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Impact of Repeated Virtual Reality Safety training on the Construction Worker Risk Habituation

Muhammad UMAIR[1]*, JoonOh SEO[2], Choongwan Koo[3]

[1] *Department of Building and Real Estate, Faculty of Construction and Environment, The Hong Kong Polytechnic University, Hong Kong,* E-mail address: umairchughata@gmail.com
[2] *Department of Building and Real Estate, Faculty of Construction and Environment, The Hong Kong Polytechnic University, Hong Kong,* E-mail address: joonoh.seo@polyu.edu.hk
[3] *Division of Architecture and Urban Design, Incheon National University, Incheon 22012, Republic of Korea,* E-mail address: cwkoo@inu.ac.kr

Abstract: Construction is considered one of the most hazardous industries because of fatalities on site due to workers' unsafe behaviour. Occupational Health and Safety Practitioners are providing safety training through modern technologies like immersive and non-immersive Virtual Reality (VR). Workers are repeatedly exposed to construction hazards and thus become accustomed to underlying hazards. Providing simulated accidents in VR safety training aims to minimize worker risk habituation but repeated exposure to accidents can affect risk habituation toward the underlying construction risk. To this end, this study proposes a simulated accident VR safety training environment that exposes workers to repeated construction hazards and simulates a fall accident when workers don't follow the safety procedure. Longitudinal experiments were conducted, and participants' risk perception was measured using questionnaires. The results revealed that simulated accident safety training has potential effects on construction workers. The outcomes of this study lay the foundation for further studies to employ a VR safety training environment that enables workers to experience simulated accidents. This contributes to the development of an improved VR safety training design, taking into account the appropriate interval at which it should be provided. Such an approach can help workers become more sensitized to construction risks.

Key words: Accident Experience, Worker Safety, Safety Training, Risk Perception, Risk Habituation

1. INTRODUCTION

In terms of worker safety, the construction industry is widely recognized as one of the high-risk sectors [1]. The construction industry in Hong Kong reported the highest number of accidents and fatalities compared to other industries, with 3,046 accidents and 17 fatalities recorded in 2022. Over the past five years, the average number of accidents was 3,035, with 18 fatalities [2], [3]. In India, over a two-year period, it was found that 73.4% of workers who fell from heights were construction workers [4]. The study by Guo in 2017 reports that injury rate in the construction industry is two time higher than the average rate in other industries [5]. Construction workers working on scaffolding are exposed to fall hazard due to inadequate safety knowledge and training [6]. They are provided with safety training to enhance their knowledge of hazard identification, enabling them to better understand the hazards present in the workplace. However, repeated exposure to simulated accidents in the same work environment or hazardous situations can result in the underestimation of risks [7], [8].

The process in which individuals becomes less sensitive to repeated exposure to specific risk or alerting stimulus is called risk habituation [9]–[11]. The workers are unconsciously learning that accident will not happen as they have adequate knowledge to overcome the risk, this biased risk perception can lead

to risk habituation. Therefore, it is important to measure the effect of providing the repeated simulated accident safety training on worker risk habituation level. Previous studies have shown that large number of construction accidents are due to worker unsafe behavior [6], [12], [13]. Specifically, repeated exposure to hazards can lead to a decline in workers' attentiveness and vigilance, consequently raising the risk of fatal accidents [14]. Hence, it is crucial to address the lower perception of risk among workers who are repeatedly exposed to simulated accident safety training. This will aid in the improvement of safety training design to minimize the risk habituation among workers. It is difficult to measure workers' risk habituation with any instrument, current simulated safety training primarily focuses on the decrease in a risk perception as a measure of risk habituation. present at the site to provide better understanding of consequence of not complying with safety standards.

2. LITERATURE REVIEW

2.1. VR Safety Training in Construction

Construction workers plays an important role in determining the safety of themselves and of their working environment through their safe and unsafe behavior [15]. Despite the health and safety organizations effort to take a reasonable precaution such as improving site conditions, enforcing safety compliance, providing safety training and equipping the workers with personal protective equipment, there is possibility that workers may still choose to engage in a risky behavior [15]. Recent advancements in construction safety have resulted in the adoption of virtual reality (VR) technology as a means to examine the factors that contribute to workers' engagement in unsafe behaviors within hazardous situations [16]. By using VR, researchers can expose workers to simulated hazardous scenarios and observe their behaviors without subjecting them to actual harm [17]. Previous studies have employed VR to assess and enhance individual workers' hazard recognition skills [18], [19]. Additionally, Hasanzadeh utilized VR to investigate the correlation between risk-taking behaviors of roofers and the implementation of safety measures [20]. Although these studies demonstrate the potential of VR in identifying factors impacting workers' unsafe behaviors, there is a scarcity of research examining how repeated simulated accident safety training influences workers' habituation to risk.

2.2. Accident Experience and Risk Habituation

Safety training is considered effective when workers achieve the required training goals. It can be evaluated through their outcome criteria such as their performance, improved hazard identification, better awareness [21]. There is need for innovative approaches to effectively train and promote the safe working environment. One training approach of simulated accident experience has been overlooked in construction industry. Although earlier researchers suggested that experience of accidents could significantly impact the workers subsequent behavior [22], [23]. Researcher are providing the safety reminding interventions through virtually simulated accident to increase the awareness of the worker, but the researchers have found that repeated exposure to accident fatal situations without having any negative consequences, workers may underestimate the risk, which in turn develops the risk habituation to the particular risk [11], [24].

3. METHODOLOGY

The objective of this study was to assess the impact of a simulated accident experience on workers operating on the scaffolding of high-rise buildings. Participants were instructed to traverse the length of the scaffolding from one end to the other. The study aimed to measure the extent of risk habituation among participants by analyzing changes in their risk perception throughout the pilot study. Data analysis was conducted to investigate the effects of the simulated accident experience on workers' risk habituation, considering the potential for fatal injuries in the construction industry.

3.1. Accident Scenario and Virtual Reality Environment

The experimental VR safety training program focused on steel scaffolding work in a high-rise building, as falling from heights remains a significant cause of fatalities in construction sites. A specifically designed VR scenario was created to assess workers' risk habituation and safety behaviors in identifying

risks while repeatedly exposed to hazards. This simulated VR safety training exposed workers to multiple fall hazards while working on the platform. During the safety training, participants were instructed to perform four tasks, involving traversing from one end of the scaffolding to the other. Throughout these tasks, participants were required to wear safety helmets, put on safety harnesses, inspect for incomplete scaffolding, and identify corroded working platforms as shown in the figure 1. These tasks were intentionally designed to expose participants to risky environments repeatedly, emphasizing the importance of following safety protocols. Failure to adhere to the safety protocols during task performance could result in accidents. One of the tasks was specifically designed to include a scenario that simulated a near-miss accident. This deliberate inclusion aimed to underestimate the significance of adhering to safety protocols, as it demonstrated the potential risks and consequences that could arise if safety regulations were not followed diligently.

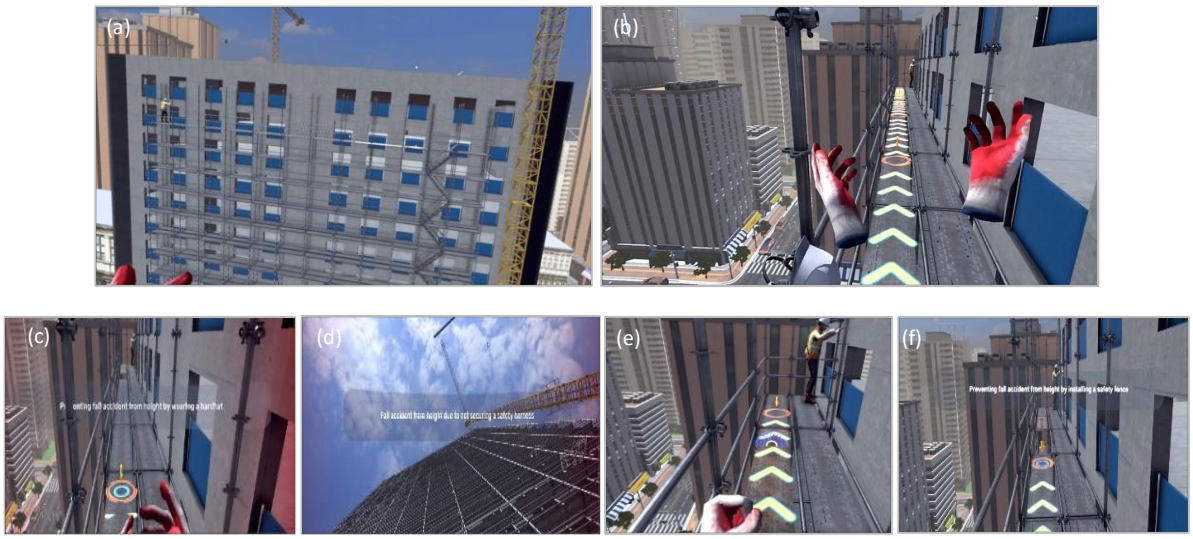


Figure 1. The simulated steel scaffolding environment: (a-b) show the overview of scaffolding and task performing area, (c) brick falling hazard when not wearing the hardhat; (d) falling accident when not wearing safety harness; (e) identification for corroded working platform; (f) preventing fall accident by identifying the absent safety fence.

All components of the VR safety scenario were developed using Unity 3D. The model was integrated with the HTC Vive Pro to create an immersive VR environment. The controller was utilized for navigation, object manipulation, and the simulation of wearing personal protective equipment. The HTC Vive head-mounted display (HMD) enabled eye tracking, which was utilized in two specific tasks to ensure accurate fixation on the intended target. To ensure a virtual environment that closely resembled reality, meticulous attention was given to designing realistic ambient sounds. Sound effects were incorporated to accurately depict participants correctly picking up objects, wearing and securing the virtual safety harness, and the sound of the harness hitting against the steel scaffolding. Additionally, background sounds of construction work were implemented to enhance the overall immersive experience.

3.2. Risk Habituation Measurement

The risk habituation of participants to falling from height accidents was measured using repeated risk perception scores obtained through subjective measures. Risk perception serves as a measure of how individuals estimate and evaluate risks, including the possibility of underestimating or overestimating those risks. A study conducted by Leavens suggested that polytobacco users exhibited lower perceived risk, potentially indicating habituation to the harmful effects of tobacco products due to frequent exposure [25]. Before the start of the VR safety training, participants were asked to complete a questionnaire to evaluate their baseline perceived acceptable risk. Immediately following this, they undergone simulated accident experience safety training to observe any changes in their risky behavior, as measured by the risk perception questionnaire. This process was repeated three times, with a one-week interval between each session, to assess any further changes in risk perception scores over time.

3.3. Simulated Accident Experience

To examine the effect of repeated simulated accident experience on the participant's risk habituation to working on height risk, safety training simulates the fall accident in the VR environment. Working on the scaffolding to wear the personal protective equipment's and intentionally providing the accident experience to decrease their risk habituation. Participants were asked to wear the safety helmet as tower crane was passing above them which moves the construction from one place to the other. When participants do not wear the safety helmet, construction object will fall on him and serious injury will occur. To create a realistic accident experience, the training incorporates the hitting of an object sound effect, accompanied by visual cues such as a shaking and red-tinted display screen. Furthermore, haptic feedback is provided through motion controllers. After experiencing the accident they will placed automatically to the specific task starting.

3.4. Experimental Procedure

The experiment was conducted in the construction sensing and analytics laboratory at Hong Kong Polytechnic University. Participants were invited through university email, and all were the PhD student of Department of Building and Real Estate. A total of forty-five participants were recruited for the safety training. Firstly, participants were provided with consent. Secondly, before the experiment all the participants were briefed about the safety training of working at the multistorey building. Pre training session was provided to participants on the HTC Vive to get familiar with the VR environment and how to use controller for VR experiment.

4. RESULTS AND FINDINGS

Data obtained from the participants' risk perception scores over the course of three experimental weeks were analyzed using the statistical software SPSS. Descriptive statistics were performed on the risk perception scores, indicating that the highest mean score of 5.70 was observed after the first training session. Subsequently, the mean score decreased to 5.22 after the second VR safety training and further decreased to 4.97 after the third training. The standard deviations of the risk perception scores exhibited an increasing trend, starting from 0.64 pre-training and rising to 0.98, 1.00, and 1.01 after the first, second, and third training sessions, respectively as shown in the **Table 1**.

Table 1. Descriptive Statistics of Risk Perception Scores

Risk Perception Scores	Mean (Std)
Pre-Training	5.18 (0.64)
Training-I	5.70 (0.98)
Training-II	5.22 (1.00)
Training-III	4.97 (1.01)

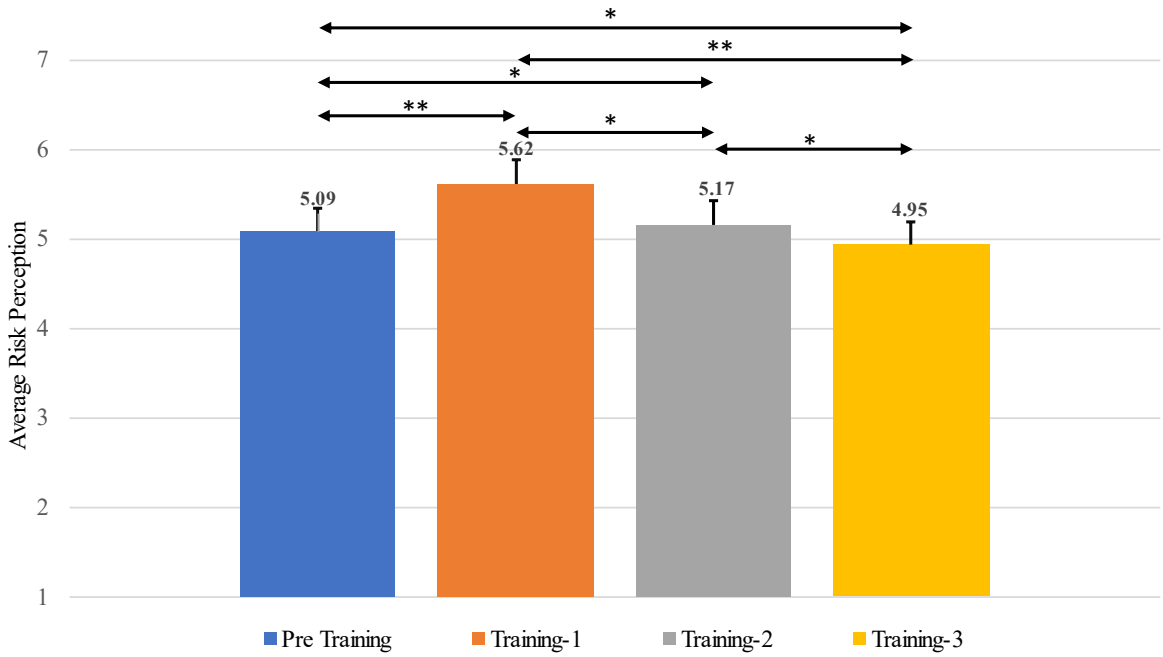
Post Hoc Tukey HSD was performed in the context of analysis of variance (ANOVA) on the data to find the differences among the groups. Statistically significant difference was found between the Pre-training and first post training perception scores, and first post training and third post training and the p-values for the comparison between these two conditions were 0.049 and 0.002, respectively. All the other combinations of groups were not statistically significantly different and p values was higher than 0.05 as shown in the table 2 and figure 2.

Table 2. Summary of Tukey HSD Results

No	Risk Perception		Mean Difference (I-J)	Std. Error	Sig.[a]	95 % Confidence Interval	
						Lower Bound	Upper Bound
1	Pre-training	Training-I	-0.517	0.214	0.049*	-1.033	0.019
		Training-II	-0.038	0.204	0.998	-0.553	0.478
		Training-III	0.215	0.230	0.701	-0.300	0.730
2	Training-I	Training-II	0.480	0.204	0.078	-0.036	1.25
		Training-III	0.733	0.230	0.002*	0.216	1.248
3	Training-II	Training-III	0.253	0.220	0.582	-0.262	0.768

[a] Tukey HSD

* Mean difference is significant at 0.05.



Note. *= No significant difference (p >0.05); **= Significant difference (p<0.05).

Figure 2. Comparison of average risk perception scores measured at different time points.

4.1 Discussion

The results of this study suggest that the risk habituation of participants can be significantly influenced by repeated exposure to simulated accident experiences during VR safety training. Initially, participants' risk habituation decreased because of experiencing the accident scenario. This can be attributed to the fact that experiencing or visualizing unpleasant events can enhance awareness of potential risks. These findings support the argument that when individuals are exposed to unpleasant situations, they tend to overestimate the risks associated with those situations and become more vigilant about hazardous conditions. After the initial training, construction workers underwent a second safety training session with a one-week interval. Surprisingly, it was found that their risk habituation increased following this second training. The analysis of the second experiment indicated that repeated exposure to simulated accident experience safety training could actually decrease workers' risk perception. In other words, the workers became less sensitive to the risks presented in the training after encountering it for a second time. To further investigate the impact of repeated simulated accident experience safety training, the

workers underwent another round of safety training. Remarkably, the results showed a further decrease in risk perception, indicating an even higher level of risk habituation. When comparing the original risk habituation of the workers with the third safety training, it was observed that despite the intermittent provision of repeated safety training, the level of risk habituation continued to increase. These findings highlight the importance of considering the potential for habituation effects in safety training programs. It suggests that simply repeating the same training may lead to decreased risk perception among workers. Therefore, it is crucial to continuously update and innovate safety training approaches to ensure the effectiveness of such programs and maintain workers' awareness of potential risks.

4.2 Conclusion

This study introduces a simulated VR environment that exposes workers to fall from height accidents and hazards during safety training. The simulation incorporates visual, and auditory feedback to create a realistic accident experience. The outcomes of the repeated safety training experiment indicate that the simulated fall accident in the virtual environment increases risk habituation behavior. However, when compared to the initial risk habituation, the results show that the simulated accident experience safety training has no effect on worker risk habituation. These findings emphasize the potential of using VR to observe a decrease in workers' risk habituation to workplace hazards. Nonetheless, if the training is provided repeatedly, it can lead to the negative consequence of higher risk habituation to hazards in the workplace. This offers evidence to support a shift from conventional safety knowledge-focused training to behavioral intervention-focused safety training. Overall, this study highlights the benefits and drawbacks of using VR in safety training. While it can effectively reduce risk habituation, caution should be exercised in providing repeated exposure to ensure that workers maintain their ability to identify and respond to workplace hazards effectively.

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