Enhancing Construction Managers' Risk Perception and Lowering Risk Tolerance toward Unsafe Behaviors Through Experiential Safety Training

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Abstract: The training effect can be enhanced when trainees/learners interact with real-world environments and construct personal knowledge from those direct experiences. Leveraging such experiential learning strategies for occupational training has been widely discussed due to its effectiveness. The construction industry has also been focusing on experiential safety training to address the limitations in conventional classroom-based training, such as passive learning and limited interaction with actual physical hazards. Recently, government organizations and construction companies have started to operate safety training facilities, where trainees can physically experience the negative consequences of unsafe behaviors (without actual injuries). Although the effect of experiential safety training at those facilities has been anecdotally noted, no study has empirically investigated its effectiveness in enhancing trainees' risk perception toward unsafe behaviors. To this end, this study examined the effectiveness of experiential safety training in enhancing construction managers' risk perception toward workers' unsafe behaviors and their intention to stop workers from working in dangerous situations. The results, based on answers to survey questions showing scene images of unsafe behavior related to the risk of a fall, show that construction managers who participated in experiential safety training perceived a higher risk regarding workers' unsafe behaviors in less obviously risky situations, and exhibited a stronger intention to immediately stop workers from working in subtly unsafe conditions. This study contributes empirical evidence about the effectiveness of experiential safety training at safety training centers, thereby promoting the wide adoption of experiential safety training and advancing safety engineering and management strategies in the construction industry. **DOI: 10.1061/JMENEA.MEENG-6283.** *© 2024 American Society of Civil Engineers.*

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Introduction

Despite significant efforts to prevent injuries and accidents in construction sites, the construction industry still reports high accident rates (Chan et al. 2023; Hong et al. 2023; Namian et al. 2022). In 2022, the US construction industry reported 1,056 fatal accidents, which accounted for 19.2% of total workplace fatalities, the highest rate for any industry [(BLS (US Bureau of Labor Statistics 2023)]. Studies have shown that the majority of workplace accidents result from workers' unsafe behaviors (Abdelhamid and Everett 2000; Choudhry and Fang 2008; Kim et al. 2021c; Suh 2023) and that construction managers (e.g., project managers, project engineers, supervisors, and front-line managers) are key players in preventing/reducing workers' unsafe behaviors (Fang et al. 2020; Li et al. 2020). When construction managers are highly perceptive of the risk associated with workers' unsafe behaviors, they are more likely to intervene in such unsafe behaviors (Choudhry and Fang 2008). Therefore, construction managers' heightened risk perception and prompt intervention of workers' unsafe behaviors can lead to enhanced safety performance in construction sites.

In order to enhance construction managers' risk perception toward workers' unsafe behaviors and to encourage managers to immediately provide feedback when they encounter workers' unsafe behaviors, construction companies require construction managers to participate in periodic safety training and obtain continuing education units associated with safety management (Zohar 2002). However, strong evidence indicates that conventional classroom-based safety training is not effective in enhancing individuals' risk perception toward unsafe behaviors (Liang et al. 2022; Rafindadi et al. 2023; Zhang et al. 2022). Previous studies pointed out the several limitations of conventional instructor-led safety training: (1) passive learning - in instructor-led safety training, trainees passively receive and acquire information, which may lead to trainees' disengagement and deficiencies in retaining safety knowledge (Eiris et al. 2018, 2021; Han et al. 2022; Seo et al. 2024). (2) Limited interaction with physical hazards - in conventional training, trainees rarely interact with physical hazards; thus, they would likely not properly perceive risks associated with workers' unsafe behaviors (Christensen et al. 2020). (3) A non-work-related

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context - acquiring knowledge and skills in the context of real-life situations is an essential principle of occupational training, but conventional safety training excludes the context of real-life work situations (Makransky et al. 2019; Polmear and Simmons 2022).

Construction managers do have the authority and responsibility to halt work until workers stop engaging in unsafe behaviors or until unsafe working conditions are eliminated (Lim et al. 2022; Pratt et al. 2001; Simons et al. 2019). However, managers are likely to perceive low levels of risk when they encounter workers' unsafe behaviors due to the limitations of the conventional safety training and are unlikely to provide prompt interventions for workers when prioritizing productivity over safety (Bussier and Chong 2022; Byrd et al. 2018). To this end, it is critical to transform conventional safety training into experiential safety training which involves trainees' hands-on experience by interacting with physical workplace hazards and experiencing potential results of unsafe behaviors.

Integrating the principles of experiential learning into construction safety training has been widely suggested as a possible strategy to overcome the inherent limitations of conventional safety training (Bhandari et al. 2019; Hasanzadeh et al. 2017; Kim et al. 2021a; Le et al. 2015; Molenaar et al. 2009; Ogunseiju et al. 2023; Ye et al. 2021). Experiential learning involves learners' interactions with real-world environments (Fowler 2008; Kolb 2014; Lehane 2020; Miettinen 2000). Such active interaction catalyzes and leads to changes in learners' behaviors (Taras et al. 2013). Previous studies have explored how to integrate experiential learning into construction safety training to leverage its advantages. Eiris et al. (2018, 2020b) investigated the effectiveness of experiential safety training in enhancing trainees' active engagement in training. The results showed that trainees who took safety training with immersive storytelling and 360-degree panoramas of actual construction sites were more actively engaged in the training and identified more workplace hazards. Other studies showed that trainees with interactive training in a virtual reality environment had better spatial memory and wayfinding performance than trainees who received conventional training (Lin et al. 2023; Shi et al. 2021; Yan et al. 2022; Ye et al. 2021). The outcomes of those studies indicate that integrating experiential learning into safety training leads to better learning outcomes.

To take advantage of experiential safety training, many countries' government organizations and construction companies operate safety training facilities to provide physical experiences (Cardno 2019; Razner 2018). The construction industry has also provided experiential safety training where trainees can physically experience the negative consequences of unsafe behaviors in construction sites, without risking actual injury (3M 2022; ACUTE Inc. 2024; Ahn et al. 2020; Fyffe 2019; Smith 2019). The training is conducted at specially designed facilities that can simulate physical accidents (e.g., falls, collapses of scaffolding structures, and electrocutions).

Although the efficacy of experiencing physically simulated accidents at those training centers has been anecdotally noted based on trainees' satisfaction after the training (Joshi et al. 2021; Makransky et al. 2019), no study has empirically investigated its effectiveness in enhancing trainees' risk perception toward unsafe behaviors. Building a safety training center demands huge upfront costs, as well as ongoing operation and maintenance costs (Park 2015). Furthermore, providing the training itself costs substantially more than providing conventional safety training. Empirically validating its training effect is thus critical to promoting the wide adoption of experiential safety training in the construction industry. Validating the training effect would allow researchers and practitioners to better understand how integrating the principles of experiential learning into construction safety training can advance safety management. This study aimed to examine the effectiveness of experiencing physically simulated accidents in enhancing construction managers' risk perception toward workers' unsafe behaviors.

We performed a set of experiments that evaluated the training effect on construction managers' risk perception and risk tolerance regarding workers' risky behaviors, specifically associated with fall accidents. Participants were asked to experience physically simulated falls at a safety training center and answer survey questions about their level of perceived risk related to scene images that show workers' unsafe behaviors. Through statistical analyses, significant effects were identified. The results show that construction managers who participated in experiential safety training perceived a higher risk regarding workers' unsafe behaviors and exhibited a stronger intention to immediately stop workers from working in unsafe conditions. The findings of this study also provide new knowledge about how to empirically measure the training effect of experiential safety training at safety training facilities and advancing safety engineering and management strategies in the construction industry.

Research Background and Hypothesis Development

Recent studies in the field of construction safety management have integrated the principles of experiential learning into safety training to advance safety performance in the construction industry (Choi and Koo 2023; Choi et al. 2023; Park and Koo 2022). In the following sections, we review the theoretical foundations of perception of safety risk and experiential learning in safety training. Then, we review efforts for adopting experiential safety training in the construction industry, and we further identify the knowledge gaps that exist for empirically assessing the effectiveness of experiencing physically simulated accidents at safety training centers in enhancing risk perception toward unsafe behaviors.

Risk Perception, Risk Tolerance, and Safety Training

Risk has been defined by the National Safety Council as "a measure of the probability and severity of adverse effects" (National Safety Council 2003). Responding appropriately with corrective or mitigative actions to identify risks plays a crucial role in preventing injuries and accidents in workplaces. Accordingly, numerous studies in construction safety have highlighted the importance of enhancing individuals' *risk perception* abilities (Rohrmann and Renn 2000). Risk perception is a process of assessing the probability and severity of potential outcomes associated with encountered risks (Wickens et al. 2004). In high-risk workplaces, such as construction sites, the assessment of safety risks mostly relies on an individual's perceived risk level (Inouye 2014; Namian et al. 2018; Park et al. 2022). Inappropriate risk perception could include unsafe behaviors that may lead to negative consequences (Anderson et al. 2023; Hallowell 2010; Kim et al. 2021b). Therefore, construction safety training generally aims to equip individuals working at construction sites with high levels of risk perception abilities (Man et al. 2019).

Risk tolerance is another conceptualization that explains an underlying mechanism of individuals' risky or unsafe behaviors (Rohrmann and Renn 2000). Risk tolerance can be defined as the amount of risk that someone is willing to accept to achieve a desired goal (Hunter 2002). Individuals who have higher risk tolerance levels are more likely than others to engage in unsafe behaviors in workplaces. Risk tolerance is closely tied to risk perception (Inouye 2014; Kwak and LaPlace 2005), and low levels of risk perception are highly associated with high levels of risk tolerance (Salas et al. 2020). In the real world, construction sites expose workers to various workplace hazards, and construction workers and managers tend to become habituated to frequently encountered hazards (Chae et al. 2024; Cenfei et al. 2020). Thus, individuals are likely to perceive less risks and have high levels of risk tolerance (Kim et al. 2023b; Wang et al. 2016). However, an individual's high level of risk tolerance can be mitigated with properly designed education and training (Jayalath and Premaratne 2021).

Experiential Learning and Safety Training

Experiential learning has been defined as a process where trainees/learners interact with real-world environments and construct personal knowledge from those direct experiences (Kolb 2014; Warner Weil and McGill 1989). Kolb's experiential learning cycle is one of the most widely accepted models of experiential learning (Shoulders and Myers 2013); it consists of four stages of learning: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb 2014). In the concrete experience stage, learners engage in activities and interact with environments (Chiang et al. 2021). Then, learners consciously reflect on what they learned in the experience stage (Lehane 2020). In the abstract conceptualization stage, learners relate their understanding of the experience to the knowledge they already have. In the active experimentation stage, learners apply the new knowledge to their daily lives (Chavan 2011). Numerous studies have shown that experiential learning improves the quality of learning and increases the likelihood that learners can apply acquired knowledge to their lives (Dhanapal and Shan 2014; Eyler 2009).

Leveraging experiential learning strategies for occupational training has been widely discussed due to its effectiveness in achieving improved skill acquisition and sustained knowledge (Hoover et al. 2010; Muscat and Mollicone 2012; Singleton 2015). Studies in the field of construction safety management have used experiential learning to overcome limitations in conventional safety training and enhance safety performance (Fang et al. 2020; Li et al. 2020). Advances in virtual reality (VR), augmented reality (AR), and other information technologies have enabled researchers and safety practitioners to integrate the principles of experiential learning into construction safety training (Eiris et al. 2020a; Yan et al. 2022; Zhang et al. 2022). In those training environments, trainees can experience unsafe situations without risk of actual injury (Bao et al. 2022; Kim and Ahn 2020). Recent studies have validated the efficacy of experiential safety training in developing trainees' hazard recognition and risk assessment skills (Bhandari et al. 2019; Kim et al. 2022; Le et al. 2015; Ojha et al. 2024; Stuart 2014). However, there are still challenges in fully leveraging the advantages of experiential learning with such VR/AR technologies. Although a VR/AR environment can provide better training experiences than conventional classroom-based safety training, participants' movements in a virtual environment are somewhat limited, and interaction with virtual objects through controllers are still less immersive than direct physical interaction in real-world settings (Harichandran and Teizer 2022).

Facilities for Experiential Safety Training

As another approach to address limitations in conventional safety training, many countries' government organizations and construction companies operate safety training facilities to provide physical experiences (3M 2022; Cardno 2019; Fyffe 2019; RETTEW Inc. 2023; Smith 2019). For example, many state agencies in the US have built safety training facilities and provide experiential safety training to fire fighters and police officers (Prestebak 2015; Razner 2018). In Japan, about 160 public safety training facilities have been built and provide disaster preparedness education (Park 2016). Those facilities enable trainees to practice safe escape from simulated disaster situations (Tokyo Fire Department 2019).

The construction industry specifically has provided experiential safety training at safety training facilities where trainees can physically experience negative consequences of unsafe behaviors in construction sites (ACUTE Inc. 2024; Cho 2023; Park 2016; RETTEW Inc. 2023; Smith 2019). These facilities provide hands-on safety training related to construction hazards such as falls, drops, collapses, collisions, jams, and electrocutions.

Simulated Accident Experience in Safety Training

Individuals involved in an injury or accident in the past perceive higher risk than others not involved in an injury or accident (Burke et al. 2007; Duchon and Laage 1986). Emotionally negative experiences, such as accident experiences, can capture more attention and be remembered for a long time (Carstensen 2006). Studies show that virtually experiencing a possible injury or accident could have a similar effect on an individual's risk perception and risk tolerance (Bohm and Harris 2010; Daalmans and Daalmans 2012; Kim et al. 2021a, 2023a). To investigate this effect, researchers have examined the effectiveness of simulated accident experience in enhancing construction workers' risk perception. Bhandari and Hallowell (2017) showed that a naturalistic injury simulation (where the cause and effect of a hand injury is demonstrated using realistic scenarios and a hyperrealistic replica of a human hand) is effective in arousing negative emotions associated with workplace hazards and increasing risk perception. Kim et al. (2021a, 2023a) demonstrated that experiencing a virtually simulated struck-by accident in a virtual environment is effective in enhancing workers' attention to frequently encountered workplace hazards, thereby contributing to reducing workers' unsafe behaviors. Another study showed that even seeing someone's fall accident scene in a virtual environment significantly affected workers' fall risk behaviors (Shi et al. 2019).

Construction Managers' Responsibility toward Workers' Unsafe Behaviors

Building a positive safety culture has been discussed as one of the most effective ways to enhance safety performance in the construction industry. When organizations and individuals assign the highest priority to safety, workers are constantly aware of risks associated with workplace hazards and less likely to engage in unsafe behaviors (Choudhry et al. 2007). Construction managers and supervisors (hereafter, construction managers) especially play critical roles in building a positive safety culture in construction sites (Fang et al. 2020). Construction managers' responses to workers' unsafe behaviors significantly affect workers' safety attitude. When construction managers have high levels of risk perception and low levels of risk tolerance toward workers' unsafe behaviors, they are likely to notice and stop these unsafe behaviors. However, construction managers who prioritize productivity over safety are unlikely to provide prompt interventions for workers. Consequently, workers are likely to engage in unsafe behaviors more frequently. Therefore, construction managers' heightened risk perception and prompt intervention on workers' unsafe behaviors can lead to enhanced safety performance in construction sites.

Hypothesis Development

There is anecdotal evidence that experiencing *physically* simulated (which does not refer to *virtually* simulated) accidents at safety training facilities is more effective than conventional classroom-based, instructor-led safety training (Bhandari et al. 2019). Although some studies have tried to examine its effectiveness by measuring trainees' satisfaction after the training, no study has empirically examined the effect of construction safety training at training facilities. The return on investment for the construction and operation of construction safety training facilities is not clear. Therefore, only a few large construction companies have built and operated construction safety training facilities. Providing evidence of the training effect would promote the wide adoption of experiential safety training in the construction industry. To this end, this study examined whether experiencing physically simulated accidents at training facilities can enhance construction managers' risk perception and lower risk tolerance toward workers' unsafe behaviors that may lead to fall accidents.

Note that construction workers are temporarily hired for a project for a limited time (Choi et al. 2017). Therefore, currently, most construction companies provide experiential safety training at training facilities only to construction managers who are permanently employed (Seo et al. 2021). Thus, this study focused on evaluating the training effect on construction managers' risk perception and risk tolerance. The following six hypotheses were developed and tested. The first four hypotheses compare managers who participated in the training to managers who did not participate in the training; the last two hypotheses compare individual managers before and after the training.

Hypothesis 1a (between-subject effect): Construction managers who experienced physically simulated accidents at a safety training facility will perceive higher levels of risk toward workers' unsafe behaviors than others who did not participate in the safety training.

Hypothesis 1b (between-subject effect): Construction managers who experienced physically simulated accidents at a safety training facility will have lower levels of risk tolerance and will be more likely to stop workers' unsafe behaviors than others who did not participate in the safety training.

If the experiential safety training has a significant influence on managers' risk perception and risk tolerance, managers will be more sensitive to subtly unsafe behaviors *that may seem safe at first glance* and that require construction managers *to carefully pay attention* to evaluate risks of workers' unsafe behaviors (Fang et al. 2020).

Hypothesis 2a (between-subject effect): The training effects, enhancing risk perception, will be more significant in situations showing subtle safety violations.

Hypothesis 2b (between-subject effect): The training effects, lowering risk tolerance, will be more significant in situations when construction managers are required to carefully pay attention to evaluate risks of unsafe behaviors. Thus, construction managers with physically simulated experience will be more willing to stop workers' unsafe behaviors than others without the experience.

The effectiveness of training is typically evaluated by comparing behavioral changes before and after training (Joshi et al. 2021; Makransky et al. 2019).

Hypothesis 3a (within-subject effect): Experiencing physically simulated accidents at a training facility increases an individual construction manager's risk perception toward workers' unsafe behaviors.

Hypothesis 3b (within-subject effect): Experiencing physically simulated accidents at a training facility lowers an individual construction manager's risk tolerance toward workers' unsafe behaviors. After taking the training, a construction manager will be more willing (than he/she was before training) to stop workers from working in unsafe conditions.

Research Methods

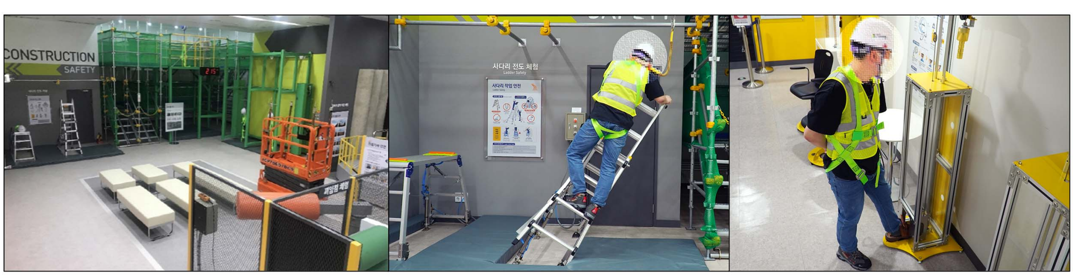
To test our six hypotheses, we designed experiments to measure changes in participants' risk perception and risk tolerance after taking the experiential safety training. The experimental settings and the data analysis process are described below.

Experiential Safety Training Facility and Experimental Setting

Experimental Environment

The experiments were performed at a safety training center of Hyundai Engineering and Construction in Seoul, South Korea. The training facility offers 19 different experiential safety training modules. Participants can experience physically simulated accidents (e.g., fall from an opening, collapse of scaffolding structures, and electrocution) and observe how safety hats and safety shoes protect one from the impact of falling objects (Fig. 1).

Accidental falls from a height to a lower level account for about 35% of fatalities in the construction industry (Grace et al. 2023). To limit the scope of our study, we focused on the training effect on participants' risk perception and risk tolerance associated with accidental falls. In the experiments, all participants experienced two safety training modules that physically simulate accidental falls: (1) experiencing the proper use of a safety harness during a fall (Fig. 2); and (2) falling to a lower level through an opening (Fig. 3). In the falling simulation training, participants were required to wear safety harnesses. The hooks of the safety harnesses were connected to a hoist designed to lift participants to a height of 3 meters. Then, participants experienced a free fall to a height of 30 cm above the ground. In the falling through an opening simulation, participants were required to climb up to the second level of the scaffolding and stand in the center of the scaffolding while wearing safety harnesses connected to a pulley. After confirming that participants were



(a) (b) (c)

Fig. 1. Experimental environment: (a) overview scene of the Hyundai engineering and construction safety training center; (b) ladder safety training module; and (c) personal protective equipment training module.

Fig. 2. Falling simulation: (a) overview scene of the training module; (b) wearing a safety harness on the ground; and (c) hanging after experiencing a fall.

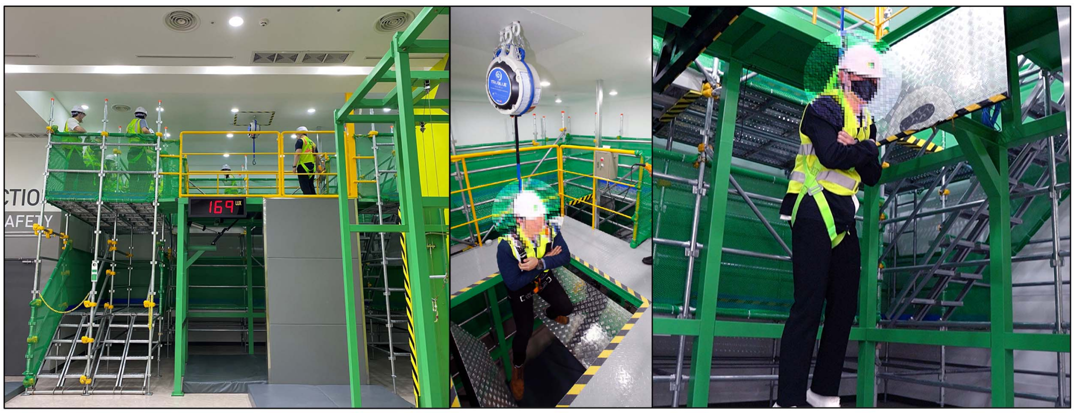


Fig. 3. Falling through an opening simulation: (a) overview scene of the training module; (b) falling through an opening; and (c) after falling.

wearing the safety harnesses correctly, the center part of the scaffolding opened, and participants fell through the opening.

Measurement of Risk Perception and Risk Tolerance

Risk perception is an individual's ability to recognize a specific level of risk, and risk tolerance refers to the level of risk that an individual is willing to take (Hunter 2002; Wickens et al. 2004). The measurement of risk perception and risk tolerance involves individuals' evaluation process of presented stimuli (Glendon and Clarke 2015). Previous studies have quantitatively measured risk perception and risk tolerance from a psychometric standpoint (Sjöberg et al. 2004; Slovic 1987; Weber et al. 2002). A measurement of risk perception generally focuses on the cognition of presented stimuli, and a measurement of risk tolerance focuses on an individual's behavioral intention associated with perceived risk (Shou and Olney 2022). One of the most widely adopted methods of measuring individuals' risk perception is asking individuals to gauge how risky presented hazards or activities might be (Niens et al. 2014). This approach is mostly done with the one-dimension measure (e.g., "How risky/dangerous is X?") with intuitive perception of presented stimuli (Wilson et al. 2019; Zhang et al. 2024). Previous studies on risk perception in the construction industry have measured construction workers' and managers' risk perception by presenting images or videos capturing unsafe working conditions or unsafe behaviors (Habibnezhad and Esmaeili 2016; Namian et al. 2018). Similarly, previous studies which focused on risk tolerance in the construction industry have quantitatively measured individuals' intentions to engage in risk-taking behaviors or physical engagements in risk-taking behaviors (Bhandari et al. 2021; Lee et al. 2022; Shi et al. 2019). Referring to the previous studies, this study measured participants' risk perception and risk tolerance by presenting images and asking participants to fill out survey questions.

In the experiments, participants' risk perception and risk tolerance toward workers' unsafe behaviors were measured using a survey. The survey consisted of four scene images, taken at a construction site, each showing a worker engaging in an unsafe behavior that violated a safety regulation and that exposed the worker to the risk of an accidental fall. Table 1 shows the four scene images and describes the unsafe behaviors. The expected effects of experiencing physically simulated falls are to enhance a construction manager's risk perception and lower the manager's risk tolerance toward workers' unsafe behaviors that may lead to an accidental fall. Thus, to rigorously evaluate the training effects, the scene images were divided into two categories: more obvious unsafe behaviors and more subtle unsafe behaviors. Scene images 1 and 4 in Fig. 4 show workers engaging in more obvious unsafe behaviors and being exposed to a significant risk of an accidental fall, while scene images 2 and 3 show workers engaging in more subtle unsafe behaviors that may seem safe at first glance and that require survey participants to carefully identify if a safety regulation is being violated. The level of perceived risk was measured using a 5-point

J. Manage. Eng., 2025, 41(1): 04024067

Table 1. Summary of hypothesis testing

No.	Hypothesis	Independent variable	Dependent variable	Effect	Statistical test
1a	Construction managers who experienced physically simulated accidents at a safety training facility will perceive higher levels of risk toward workers' unsafe behaviors than others who did not participate in the safety training.	Experiential safety training	Mean of risk perception score	Between-subject effect	Independent samples t-test
1b	Construction managers who experienced physically simulated accidents at a safety training facility will have lower levels of risk tolerance and will be more likely to stop workers' unsafe behaviors than others who did not participate in the safety training.	Experiential safety training	Mean of intention to stop score	Between-subject effect	Independent samples t-test
2a	The training effects, enhancing risk perception, will be more significant in situations showing subtle safety violations.	Experiential safety training, Scenes	Mean of risk perception score	Between-subject effect	Two-way analysis of variance (ANOVA) test
2b	The training effects, lowering risk tolerance, will be more significant in situations when construction managers are required to carefully pay attention to evaluate risks of unsafe behaviors.	Experiential safety training, Scenes	Mean of intention to stop score	Between-subject effect	Two-way analysis of variance (ANOVA) test
3a	Experiencing physically simulated accidents at a training facility increases an individual construction manager's risk perception toward workers' unsafe behaviors.	Experiential safety training	Mean of risk perception score	Within-subject effect	Paired samples t-test
3b	Experiencing physically simulated accidents at a training facility lowers an individual construction manager's risk tolerance toward workers' unsafe behaviors.	Experiential safety training	Mean of intention to stop score	Within-subject effect	Paired samples t-test

No.	Scene image	Category	Unsafe behavior
1		Obvious unsafe behavior	A worker is on a scaffold that does not have an upper guard rail.
2		Subtle unsafe behavior	A worker is on a scissor lift but is not wearing a safety harness.
3		Subtle unsafe behavior	A worker is on a scaffold that does not have properly installed middle and upper guard rails.
4		Obvious unsafe behavior	A worker is on a bench ladder and is trying to climb a wall.

Fig. 4. Construction workers' unsafe behaviors presented in the survey.

Likert scale (1 = very unsafe, 2 = unsafe, 3 = neutral, 4 = safe, 5 = very safe). Then, the level of risk tolerance was measured using a dichotomous question that asked if the work should be stopped (0 = stop, 1 = don't stop). See Appendix I for details of the survey questions.

Experimental Procedure and Hypotheses Testing

Experimental Procedure

A total of 120 participants (106 male and 14 female) participated in the experiment; they were recruited from large construction

J. Manage. Eng., 2025, 41(1): 04024067

companies in South Korea who had arranged for their employees to be trained at the training center. All participants were construction managers working in residential and commercial building construction projects; 53% of the participants had less than 5 years of working experience in the construction industry; 19% of the participants had more than 5 years and less than 10 years of experience; 15% of the participants had more than 10 years and less than 20 years of experience; and 13% of the participants had more than 20 years of experience. All participants received conventional safety training provided by construction companies they are employed. The study proposal was approved by the Institutional Review Board (IRB) at Yonsei University (IRB 202312-HR-3616-03).

To test Hypotheses 1 and 2, participants were divided into two groups: the experiential safety training group (EST) composed of 70 participants and the non-experiential safety training group (No-EST) composed of 50 participants. To clarify, the No-EST group was composed of participants who were at the training center to receive training at their employer's request, but they filled out the survey questionnaire before their training. The EST group was asked to take the survey after experiencing physically simulated falls. To test Hypothesis 3 (comparing individuals before and after the training), a total of 30 participants were randomly selected from the EST group and were asked to take the survey both before and after the safety training.

Hypotheses Testing

Hypotheses 1a and 1b were tested using independent sample t-tests. Participants' answers to each of the four survey questions were summed up to obtain a total risk perception score (from 5 to 20; each answer could be from 1 to 5) and a total risk tolerance score (from 0 to 4; each answer could be either "yes" or "no," where 0 = yes, stop working, and 1 = no, don't stop). The assumptions of independent sample t-tests were tested. The risk perception data were normally distributed, but the risk tolerance data were not normally distributed. However, the sample size of this study was large enough to find statistical significance in the results (Ghasemi and Zahediasl 2012). With large sample sizes (larger than 30 or 40), violating the normality assumption does not cause major problems (Elliott and Woodward 2007; Pallant 2020). The homoscedasticity of the risk tolerance data was significant. However, the ratio of maximum group variance to minimum group variance was less than 10:1, and the sample size per group was larger than 20. Thus, the test was robust to heteroskedasticity (Bray and Maxwell 1985; Brostrand 2006; Garson 2012). Although the sample size was large enough and the robustness to heteroskedasticity was tested, to further validate the results of the independent samples t-test, nonparametric test, and the Wilcoxon rank-sum test were performed to examine the significant difference in risk tolerance between the EST group and the No-EST group.

Two-way analysis of variance (ANOVA) tests were performed to test Hypotheses 2a and 2b. Participants' risk perception and risk tolerance scores for each scene image were used as individual sample data points. Thus, the risk perception score for each image ranged from 1 to 5, and the risk tolerance score for each image was either 0 or 1. The main effects of two variables (experiential safety training and different images of worker scenes) on participants' risk perception and intention to immediately stop workers' unsafe behavior s were tested; also tested were the interaction effects between those two variables. The number of participants in both groups were different. The Games–Howell test is recommended when sample sizes are not equal (Games et al. 1981; Games and Howell 1976; Sauder and DeMars 2019; Zgueb et al. 2020). Thus, post hoc analyses were conducted with the Games–Howell test for multiple comparisons.

Hypotheses 3a and 3b were tested using paired samples t-test and Wilcoxon rank-sum test on paired samples. The training effects (pretraining versus posttraining) on participants' risk perception and risk tolerance were evaluated. Analysis results are presented as mean (M) ± standard deviation (SD). The magnitudes of the effect of the training were measured using Cohen's effect sizes (d), with the following criteria: 0.2 = small effect, 0.5 = moderate effect, and 0.8 = large effect (Cohen 1992; Koral et al. 2018). Table 1 shows the summary of hypothesis testing on all constructed and tested hypotheses.

Results

Hypothesis 1 Results

Hypothesis 1a was confirmed through an independent samples t-test. There was a significant difference in the risk perception scores between the EST group ($M = 6.22, SD = 1.77$) and the No-EST group ($M = 7.62, SD = 2.05$); $t(118) = 3.97$, $p < 0.001$ (Fig. 5). The result indicates that individuals who participated in the experiential safety training perceived higher risks associated with unsafe behaviors in scene images than those who did not participate in the training.

The results of the Hypothesis 1b tests were consistent with the results of the Hypothesis 1a test. There was a significant difference in participants' intention to stop workers from working in unsafe conditions between the EST group ($M = 0.16, SD = 0.40$) and the No-EST group ($M = 0.54, SD = 0.78$); $t(118) = -3.48$, $p = 0.0012$. A lower score means the participant answered "yes (stop work)" more often than a participant with a higher score (Fig. 6). The result of the Wilcoxon rank-sum test was also significant. The No-EST group had a higher level of risk tolerance than the EST group, $W = 2{,}166$, $p = 0.002$ (see Table 2). Those results indicate that the EST group was more likely to immediately stop workers from working in unsafe conditions than the No-EST group, meaning the EST group had a lower tolerance for unsafe conditions.

Hypothesis 2 Results

Hypotheses 2a and 2b (referring to subtly unsafe situations) were confirmed by comparing the main effects of two variables

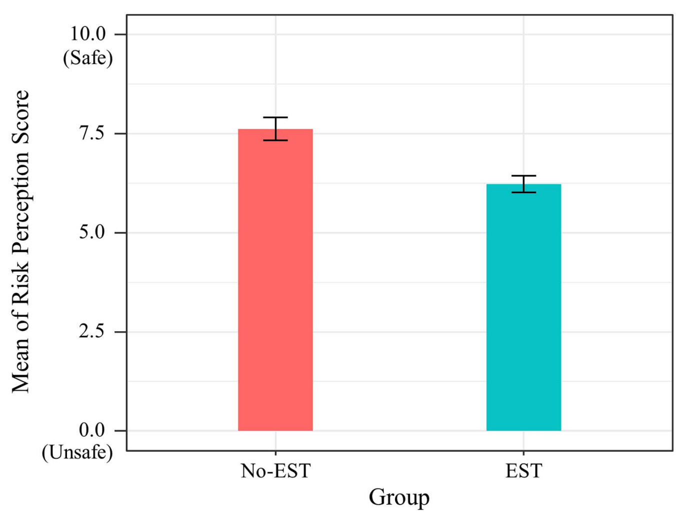


Fig. 5. Depiction of mean risk perception score (a lower score equates to a perception of higher risk). Standard error bars are included.

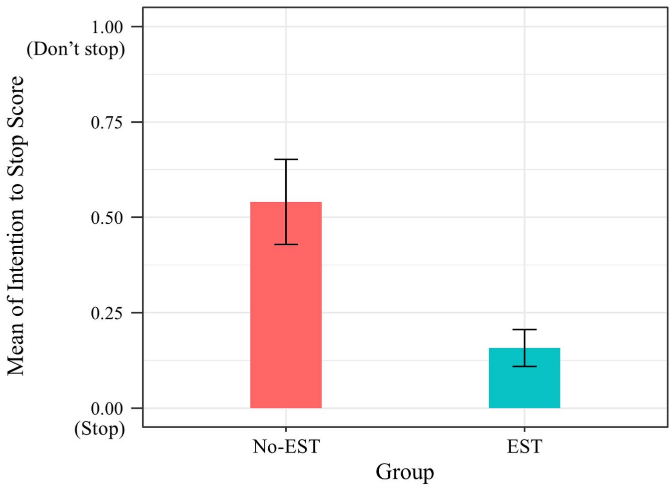


Fig. 6. Depiction of mean risk tolerance score (a lower score equates to a higher intention to stop workers' unsafe behaviors). Standard error bars are included.

Table 2. Wilcoxon rank-sum test result of risk tolerance

Group	Intention to stop score: Median	IQR	W	Z	*p*-value
No-EST	0	1	2,166	−2.995	0.002*
EST	0	0			

Note: *Significant at the $p = 0.05$ level.

Table 3. Two-way ANOVA results of risk perception: main and interaction effects of experiential safety training and scenes

Measure	Sum of squares	*df*	*F*	*p*-value
Safety training	14.12	1	26.818	<0.0001*
Scenes	31.16	3	19.730	<0.0001*
Safety training × scenes	1.89	3	1.198	0.310

Note: *Significant at the $p = 0.05$ level.

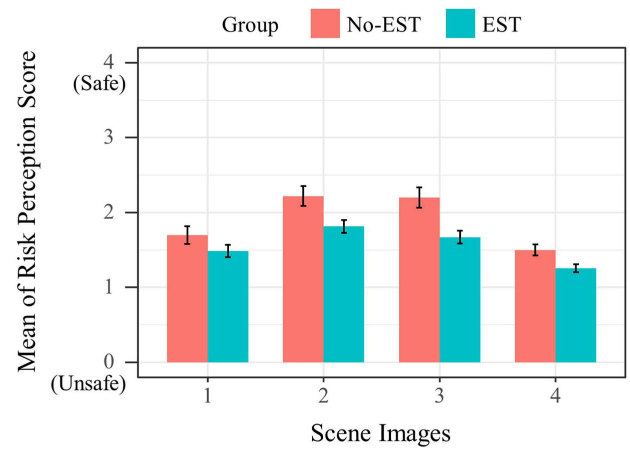


Fig. 7. Estimated marginal means of risk perception score (a lower score equates to a perception of higher risk).

(experiential safety training and scene images of worker behavior) and the interaction effects between those two variables on participants' risk perception and intention to immediately stop workers' unsafe behaviors.

Two-way ANOVA tests were conducted on the influence of two independent variables (safety training and scene images) on participants' risk perception and intention to immediately stop workers' unsafe behaviors. The safety training variable consisted of two levels (EST group and No-EST group) and the scenes variable consisted of four levels (four images that captured workers' unsafe behaviors).

Hypothesis 2a was tested using a two-way ANOVA to compare the main effects of safety training and scene images as well as their interaction effects on participants' risk perception. Experiential safety training and scene images were statistically significant at $p < 0.001$. The main effect of experiential safety training yielded an F ratio of $F(1{,}472) = 26.82$, $p < 0.001$, indicating a significant difference between the EST group ($M = 1.56, SD = 0.68$) and the No-EST group ($M = 1.91, SD = 0.88$). The marginal means by safety training groups were significantly different. The main effect of scene images yielded an effect size of 0.114. That is, 11.4% of the variance in participants' risk perception was explained by scene images $F(3{,}472) = 31.16$, $p < 0.001$, indicating that the effect of each scene was significant: Scene 1 ($M = 1.56, SD = 0.75$), Scene 2 ($M = 1.98, SD = 0.83$), Scene 3 ($1.89, SD = 0.86$), and Scene 4 ($M = 1.36, SD = 0.48$). The marginal means of different scene images were significantly different. However, the interaction effect was not significant $F(3{,}472) = 1.20$, $P = 0.31$ (Table 3 and Fig. 7).

The results of pairwise comparisons showed that the EST group's risk perception scores for Scenes 2 and 3 were significantly lower than those for the No-EST group (Table 4) (a lower score equates to a perception of higher risk). However, there were no significant differences in the risk perception scores for Scenes 1 and 4 between the two groups. This indicates that the training effect for Scenes 1 and 4, which all participants from both groups perceived as high risk, was not significant. However, the training effect was significant for Scenes 2 and 3, which the No-EST group perceived as low risk.

Hypothesis 2b was also tested with a two-way ANOVA test. All effects were statistically significant at a 0.05 significance level. The main effect for experiential safety training yielded an F ratio of $F(1{,}472) = 15.92$, $p < 0.001$, indicating a significant difference between the EST group ($M = 0.04, SD = 0.19$) and the No-EST group ($M = 0.14, SD = 0.34$). The main effect for scene images yielded an F ratio of $F(3{,}472) = 8.54$, $p < 0.001$, indicating that the effect for scene images was significant: Scene 1 ($M = 0.06, SD = 0.23$), Scene 2 ($M = 0.13, SD = 0.34$), Scene 3 (0.13, $SD = 0.33$), and Scene 4 ($M = 0, SD = 0$). Experiential safety training and scene images also interact in predicting a participant's intention to stop workers from working in unsafe conditions: $F(3{,}472) = 4.12$, $P = 0.007$ (Table 5 and Fig. 8).

The result of a Games–Howell post hoc test showed that the EST group's scores for their intention to stop workers from working in unsafe conditions for Scenes 2 and 3 were significantly lower than those for the No-EST group (a lower score means a stronger intention to stop the work). However, there were no significant differences in the intention to stop work scores for Scenes 1 and 4 between the two groups (Table 6). This indicates that the training effect for Scenes 1 and 4, in which all participants from both groups answered that they would immediately stop workers, was not significant. However, the experiential safety training effect was

Table 4. Pairwise comparisons: type of safety training × risk perception score

Training type (1)	Group (i)	Training type (2)	Group (j)	Mean difference (i-j)	S.E.	*p*-value
No-EST	Scene 1	No-EST	Scene 4	0.200	0.145	0.1688
		EST	Scene 1	0.214	0.134	0.1114
			Scene 3	0.029	0.134	0.8317
			Scene 4	0.443	0.134	0.0011*
	Scene 2	No-EST	Scene 1	0.520	0.145	0.0004
			Scene 3	0.020	0.145	0.8904
			Scene 4	0.720	0.145	<0.0001*
		EST	Scene 1	0.734	0.134	<0.0001*
			Scene 2	0.406	0.134	0.0027*
			Scene 3	0.549	0.134	<0.0001*
			Scene 4	0.963	0.134	<0.0001*
	Scene 3	No-EST	Scene 1	0.500	0.145	0.0006*
			Scene 4	0.700	0.145	<0.0001*
		EST	Scene 1	0.714	0.134	<0.0001*
			Scene 2	0.386	0.134	0.0043*
			Scene 3	0.529	0.134	<0.0001*
			Scene 4	0.943	0.134	<0.0001*
	Scene 4	EST	Scene 1	0.014	0.134	0.9154
			Scene 4	0.243	0.134	0.0713
EST	Scene 1	EST	Scene 4	0.229	0.123	0.0630
	Scene 2	No-EST	Scene 1	0.114	0.134	0.3954
			Scene 4	0.314	0.134	0.0197*
		EST	Scene 1	0.329	0.123	0.0076*
			Scene 3	0.143	0.123	0.2447
			Scene 4	0.557	0.123	<0.0001*
	Scene 3	No-EST	Scene 4	0.171	0.134	0.2026
		EST	Scene 1	0.186	0.123	0.1306
			Scene 4	0.414	0.123	0.0008*

Note: *Significant at the $p = 0.05$ level. S.E. = standard error.

Table 5. Two-way ANOVA results of intention to immediately stop workers from working in unsafe conditions: main and interaction effects of experiential safety training and scenes

Measure	Sum of squares	*df*	*F*	*p*-value
Safety training	1.07	1	15.921	<0.0001*
Scenes	1.72	3	8.543	<0.0001*
Safety training × scenes	0.83	3	4.115	0.0067*

Note: *Significant at $p = 0.05$.

significant for Scenes 2 and 3, in which most participants in the No-EST group answered that they would not stop workers.

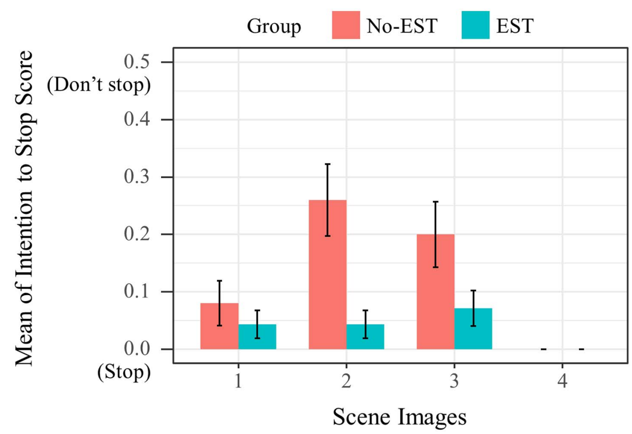


Fig. 8. Estimated marginal means of intention to immediately stop workers from working in unsafe conditions (a lower score equates to a higher intention to stop workers' unsafe behaviors).

Hypothesis 3 Results

Hypothesis 3a and 3b (comparing individuals before and after training) were confirmed through paired samples t-tests: (1) there was a significant increase in each participant's risk perception after taking the experiential safety training ($M = 6.20, SD = 1.40$) than before the training ($M = 10.03, SD = 2.44$); $t(29) = -10.15$, $p < 0.001$. The effect size (d) was 1.93, considered large by Cohen (2013); and (2) there was a significant increase in intention to immediately stop workers' unsafe behaviors after taking the experiential safety training ($M = 0.10, SD = 0.06$) than before the training ($M = 1.37, SD = 0.20$); $t(29) = -6.42$, $p < 0.001$. The effect size (d) was 1.57, considered large (see Tables 7 and 8). To further validate the results of Hypothesis 3b testing, a Wilcoxon rank-sum test on paired samples was performed. This result also confirmed Hypothesis 3b. The median weight of participants' intentions to immediately stop workers' unsafe behaviors before the training was significantly lower than after the training, $V = 276$, $p < 0.001$ (see Table 9).

Discussion

Conventional safety training (i.e., classroom-based safety training) in the construction industry has not resulted in significant decreases in accidents and injuries (Liang et al. 2022; Namian et al. 2018; Zhang et al. 2022). To address the limitation in conventional safety training and to leverage experiential learning strategies for safety training, the construction industry operates safety training facilities allowing trainees to experience physically simulated accidents (Chan et al. 2023; Fyffe 2019; Park 2016; Smith 2019). Although previous studies demonstrated that experiencing simulated accidents could arouse negative emotions and would increase the level of risk

Table 6. Post hoc comparisons: type of safety training × intention to stop workers from working in unsafe conditions

Training type (1)	Group (i)	Training type (2)	Group (j)	Mean difference (i-j)	S. E.	p-value
No-EST	Scene 1	No-EST	Scene 4	0.080	0.052	0.123
		EST	Scene 1	0.037	0.048	0.439
			Scene 2	0.037	0.048	0.439
			Scene 3	0.009	0.048	0.858
			Scene 4	0.080	0.048	0.096
	Scene 2	No-EST	Scene 1	0.180	0.052	0.001*
			Scene 3	0.060	0.052	0.248
			Scene 4	0.260	0.052	<0.0001*
		EST	Scene 1	0.217	0.048	<0.0001*
			Scene 2	0.217	0.048	<0.0001*
			Scene 3	0.189	0.048	<0.0001*
			Scene 4	0.260	0.048	<0.0001*
	Scene 3	No-EST	Scene 1	0.120	0.052	0.021*
			Scene 4	0.200	0.052	0.000*
		EST	Scene 1	0.157	0.048	0.001*
			Scene 2	0.157	0.048	0.001*
			Scene 3	0.129	0.048	0.008*
			Scene 4	0.200	0.048	<0.0001*
EST	Scene 1	No-EST	Scene 4	0.043	0.048	0.372
		EST	Scene 4	0.043	0.044	0.328
	Scene 2	No-EST	Scene 4	0.043	0.048	0.372
		EST	Scene 1	0.000	0.044	1.000
			Scene 4	0.043	0.044	0.328
	Scene 3	No-EST	Scene 4	0.071	0.048	0.137
		EST	Scene 1	0.029	0.044	0.515
			Scene 2	0.029	0.044	0.515
			Scene 4	0.071	0.044	0.104
	Scene 4	No-EST	Scene 4	0.000	0.048	1.000

Note: *Significant at the $p = 0.05$ level. S.E. = standard error.

Table 7. Effect of experiential safety training on risk perception: paired samples t-test and effect size

Parameter	Value
Risk perception	
Before	
M	10.03
SD	2.44
After	
M	6.2
SD	1.4
t	−10.15
p-value	<0.001*
Cohen's d (effect size)	1.93 (large)

Note: *Significant at $p = 0.05$.

Table 8. Effect of experiential safety training on intention to stop workers from unsafe conditions: paired samples t-test and effect size

Parameter	Value
Intention to stop	
Before	
M	1.37
SD	0.20
After	
M	0.10
SD	0.06
t	−6.42
p-value	<0.001*
Cohen's d (effect size)	1.57 (large)

Note: *Significant at $p = 0.05$.

Table 9. Wilcoxon rank-sum test result of risk tolerance

Experiential safety training	Intention to stop score		V	Z	p-value
	Median	IQR			
Before	1	1	276	−4.287	<0.001*
After	0	0			

Note: *Significant at the $p = 0.05$ level.

perception toward workplace hazards (Bhandari and Hallowell 2017; Duffy et al. 2004), there remains a paucity of empirical evidence on the effectiveness of experiencing physically simulated accidents in enhancing trainees' risk perception toward unsafe behaviors. To this end, this study assessed changes in construction managers' risk perception and risk tolerance toward workers' unsafe behaviors. The findings of this study provide initial evidence on the effectiveness of leveraging experiential learning strategies for construction safety training, thereby promoting the wide adoption of experiential safety training in the construction industry.

Training Effects of Physical Accident Simulations

Previous studies that investigated the effectiveness of construction safety training have mostly focused on measuring trainees' hazard identification capabilities (Albert et al. 2014; Eiris et al. 2021; Sacks et al. 2013). However, having a high level of hazard identification does not mean that an individual properly perceives risks of identified hazards (Anderson et al. 2023; Inouye 2014). The levels of individuals' risk perception and risk tolerance are closely associated to behavioral responses (Shi et al. 2019; Weyman and Clarke 2003). To this end, this study examined changes in participants' risk perception and risk tolerance.

J. Manage. Eng., 2025, 41(1): 04024067

The result of testing Hypothesis 1 supports previous studies that explored the potential effectiveness of experiential safety training (Bhandari and Hallowell 2017; Eiris et al. 2020b). The result shows that, overall, construction managers who participated in the experiential safety training perceived higher risk than other managers who did not participate in the training. The enhanced risk perception contributed to construction managers' intention to intervene and correct workers' unsafe behaviors by immediately ordering workers to stop working in hazardous conditions.

Risk tolerance has been discussed as a mediating factor of risk perception and unsafe behaviors in workplaces (Salas et al. 2020). Lowering risk tolerance would reduce individuals' engagements in risky/unsafe behaviors. Thus, risk tolerance should be considered as an important factor in safety management (Robson et al. 2007). However, due to disparities in the levels of individuals' risk tolerance, it is challenging to measure the effectiveness of safety training in risk tolerance changes. Wang et al. (2016) found that lowering the intolerable level of perceived risk could promote individuals' safe decisions even when perceived risk of hazards is not very high. Referring to the previous findings, Hypothesis 2 testing further investigated how the training effect varies in more subtly risky situations. For Scenes 1 and 4 in Table 1 that show workers are engaged in more obviously unsafe behaviors and are exposed to a significant risk of a fall, both groups perceived high risks, and all participants answered that they would immediately intervene and correct the workers' unsafe behaviors. Therefore, there was no significant difference between the two groups' responses. However, the training effect was significant for situations showing subtle safety violations (Scenes 2 and 3 in Table 1) where participants needed to carefully identify if a safety regulation was being violated. In contrast, the No-EST group's level of perceived risk was low for these scenes, and most of them answered that they would not stop the work. However, the EST group perceived higher risks and was willing to immediately stop the worker. This result implies that the experiential safety training at a training center is especially effective in situations that may seem safe at first glance and require construction managers to carefully pay attention to evaluate risks associated with workers' unsafe behaviors. This finding further implies that participating in experiential safety training is effective in lowering construction managers' risk tolerance, thereby helping them become more sensitive to workers' unsafe behaviors and to workplace hazards in construction sites. Furthermore, this outcome is in accordance with a related study that examined the effectiveness of experiencing injury simulations in arousing negative emotions and its potential contribution in enhancing risk perception toward workplace hazards (Bhandari et al. 2019; Bhandari and Hallowell 2017).

The results of testing Hypothesis 3 (comparing individuals before and after training) also show that training had a significant effect on construction managers' risk perception levels and on their willingness to stop workers from working in unsafe conditions. Before the training, participants perceived low levels of risks associated with workers' unsafe behaviors. However, after taking the training, participants' risk perception levels were significantly increased, and participants responses to workers' unsafe behaviors were more rigorous. The intention to stop workers' working significantly increased. These findings indicate that experiential safety training at training centers would be specifically effective for construction managers who perceive relatively low risk toward workers' unsafe behaviors in construction sites.

Separately, an additional experiment within a virtual environment was conducted. However, this experiment had limitations, so its results are reported as supplemental information here, rather than above in the results section. The safety training center where the main experiment was performed also has a VR safety training system that allows trainees to experience a fall accident in a virtual environment (Appendix II). Virtual reality-based safety training has been recently gaining attention as another experiential safety training method. Thus, as a part of this study, the difference in the effectiveness of experiencing a *physical* fall accident and experiencing a virtual fall accident in a virtual environment was examined. A total of 30 additional participants experienced the virtual fall accident in the virtual environment and were asked to answer the same survey questions used in the main experiment. All additional participants were also construction managers.

The result of an independent samples t-test demonstrated a significant difference in the risk perception scores for the EST group ($M = 6.22, SD = 1.77$) and the virtual accident group ($M = 8.5, SD = 2.58$); $t(68) = -4.09$, $p < 0.001$. Likewise, the result of an independent samples t-test demonstrated a significant difference in the intention to immediately stop workers for the EST group ($M = 0.2, SD = 0.46$) and the virtual accident group ($M = 0.8, SD = 0.97$); $t(68) = -3.36$, $p = 0.001$. The results indicate that *physically* experiencing fall accidents is more effective than *virtually* experiencing fall accidents in promoting construction managers' risk perception toward workers' unsafe behaviors.

Although a VR environment can provide immersive training experiences, participants' movements in a VR environment were somewhat limited (Li et al. 2018), and the visualization of physical effects are still less immersive than a physically simulated experience at a real-world training center. These limitations of the VR training system may have led to the differences in the training effects between the two groups. However, in this experiment, the duration of the VR training was shorter than the duration of the physical safety training, so this could also affect the results. Additionally, in the facility where this experiment was conducted, the VR training covered fewer topics than the physical safety training.

Limitations

This study has three limitations. First, although most safety training centers are equipped with *similar* training facilities that allow trainees to physically experience negative consequences of unsafe behaviors in construction sites, each training center may provide different training experiences. The training for this study was performed at a safety training center in South Korea. To generalize the results of this study, future studies should be performed at different training centers. Second, the sample sizes of the two experimental groups were not equal. The participants were randomly recruited from groups of trainees who were at the center and were required by their employers to take the experiential safety training. Thus, the numbers of trainee groups were different every day. Participants from the same company were assigned to the same experiment group (either the EST group or the No-EST group). During data analysis, this limitation was addressed by adopting the Games–Howell post hoc test, which is widely used in the analysis of main or simple effects of independent variables on a dependent variable using data from unequally distributed samples. Third, participants from the same company share the same safety culture of their company, and such a safety culture may have affected the participants' risk perception. However, the influence of the safety climate and the safety culture of the participants' company were not considered in this study. Future studies will investigate how the differences in the safety climate and the safety culture of construction companies affect the effectiveness of experiential safety training at safety training centers. Fourth, this study examined the effectiveness of experiential safety training which is provided in a safety training facility. The participants of this study visited this training center as customers as well as trainees, and employers of participants made payments for the training. Although participants voluntarily participated in this study, they had to take all types of training in a limited time. Thus, the study had to be concise, and a limited number of scene images were used for the survey questions. Including more scene images would significantly support the results of this study. Fifth, Kolb's experiential learning cycle involves not only short-term experience but also long-term learning in one's life situation (Kolb 2014). Thus, providing the experiential safety training as a long-term experience and examining its long-term effect on participants' risk perception and risk tolerance would be important. However, this study only measured immediate perception change after participating in the experiential safety training.

Conclusion

This study investigated the effectiveness of experiential safety training at training facilities that allows trainees to physically experience possible accidents in construction sites. In particular, this study focused on risk perception of unsafe behaviors that may lead to crucial fall accidents.

Our results show that construction managers who received training showed significantly enhanced risk perception in situations that presented subtle safety risks (that is, in situations that looked safe at first glance and required managers to carefully pay attention to determine the risks associated with workers' unsafe behaviors) compared to those managers who had not received training. Construction managers who received training showed significantly lower risk tolerance and a stronger intention to intervene in workers' unsafe behaviors than managers who had not received training. This result implies that the experiential safety training at physical training facilities helps construction managers more rigorously evaluate and perceive workers' unsafe behaviors. Moreover, the finding from the pre- and posttreatment analysis of individuals suggests that the experiential safety training is effective for managers who initially tend to perceive less risk toward workers' unsafe behaviors.

Therefore, the results also broadly support the effectiveness of experiential safety training in establishing a better safety climate and a safety culture in construction sites. The outcomes of this study contribute to the existing body of knowledge by providing empirical evidence on the effectiveness of experiential safety training at safety training centers, thereby promoting the wide adoption of experiential safety training in the construction industry. The findings of this study also provide new knowledge about how to empirically measure the training effect of experiential safety training at safety training facilities and advancing safety engineering and management strategies in the construction industry.

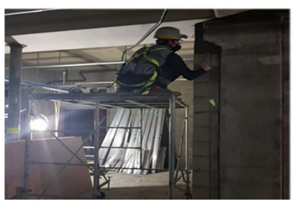
No.	Scene image	Question	Answer
1		How dangerous is this workers' behavior?	1 = very unsafe 2 = unsafe 3 = neutral 4 = safe 5 = very safe
2		How dangerous is this workers' behavior?	1 = very unsafe 2 = unsafe 3 = neutral 4 = safe 5 = very safe
3		How dangerous is this workers' behavior?	1 = very unsafe 2 = unsafe 3 = neutral 4 = safe 5 = very safe
4		How dangerous is this workers' behavior?	1 = very unsafe 2 = unsafe 3 = neutral 4 = safe 5 = very safe

Fig. 9. Survey questionnaire for the risk perception measurement.

This study only examined the effectiveness of the experiential safety training in enhancing construction managers' risk perception toward workers' unsafe behaviors. All participants were construction managers. Therefore, the effectiveness of the training for construction workers was not examined. Thus, further experiments with construction workers are an essential next step to validate the experiential safety training at training centers. A future study will investigate the efficacy of experiential safety training in a real-world setting by assessing construction managers' attention and sensitivity toward workers' unsafe behaviors.

Existing experiential safety training centers include many other types of training facilities that allow trainees to experience different hazardous situations, such as working on a step ladder and working close to electrical hazards. Examining the effectiveness of the experiential safety training in enhancing risk perception toward other types of hazards is an important future study that may generalize the training effect and promote the wide adoption of experiential safety training in other high-risk industries, such as mining and agricultural, which consistently record high accident rates.

Appendix I. Survey Questionnaires for the Risk Perception and Tolerance Measurement

Figs. 9 and 10 show survey questionnaires provided to participants to examine the risk perception and the risk tolerance levels, respectively.

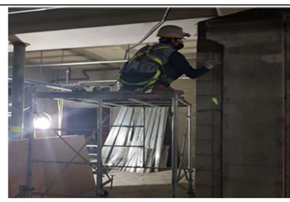
No.	Scene image	Question	Answer
1		Will you immediately stop this worker from working in this condition?	Yes = Stop working No = Don't stop
2		Will you immediately stop this worker from working in this condition?	Yes = Stop working No = Don't stop
3		Will you immediately stop this worker from working in this condition?	Yes = Stop working No = Don't stop
4		Will you immediately stop this worker from working in this condition?	Yes = Stop working No = Don't stop

Fig. 10. Survey questionnaire for the risk tolerance measurement.

(a) (b) (c)

Fig. 11. VR safety training system at the training center: (a) overview of the VR training module; (b) walking a construction site in the VR environment; and (c) fall from height in the VR environment.

Appendix II. Virtual Reality Safety Training System at the Training Center

Fig. 11 illustrates the virtual reality-based safety training at the training center.

Data Availability Statement

All data, models, and code generated or used during the study appear in the published article.

Acknowledgments

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