modify and scale-up digital platforms, a software-based program can be more easily re-developed and improved compared to a static application [1].

According to Pham et al. (2018), construction sites are among the most complicated and risky locations in which to work. Because of this, to ensure the safety of building projects, knowledgeable and skilled professionals are needed. Construction safety education at the tertiary level can help students gain practical safety knowledge and improve their safety awareness before they enter a construction site. However, traditional approaches fail to provide practical experience and sufficiently engage students in acquiring safety knowledge, and safety topics are not adequately addressed in most construction curricula. VR, which emerged over two decades ago, has been applied and proven beneficial to various industries and educational disciplines [2].

Lucas et al.'s (2008) research in safety training is one of the very few examples of the use of VR for construction safety training. The researchers' findings, as well as the discussion surrounding VR, indicate several significant benefits of virtual reality environments for construction safety instruction. VR is capable of immediately revealing threats to trainees without jeopardizing their safety. In addition, research has shown that virtual reality safety instruction retains trainees' attention better than traditional classroom training [3].

Wilkins (2011) expressed major concerns about the effectiveness and content of current construction safety training in the United States. His assessment of 105 construction workers who had completed the ten-hour Occupational Safety and Health Administration (OSHA) "Construction Safety Training Course" found that they were dissatisfied with the manner in which the courses were offered. Wilkins emphasized the importance of training, including content relevant to the trainee's life, having a skilled trainer deliver the material, and augmenting training with practical resources that are easy to understand [4].

When compared to more engaging forms of instruction, construction training with low engagement (via lectures, recordings, or demonstrations) has proven less effective [5]. Finally, virtual reality may be utilized to give trainees a sense of control over their surroundings, thereby reinforcing their learning [6].

One strategy that can help improve training effectiveness is to heighten awareness of workers to detect hazards and avoid or prevent them. Construction workers' lack of awareness of hazards was discovered to be a key contributing factor to the occurrence of accidents [7].

What is needed is a data source that can be used for analysis and development of an automatic computer vision-based safety monitoring system. As digital technologies mature, they can be applied to create robust learning environments [8].

2. PROBLEM STATEMENT

Evidence regarding correlations between construction industry experience or OSHA training credentials of individuals and their hazard awareness knowledge is insufficient. To address this problem, this research was guided by the following questions:

(a) Does VR improve hazard recognition awareness? (b) Is the VR experience convenient for users compared to conventional methods of training? and (c) Do immersive visuals improve safety knowledge retention more than conventional training methods?

3. METHODOLOGY

This research study was conducted by Texas A&M University University in collaboration with The Haskell Company. The research secured IRB (Institutional Review Board) approval before proceeding, as required. A total of 100 participants were initially recruited via email. At the end of the study, a total of 63 participants had taken part in all the modules of the research. The study was conducted over approximately two months with a total time commitment of two hours for each participant, which consisted of the user taking two surveys (demographic and post-completion) requiring five minutes each, watching a safety awareness video for one-hour, engaging in a VR simulation for 15 minutes, and taking a pre-test, a post-test and a second post-test which required ten-minutes per test. Participants for the research study were recruited by sending an initial recruitment email and a demographic survey. Demographics such as participant's gender, age, disciplinary major at Texas A&M University, years of construction industry experience, OSHA training credentials and prior experience with VR were collected. Students were recruited in such a manner that there was a diverse population with respect to their initial response from the demographic survey.

Participating students were divided randomly into two research groups based on their responses. Once the experimental and control groups were determined, participants were emailed a link to complete a pre-test quiz administered through a Qualtrics™ online survey. The pre-test included several multiple choice questions containing graphics with potential safety hazards and their respective categories on a job-site (e.g. guarding, housekeeping, crane, trenching, elevated platforms, fire protection, electrical and welding); there was a "safe" category as well as a category entitled "no potential hazard present." Participants were required to identify the hazard category from a dropdown list by choosing an option that they deemed appropriate; this helped to assess their past knowledge of construction safety. Participants also watched a one-hour safety awareness video to contribute to their safety knowledge. After a two-week duration, the experimental group participated in the VR safety training simulation which took approximately 15 minutes per participant. The virtual simulation consisted of a jobsite exposed to several potential safety hazards where participants were asked to identify the hazards within 15 minutes by interacting with objects in the VR environment. The accuracy of each participant's performance was then evaluated. The control group watched a 360-degree-recorded video showing a construction job-site tour. To eliminate the use of a headset as a potential confounding variable, the content for both the control and experimental groups was delivered using VR headsets. Both the groups took a post-test after their respective VR slots; the post-test was similar to the pre-test, but with different pictures of hazards. Two weeks after the completion date of the post-test, both groups were sent a second post-test quiz similar to the first two tests, but depicting different scenarios to determine their knowledge retention after the passage of time. Finally, a post-completion survey was circulated to participants of both groups asking participants to rate their research experience using a 1 to 5 point Likert scale. Participants were compensated for their time and effort with a $70 Visa™ gift card at the end of the study. This research used a quantitative approach to compare participant's scores before and after being exposed to the VR safety training. A Qualtrics survey was used to conduct the series of tests; other appropriate statistical tests using Minitab™ were conducted as well.

4. RESEARCH HYPOTHESIS

The hypothesis for this research was that immersive, interactive VR simulation training is more effective in increasing a participant's construction safety and hazard recognition awareness than passive methods of safety training—such as a recording of a conventional job site talk.

5. RESULTS

To collect results, the participants were divided into two groups: an experimental group (EG) and a control group (CG) based on their responses from the demographic survey. Selection was made to maintain a relatively equal balance between both the groups based on gender, age, experience in the construction industry, prior VR experience, level of study at Texas A&M University (TAMU) and OSHA training credentials.

5.1 Demographic Survey Results

Approximately half of the recruited population were graduate students and the rest included undergraduate students across all academic years of study. The study population was selected in such a way so as to represent diversity in participants' work experience in the construction industry in terms of time spent in the industry. Work experience ranged from no prior work experience to some participants having more than three years of construction work experience. Some priority was given to select participants based on their prior use of a VR headset. Self-reported data obtained from the demographic survey revealed that only 20% of participants had previously taken OSHA training before participating; 63.3% had not had any OSHA training, and 16.7% were not sure if they had. Students were recruited from a variety of subject majors and were not limited to those with construction as their study major. This was done to maintain a diversified population and to obtain results that were as accurate as possible from a mixed cohort. The following is the list of different study majors from which participants were recruited: Accounting, Architecture, Business, Construction, Economics, English, History, Marketing, Neuroscience, Psychology, Public Health, University Studies, Urban Planning, and Visualization.

5.2 Pre-Test and Post-Test

Figure 1 shows two sample questions taken from the actual pre- and post-test that were given to the participants. There were nine potential hazard categories from which particiants were required to choose using a dropdown menu. The answer to the sample pre-test question would be "trenching hazard" based on the worker's environment from the picture in Figure 1 (*left*). The answer to a sample post-test question in Figure 1 (*right*) would be "guarding hazard" as there are no barricades or sufficient supports to stop a worker from potentially falling. Participants were given nine options to select an appropriate hazard category. There were a total number of 18 questions in each quiz covering various categories of potential hazards across the pre-, post-, and second post-test. The one-hour safety training video that participants watched had seven modules covering various attributes related to construction safety (e.g., General Work Rules, Process and Electrical, Trenching Excavation, Fire Protection, Vehicles and Equipment, Work at Elevations, and Other Safety Issues).

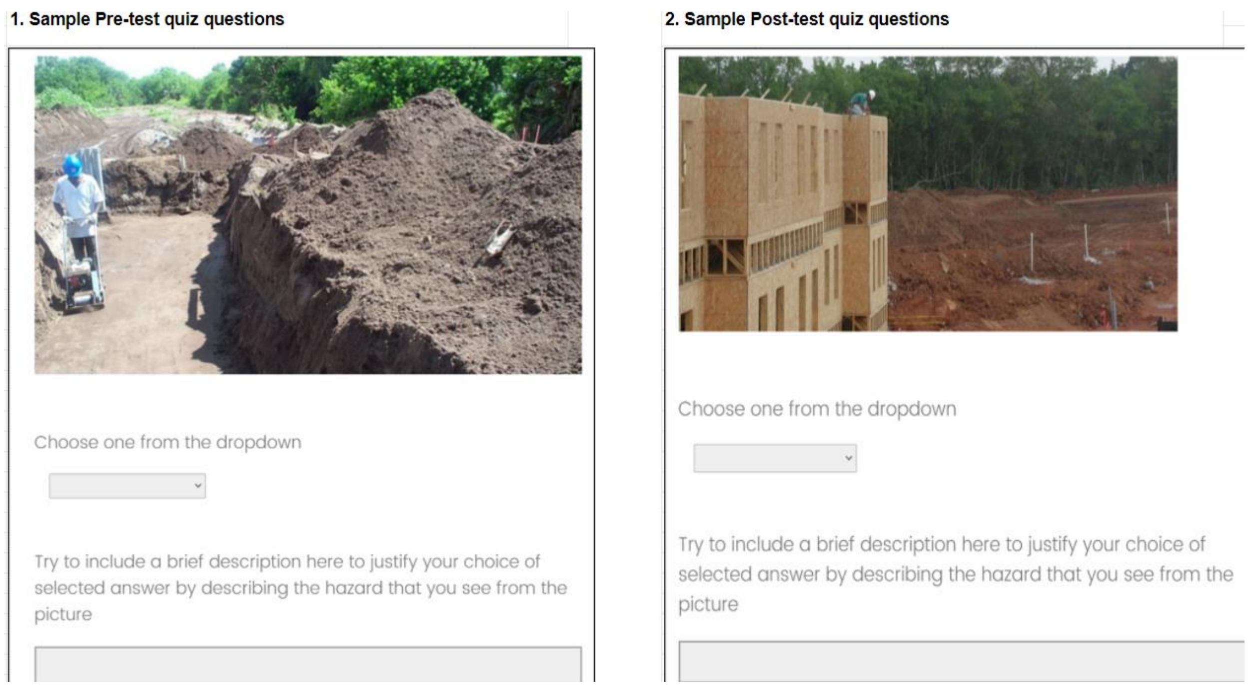

Figure 1. Sample pre-and post-test quiz questions

5.3 Virtual Reality Experience for Participants

Figure 2 shows a participant from the experimental group experiencing the VR safety training simulation video provided by The Haskell Company, and taking approximately 15 minutes per participant. The virtual simulation consisted of a job site exposed to several potential safety hazards that participants were asked to identify within the given time. Figure 3 depicts a control group participant watching a 360 degree recorded VR video simulation showing a construction job-site tour which was provided by The Haskell Company.

5.4 Statistical Test Results

The results shown in Figure 4 were obtained using Minitab and depict means and standard deviations of the post-test quiz scores of those in the experimental (μ=11.09; SD=2.11) versus those in the control group (μ=10.1; SD=1.86). The difference is statistically significant (p=0.05). However, since the experimental and control simulations contained some confounding viariables (e.g. interactive versus passive user participation, as well as animated versus filmed simulations), a more meaningful comparison is arguably the amount of improvement (delta) between the pre- and post-test scores within the experimental and the control groups, respectively (Figure 5). Participants in the experimental group showed a greater improvement (17.8%) in their pre- and post-test scores than those of the control group (11.9%). These results suggest that immersive, interactive, VR safety training can offer a be more effective form of knowledge transfer rather than a passive pre-recorded job-site tour.

6. RESEARCH LIMITATIONS

This research certainly has some limitations. For example, only nine hazard categories were taken into consideration, where in reality there are more. Also, The Haskell Company provided the VR simulation and potential hazard visuals; this made it impossible to make changes to the visuals. Additionally, it must be acknowledged that there were some confounding variables in this research. Although there was an attempt to mitigate the potential influence of the headset by having content delivered using a headset for both the experimental and control groups, the control group's content took the form of a passive recorded presentation on a actual jobsite whereas the VR simulation was digitally rendered. Also, it important to note that four participants from the experimental group and two from the control group experienced negative effects during their training (e.g. VR vertigo, motion sickness); these data points were ultimately removed from the calculations as these they were essentially meaningless. Finally, this research study was limited to recruiting Texas A&M University students as participants who fall between the age categories of 18 to 35 years, which is not necessarily representative of the demographics of actual workers on a construction site.

Figure 2. Participant of the experimental group actively engaging the VR simulation.

Figure 3. Participant of control group watching passive video of job site safety session

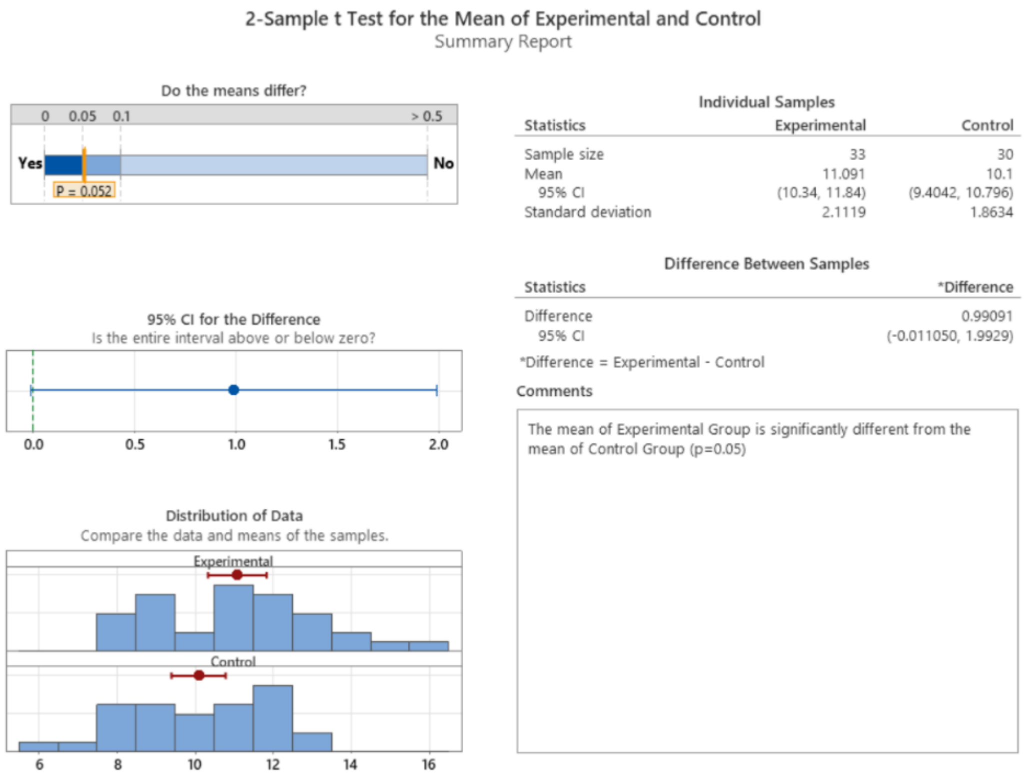

Figure 4. A comparison of experimental versus control group post-test scores using two sample t-tests (p=0.05)

	Experimental		Control	
	Pre-test	***Post-test***	***Pre-test***	***Post-test***
Mean	8.17	11.38	7.93	10.07
Delta		3.21 (17.8%)	2.14 (11.9%)	

Figure 5. A comparison of post- versus pre-test score improvement (delta) for experimental and control group participants. Scores are out of 18 possible points.

7. CONCLUSION

This research investigated the impact of VR training on construction worker safety and hazard awareness compared to more conventional methods of safety training. Of the total particpants tested, 98% rated as “very favorable” their experience in being part of this research study and strongly agreed that safety training using VR helped to grow their knowledge about construction safety and hazard awareness. In total, 90% of the particpants indicated that their construction safety awareness significantly improved after participating, compared to their past awareness. Indeed, the data suggest that immersive, interactive, VR safety training can offer a more effective form of knowledge transfer rather than a passive pre-recorded jobsite tour. In fact, those trained using immersive VR experienced a pre- and post-test score improvement of 17.8% compared to 11.9% improvement for those who were trained using more conventional, passive methods. Although these data are preliminary and have some stated limitations, it is recommended that VR offers strong potential as a platform for safety training and that further research should be pursued in this area. Providing background sound effects for the animated VR simulation may further increase hazard awareness retention and is worthy of additional exploration.

ACKNOWLEDGMENTS

The support of The Haskell Company/Dysruptek, the Texas A&M President's Excellence Fund (X-Grant), and Texas A&M's Department of Construction Science for partial funding of this research study are gratefully acknowledged.

REFERENCES

[1] D. Zhao and J. Lucas, "Virtual reality simulation for Construction Safety Promotion," International Journal of Injury Control and Safety Promotion, vol. 22, no. 1, pp. 57–67, 2014.

[2] H. C. Pham, N. Dao, A. Pedro, Q. T. Le, R. Hussain, S. Cho, C. S. I. K. Park, "Virtual field trip for mobile construction safety education using 360-degree panoramic virtual reality," International journal of engineering education, vol. 4, no. 34, pp. 1174-1191, 2018.

[3] J. Lucas, W. Thabet, P. Worlikar, "A VR-based training program for conveyor belt safety", <https://vtechworks.lib.vt.edu/handle/10919/92615)> (accessed 18 November 2021), 2008.

[4] J. R. Wilkins, "Construction workers' perceptions of health and Safety Training Programmes," Construction Management and Economics, vol. 29, no. 10, pp. 1017–1026, 2011.

[5] M. J. Burke, S. A. Sarpy, K. Smith-Crowe, S. Chan-Serafin, R. O. Salvador, and G. Islam, "Relative effectiveness of worker safety and Health Training Methods," American Journal of Public Health, vol. 96, no. 2, pp. 315–324, 2006.

[6] R. Sacks, A. Perlman, and R. Barak, "Construction safety training using immersive virtual reality," Construction Management and Economics, vol. 31, no. 9, pp. 1005–1017, 2013.

[7] T. S. Abdelhamid and J. G. Everett, "Identifying root causes of construction accidents," Journal of Construction Engineering and Management, vol. 126, no. 1, pp. 52–60, 2000.

[8] W. Fang, L. Ding, P. E. D. Love, H. Luo, H. Li, F. Peña-Mora, B. Zhong, and C. Zhou, "Computer vision applications in construction safety assurance," Automation in Construction, vol. 110, p. 103013, 2020.