

## **ABSTRACT**

NAMIAN, MOSTAFA. Factors Affecting Construction Hazard Recognition and Safety Risk Perception. (Under the direction of Dr. Alex Albert).

Construction hazard recognition and the accurate perception of safety risk are fundamental to the success of any safety management program. When hazards remain unrecognized, or the associated safety risk is underestimated, the likelihood of catastrophic and unexpected injuries dramatically increases. Unfortunately, recent research has shown that a large number of hazards remain unrecognized in construction workplaces. Likewise, past studies have demonstrated that safety risk is widely underestimated within construction. Therefore, to improve safety performance, a proper understanding of factors that influence hazard recognition and safety risk perception is vital. Towards achieving this goal, the objective of the research was to evaluate the effects of three factors – namely (1) safety training methods, (2) training transfer elements, and (3) workplace distractions – on hazard recognition and safety risk perception.

The research objectives were accomplished through three independent studies. Study I focused on evaluating the effect of training on hazard recognition performance and safety risk perception, Study II focused on evaluating the role of training transfer elements in ensuring that concepts learned in training are adopted at the workplace, and Study III examined the effect of distraction on hazard recognition and safety risk perception.

The objectives of Study I and Study II were accomplished by gathering empirical data from 51 active projects in the United States. Specifically, data pertaining to the training method (i.e., high-engagement versus low-engagement training) and training transfer elements adopted at the project level were gathered, following which the hazard recognition ability of representative workers and their safety risk perception levels were measured. The results

revealed that (1) compared to low-engagement training, high-engagement training is associated with higher levels of hazard recognition and safety risk perception; (2) the effect of training on safety risk perception is mediated by hazard recognition performance; and (3) training efforts may be undermined if training transfer elements are not synergistically adopted.

The objectives of Study III were accomplished through an experimental effort involving 70 construction workers who were randomly assigned to a distracted or an undistracted condition. While in the assigned condition the worker's hazard recognition performance and safety risk perception levels were measured using construction case images captured from real projects. The findings revealed that the distracted workers recognized a smaller proportion of hazards compared to the undistracted workers. However, there were no significant differences in the level of perceived safety risk between the two groups.

This study advances knowledge by examining factors that affect hazard recognition and safety risk perception levels among construction workers. It is expected that the research, presented in this dissertation, will be beneficial to construction professionals and workers seeking to improve hazard recognition levels and safety outcomes in construction.

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Factors Affecting Construction Hazard Recognition and Safety Risk Perception

by  
Mostafa Namian

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APPROVED BY:

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Alex Albert, Committee Chair

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Edward Jaselskis

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Kevin Han

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Jing Feng

## DEDICATION

To my Dad, Asadollah Namian, who has been dedicating his life to his family;

To my Mom, Zahra Cheraghsepehr, my very first teacher, for her endless love;

To my sisters, Tahereh and Samaneh, who have always loved me unconditionally;

To my nephew and niece, Hossein and Fatemeh, who are part of my heart;

And

To my lovely wife, Mona Doostmohammadi, who loved and accompanied me during this journey. Without her endless sacrifice and support, this could not have been accomplished; and

To my daughter, who will be born soon but she has already changed my life and made me a better person!

I am truly blessed to have them all in my life.

And last but not least,

*To the ancient immigrants and my ancestors, who were truly motivated to overcome life-threatening challenges.*

## **BIOGRAPHY**

Mostafa Namian was born in Hamedan, Iran on September 19, 1985. His parents encouraged and helped him to succeed and prospered in education. Mostafa attended the Allameh-Helli School for exceptional talented students and graduated in 2003. He enrolled at Buali-Sina University to pursue his bachelors' in Civil Engineering. After he graduated in 2007, he continued his education in construction, engineering, and management at Amirkabir University of Technology (Tehran Polytechnic). Mostafa studied fuzzy expert systems to apply them in construction for his Master's research.

Following graduation in 2010, he worked in a construction field for several years until he moved to the United States in 2014 to continue his academic journey pursuing a Doctor of Philosophy degree in construction engineering under the direction of Dr. Alex Albert at North Carolina State University (NCSU).

During his Ph.D., Mostafa studies the factors that impact construction workers' hazard recognition performance and how their safety risk perception is affected by the factors. Strictly speaking, he explored safety training method, training transfer elements, and distraction on the safety performance of workers in construction.

Mostafa's research interests include but are not limited to construction safety, hazard recognition, safety risk perception, construction workers' behavior, and visual sensing in construction. Moreover, he is an FAA certified remote sensing pilot, permitted to commercially fly Unmanned Aerial Vehicles (UAVs). He tries to adopt the emerging technologies to the construction industry.

Mostafa is also a social entrepreneur. Along with his academic education at NC State, Mostafa had been following his dream to make an impact on societies. He led the NC State

University's team competing for the Hult Prize in 2015. His idea, "cense," had been chosen from an applicant pool of 25,000. "cense" is an advertising platform for street vendors in slum areas. As now, Mostafa is working on another idea to help people in all over the world to improve their lives. Besides, he is collaborating with scholars to expand his PhD research and conducting further studies in construction.

This document presents the culmination of the study and knowledge gained during his Ph.D. journey at NC State.

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# **CHAPTER I: INTRODUCTION**

## **PROBLEM STATEMENT AND RESEARCH SCOPE**

Every year, over 60,000 fatalities are reported from construction projects around the globe (Lingard 2013). Despite improvements in safety management practices, the number of fatal and non-fatal injuries in construction are unacceptably high. In fact, the number of fatal construction injuries in the United States increased from 781 in 2011 to 937 in 2015 (BLS 2015; BLS 2012). Likewise, more than 200,000 non-fatal construction injuries have been reported in 2015 (BLS 2015). These injuries result in substantial losses, not only to workers and employers but also to the society as a whole (Ikpe et al. 2012). In fact, evidence suggests that the cost of construction injuries in the United States exceed \$48 billion each year (Ahmed et al. 2006).

To address the issue of poor safety performance and high injury rates, scholars and construction professionals have dedicated much effort to studying and identifying precursors to safety incidents. More specifically, researchers have reviewed and analyzed construction injury reports to understand injury causal factors. Among these, human factors have received much recent attention. For example, Rasmussen (1997) found that human error is a key causal factor in 70% to 80% of safety incidents in construction. More recently, Haslam et al. (2005) reviewed 100 construction injury reports and found that over 70% of the injuries can be attributed to unsafe behavior.

Evidence suggests that the underlying reason for much of the observed unsafe behaviors in construction is poor hazard recognition and safety risk perception among workers (Fang et al. 2016). In fact, past research has demonstrated that over two out of every five construction injuries are associated with worker-related factors including inferior hazard recognition and the inaccurate perception of safety risks (Haslam et al. 2005).

Hazard recognition is generally regarded as the first step in the safety management process. This is followed by the assessment of safety risk and the adoption of effective safety risk control measures for injury prevention. When workers fail to recognize safety hazards or underestimate the associated safety risk, they are more likely to indulge in risk-taking behaviors (Carter and Smith 2006). On the other hand, when workers are able to identify safety hazards and accurately assess the associated safety risks, most construction injuries can be prevented (Albert and Hallowell 2012).

Despite the key role of hazard recognition in injury prevention, a large number of hazards remain unrecognized in construction workplaces. Several studies from the United States have shown that over 40% of safety hazards remain unrecognized in typical work environments (Albert et al. 2014). Likewise, case studies from the United Kingdom revealed that up to one-third of hazards remain unrecognized in projects that were examined (Carter and Smith 2006). More shockingly, an independent study from Australia found that novice workers fail to recognize more than 57% of hazards in work representative environments (Bahn 2013).

In addition to their poor hazard recognition performance, construction workers largely underestimate safety risk associated with hazards (Albert et al. 2014). However, when safety risk is accurately perceived, workers are more likely to adopt responsive safety measures to prevent injuries (Arezes and Miguel 2008). On the other hand, when safety risk is underestimated or inaccurately perceived, safe decisions are unlikely to logically follow – and the likelihood of workplace injuries increases (Taylor and Snyder 2017). Apart from safety risk management, the underestimation of safety risk is also highly correlated with risk-taking behaviors (Patel and Jha 2014; Tixier et al. 2014). For example, studies have shown that experienced workers that frequently use ladders to work at heights (e.g., ironworkers and

painters) may become desensitized to the associated safety risk, even when they recognize fall-potential as a relevant safety hazard (Perlman et al. 2014). Other commonly observed risk-taking behaviors that result from the underestimation or the inaccurate perception of safety risk include working without the required personal protective equipment (PPE), entering restricted work areas, operating equipment at unsafe speeds, and the removal of equipment safety features (Bohm and Harris 2010; Chi et al. 2012; Choudhry and Fang 2008). Such risk-taking behaviors are extremely common in construction workplaces and account for the majority (up to 70%) of workplace safety incidents (Haslam et al. 2005).

Therefore, a thorough understanding of factors that impact the hazard recognition performance and safety risk perception of workers is essential. Among other factors, safety training and distraction have received much recent attention of researchers and practitioners (Namian et al. 2016; Albert et al. 2014; Hinze 1997). Employers adopt a wide variety of training programs to improve hazard recognition and safety risk perception. However, the prevalent use of ineffective, unengaging, and poorly designed training programs significantly impedes training outcomes (Wilkins 2011). In fact, Li et al. (2012) claimed that a positive correlation does not exist between traditional safety training and safety performance. Not surprisingly, workers lack essential safety knowledge despite having received substantial safety training (Haslam et al. 2005). Moreover, distractions are ubiquitous in dynamic environments such as construction.

Accordingly, the focus of the current study was to assess the effect of training, training transfer elements, and distraction on hazard recognition and safety risk perception. For effective training, employers must adopt training practices that will yield maximum benefits. The goal of these training programs is to help and equip workers with the effective skills

necessary to identify and manage hazards in complex environments (Hinze and Gambatese 2003). Moreover, the issue of training transfer in construction largely remains unaddressed. Training transfer refers to the extent to which concepts and practices learned via training is actually transferred or replicated in the workplace (Blume et al. 2010). The topic of training transfer is important because estimates reveal that only 10 to 15% of training investments translate into desirable workplace changes, practices, or benefits (Baldwin and Ford 1994; Cromwell and Kolb 2004). In other words, the bulk of training expenditure does not translate into tangible benefits but is reduced to wasted resources.

Further, distraction has been argued to have adverse effects on construction safety. Although a number of studies have examined the effect of distraction in other domains such as transportation, aviation, and medicine (Rivera-Rodriguez and Karsh 2010; Young and Salmon 2012), only anecdotal and theoretical propositions (e.g., Hinze's distraction theory) are available in the construction literature (Hinze 1997). The current research represents the first attempt to test these propositions using an experimental approach.

## RESEARCH OBJECTIVES

The objective of the research was to identify and evaluate factors that impact construction hazard recognition and safety risk perception. Based on a review of past literature, the following hypotheses were developed and tested as presented in the subsequent chapters.

***Hypothesis 1:*** High engagement training will be associated with higher levels of *hazard recognition* compared to low engagement training.

***Hypothesis 2:*** High engagement training will be associated with higher levels of *perceived safety risk (i.e., safety risk perception)* compared to low engagement training.

***Hypothesis 3:*** The relationship between training methods (i.e., low engagement training vs. high engagement training) and hazard recognition performance will depend on the training transfer level.

***Hypothesis 4:*** Distracted workers will recognize a smaller proportion of construction hazards compared to undistracted workers.

***Hypothesis 5:*** Distracted workers will perceive lower levels of safety risk (i.e., safety risk perception) compared to undistracted workers.

## **ORGANIZATION OF RESEARCH DISSERTATION**

This dissertation is organization in the format of three accepted journal articles. Therefore, each subsequent chapter includes an abstract, introduction, research objectives, research methods, contributions and referenced articles. Chapter 2, 3, and 4 presents the motivation, methods, and findings of Study I, II, and III, respectively. Finally, Chapter 5 summarizes the main findings and contributions of this research.

## REFERENCES

- Ahmed, S. M., Azhar, S., Forbes, L. H. (2006). "Costs of Injuries/Illnesses and Fatalities in Construction and their Impact on the Construction Economy." *CIB W99" Jian Zhu an Quan Yu Jian Kang De Quan Qiu He Zuo" Guo Ji Hui Yi Lun Wen Ji*, 363.
- Albert, A., and Hallowell, M. R. (2012). "Hazard Recognition Methods in the Construction Industry." *Construction Research Congress 2012*.
- Albert, A., Hallowell, M. R., Kleiner, B., Chen, A., Golparvar-Fard, M. (2014). "Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality." *J. Constr. Eng. Manage.*, 140(7).
- Arezes, P. M., and Miguel, A. S. (2008). "Risk Perception and Safety Behaviour: A Study in an Occupational Environment." *Saf. Sci.*, 46(6), 900-907.
- Bahn, S. (2013). "Workplace Hazard Identification and Management: The Case of an Underground Mining Operation." *Saf. Sci.*, 57, 129-137.
- Baldwin, T. T., and Ford, J. K. (1994). "Transfer of Training: A Review and Directions for Future Research." *The Training and Development Sourcebook*, 180-207.
- Blume, B. D., Ford, J. K., Baldwin, T. T., Huang, J. L. (2010). "Transfer of Training: A Meta-Analytic Review." *Journal of Management*, 36(4), 1065-1105.
- Bohm, J., and Harris, D. (2010). "Risk Perception and Risk-Taking Behavior of Construction Site Dumper Drivers." *Int. J. Occup. Saf. Ergonomics*, 16(1), 55-67.

Bureau of Labor Statistics (BLS). "Injuries, illness, and fatalities." <<http://www.bls.gov/iif/>> December 2014).

Bureau of Labor Statistics (BLS). "National census of fatal occupational injuries in 2014." <<http://www.bls.gov/news.release/cfoi.nr0.htm>> October 2015).

Carter, G., and Smith, S. (2006). "Safety Hazard Identification on Construction Projects." *J. Constr. Eng. Manage.*, 132(2), 197-205.

Chi, S., Han, S., Kim, D. Y. (2012). "Relationship between Unsafe Working Conditions and Workers' Behavior and Impact of Working Conditions on Injury Severity in US Construction Industry." *J. Constr. Eng. Manage.*, 139(7), 826-838.

Choudhry, R. M., and Fang, D. (2008). "Why Operatives Engage in Unsafe Work Behavior: Investigating Factors on Construction Sites." *Saf. Sci.*, 46(4), 566-584.

Cromwell, S. E., and Kolb, J. A. (2004). "An Examination of Work-Environment Support Factors Affecting Transfer of Supervisory Skills Training to the Workplace." *Human Resource Development Quarterly*, 15(4), 449.

Fang, D., Zhao, C., and Zhang, M. (2016). "A Cognitive Model of Construction Workers' Unsafe Behaviors." *Journal of Construction Engineering and Management*, 142(9), 04016039.

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., Duff, A. R. (2005). "Contributing Factors in Construction Accidents." *Appl. Ergon.*, 36(4), 401-415.

Hinze, J. (1997). "The distractions theory of accident causation." CIB Rep., A.A. Balkema, Rotterdam, Netherlands.

Hinze, J., and Gambatese, J. (2003). "Factors that Influence Safety Performance of Specialty Contractors." *J. Constr. Eng. Manage.*, 129(2), 159-164.

Ikpe, E., Hammon, F., and Oloke, D. (2012). "Cost-Benefit Analysis for Accident Prevention in Construction Projects." *J. Constr. Eng. Manage.*, 138(8), 991–998.

Li, H., Chan, G., Skitmore, M. (2012). "Visualizing Safety Assessment by Integrating the use of Game Technology." *Autom. Constr.*, 22, 498-505.

Lingard, H. (2013). "Occupational Health and Safety in the Construction Industry." *Constr. Manage. Econ.*, 31(6), 505-514.

Namian, M., Zuluaga, C. M., and Albert, A. (2016). "Critical Factors That Impact Construction Workers' Hazard Recognition Performance." *Construction Research Congress 2016*.

Patel, D., and Jha, K. (2016). "Evaluation of construction projects based on the safe work behavior of co-employees through a neural network model." *Saf. Sci.*, 89, 240–248.

Perlman, A., Sacks, R., Barak, R. (2014). "Hazard Recognition and Risk Perception in Construction." *Saf. Sci.*, 64, 22-31.

Rasmussen, J. (1997). "Risk Management in a Dynamic Society: A Modelling Problem." *Saf. Sci.*, 27(2), 183-213.

Rivera-Rodriguez, A. J., and Karsh, B. T. (2010). "Interruptions and Distractions in Healthcare: Review and Reappraisal." *Qual. Saf. Health. Care.*, 19(4), 304-312.

Taylor, W. D., and Snyder, L. A. (2017). "The Influence of Risk Perception on Safety: A Laboratory Study." *Saf. Sci.*, 95, 116-124.

Tixier, A. J., Hallowell, M. R., Albert, A., van Boven, L., Kleiner, B. M. (2014). "Psychological Antecedents of Risk-Taking Behavior in Construction." *J. Constr. Eng. Manage.*, 140(11), 04014052.

Young, K. L., and Salmon, P. M. (2012). "Examining the Relationship between Driver Distraction and Driving Errors: A Discussion of Theory, Studies and Methods." *Saf. Sci.*, 50(2), 165-174.

Wilkins, J. R. (2011). "Construction Workers' Perceptions of Health and Safety Training Programmes." *Constr. Manage. Econ.*, 29(10), 1017-1026.

## **CHAPTER II: ROLE OF SAFETY TRAINING (STUDY I)**

## **ABSTRACT**

Hazard recognition and the accurate perception of safety risk are fundamental to the success of any safety program. When hazards remain unrecognized, or the associated safety risk is underestimated, the likelihood of catastrophic and unexpected injuries dramatically increase. Unfortunately, recent research has found that a large number of hazards in construction remain unrecognized. Likewise, past studies have demonstrated that safety risk is widely underestimated within construction. To improve hazard recognition and the accurate perception of safety risk, employers adopt a wide variety of training programs. However, the prevalent use of ineffective and unengaging training methods have significantly impeded training efforts in construction. The purpose of this research was to assess the impact of safety training on two objective training outcomes: hazard recognition performance and safety risk perception. The research objectives were accomplished by gathering empirical data from 51 active projects in the United States. Specifically, data pertaining to the training method (i.e., high-engagement versus low-engagement training) adopted at the project level were gathered, following which the hazard recognition ability of representative workers and their safety risk perception levels were measured. The results of the study revealed that (1) compared to low-engagement training, high-engagement training is associated with higher levels of hazard recognition and safety risk perception; and (2) the effect of training on safety risk perception is mediated by hazard recognition performance. Therefore, workers representing projects that offered high-engagement training were able to identify a larger proportion of hazards, and consequently perceived that safety risk was relatively higher. The findings of this study will be useful to practicing professionals seeking to improve training delivery, hazard recognition performance, and the perception of safety risk within construction. This study represents the

first formal attempt to empirically evaluate the holistic relationship between training, hazard recognition, and safety risk perception in the construction context.

## **INTRODUCTION**

Every year, more than 60,000 fatalities are reported from construction projects around the world (Lingard 2013). In the United States, the Bureau of Labor Statistics reported 908 fatal injuries and more than 200,000 non-fatal injuries in 2014 (BLS 2015). Despite significant advances in safety management research and practice, unacceptable injury rates in construction continue to be a worldwide pattern. Apart from emotional and physical distress, the annual cost of these injuries exceed 48 billion in the United States (Ahmed et al. 2006), and adversely impact profit margins and project success (Zou and Sunindijo 2015).

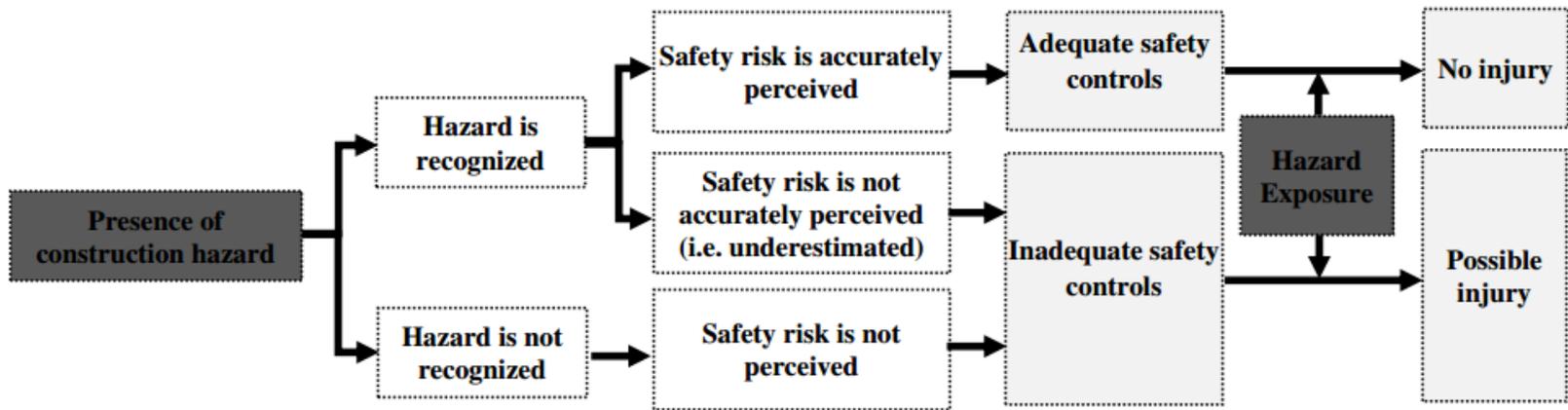
To address poor safety performance, researchers and construction professionals have devoted much effort to understanding and identifying precursors to injury incidents. Among others, human factors have received much recent attention. For example, Hinze et al. (2006) and Haslam et al. (2005) found that over 70% of construction injuries involve unsafe worker actions. Tixier et al. (2012) explain that such unsafe worker actions are not deliberate safety violations, but are rather outcomes resulting from poor hazard recognition and safety risk perception.

To illustrate the importance of hazard recognition and safety risk perception, a simple conceptual model of the safety management process is proposed as shown in Figure 2.1. As the model illustrates, hazard recognition is generally regarded as the first step in the safety management process. This is followed by the assessment of safety risk and the adoption of effective safety controls to prevent injury. Therefore, when hazards are not recognized, or

when the safety risk is not accurately perceived, workers may not be able to adopt effective safety measures to prevent injury (Albert et al. 2014). Unfortunately, recent studies have found that a large number of construction hazards remain unrecognized (Albert et al. 2014; Bahn 2013; Carter and Smith 2006). Further, studies have shown that the underestimation of safety risk, even when hazards are recognized, is a widespread problem within construction (Shin et al. 2014).

To overcome these issues, employers adopt a wide variety of training programs to improve hazard recognition and safety risk perception. However, the prevalent use of ineffective, unengaging, and poorly designed training programs significantly impede training efforts (Wilkins 2011). In fact, Li et al. (2012) argue that a positive correlation does not exist between traditional safety training and safety performance. Not surprisingly, workers lack essential safety knowledge despite having received substantial safety training (Haslam et al. 2005).

For effective training, employers must adopt training practices that will yield maximum benefits. However, there is a dearth of research in construction that evaluates the relationship between training efforts and objective training outcomes such as hazard recognition and safety risk perception. The aim of this study is to evaluate the relationship between training, hazard recognition performance, and the perception of safety risk among construction workers.



**Figure II.1.** Conceptual safety management process

## **BACKGROUND**

To provide context for discussing the motivation and the point of departure for the current study, literature review relevant to the area of hazard recognition, safety risk perception, and safety training is presented below.

### **Construction Hazard Recognition**

Hazard recognition is often referred to as the first step in the safety management process (Perlman et al. 2014). When safety hazards remain unrecognized, the likelihood of hazard exposure and injury increases substantially. In other words, workers are more likely to be injured on-the-job when safety hazards remain unrecognized, and the associated safety risk remains unmitigated (Carter and Smith 2006).

Because hazard recognition is fundamental to the safety management process, several methods are adopted to improve hazard recognition in construction. These methods can generally be classified as either being predictive or retrospective in nature (Albert et al. 2014). Predictive hazard recognition methods such as the Job Hazard Analysis (JHA) require workers to mentally visualize tasks that will be performed in the near future and predict expected hazards (Rozenfeld et al. 2010). Other predictive hazard recognition methods include pre-task safety meetings and task demand assessments (Mitropoulos and Namboodiri 2011). Retrospective hazard recognition methods, on the other hand, such as lessons learned, rely on generalizing knowledge gained from past safety incidents and injuries (Behm and Schneller 2012; Goh and Chua 2009) to new situations and projects.

Despite the value of predictive and retrospective methods, several limitations of these methods prevent thorough hazard recognition in practice. For example, predictive hazard

recognition methods assume that workers can accurately visualize future tasks, and can precisely predict expected hazards. However, past research has demonstrated that even experienced workers and supervisors struggle with task-visualization and the prediction of associated hazards (Fleming 2009). Moreover, tasks, as imagined or planned, are often substantially different from how they are performed in the field (Borys 2012). Apart from these primary limitations, predictive methods generally do not facilitate the identification of hazards imposed by adjacent crews, work scope changes, and unanticipated field conditions (Rozenfeld et al. 2010).

Limitations of retrospective methods such as lessons learned include the fact that injury reports often do not capture detailed information for efficient future learning; and useful information remains uncaptured from near misses and unreported safety incidents (Dong et al. 2011; Shen and Marks 2015a). Further, the extrapolation of past experiences and incidents to systematically different projects, setting, conditions, and environments is often not viable or valid.

Partly because of these limitations, a large proportion of hazards remain unrecognized in construction projects. For example, Bahn et al. (2013) demonstrated that novice workers in Australia were unable to recognize 57% of hazards in representative work environments. Similarly, Carter and Smith (2013) revealed that up to 33% of hazards remain unrecognized in U.K. projects. More recently, studies in the United States in diverse projects revealed that over 40% of hazards remained unidentified by field workers (Albert et al. 2014). These hazards expose workers to unexpected safety risk that can potentially result in catastrophic safety incidents.

## **Construction Safety Risk Perception**

Like proper hazard recognition, the accurate perception of safety risk is fundamental to the success of any safety program (Hallowell 2010). When workers underestimate safety risk, they are more likely to indulge in risk-taking behavior (Patel and Jha 2014; Tixier et al. 2014). For example, workers that frequently use ladders during work (e.g., painters) may recognize fall potential as a relevant hazard, but often become desensitized to the associated safety risk (Perlman et al. 2014). Other frequently observed risk-taking behaviors in construction include operating equipment without securing seatbelts, walking below suspended loads, improper use of Personal Protective Equipment (PPE), and tampering with equipment safety features (Bohm and Harris 2010; Chi et al. 2012; Choudhry and Fang 2008).

Although empirical research in construction risk-taking is limited, a large body of research has focused on antecedent factors associated with safety risk perception. Among others, the most influential element that impact risk perception is the fact that workers do not always experience injury while indulging in risk-taking behavior. According to Geller (2001), when workers repetitively adopt risky behavior without encountering any negative outcome (e.g., injury), their safety risk perception levels decline with time. Such phenomena partly explain why some workers may not appreciate the value of Personal Protective Equipment (PPE) in high-risk environments (Zhang and Fang 2013).

On the other hand, studies have found a strong positive correlation between past injury experience and safety risk perception levels for individual workers (Shin et al. 2014). Other factors shown to influence safety risk perception include project-level factors such as safety climate and culture, worker characteristics such as safety knowledge, and social factors such

as the value assigned to human life and wellbeing (Jiang et al. 2014; Lopez del Puerto et al. 2013).

Apart from risky behavior, the underestimation of safety risk is a principal barrier to adopting effective safety practices. When safety risk is not accurately perceived, it is unlikely that safe decisions will follow (Zhang et al. 2014). In other words, the ability of workers to manage safety risk efficiently is impaired when safety risk is not accurately perceived in the first place. Unfortunately, the underestimation of safety risk is a widespread issue within construction; and the evaluation of interventions to influence safety risk perception is a promising area for research inquiry.

### **Construction Safety Training**

Every year, millions of dollars are invested towards training the workforce on issues such as hazard recognition, risk management, and injury prevention. Hundreds of research articles have focused on evaluating and developing effective training interventions (e.g., Burke et al. 2011; Ruttenberg 2013; Weidman et al. 2015). However, ironically, research in construction safety continues to show alarming deficits in safety knowledge among construction workers. For example, Haslam et al. (2005) found that more than 70% of construction injuries were associated with poor safety knowledge. Estimates have also revealed that only 10 to 15% of training investments translate into tangible benefits (Baldwin and Ford 1994; Cromwell and Kolb 2004). Not surprisingly, most injury investigations recommend more training to prevent injury recurrence (NIOSH 2015).

Few studies have focused on understanding why training efforts fail in construction. For example, Goldenhar et al. (2001) explain that industry characteristics such as the transient

nature of the workforce and the temporal basis of projects discourage employers from adopting comprehensive, more expensive, and resource-intensive training methods. Other common challenges to effective training include schedule constraints and conflicts in projects, language barriers among workers, and difficulty of quantifying and communicating training benefits (Wang et al. 2008).

Besides these industry challenges, training efforts fail due to a variety of reasons such as ineffective instructional methods, incompetent instructors, and improper training material (Demirkesen and Arditi 2015). Most safety training programs within construction use conventional classroom techniques that do not sufficiently engage workers (Wilkins 2011). According to Haslam et al. (2005) such passive and ineffective instructional methods have limited value, and can sometimes instigate negative attitudes among workers to safety issues.

To improve safety training effectiveness, Wilkins (2011) recommends replacing traditional classroom-type training with andragogical approaches that are more effective in engaging adult learners. Burke et al. (2011) recently argued that more engaging training methods can improve knowledge gain. However, a thorough investigation of the impact of training on objective outcomes such as hazard recognition and safety risk perception is necessary.

## **MOTIVATION AND RESEARCH OBJECTIVES**

As discussed above, both hazard recognition and safety risk perception are prerequisites to managing safety risk effectively. Unfortunately, past research has revealed that workers fail to recognize a large proportion of hazards in practice and often underestimate safety risk. To improve hazard recognition and safety risk perception, employers adopt a wide variety of

safety training methods. However, industry barriers and weaknesses in traditional training methods considerably undermine training efforts (Wang et al. 2008; Wilkins 2011). To improve safety performance, a deeper understanding of the interrelationship between training, hazard recognition, and safety risk perception is necessary.

The aim of this study was to evaluate the impact of training methods on two objective safety outcomes: hazard recognition and safety risk perception. Therefore, the following two null hypotheses were tested:

***Hypothesis 1:*** High engagement training will be associated with higher levels of *hazard recognition* compared to low engagement training.

***Hypothesis 2:*** High engagement training will be associated with higher levels of *perceived safety risk (i.e., safety risk perception)* compared to low engagement training.

As per Figure 2.1, hazard recognition is a necessary prerequisite to the perception of associated safety risk. In other words, safety risk cannot be perceived when hazards are not recognized (Carter and Smith 2006). Therefore, if training improves hazard recognition performance, this may, in turn, facilitate the perception of associated safety risk. To test this proposition, the following hypothesis was tested:

***Hypothesis 3:*** The impact of training on safety risk perception is mediated by hazard recognition performance.

This research represents the first attempt to evaluate the mechanism through which safety training exerts its effect on safety risk perception. This study seeks to advance theory in the area of construction safety, safety training, hazard recognition, and safety risk perception.

## **RESEARCH METHODS**

Data for the study were gathered from 51 case projects in the United States over a 15-month period beginning in the summer of 2014. The participating projects included a convenient sample of commercial (31%), industrial (12%), infrastructure (33%), and residential (24%) projects that were at least 25% complete at the time of participation. Contacts with most sites were initiated by directly contacting the project-level leadership (90%), but a few others were initiated through industry contacts known to the researchers (10%). Forty-six of the projects were located in the Southeastern United States, and the remaining five were located in the Midwestern, Western, and Southern United States.

For each project, after gathering project demographics from the project manager, data relevant to the hypotheses were gathered in three complementary stages during one site visit. First, the training method (i.e., high engagement or low engagement) adopted at the project level was assessed by interviewing a representative worker. Second, the hazard recognition ability of the representative worker was assessed using a random set of construction case images validated in previous research. Finally, safety risk perception of the worker was measured using the construction case images and established scales for risk quantification. In each stage, participation was voluntary, and no participant identifiers were gathered in accordance with the institutional review board (IRB) protocol to protect the workers. In

addition, the researchers ensured that the gathered data was confidential, and was not shared with the employers or supervisors.

It is important to note that the study gathered the data from only one worker per project. The researchers decided to make this tradeoff because of resource constraints, and their desire to study a larger cohort of projects rather than conducting a few in-depth case studies.

### **Stage I: Training Method Evaluation**

For each project, the training method adopted at the project level was gathered. To minimize potential bias, this data was gathered from a representative worker rather than the project manager. A representative worker was defined as someone who had spent at least three months on the project and had received substantial project-level training during this period. Whenever possible, the representative worker was randomly solicited during break sessions from the breakroom. When access to workers was not possible directly, the project manager was encouraged to randomly seek voluntary participation from a representative worker. To reduce selection bias, although the manager was aware of the study's focus on construction safety, specific details of the data type being gathered from workers were not communicated.

Table 2.1 presents the criteria and description based on which the project-level training method was evaluated. The criteria were developed based on the standards proposed by Robson et al. (2012) to differentiate engaging training methods from less engaging training methods. The participating worker from each project was provided the information in the form of a questionnaire and was asked to select the training method that was representative of the training they received at their project. In addition, workers were asked to provide a brief description of the training procedures adopted at the project level to ensure data reliability and

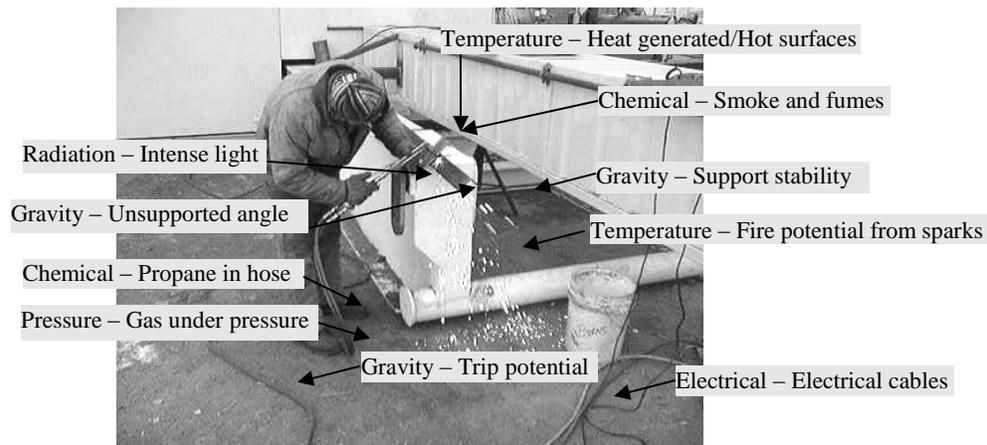
validity. If multiple forms of training were provided at the project-level that include both high engagement and low engagement methods, workers were advised to select the higher engagement training method (i.e., high engagement training) for the purposes of this study.

**Table II.1.** Training method evaluation criteria

Training method/type	Training method Characteristics	Description
<b>Low-engagement training</b>	<ul style="list-style-type: none"> <li>• Trainer-centric</li> <li>• Requires only attentiveness</li> <li>• Minor discussions may be encouraged and permitted</li> <li>• No interaction to moderate level of interaction</li> <li>• No feedback provided</li> <li>• Off-site</li> </ul>	<p>Training is provided by an expert source (e.g., trainer) that may include oral, written, or multimedia presentations of common construction hazards (e.g., lectures). To participate, the only thing required is to be attentive. Minor discussions are encouraged, but feedback regarding performance in the field or during training is generally not provided.</p>
<b>High-engagement training</b>	<ul style="list-style-type: none"> <li>• Trainee-centric</li> <li>• Requires active participation</li> <li>• Discussions are encouraged</li> <li>• High level of interaction among workers and the</li> <li>• facilitator</li> <li>• Feedback provided</li> <li>• On-site or off-site</li> </ul>	<p>Training requires that workers play an active role in the learning process. Training encompasses a high level of interaction between an expert facilitator and among workers. Training may be provided either off-site (e.g., interactive case study) or on the job (on-site mentoring) to provide context. Feedback regarding performance in the field and during training is frequently provided to encourage improvement.</p>

## Stage II: Measuring Hazard Recognition Ability

The second stage focused on measuring the hazard recognition ability of the participating workers representing each project. To reliably measure hazard recognition ability, a pre-selected set of construction case images captured from real projects within the construction industry was used. The case images were gathered in a previous study by an expert panel of 17 construction professionals representing Construction Industry Institute (CII) member organizations (Albert et al. 2013). From an initial population of more than 100 case images, the expert panel selected 16 case images that were representative of a diverse number of construction operations with a wide variety of hazards. After selection, the expert panel pre-identified hazards present in each case image through brainstorming sessions. An example case image with pre-identified hazards is presented as Figure 2.2 The total number of hazards in each case image ranged between 8 and 17.



**Figure II.2.** Example case image for assessing hazard recognition performance (republished from Albert et al. 2013, © ASCE)

In the current study, a random sample of four construction case images from the initial population of 16 was used to assess the hazard recognition ability of the participating workers.

For each case image, the representative worker was asked to identify all relevant hazards, and the corresponding hazard recognition performance was computed using Equation 2.1 (i.e., the proportion of hazards recognized). The overall hazard recognition performance of each worker representing each project was estimated as the average performance across the four construction case images expressed as a percentage (i.e.  $HR_i = \sum_1^4 HR_{ij} / 4$  ). The researchers decided to use four construction case images, as opposed to using fewer, to reduce any bias that may be introduced due to performance variability associated with a particular case image. For example, an electrician may more thoroughly recognize hazards associated with electrical works; however, his performance across four diverse case images may be more reflective of his true hazard recognition ability.

$$HR_{ij} = \frac{H_{ij}}{H_j} \quad (2.1)$$

Where  $HR_{ij}$  is the hazard recognition performance of the worker from project  $i$  for a particular case image  $j$ ;  $H_{ij}$  is the number of hazards identified by the worker from project  $i$  in a particular case image  $j$ , and  $H_j$  is the total number of unique hazards in a particular case image  $j$  which included hazards identified by the expert panel from the previous study and the worker in the current study.

### **Stage III: Measuring Safety Risk Perception**

Safety risk perception is commonly defined as one's subjective judgment of the frequency and severity of harm (e.g., safety incident) for a given scenario (Fung et al. 2010). Typically, safety risk perception has been measured by presenting a stimulus (e.g., work activity or hypothetical scenario) to study participants and to gather their assessment of risk in terms of expected frequency and severity of undesirable safety outcomes (e.g., Zhao et al. 2016). The product of the frequency and severity, as presented in Equation 2.2, is mathematically representative of the individual's level of perceived safety risk. This approach has been successfully adopted in construction safety research and validated in previous research efforts (e.g., Hallowell and Gambatese 2009).

$$\text{Safety Risk} = \text{Frequency of incidents} \times \text{Severity of incidents} \quad (2.2)$$

Where frequency of incidents (e.g., injury frequency) is usually measured as the no. of incidents within a specific time period (e.g., # of injuries/ worker-hour), and the severity of incidents is representative of the magnitude or seriousness of the undesirable safety outcome (e.g., severity/ incident).

In this study, safety risk perception was measured using the instrument proposed by Tixier et al. (2014). Specifically, for each construction case image, workers representing each project assessed the associated safety risk using the risk measurement instrument presented in Figure 2.3. Workers were asked to indicate the expected frequency of injury for each of the severity levels, or injury outcomes (e.g., first aid) with respect to a particular work scenario depicted in the case image. To ensure consistency in workers' understanding of the risk

instrument, the following definition of injury outcomes were provided to the participating workers:

- Discomfort/Pain: Incidents that result in temporary or persistent pain, but do not prevent workers from performing work in normal capacity
- First aid: Incidents that require treatment for cases such as minor cuts, scratches, and sprains; where the worker is able to return to work immediately following treatment
- Medical case: Work-related injuries or illnesses that require care or treatment from medical professionals beyond first aid; where the worker is able to return to regular work under normal capacity
- Lost work time: Work-related injuries or illnesses that restrict workers from returning to work on the following day
- Permanent disability or fatality: Work-related injuries or illnesses that result in permanent disablement or death of worker
- Direction: In your opinion, what will be the expected frequency of each injury type (classified based on injury severity) in the work scenario depicted in the case image?

### Injury Frequency

	Once every week (~ 40 worker- hours)	Once every month (~ 167 worker- hours)	Once every year (~ 2000 worker- hours)	Once every ten years (~ 20000 worker- hours)
<b>Discomfort/Pain</b>				
<b>First aid</b>				
<b>Medical Case</b>				
<b>Lost work time</b>				
<b>Permanent disablement or fatality</b>				

**Figure II.3.** Safety risk measurement instrument

**Table II.2.** Safety risk perception values for each combination of severity and frequency

**Injury Frequency**

	<b>Severity score</b>	<b>Once every week (~ 40 worker-hours)</b>	<b>Once every month (~ 167 worker-hours)</b>	<b>Once every year (~ 2000 worker-hours)</b>	<b>Once every ten years (&gt; 20000 worker-hours)</b>
<b>Discomfort/Pain</b>	7.5	0.19	0.04	$3.75 \times 10^{-3}$	$3.75 \times 10^{-4}$
<b>First aid</b>	45.25	1.13	0.27	$2.26 \times 10^{-2}$	$2.26 \times 10^{-3}$
<b>Medical Case</b>	128	3.20	0.77	$6.40 \times 10^{-2}$	$6.40 \times 10^{-3}$
<b>Lost work time</b>	256	6.40	1.53	$1.28 \times 10^{-1}$	$1.28 \times 10^{-2}$
<b>Permanent disablement or fatality</b>	13619	340.48	81.55	6.81	$6.81 \times 10^{-1}$

To calculate the safety risk perception scores, the severity scale validated by Tixier et al. was adopted as follows: discomfort or pain (7.5), first aid (45.25), medical case (128), lost work time (256), and permanent disablement or fatality (13619). Table 2.2 presents the risk perception values corresponding to each combination of frequency and severity

Using the values presented in Table 2.2, the aggregate risk perception scores were calculated for each worker and each case image. As an example, for a depicted case image, if a worker believed that discomfort or pain would be experienced every week, first aid and medical case would occur every month, and lost work time and permanent disablement or fatality would occur every year, then the corresponding risk perception score will be 8.16 (i.e.,  $0.19 + 0.27 + 0.77 + 1.28 \times 10^{-1} + 6.81$ ).

To effectively compare safety risk perception levels among participating workers, Tixier et al. (2014) recommended standardizing the safety risk perception scores using Equation 2.3. The standardization process simplifies the interpretation of the results. For example, a standardized safety risk perception score that is positive will indicate that a particular worker perceived that the safety risk was higher than the average worker. On the other hand, a negative score will indicate that the worker perceived less risk than the average worker. A standardized score of zero for a worker would suggest that the worker's risk perception is equivalent to the average worker.

$$SRP_{ij} = \frac{RP_{ij} - \overline{RP}_j}{\sigma_j} \quad (2.3)$$

Where  $SRP_{ij}$  is the standardized safety risk perception score for the worker project  $i$  for case image  $j$ ;  $RP_{ij}$  is the raw safety risk perception score for the worker from project  $i$  for case image  $j$ ;  $\overline{RP}_j$  is the mean safety risk perception score for case image  $j$  for all participating workers; and  $\sigma_j$  is the standard deviation of the safety risk perception scores for case image  $j$  from all participating workers

The standardization also facilitates the comparison of performance across situations (e.g., case images) where the underlying risk may be different. For example, hot work performed in a confined space may be inherently more risky than other work situations. But the standardization of scores facilitates the interpretation of safety risk perception based on the number of standard deviations from the mean. For example, if the safety risk perception score for a worker assessing a particular case image  $j$  is 8, while the average of all the workers is 16 with a standard deviation of 4; then the safety risk perception score of the particular worker is 2 standard deviations below the mean of all workers.

Finally, the overall safety risk perception score for each worker was calculated as the average performance of each worker across the four case images (i.e.  $RP_i = \sum_1^4 SRP_{ij}/4$ ). Therefore, each worker was assigned a unique standardized safety risk perception score based on their perceived safety risk.

## **DATA ANALYSIS APPROACH**

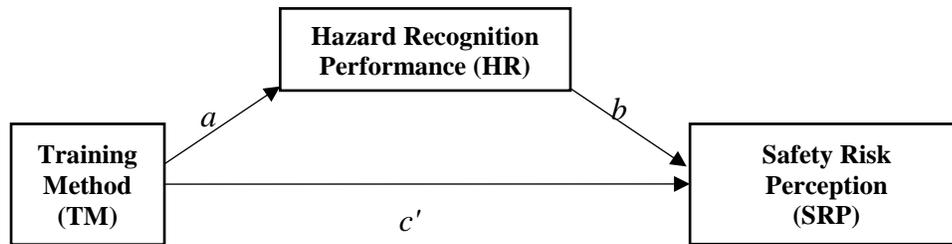
Following the above approach, the training method (i.e., high engagement or low engagement training), a unique hazard recognition performance score  $HR_i$  (expressed as a percentage), and a standardized safety risk perception score  $RP_i$  (henceforth discussed as safety risk perception for simplicity) was obtained for each project. The gathered data were analyzed in two phases. The first phase focused on testing Hypotheses 1 and 2; whereas the second phase focused on testing Hypothesis 3. The following sections describe the data analysis approach that was undertaken.

### **Phase I: Direct effect of training on training outcomes (Hypotheses 1 & 2)**

Hypothesis 1 predicted that high engagement training will be associated with higher levels of hazard recognition when compared with low engagement training methods. Likewise, hypothesis 2 predicted that high engagement training will be associated with higher levels of safety risk perception. To test the two hypotheses, the data were segregated into two groups based on the training method at the project level. Following this, the two groups were compared for a statistical difference in hazard recognition performance scores and the standardized safety risk perception. Specifically, two-sample tests for independent measures were adopted. Based on the skewness and kurtosis test for normality of the data, two-sample parametric  $t$ -test or the Mann-Whitney  $U$ -test was used to compare the two data groups.

### Phase II: Indirect effect of training on safety risk perception (Hypotheses 3)

Hypothesis 3 is schematically represented by the path diagram shown in Figure 2.4. The path diagram includes two outcome variables: hazard recognition performance and safety risk perception. The model also includes two predictor variables: training method and hazard recognition performance. Specifically, training method impacts safety risk perception and hazard recognition performance, whereas hazard recognition performance influences safety risk perception. The relationship between the variables in Figure 2.4 can be mathematically expressed using regression equations as shown in Equation 2.4 and Equation 2.5.



**Figure II.4.** Schematic representation of Hypothesis 3

$$HR_i = i_1 + aTM_i + \varepsilon \quad (2.4)$$

$$RP_i = i_2 + c'TM_i + bHR_i + \varepsilon \quad (2.5)$$

Where,  $HR_i$  is the hazard recognition performance of the worker representing project  $i$ ;  $RP_i$  is the safety risk perception (i.e., standardized) for the worker representing project  $i$ ;  $i_1$  and  $i_2$  are regression intercepts;  $\varepsilon$  is the error in the estimation of the respective dependent variable;  $TM_i$  is the training method adopted at project  $i$  (0 for low engagement training and 1 for high engagement training);  $a$ ,  $b$ , and  $c'$  are the regression coefficients for the corresponding variables.

Based on the figure and as expressed in the equations, there are two potential pathways through which training can impact safety risk perception. In the first pathway called the *direct effect* ( $c'$ ), the effect of training directly impacts safety risk perception without influencing hazard recognition performance. In the second pathway called the *indirect effect* ( $ab$ ), the impact of training on safety risk perception is translated through hazard recognition performance. In other words, training first impacts hazard recognition performance ( $a$ ), which in turn impacts safety risk perception levels ( $b$ ).

The regression coefficients in Figure 2.4 and in the two equations can be interpreted using customary regression analysis conventions. The *direct* effect of training on safety risk perception ( $c'$ ) is the average difference in safety risk perception between two projects offering the different training methods (i.e., high engagement vs. low engagement training), while holding hazard recognition performance constant. In other words, workers from two projects with different training methods, but equivalent hazard recognition performance, can be expected to differ in the perception of safety risk by  $c'$  units.

The *indirect* effect is the product of  $a$  and  $b$ , where  $a$  is the mean difference in hazard recognition performance between the two training groups; and  $b$  is the difference in safety risk perception when hazard recognition changes by one unit (i.e., 1%) but training is held constant. The *indirect* effect  $ab$  represents the difference in safety risk perception between the two training groups due to the effect of training on hazard recognition performance which, in turn, impacts safety risk perception. In other words, it is the *indirect* effect of training on safety risk perception which is translated through hazard recognition performance.

The total effect of training on safety risk perception is the sum of both the *direct* and *indirect* effect and can be calculated using Equation 2.6. The total effect  $c$  quantifies the

difference in safety risk perception between the two training methods. The total effect calculated using Equation 2.6 is equivalent to  $c$  that can be derived by directly regressing the risk perception scores on training method as shown in Equation 2.7.

$$c = c' + ab \quad (2.6)$$

$$RP_i = i_3 + cTM_i + \varepsilon \quad (2.7)$$

Where  $c$  is the total effect of training on safety risk perception;  $a$ ,  $b$ , and  $c'$  are regression coefficients from Equation 2.4 and 2.5;  $RP_i$  is the safety risk perception (i.e., standardized) of the worker representing project  $i$ ;  $i_3$  is the regression intercept for Equation 2.7;  $TM_i$  is the training method adopted at project  $i$  (0 for low engagement training and 1 for high engagement training);  $\varepsilon$  is the error in the estimation of  $RP_i$ .

To test whether the *indirect effect* ( $ab$ ) is statistically significant (i.e., hypothesis 3), the bootstrapping procedure recommend by Preacher and Hayes (2008) was adopted. Bootstrapping methods, also commonly known as resampling methods, do not require specific assumptions regarding the underlying sample distribution as required by tests such as the Sobel test (Mooney et al. 1993). The bootstrapping procedure is especially robust when underlying sample distribution is irregular or the requirements of data normality may not be assumed. As per the procedure, the 95% confidence interval around the estimate of the *indirect effect* ( $ab$ ) was estimated with 10,000 resamples. Evidence of a significant *indirect effect* exists when the bias-corrected 95% confidence interval excludes zero as a potential value of the *indirect effect*.

## **RESULTS AND DISCUSSIONS**

### **Phase I: Direct effect of training on training outcomes (Hypotheses 1 & 2)**

Table 2.3 presents the means, the standard deviations, and the results of testing hypotheses 1 and 2. As can be seen, 61% of the projects ( $n = 31$ ) adopted less engaging training methods. Only 39% ( $n = 20$ ) of projects adopted high engagement training methods. Further, as expected, workers from projects that adopted high engagement training were able to identify a larger proportion of hazards ( $M = 61.13\%$ ) than average ( $M = 54.03\%$ ); and perceived safety risk levels ( $M=0.22$ ) as being higher than average. Among project types, high engagement training was found in 17% of infrastructure projects, 11% of commercial projects, 6% of industrial projects and 5% of residential projects.

**Table II.3.** Direct effect results (Hypotheses 1 & 2)

	Hazard recognition performance						Safety risk perception				
	<i>n</i>	<i>M</i>	<i>SD</i>	$\Delta$	<i>t</i> -value	<i>p</i> -value	<i>M</i>	<i>SD</i>	$\Delta$	Mann-Whitney U	<i>p</i> -value
<b>Training method</b>											
<b>Low engagement</b>	31	49.45	11.80	11.68	-3.18	0.002 <sup>a</sup>	-0.14	0.64	0.37	218.00	0.076 <sup>b</sup>
<b>High engagement</b>	20	61.13	13.61				0.22	0.79			
<b>Overall</b>	51	54.03	13.68	-	-	-	0.00	0.72	-	-	-

Note: *n* = number of projects; *M* = mean; *SD* = standard deviation;  $\Delta$  = effect size.

<sup>a</sup> *p*-value < 0.01

<sup>b</sup> *p*-value < 0.01

As can be seen in Table 2.3, workers representing projects with high engagement training methods were able to identify approximately an additional 12% (~11.68) hazards compared to workers that received low engagement training ( $p$ -value < 0.01). Similarly, workers representing projects that provided high engagement training perceived safety risk to be significantly higher by 0.37 standard deviations on average ( $p$ -value < 0.1) when assuming an alpha level of 0.1.

### **Phase II: Indirect effect of training on safety risk perception (Hypotheses 3)**

To estimate the direct, indirect and total effects of training, the coefficients of Equation 2.3 and Equation 2.4 were estimated by regressing the outcome variables on the respective predictor variables. The results of the analysis are reported in Table 2.4. As can be seen, the regression coefficients were:  $a = 11.679$ ,  $b = 0.025$ ,  $c' = 0.077$ . The regression coefficient  $a$ , as also reported in Table 2.3, suggests that the high engagement training project group was able to recognize approximately 12% more hazards than the low engagement training group. The regression coefficient  $c'$ , shows that two projects with different training methods but equivalent hazard recognition performance are estimated to differ by 0.025 standard deviations in the perception of safety risk. The positive nature of the relationship (+ve number) suggests that the safety risk perception levels of the high engagement training project group is relatively higher.

**Table II.4.** Indirect effect results (Hypothesis 3)

<b>Model</b>	<b>Predictors</b>	<b>Coefficient</b>	<b>Std. Error</b>	<b>t-value</b>	<b>p-value</b>	<b>LLCI</b>	<b>ULCI</b>	<b>r<sup>2</sup></b>
<b>Eq. (2.5)</b>	Constant	-1.376	0.377	-3.651	0.001	-2.134	-0.618	0.208
	Training Method (c')	0.077	0.201	0.384	0.702	-0.328	0.482	
	Hazard Recognition (b)	0.025	0.007	3.430	0.001 <sup>a</sup>	0.010	0.040	
<b>Eq. (2.4)</b>	Constant	49.453	2.251	21.972	0.000	44.930	53.976	0.177
	Training Method (a)	11.679	3.594	3.250	0.002 <sup>a</sup>	4.456	18.902	

Note: LLCI & ULCI - Lower and upper limit confidence intervals

<sup>a</sup>p-value < 0.01

The indirect effect ( $ab = 0.291$ ) was calculated as the product of the effect of training on hazard recognition performance ( $a$ ), and the effect of hazard recognition performance on safety risk perception ( $b$ ). The findings suggest that relative to projects that offered low engagement training, workers from projects that offered high engagement training, on average, perceived safety risk to be higher by 0.291 standard deviations.

The direct effect of training on safety risk perception suggests that two projects with different training methods can be estimated to differ by 0.07 standard deviations in the perception of safety risk while controlling for hazard recognition performance. In other words, independent of the effect of hazard recognition performance, high engagement training was associated with a higher level of perceived safety risk.

Using the computed coefficients, the estimated value of safety risk perception for the various combinations of hazard recognition ability and training method can be estimated. For example, a worker representing a project with high engagement training and average hazard recognition ability ( $HR = 54.03\%$ ) will be estimated to have a safety risk perception score that is 0.051 standard deviation [i.e.,  $-1.376 + 0.077 (1) + 0.025 (54.03)$ ] above average. Whereas, a worker with similar hazard recognition ability but representing a project with low engagement training is estimated to have a safety risk perception score that is 0.025 (-ve) standard deviations below average [i.e.,  $-1.376 + 0.077 (0) + 0.025 (54.03)$ ]. As mentioned earlier, the total difference in perceived risk between these two workers is estimated to be 0.07 standard deviations [i.e.,  $0.051 - (-0.025) = 0.077$ ]. This difference is equivalent to  $c' = 0.077$  in Table 2.4.

The results of testing Hypothesis 3 using the bootstrapping method is presented in Table 2.5. As can be seen, the 95% confidence interval excluded zero as a potential value of

the indirect effect. Therefore, the evidence suggests that the indirect effect is positive and statistically significant. In other words, hazard recognition is a mediator of the effect of training on safety risk perception.

**Table II.5.** Bootstrap confidence interval for indirect effect

<b>Bootstrap Estimates</b>				
	<b>Effect</b>	<b>Std. Error</b>	<b>LLCI</b>	<b>ULCI</b>
<b>Indirect effect (ab)</b>	0.291	0.151	0.071	0.68

LLCI & ULCI - Lower and upper limit confidence intervals

Apart from the primary results, the data revealed a positive correlation between experience and hazard recognition performance, and between experience and safety risk perception. Similarly, there was a positive correlation between age and hazard recognition performance, and age and safety risk perception. However, these relationships were not statistically significant.

## **THEORETICAL AND PRACTICAL IMPLICATIONS**

The results of this study advance theoretical knowledge in the area of construction safety and have practical implications for the industry. The current study represents the first comprehensive empirical effort to evaluate the interrelationship between safety training, hazard recognition, and safety risk perception. The theoretical and practical implications of the study findings are discussed below.

First, the findings of this study suggest that project-level training methods can impact both hazard recognition and safety risk perception. More specifically, safety training methods can impact hazard recognition performance; which in turn can affect the project-level perception of safety risk. These findings are significant because both hazard recognition and the perception of safety risk are essential prerequisites for effective safety management and safe behavior. When hazards remain unrecognized, or the associated safety risks remain unperceived, the likelihood of catastrophic and unexpected injuries dramatically increase (Albert et al. 2014b).

Second, this study represents one among the few studies that evaluated the effects of training on objective safety training outcomes. Unlike previous efforts that relied on proxy measures of training effectiveness such as industry relevance and knowledge gain, this study evaluated the effect of training on two objective training outcomes: hazard recognition performance and safety risk perception.

Third, the study findings suggest that high engagement training that encourages trainee interaction, feedback, and action are preferable to lesser engaging training methods. Workers representing projects with high engagement training were able to identify a larger proportion of safety hazards and perceive higher levels of safety risk. Given the unique nature of the construction industry and the transient nature of the workforce, employers may be prudent to evaluate previous training experiences of their recruited workers and provide remedial training when necessary. For example, if an employer evaluates that a worker has received low-engagement training in his prior work history, the employer may decide to provide high engagement preparatory training sessions prior to initiation high-risk work activities. Such

proactive measures may lead to improvements in hazard recognition, safety risk perception, and safety performance.

Fourth, the study results indicate that training efforts are a viable intervention to improve the perception of safety risk. This is an important finding because practitioners have expressed serious concerns regarding the widespread underestimation of safety risk among workers; which can result in unsafe behavior and unintended safety violations (Tixier et al. 2014). Further, recent research has focused on examining differences in safety risk perception among and within workgroups (Zhao et al. 2016). The current study contributes to this area of inquiry by suggesting that these differences may arise due to variability in an individual's ability to recognize safety hazards, or as a function of training received.

Finally, the data gathered in this study suggests that less than 40% of projects adopted high engagement training methods. In other words, less engaging training methods appear to be the predominant approach to safety training within construction. This finding may partly explain why previous studies have not found a positive correlation between traditional training and safety performance. Further, this finding is alarming because Haslam et al. (2005) found that poor safety training practices can instigate negative attitudes among workers to safety issues. It is expected that the findings of this study will guide practicing professionals and employers to adopt more engaging, effective, and efficient training interventions.

## **STUDY LIMITATIONS**

Despite the strengths, the current study has limitations that may be addressed in future research. Among the most important limitations is the assumption that one worker was representative of each project. For example, the hazard recognition performance and the safety risk perception of one worker, rather than a cohort of workers from each project, was assumed to represent project-level performance. The researchers decided to make this tradeoff because of their desire to study a larger cohort of projects rather than conducting a few in-depth case studies. The sample of 51 projects was adequate for the purposes of performing the inferential statistical analysis. However, given that only 51 projects were examined in the current study, future efforts must focus on examining a larger number of projects distributed across the United States to ensure external validity of findings.

Second, the study used case images for measuring hazard recognition performance and safety risk perception of representative workers. While the case images standardized the measurement of the dependent variables and preserved internal validity, the true dynamic nature of construction operations isn't represented in case images. Nonetheless, previous studies have found a strong correlation between performance in case images and actual construction environments (Albert et al. 2013).

Finally, because safety risk perception is a relative measure rather than an absolute measure, the study assumed that higher levels of safety risk perception are desirable. While this has not been empirically tested, previous studies have found a positive correlation between higher risk perception levels and the adoption of protective and safe measures (Sheeran et al. 2014). Further, studies have argued that workers who perceive higher levels of safety risk are less prone to adopting risk-taking behavior (Tixier et al. 2014).

## CONCLUSION

Both hazard recognition and the perception of safety risk are essential elements for successful safety management. However, poor hazard recognition and low safety risk perception levels are widely reported in construction literature. When hazards remain unrecognized, or the associated risk is underestimated, the likelihood of injuries dramatically increase. To improve safety performance, employers adopt a wide variety of training programs; however, desirable levels of performance have not been achieved. In fact, past research suggests that less than 10 to 15% of training expenditure translate into true tangible benefits.

To advance knowledge and practice in the area of construction safety, the current study gathered empirical data from 51 case projects within the United States. Specifically, data pertaining to training methods, hazard recognition performance, and safety risk perception were gathered from representative workers.

The results of the study suggest that high engagement training is associated with higher levels of hazard recognition and the perception of safety risk compared to low engagement training methods. In addition, the effect of training on safety risk perception is mediated by hazard recognition performance. In other words, projects offering high engagement training can expect higher hazard recognition levels; which will also improve project-level risk perception levels. The findings of the study will help practicing professionals adopt, design, and implement better training approaches. The current study represents the first comprehensive study to examine the relationship between training, hazard recognition performance, and safety risk perception in the construction context.

Future research must focus on identifying and evaluating other factors that impact hazard recognition and safety risk perception of workers. This is important given that the

current study explained only 17.7% of the variability in hazard recognition performance and 20.8% of the variability of safety risk perception (see Table 2.4). Further, future studies must focus on evaluating the impact of safety training, hazard recognition, and safety risk perception on lagging indicators of safety performance such as recordable injury rates.

## REFERENCES

- Ahmed, S. M., Azhar, S., Forbes, L. H. (2006). "Costs of Injuries/Illnesses and Fatalities in Construction and their Impact on the Construction Economy." *CIB W99" Jian Zhu an Quan Yu Jian Kang De Quan Qiu He Zuo" Guo Ji Hui Yi Lun Wen Ji*, 363.
- Albert, A., Hallowell, M. R., Kleiner, B. M. (2014b). "Experimental Field Testing of a Real-Time Construction Hazard Identification and Transmission Technique." *Constr. Manage. Econ.*, 32(10), 1000-1016.
- Albert, A., Hallowell, M. R., Kleiner, B., Chen, A., Golparvar-Fard, M. (2014a). "Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality." *J. Constr. Eng. Manage.*, 140(7).
- Albert, A., Hallowell, M. R., Kleiner, B. M. (2013). "Enhancing Construction Hazard Recognition and Communication with Energy-Based Cognitive Mnemonics and Safety Meeting Maturity Model: Multiple Baseline Study." *J. Constr. Eng. Manage.*, 140(2), 04013042.
- Bahn, S. (2013). "Workplace Hazard Identification and Management: The Case of an Underground Mining Operation." *Saf. Sci.*, 57, 129-137.
- Baldwin, T. T., and Ford, J. K. (1994). "Transfer of Training: A Review and Directions for Future Research." *The Training and Development Sourcebook*, 180.

Behm, M., and Schneller, A. (2012). "Application of the Loughborough Construction Accident Causation Model: A Framework for Organizational Learning." *Constr. Manage. Econ.*, (ahead-of-print), 1-16.

Bohm, J., and Harris, D. (2010). "Risk Perception and Risk-Taking Behavior of Construction Site Dumper Drivers." *Int. J. Occup. Saf. Ergonomics*, 16(1), 55-67.

Borys, D. (2012). "The Role of Safe Work Method Statements in the Australian Construction Industry." *Saf. Sci.*, 50(2), 210-220.

Bureau of Labor Statistics (BLS). "National census of fatal occupational injuries in 2014." <<http://www.bls.gov/news.release/cfoi.nr0.htm>> October 2015).

Burke, M. J., Salvador, R. O., Smith-Crowe, K., Chan-Serafin, S., Smith, A., Sonesh, S. (2011). "The Dread Factor: How Hazards and Safety Training Influence Learning and Performance." *J. Appl. Psychol.*, 96(1), 46.

Carter, G., and Smith, S. (2006). "Safety Hazard Identification on Construction Projects." *J. Constr. Eng. Manage.*, 132(2), 197-205.

Chi, S., Han, S., Kim, D. Y. (2012). "Relationship between Unsafe Working Conditions and Workers' Behavior and Impact of Working Conditions on Injury Severity in US Construction Industry." *J. Constr. Eng. Manage.*,

Choudhry, R. M., and Fang, D. (2008). "Why Operatives Engage in Unsafe Work Behavior: Investigating Factors on Construction Sites." *Saf. Sci.*, 46(4), 566-584.

Cohen, A., Colligan, M. J., Sinclair, R., Newman, J., Schuler, R. (1998). "Assessing Occupational Safety and Health Training." *Cincinnati, OH: National Institutes of Health*, 1-174.

Cromwell, S. E., and Kolb, J. A. (2004). "An Examination of Work-Environment Support Factors Affecting Transfer of Supervisory Skills Training to the Workplace." *Human Resource Development Quarterly*, 15(4), 449.

Dong, X. S., Fujimoto, A., Ringen, K., Stafford, E., Platner, J. W., Gittleman, J. L., Wang, X. (2011). "Injury Underreporting among Small Establishments in the Construction Industry." *Am. J. Ind. Med.*, 54(5), 339-349.

Fleming, M. A. (2009). "Hazard Recognition Techniques." *By Design, ASSE*, 9(3), 15-18.

Fung, I. W., Tam, V. W., Lo, T. Y., Lu, L. L. (2010). "Developing a Risk Assessment Model for Construction Safety." *Int. J. Project Manage.*, 28(6), 593-600.

Geller, E. S. (2001). *Working Safe: How to Help People Actively Care for Health and Safety*, CRC Press,.

Goldenhar, L. M., Moran, S. K., Colligan, M. (2001). "Health and Safety Training in a Sample of Open-Shop Construction Companies." *J. Saf. Res.*, 32(2), 237-252.

Hallowell, M. (2010). "Safety Risk Perception in Construction Companies in the Pacific Northwest of the USA." *Constr. Manage. Econ.*, 28(4), 403-413.

Hallowell, M. R., and Gambatese, J. A. (2009). "Activity-Based Safety Risk Quantification for Concrete Formwork Construction." *J. Constr. Eng. Manage.*, 135(10), 990-998.

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., Duff, A. R. (2005). "Contributing Factors in Construction Accidents." *Appl. Ergon.*, 36(4), 401-415.

Hinze, J., and Gambatese, J. (2003). "Factors that Influence Safety Performance of Specialty Contractors." *J. Constr. Eng. Manage.*, 129(2), 159-164.

Jiang, Z., Fang, D., Zhang, M. (2014). "Understanding the Causation of Construction Workers' Unsafe Behaviors Based on System Dynamics Modeling." *J. Manage. Eng.*, 04014099.

Li, H., Chan, G., Skitmore, M. (2012). "Multiuser Virtual Safety Training System for Tower Crane Dismantlement." *J. Comput. Civ. Eng.*, 26(5), 638-647.

Li, H., Chan, G., Skitmore, M. (2012). "Visualizing Safety Assessment by Integrating the use of Game Technology." *Autom. Constr.*, 22, 498-505.

Lingard, H., Pink, S., Harley, J., Edirisinghe, R. (2015). "Looking and Learning: Using Participatory Video to Improve Health and Safety in the Construction Industry." *Constr. Manage. Econ.*, 33(9), 740-751.

Lingard, H., Pink, S., Harley, J., Edirisinghe, R. (2015). "Looking and Learning: Using Participatory Video to Improve Health and Safety in the Construction Industry." *Constr. Manage. Econ.*, 33(9), 740-751.

Lingard, H. (2013). "Occupational Health and Safety in the Construction Industry." *Constr. Manage. Econ.*, 31(6), 505-514.

Mitropoulos, P., Abdelhamid, T. S., Howell, G. A. (2005). "Systems Model of Construction Accident Causation." *J. Constr. Eng. Manage.*, 131(7), 816-825.

Mitropoulos, P., and Namboodiri, M. (2011). "New Method for Measuring the Safety Risk of Construction Activities: Task Demand Assessment." *J. Constr. Eng. Manage.*, 137(1), 30-38.

Mooney, C. Z., Duval, R. D., Duval, R. (1993). *Bootstrapping: A Nonparametric Approach to Statistical Inference*, Sage,

National Institute of Occupational Safety and Health (NIOSH). "Fatality assessment and control (FACE) program." <<http://www.cdc.gov/niosh/face/default.html>> October 2015).

Perlman, A., Sacks, R., Barak, R. (2014). "Hazard Recognition and Risk Perception in Construction." *Saf. Sci.*, 64, 22-31.

Robson, L. S., Stephenson, C. M., Schulte, P. A., Amick III, B. C., Irvin, E. L., Eggerth, D. E., Chan, S., Bielecky, A. R., Wang, A. M., Heidotting, T. L. (2012). "A Systematic Review of the Effectiveness of Occupational Health and Safety Training." *Scand. J. Work Environ. Health*, 193-208.

Rozenfeld, O., Sacks, R., Rosenfeld, Y., Baum, H. (2010). "Construction Job Safety Analysis." *Saf. Sci.*, 48(4), 491-498.

Ruttenberg, R. (2013). *The Economic and Social Benefits of OSHA-10 Training in the Building and Construction Trades*, The center for construction research and training (CPWR), Maryland.

Shen, X., and Marks, E. (2015). "Near-Miss Information Visualization Tool in BIM for Construction Safety." *J. Constr. Eng. Manage.*, 04015100.

Shin, M., Lee, H., Park, M., Moon, M., Han, S. (2014). "A System Dynamics Approach for Modeling Construction Workers' Safety Attitudes and Behaviors." *Accident Analysis & Prevention*, 68, 95-105.

Shin, M., Lee, H., Park, M., Moon, M., Han, S. (2014). "A System Dynamics Approach for Modeling Construction Workers' Safety Attitudes and Behaviors." *Accident Analysis & Prevention*, 68, 95-105.

Tixier, A. J., Hallowell, M. R., Albert, A., van Boven, L., Kleiner, B. M. (2014). "Psychological Antecedents of Risk-Taking Behavior in Construction." *J. Constr. Eng. Manage.,.*

Wang, Y., Goodrum, P. M., Haas, C., Glover, R., Vazari, S. (2010). "Analysis of the Benefits and Costs of Construction Craft Training in the United States Based on Expert Perceptions and Industry Data." *Constr. Manage. Econ.*, 28(12), 1269-1285.

Weidman, J., Dickerson, D. E., Koebel, C. T. (2015). "Intervention to Improve Purchasing Decision-Maker Perceptions of Ventilated Tools." *J. Constr. Eng. Manage.*, 141(6), 04015007.

Wilkins, J. R. (2011). "Construction Workers' Perceptions of Health and Safety Training Programmes." *Constr. Manage. Econ.*, 29(10), 1017-1026.

Zhang, M., and Fang, D. (2013). "A Cognitive Analysis of Why Chinese Scaffolders do Not use Safety Harnesses in Construction." *Constr. Manage. Econ.*, 31(3), 207-222.

Zhang, P., Lingard, H., Blismas, N., Wakefield, R., Kleiner, B. (2014). "Work-Health and Safety-Risk Perceptions of Construction-Industry Stakeholders using Photograph-Based Q Methodology." *J. Constr. Eng. Manage.*,.

Zhao, D., McCoy, A. P., Kleiner, B. M., Mills, T. H., Lingard, H. (2016). "Stakeholder Perceptions of Risk in Construction." *Saf. Sci.*, 82, 111-119.

Zou, P. X., and Zhang, G. (2009). "Comparative Study on the Perception of Construction Safety Risks in China and Australia." *J. Constr. Eng. Manage.*, 135(7), 620-627.

Zou, P. (2015). *Strategic Safety Management in Construction and Engineering Electronic Resource*, Wiley, Hoboken.

**CHAPTER III: INTEGRATING STRATEGIES FOR  
TRAINING TRANSFER (STUDY II)**

## **ABSTRACT**

Most construction safety activities focus on managing identified hazards. Hazards that remain unrecognized, and as a result unmanaged, can potentially result in catastrophic and unexpected injuries. Therefore, proper hazard recognition is foundational to the success of any safety program. However, recent research has revealed that a large proportion of construction hazards remain unrecognized in construction projects. To improve hazard recognition performance, employers provide their workers with safety and hazard recognition training. Despite these efforts, desirable levels of hazard recognition have not been achieved, and the anticipated return on investment (ROI) from training has not been attained. Such failures in training efforts are partly because knowledge acquired through training programs is often not transferred or applied in the workplace. Subsequently, training efforts do not alter work practices or behavior once workers return to the field. Other reasons for training failure include improper training delivery and the adoption of low-engagement training methods. To advance theory and practice in hazard recognition, training transfer, and training delivery, the objectives of this study were to (1) identify training transfer elements that maximize the transfer of safety training, (2) evaluate the relative effectiveness of the identified training transfer elements in transferring safety knowledge gained through training programs, and (3) assess the interaction effect between training method (i.e., high-engagement versus low-engagement training) and training transfer levels on hazard recognition performance. The objectives of the study were accomplished by gathering input from construction industry experts through interviews, questionnaire surveys, and the analysis of empirical data gathered from 51 case projects in the United States. The results of the study revealed that training efforts may be undermined if training transfer elements are not synergistically adopted. Specifically, the findings suggest

that safety training is necessary, but is not sufficient to maximize training outcomes such as hazard recognition. To maximize safety training outcomes, employers must adopt training transfer elements along with high-engagement training methods. This study represents the first formal attempt to evaluate the role of training transfer elements in the construction context.

## **INTRODUCTION**

More than 60,000 fatal injuries are reported every year from construction projects around the world (Lingard 2013). The United States Bureau of Labor Statistics (BLS) reported more than 800 fatal and 200,000 non-fatal construction injuries in 2013 (BLS 2014). More recently, the number of fatal injuries increased by 6% in 2014 representing the highest reported total since 2008 (BLS 2015). Apart from emotional distress, the cost of these injuries exceeds \$48 billion each year. These costs significantly impinge profit margins, and in some cases threaten the survival of construction companies (Ahmed et al. 2006, Zou and Sunindijo 2015).

To reduce injury rates and related outcomes, past research has focused on understanding accident causation and antecedent factors of construction incidents (Mitropoulos et al. 2005; Rajendran et al. 2009; Suraji et al. 2001). Among others, poor hazard recognition in dynamic construction environments has recently received much attention (Albert et al. 2013; Carter and Smith 2006; Goh and Chua 2009). When hazards remain unrecognized and unmanaged, the likelihood of catastrophic and unexpected injuries dramatically increase. In fact, more than 42% of injuries in construction occur because of inadequate hazard recognition and appraisal (Haslam et al. 2005).

To improve safety performance, employers invest several million dollars in designing, developing, and delivering hazard recognition and safety training programs. The goal of these

training programs is to equip workers with the skills necessary to recognize and manage hazards in complex environments (Hinze and Gambatese 2003). Despite these training efforts, desirable levels of hazard recognition have not been attained in practice, and the expected return on investments have not been achieved (Albert et al. 2013; Carter and Smith 2006; Li et al. 2012). Such failure in training efforts has generally been attributed to weaknesses in training programs including improper training delivery and inferior training material (Wilkins 2011). Other reasons for training failure such as language barriers among workers, unqualified trainers, and worker attitudes towards training have been discussed by researchers (Haslam et al. 2005; Wang et al. 2008).

Although efforts are being undertaken to address these issues, the issue of training transfer in construction largely remains unaddressed. Training transfer refers to the extent to which concepts and practices learned via training is actually transferred or replicated in the workplace (Blume et al. 2010). The topic of training transfer is important because estimates reveal that only 10 to 15% of training investments translate into desirable workplace changes, practices, or benefits (Baldwin and Ford 1994; Cromwell and Kolb 2004). In other words, the bulk of training expenditure does not translate into tangible benefits but is reduced to wasted resources.

For training efforts to yield desirable outcomes, employers must identify and implement management strategies that maximize the transfer of training. The aim of this research effort is to address the training transfer gap and advance knowledge to improve training effectiveness, training transfer, and construction hazard recognition.

## **LITERATURE REVIEW**

### **Construction Hazard Recognition**

Most field-based safety initiatives focus on managing hazards that are identified by workers. Hazards that remain unrecognized, and as a result unmanaged can potentially result in catastrophic accidents and injuries (Albert et al. 2014; Carter and Smith 2006). To protect the workforce, and improve safety performance, several hazard recognition methods are implemented in practice. These hazard recognition methods can broadly be classified into two different categories, namely: predictive methods and retrospective methods. Predictive hazard recognition methods, such as Job hazard analysis (JHA), involve visualizing construction activities that will be undertaken in the near future and identifying associated hazards (Rozenfeld et al. 2010). Examples of other predictive hazard recognition methods include task-demand assessment and pre-task safety planning sessions (Mitropoulos and Namboodiri 2011). Although beneficial, these methods have several limitations. For example, predictive hazard recognition methods assume that workers can accurately predict the sequence of work tasks in dynamic and often unpredictable environments. However, in many cases, work tasks as imagined or planned is significantly different from how they are actually performed in the field (Borys 2012). Further, predictive methods of hazard recognition assume that workers are inherently able to predict hazards that may be encountered during work – despite evidence to the contrary. Other limitations associated with predictive methods (e.g., JHAs) include failure to capture hazards imposed by adjacent crews, work scope changes, and unexpected conditions.

Retrospective hazard recognition methods, on the other hand, rely on generalizing knowledge gained from past experiences and injuries to avoid future incidents. Examples of

such methods include lessons learned and safety checklists (Behm and Schneller 2012; Zou and Zhang 2009). Like predictive methods, retrospective methods also have important limitations. For example, near misses and past injury reports often do not capture detailed information for future learning. Further, injury reports represent only a small subset of potential scenarios that unfortunately resulted in injuries (Rozenfeld et al. 2010). Also, a generalization of past injuries across projects, settings, and dynamic environments are often invalid.

Partly because of these weaknesses, a large proportion of hazards are not recognized in the workplace. For example, a study conducted in Australia revealed that novice workers failed to identify 57% of the hazards in work representative environments (Bahn 2013). Similarly, studies in the U.K found that up to 33.5% of hazards were not recognized in projects that were examined (Carter and Smith 2006). More recently, field studies conducted in the United States found that construction crews on average identified less than 40% of the hazards in diverse projects (Albert et al. 2014). These unrecognized hazards can expose workers to unanticipated safety risk with the significant potential for injury. In fact, Haslam et al. (2005) analyzed injury reports and found that more than 42% of injuries were linked to inadequate hazard recognition or appraisal.

## **Construction Safety Training**

Safety training is one of the most widely adopted interventions to improve workplace safety. Each year, organizations invest millions of dollars in training their workforce on safety issues including hazards recognition, hazard management, and safe work practices. For example, safety training is provided to promote the proper use of personal protective equipment (PPE) and to encourage the implementation of effective injury prevention strategies. Not surprisingly, hundreds of research articles emphasize the importance of safety training, and many others have established causal relationships between safety training and safety performance (Cohen et al. 1998; Lingard 2002; Ruttenberg 2013).

Because of these potential benefits, safety regulations require that employers provide their workers with safety and hazard recognition training (OSHA 2010). Despite these efforts, however, research has revealed that workers still lack essential safety skill and knowledge. In fact, examination of accident reports has identified deficits in safety knowledge as a principal contributing factor in a disproportionate number of injuries (Haslam et al. 2005). According to Haslam et al. (2005), more than 70% of accidents in construction projects are associated with poor safety knowledge. These deficits in safety knowledge and skills have traditionally been attributed to industry barriers for effective training. For example, the transient nature of the workforce discourages some employers from adopting innovative, sophisticated, and resource-intensive training programs (Goldenhar et al. 2001). Other common barriers to effective training include schedule constraints in time-sensitive projects, unavailability of funds and resources, lack of interest among workers, and the uncertainty and difficulty of quantifying training benefits (Wang et al. 2008).

Apart from these barriers, several training programs fail because of common design flaws including unorganized material, ineffective trainers, and insensitivity to effective instructional methods (Bunch 2007). Most training programs are delivered based on the naïve assumption that knowledge transfer can easily occur when conventional classroom instructional techniques are adopted. However, Haslam et al. (2005) argue that these passive instructional methods do not sufficiently engage workers and that they can instill negative attitudes among workers towards safety issues. Similarly, Wilkins (2011) suggests that pedagogical and classroom instructional methods must be replaced with andragogical approaches that encourage participation and are more suitable for adult learners. More recently, Burke et al. (2011) argued that engaging safety training methods that facilitate dialogue, feedback, and action can result in higher learning gains.

### **Training Transfer**

Although effective training can improve safety knowledge, it is not sufficient by itself to yield expected benefits. This is because workers often fail to apply learned concepts and skills once they return to work (Blume et al. 2010). In other words, knowledge transfer is not equivalent to training transfer or the application of learned concepts in practice. In fact, in most cases, only 10 to 15% of training expenditure translates into noticeable improvements in work practices and performance; the rest generally reduces to wasted resources (Baldwin and Ford 1994; Cromwell and Kolb 2004).

Evidence for the failure of training transfer is abundant within the construction industry. For example, construction managers and safety professionals have expressed frustration over their inability to reduce unsafe behavior and control injury rates – even with

adequate training (Choudhry and Fang 2008; Jha 2011). Not surprisingly, a disproportionate number of apparent safety violations are reported from construction projects on a regular basis (OSHA 2014).

Although past research has established causal links between effective training and safety knowledge gains, there is a dearth of research linking training efforts to objective safety outcomes – such as reduction in injury rates or improvements in hazard recognition performance (Brahm and Singer 2013). In fact, some studies have found evidence to the contrary suggesting that a relationship between training efforts and objective safety outcomes does not exist (Li et al. 2012). A plausible explanation for this disconnect between safety knowledge gain and objective safety outcomes is the failure of training transfer.

Given that only a small fraction of training expenditure translates into tangible safety benefits (~10 to 15%), even a minor increase in training transfer (e.g., by 30-50%) can dramatically enhance safety performance. Therefore identifying and implementing training transfer elements that facilitate the transfer of training is particularly important for the construction industry.

## **RESEARCH OBJECTIVES AND CONTRIBUTIONS**

As discussed above, poor hazard recognition in construction is a principal barrier to enhancing safety performance. While training is widely adopted to improve hazard recognition and safety performance, low-engaging training methods and the lack of training transfer significantly impede safety efforts. The purpose of this study was (1) to identify core training transfer elements that maximize the transfer of safety and hazard recognition training, (2) to assess the relative effectiveness of the identified training transfer elements in improving the transfer of

safety training, and (3) to test the null hypothesis that the relationship between training methods (i.e., low engagement training vs. high engagement training) and hazard recognition performance will depend on the training transfer level. In other words, it is hypothesized that the interaction effect between high engagement training and high training transfer levels will result in better hazard recognition performance than when low-engagement training methods are adopted.

This research represents the first known effort to assess the role of training transfer elements on the relationship between training efforts and hazard recognition performance. The findings of this study can significantly advance theory and practice in the area of construction safety, hazard recognition, training delivery, and training transfer. The results of the study will be useful to practicing professionals who are interested in designing safety training programs and improving objective safety training outcomes.

## **RESEARCH METHODS**

The objectives of the research effort were accomplished in three different phases. First, core training transfer elements that maximize the transfer of safety and hazard recognition training in the construction context were identified. Second, the relative impact of each training transfer element on improving hazard recognition and safety outcomes were assessed by industry experts. Third, empirical data were gathered from case projects in the United States to assess the relationship between training method, training transfer, and hazard recognition performance. The following sections describe the different phases in detail.

## **Phase I: Identifying Training Transfer Elements**

The research effort was initiated with an exploratory phase that focused on identifying key training transfer elements that improve the transfer of safety and hazard recognition training. Although other domains have examined the role of training transfer (e.g., Blume et al. 2010; Grossman and Salas 2011), no previous study has focused on construction in particular. The data gathered in this phase served as the underlying framework for the subsequent phases. To gather this data efficiently several research methods including a review of the literature, questionnaire surveys, focus group sessions, and expert interviews were considered. Each of these methods has their own strengths and weaknesses. For example: literature review builds on previous knowledge but is insufficient when past research in the area is limited or is not generalizable across industries or settings (Withrow 2014); questionnaire surveys are easy to administer but do not allow follow-up questions to enhance response clarity (Winchester 1999); and focus groups are time efficient but dominating personalities can unintentionally introduce bias (Langford and McDonagh 2003). After comparing these prospective methods, the research team decided to use semi-structured interviews to synthesize potential training transfer elements using expert input. Semi-structured interviews were selected because of the exploratory nature of the study and the ability to use probing questions when additional follow-up information is desirable (Johnson and Christensen 2011).

Potential expert participants were identified from the Associated General Contractors (AGC) membership database, the Construction Industry Institute (CII) membership database, and personal contacts that were available to the research team. For the purposes of this research, an expert was defined as an individual with over eight years of experience in the construction sector with extensive knowledge in project management, construction safety, and

training practices. Overall 12 project managers, 14 safety professionals, and three professional trainers agreed to participate. The accumulated experience of the expert participants exceeded 330 years. The experts represented organizations that performed construction and maintenance services for commercial and office buildings, industrial facilities, and manufacturing plants. Most participants were located in the southeast, southwest, and mountain regions of the United States.

All interviews were conducted over the phone and began with introducing the interviewees to the objectives of the study. Following the introduction, demographic information of participating experts was gathered, and key training transfer elements were elucidated and recorded. To qualify as a key training transfer element, the researchers required that at least two experts make reference to specific elements. Overall, this process resulted in 11 training transfer elements that impact hazard recognition and safety training as shown in Table 3.1.

**Table III.1.** Identified training transfer elements

<b>Training transfer elements</b>	<b>Description</b>
Upper management commitment	Upper management must explicitly recognize safety training transfer as a strategic effort to improve safety performance. Commitment to safety training transfer must be demonstrated by allocating sufficient resources and funding towards efforts that can enhance training transfer
Supervisor / Foreman support and expectations	Supervisors / Foreman must demonstrate their commitment to the transfer of safety and hazard recognition training. Commitment and support may be demonstrated by modeling trained behavior, by participating in training programs, by providing resources for effective training transfer, and by providing adequate opportunity for applying learned concepts in practice.
Training design and material	Improper training practices can impede effective learning and hinder the transfer of safety knowledge. Training must be provided by effective trainers that understand the theory of learning, and training must be designed to draw workers' attention.
Peer support and reinforcement	Workers should be supportive of applying newly learned concepts and knowledge in the workplace. For example, peers must hold each other accountable for transferring knowledge once they return to work. It is important that workers have a unified perception of the importance of safety knowledge and knowledge transfer.
Informal and formal feedback	After training efforts, worker's performance with respect to safety training transfer must be evaluated and provided as feedback (both positive and negative). The goal of providing feedback is to communicate expectations to workers and to help benchmark their performance against expectations
Field reviews evaluating transfer	Field reviews must be held on a regular basis to evaluate the degree of training transfer. This may be performed by the supervisor, safety manager, or a safety committee. When desired levels of transfer do not occur, corrective measures must be formulated and implemented.

**Table 3.1. (cont.)** Identified training transfer elements

<b>Training transfer elements</b>	<b>Description</b>
Positive reinforcement and incentives	Rewarding desired behavior through positive reinforcement and verbal incentives can motivate workers to replicate the behavior. Complimenting workers when they effectively apply knowledge gained from training can improve training transfer levels. If the transfer does not occur, workers must be encouraged to do so.
Worker motivation	Workers must be motivated to learn and apply learned concepts in the workplace. For effective transfer, workers must understand the relevance of concepts covered in training sessions and how they can benefit from applying learned practices on returning to work
Safety culture/climate	Project participants including workers, supervisors, and managers must be dedicated, aligned, and accountable for safety-related issues. Important elements of safety culture and climate include efficient safety communication, supportive and safe work environment, appreciation of safety risk, and others.
Implementation resources and guidance	Workers must be provided with implementation resources and guidance to successfully transfer knowledge gained from training programs. The resources must be explicitly designed to help workers easily transfer knowledge. Implementation resources can be in the form of checklists, pocket cards, booklets, or others.
Worker retention and aptitude	Workers must be able to retain information disseminated through safety training programs and must be able to adopt learned concepts in new environments. This requires a higher level of cognitive ability and aptitude.

## **Phase II: Relative Impact of Training Transfer Elements**

Although the training transfer elements listed in Table 3.1 were all identified as positively impacting hazard recognition and safety training transfer, the relative impact or influence of individual elements was unknown. To assist strategic efforts to improve safety training transfer, the focus of the second phase was to assess the relative contribution of individual elements to successfully transfer hazard recognition and safety training.

To gather this data, a simple questionnaire survey was designed that solicited expert ratings regarding the contribution of each training transfer element. Specifically, the questionnaire asked experts to rate the contribution of each element on hazard recognition and safety training transfer using a 5-point Likert scale (5 = extremely effective, 4 = very effective, 3 = fairly effective, 2 = slightly effective, and 1 = not effective). To ensure consistency in the expert's understanding of the training transfer elements and to improve internal validity, a brief description of each training transfer element as shown in Table 3.1 was included in the questionnaire.

Once the questionnaire was developed, the expert participants that participated in the first phase were once again contacted, and the new objectives were discussed. Following this, the questionnaire surveys were emailed to the expert participants, and their response was requested within three weeks. An email reminder and a phone reminder were provided at the end of the first and second week, respectively, to encourage participation when responses were yet to be received. Overall, 18 completed questionnaires were received constituting a response rate of over 62%.

After the data had been gathered, the Relative Impact Index (RII) of each training transfer element was computed using Equation 3.1. Several research studies in construction

have used this approach to examine factors that impact project productivity (Jarkas and Bitar 2012), construction delays (Aibinu and Odeyinka 2006; Gündüz et al. 2012), and project risk (Choudhry et al. 2014).

$$RII_i = \frac{\sum W_i}{(A N)} \quad (3.1)$$

Where  $RII$  is the Relative Impact index for a specific training transfer element  $i$ ;  $W_i$  is the sum of all ratings from all experts for a specific training transfer element  $i$ ;  $A$  is the highest possible rating permissible in the adopted scale (i.e., 5 in this case); and  $N$  is the total number of expert respondents.

RII values computed using Equation 3.1 provides an easily interpretable and standardized score that ranges between 0 and 1 (not inclusive of 0), with higher values of RII signifying higher impact. Table 3.2 presents the results where the training transfer elements are rank-ordered in accordance with their impact level on hazard recognition and safety training transfer. As can be seen, *upper management commitment* (RII = 0.933) and *supervisor support and expectations* (R = 0.911) were rated as having the highest impact on improving training transfer.

**Table III.2.** Relative impact index for training transfer elements

<b>Training Transfer Elements</b>	<b>Mean</b>	<b>Std. Deviation</b>	<b>RII</b>	<b>Rank</b>
Upper management commitment	4.67	0.49	0.933	1
Supervisor support and expectations	4.56	0.62	0.911	2
Training design and material	4.39	0.78	0.878	3
Peer support and reinforcement	4.28	0.57	0.856	4
Informal and formal feedback	4.17	0.86	0.833	5
Field reviews evaluating transfer	3.56	0.62	0.711	6
Positive reinforcement and incentives	3.39	0.85	0.678	7
Worker Motivation	3.28	0.96	0.656	8
Safety climate/Safety culture	3.17	0.99	0.633	9
Implementation resources and guidance	3.17	1.04	0.633	9
Worker retention and aptitude	2.89	1.28	0.578	11

### **Phase III: Hypothesis development and empirical testing**

As presented earlier, employers adopt a wide variety of training methods to enhance hazard recognition and safety performance. Among these methods, past research indicates that high-engagement training methods are more efficient than low-engagement methods (Burke et al. 2006). Low-engagement training methods generally require workers to be attentive but do not require active participation. On the other hand, high-engagement training methods require active worker participation, includes feedback, and substantial interaction between workers and the instructor (Robson 2010).

While the impact of training methods on training outcomes have been studied, the impact of adopting training transfer elements on the relationship between training method and training outcomes (e.g., hazard recognition) have not been examined. This study hypothesizes that the synergy between training transfer elements and training efforts will improve hazard recognition performance. Further, it is hypothesized that hazard recognition levels will be higher when high-engagement training (rather than low-engagement training) is adopted along with training transfer elements.

### **Empirical data collection for hypothesis testing**

To test the null hypothesis, empirical data were gathered from 51 case projects in the United States in three sequential steps. First, project managers representing each project were interviewed, and project demographics were gathered. Second, data pertaining to training methods and training transfer elements that were adopted at the project level were gathered. This information was gathered by interviewing a representative worker rather than the project manager from each project to minimize potential bias. The representative worker was

identified and recruited randomly whenever possible during break hours in the breakroom. When the researchers did not have access to the workers directly, the manager was encouraged to randomly select a worker to participate in the study. To reduce selection bias when the manager recruited the representative worker, the manager was not provided details regarding the data type sought from workers. Also, it was required that all participating workers had spent at least three months in the project they represented and had received training during these periods. Finally, the hazard recognition ability of workers was measured using a random set of construction case images gathered and validated by industry experts in a previous research effort.

Training methods were assessed largely based on the criteria proposed by Robson et al. (2010) Table 3.3 presents the criteria and the description of each training method based on which workers assessed the training that they received at the project-level. The training transfer level at the project level was measured using a brief questionnaire. Specifically, for each training transfer element (see Table 3.2), workers were asked to rate the level of implementation using a 5-point Likert scale ranging from strongly disagree to strongly agree. For example, the workers were asked to rate their level of agreement with the statement: *Your supervisor/foreman provides support, and opportunity to apply learned hazard recognition and safety concepts (from training) at work.*

Before administering the survey, however, two important changes were made based on pilot tests of the survey with industry professionals. First, the statement regarding training design was omitted while measuring training transfer level because data pertaining to the training method was already being gathered using the criteria presented in Table 3.3. Second, only data pertaining to the top six training transfer elements excluding *training design and*

*material* were administered. This decision was made based on the pilot test findings which suggested that including subsequent elements such as *worker motivation* would introduce bias since the data was gathered from workers themselves. Accordingly, the construct measuring training transfer was limited to a six-item questionnaire for the purposes of this study. The responses of each worker to the six-item questionnaire were then aggregated to represent the overall training transfer level for the particular project. The overall training transfer level for each project was a continuous variable that ranged between 6 and 30.

**Table III.3.** Evaluation criteria for training type

<b>Training method/type</b>	<b>Training method Characteristics</b>	<b>Description</b>
<b>Low-engagement training</b>	<ul style="list-style-type: none"> <li>• Trainer-centric</li> <li>• Requires only attentiveness</li> <li>• Minor discussions may be encouraged and permitted</li> <li>• No interaction to moderate level of interaction</li> <li>• No feedback provided</li> <li>• Off-site</li> </ul>	<p>Training is provided by an expert source (e.g., trainer) that may include oral, written, or multimedia presentations of common construction hazards (e.g., lectures). To participate, the only thing required is to be attentive. Minor discussions are encouraged, but feedback regarding performance in the field or during training is generally not provided.</p>
<b>High-engagement training</b>	<ul style="list-style-type: none"> <li>• Trainee-centric</li> <li>• Requires active participation</li> <li>• Discussions are encouraged</li> <li>• High level of interaction among workers and the facilitator</li> <li>• Feedback provided</li> <li>• On-site or off-site</li> </ul>	<p>Training requires that workers play an active role in the learning process. Training encompasses a high level of interaction between an expert facilitator and among workers. Training may be provided either off-site (e.g., interactive case study) or on the job (on-site mentoring) to provide context. Feedback regarding performance in the field and during training is frequently provided to encourage improvement.</p>

The hazard recognition ability of workers representing each project was assessed using a pre-selected set of construction case images captured from real projects in the United States. These case images were gathered during a previous study by a panel of 17 industry professionals representing Construction Industry Institute (CII) member organizations (Albert et al. 2013). From an initial population of over 100 construction case images, 16 depicting a wide range of construction operations were selected by the industry panel to assess the hazard recognition ability of project participants. Following selection, hazards were pre-identified by the industry professionals. The number of hazards in each construction case image ranged between 8 and 17.



**Figure III.1.** Hypothesized models: (a) Relation depends on training transfer levels (Model I); (b) Relation does not depend on training transfer levels (Model II)

In this study, a random sample of four case images from the initial population of 16 was used to assess the hazard recognition ability of each worker. After the workers identified the hazards, the hazard recognition ability of workers corresponding to each construction case image ( $HR_{case}$ ) was calculated using Equation 3.2. The overall hazard recognition ability ( $HR_i$ ) of each worker representing a particular project was then estimated as their average hazard recognition performance across the four construction case images (i.e., average of  $HR_{case}$  scores) expressed as a percentage. Four case images, rather than fewer, were used in

the study for each worker to reduce any bias that may result due to performance variability in a particular case image. For example, a welder may be able to identify a higher proportion of hazards associated with welding operations; however, his performance across multiple case images will be more indicative of his overall hazard recognition ability.

$$HR_{case} = \frac{H_{worker}}{H_{total}} \quad (3.2)$$

Where  $HR_{case}$  is the hazard recognition performance of a worker for a particular case image;  $H_{worker}$  is the number of hazards identified by the worker in a particular case image, and  $H_{total}$  is the total number of unique hazards identified by the workers that participated in the present study and the expert panel from the previous study for a particular case image.

### Data Analysis and Hypothesis Testing

The null hypothesis predicted that the effect of training method on hazard recognition performance will be *unaffected* or *unaltered* by the training transfer level. In contrast, the alternate hypothesis was that the effect of training method on hazard recognition performance will *depend on* training transfer levels, such that high-engagement training methods along with high training transfer levels will have a stronger effect on hazard recognition performance. Both of these relationships are conceptually presented in Figure 3.1 and mathematically expressed by regression Equation 3.3 (Model I) and Equation 3.4 (Model II).

$$Model I: \quad HR_i = \beta_0 + \beta_1 TM_i + \beta_2 TT_i + \beta_3 (TM_i \cdot TT_i) + \varepsilon_t \quad (3.3)$$

$$Model II: \quad HR_i = \beta_0 + \beta_1 TM_i + \beta_2 TT_i + \varepsilon_t \quad (3.4)$$

Where  $HR_i$  is the overall hazard recognition performance (i.e., average of  $HR_{case}$  scores ) for the worker representing project  $i$ ;  $TT_i$  is the training transfer level (ranges between 6 and 30) based on the aggregate worker response to the six-item training transfer questionnaire for project  $i$ ;  $TM_i.TT_i$  is the interaction (product) term between training method and training transfer level for project  $i$ ;  $\beta_0$  is the intercept for the hazard recognition ( $HR$ ) – training transfer ( $TT$ ) relationship when training method ( $TM$ ) equals zero;  $\beta_1$  is the slope for the hazard recognition ( $HR$ ) – training transfer ( $TM$ ) relationship when training method ( $TM$ ) equals zero;  $\beta_2$  is the change in the intercept for the hazard recognition ( $HR$ ) – training transfer ( $TT$ ) relationship when training method ( $TM$ ) increases by one unit;  $\beta_3$  is the change in slope from the hazard recognition ( $HR$ ) – training transfer ( $TT$ ) relationship when training method ( $TM$ ) increases by one unit; and  $\varepsilon_i$  is the error term included in the mathematical model.

As can be seen, only Model I includes the interaction term ( $TM_i.TT_i$ ) where the effect of training method ( $TM$ ) on hazard recognition ( $HR$ ) is dependent on the training transfer level ( $TT$ ). The inclusion of the interaction term in Model I allows the impact of the training methods on hazard recognition performance to linearly depend on the training transfer level. The corresponding regression coefficient  $\beta_3$  is of particular interest because after the model is estimated the value of  $\beta_3$  will capture the impact of training transfer levels on the relationship between training method and hazard recognition performance (Vittinghoff et al. 2012).

The first step in the analysis procedure involved comparing Model I and Model II to determine the most appropriate statistical model for inference. Both models were estimated by regressing the dependent variable ( $HR$ ) on their respective predictor variables. After the parameter estimates had been determined, the model comparison test as shown in Equation 3.5 was used to test the null hypothesis that an interaction effect between training transfer and

training method was non-existent (i.e.,  $\beta_3 = 0$ ) (Lewis-Beck et al. 2004). If the null hypothesis is accepted,  $\beta_3$  would assume the value of zero, and Equation 3.3 would reduce to Equation 3.4. In this case, Model II that excludes the interaction effect would be more representative of the data and would provide higher statistical power for inference. On the other hand, if the null hypothesis is rejected, Model II would not accurately represent the relationship between the variables, and therefore Model I will be more appropriate. Because the total sample size was only 51, a slightly liberal alpha level ( $\alpha = 0.1$ ) was used to reduce the likelihood of type II error as suggested by Burslem et al. (2005) for the statistical inference.

$$F = \frac{(SS_{Reg\ Model\ II} - SS_{Reg\ Model\ III})}{MS_{Reg\ Model\ I}} \quad (3.5)$$

where  $F$  is the calculated  $F$ -statistic;  $SS_{Reg\ Model\ I}$  is the regression sum of squares based on model I;  $SS_{Reg\ Model\ III}$  is the regression sum of squares based on model II; and  $MS_{Reg\ Model\ I}$  is the residual mean squares based on model I.

If Model I is selected as the appropriate mathematical model (i.e.,  $\beta_3 \neq 0$ ), then the conclusion would be that the effect of training method on hazard recognition is dependent on training transfer level. The interpretation of the interaction coefficient  $\beta_3$  and its associated test statistic would reveal the direction (i.e., strengthens or weakens) and extent of interaction between training method and training transfer levels. On the other hand, if Model II is selected (i.e.,  $\beta_3 = 0$ ), then the conclusion would be that the interaction effect does not exist or that training transfer levels do not impact the relationship between training method and hazard recognition performance.

### **Probing the Interaction Effect**

While the selection of Model I would indicate that an interaction effect exists, no insight on the range of training transfer values for which the interaction is significant will be known. For example, training transfer levels could be low enough to not significantly impact the relationship between training method and hazard recognition. In other words, the model selection by itself does not provide additional insight into the differential impact of low training transfer levels and high training transfer levels.

To estimate the range of training transfer values for which the interaction effect is significant, the Johnson-Neyman technique was adopted as recommended by Spiller et al. (2013). The details of the mathematical procedure can be found in Hayes and Matthes (2009). The procedure first requires the extraction of the conditional effect of training method on hazard recognition performance from Model I as shown in Equation 3.6. The conditional effect is representative of the net change in hazard recognition performance when the training method is changed (i.e. from low-engagement to high-engagement training) in Model I. The ratio of this conditional effect and the standard error, which follows a  $t$ -distribution, is then equated to the critical value of  $t$  as shown in Equation 3.7. Solving Equation 3.7 for the training transfer value corresponding to  $t_{crit}$  will provide the cutoff point that demarcates statistically significant and non-significant values of training transfer levels. These computations were performed using the MODPROBE macro developed by Hayes and Matthes (2009).

$$\theta_{TM \rightarrow HR} = \beta_1 + \beta_3 TT \quad (3.6)$$

$$t_{crit} = \frac{\theta_{TM \rightarrow HR}}{\sqrt{s_{\beta_1}^2 + 2(TT)s_{\beta_1\beta_3}^2 + TT^2 s_{\beta_3}^2}} \quad (3.7)$$

Where  $\theta_{TM \rightarrow HR}$  is the conditional effect of training method on hazard recognition performance, defined as the difference in hazard recognition performance between the two training methods expressed as a function of the training transfer level.

### Analysis Findings

Table 3.4 presents means, standard deviations, and correlations among study variables. As can be seen only 39% of projects (M=0.39) provided high-engagement training. Most projects (61%) adopted low-engagement training methods. The average hazard recognition performance was 54%, and the average training transfer level was 21.24. As expected, training method has a significant positive correlation with hazard recognition performance ( $r = 0.421$ ). That is, hazard recognition performance was greater among workers representing projects that provided high-engagement training. Also, training transfer had a significant positive correlation with hazard recognition performance ( $r = 0.459$ ) suggesting that higher training transfer levels were associated with higher hazard recognition levels.

**Table III.4.** Descriptive statistics

<b>Variables</b>	<b>Mean</b>	<b>Std. Dev.</b>	<b>TM</b>	<b>HR</b>	<b>TT</b>
<b>1. Training Method (TM)</b>	0.39	0.5	-		
<b>2. Hazard recognition performance (HR)</b>	54.3	14	0.42 <sup>a*</sup>	-	
<b>3. Training Transfer (TT)</b>	21.2	5.5	0.37 <sup>a</sup>	0.45 <sup>b*</sup>	-

Training method coded as 0 = low-engagement training, 1= high-engagement training.

<sup>a</sup>Biserial correlation    <sup>b</sup> Pearson correlation    \*  $p < 0.1$

For model comparison, Model I was estimated by regressing hazard recognition performance (HR) over the three predictor variables (*TM*, *TT*, and *TM.TT*), and Model II was estimated by regressing hazard recognition performance (*HR*) on the two predictor variables (*TM* and *TT*). This was followed by the model comparison test using Equation 3.2. The results of the model comparison procedure are presented in Table 3.5. The skewness and kurtosis test for the normality of errors yielded a *p*-value above 0.1, and the residual plots indicated that the homogeneity of error variances may be assumed.

**Table III.5.** Model comparison results

<b>Model</b>	<b>Predictor</b>	<b>Coefficient</b>	<b>Std. Error</b>	<b>t- value</b>	<b>p- value</b>	<b>r<sup>2</sup></b>	<b>r<sup>2</sup> change</b>	<b>Model comparison</b>
<b>Model I</b>	<b>Constant</b>	38.09	7.31	5.21	<0.1	0.327	0.044	Model I
	<b>Training Method</b>	-23.48	18.32	-1.28	0.21			$F_{obt} > F_{critical}$
	<b>Training Transfer</b>	0.58	0.36	1.62	0.11			$F_{obt} = 3.07$
	<b>Interaction</b>	1.38	0.39	1.75	<0.1			$F_{critical} = 2.81$
<b>Model II</b>	<b>Constant</b>	32.48	6.71	4.84	<0.01	0.283		
	<b>Training Method</b>	8.04	3.65	2.20	<0.1			
	<b>Training Transfer</b>	0.86	0.33	2.66	<0.1			

The obtained value of  $F$  ( $F_{obt} = 3.078$ ) was compared with the critical value of  $F$  ( $F_{critical} = 2.815$ ). Clearly, the model comparison test indicated that Model I was preferable to Model II. In other words, the model that included the interaction variable was significantly more predictive of hazard recognition performance.

As can be seen, Model I explained much more variability in hazard recognition performance ( $r^2 = 0.327$ ) than Model II ( $r^2 = 0.283$ ). In fact, Model I explained an additional 4.4% of the variance in hazard recognition performance over Model II which is the difference in  $r^2$  for the two models ( $0.327 - 0.283$ ). Further, the analysis revealed that the interaction effect was statistically significant ( $p$ -value  $< 0.1$ ) suggesting that training transfer levels influenced the relationship between training method and hazard recognition performance (see Figure 3.1a). The regression coefficient of the interaction term ( $\beta_3$ ) quantifies the effect of training method on hazard recognition performance for a unit increase in training transfer level. Therefore, for every unit increase in the training transfer level, workers who received the high-engagement training were able to identify an additional 1.38% hazards compared to those who received the low-engagement training (see Table 3.5). In other words, the relationship between training method and hazard recognition performance was strengthened as training transfer levels increased.

To illustrate the impact of training transfer level on the relationship between training method and hazard recognition performance, Figure 3.2 is presented. Figure 3.2 was constructed using the selected regression model (Model I) for each training type. The values for training transfer level selected were constrained to a range between 14 and 30 because more than 85% of the data fell within this range. As can be seen, for both training methods, hazard recognition performance improved as the training transfer level increased. However, the

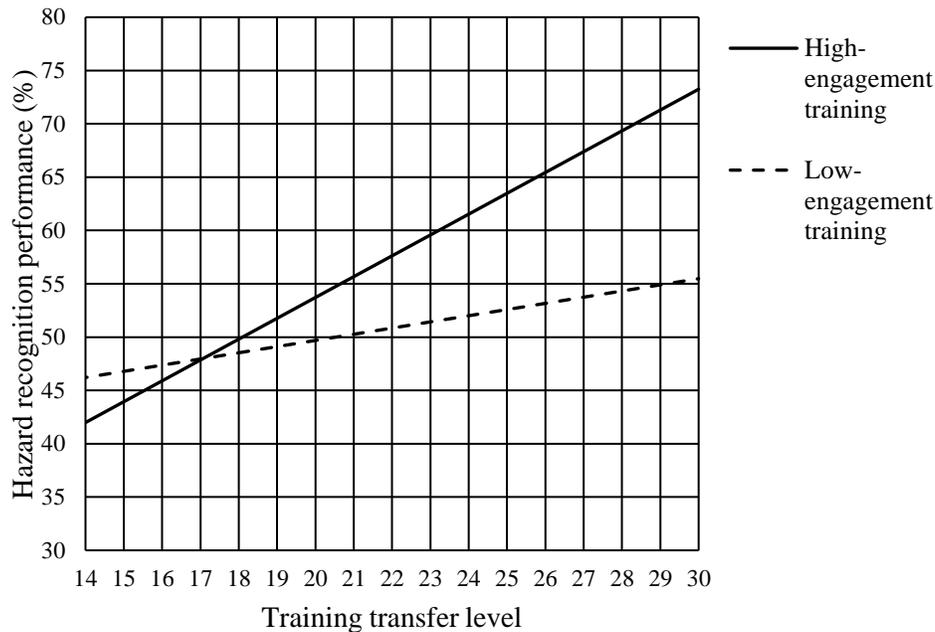
relationship was relatively stronger for the high-engagement training method. This is clear from the fact that the distance between the two lines representing both training methods increases with higher values of training transfer.

When training transfer levels were low, it appears like low-engagement training resulted in slightly better hazard recognition performance. However, whether this difference is statistically significant is discussed in the following sections. But, as can be seen, there is little difference between the two groups when training transfer levels were low.

When training transfer levels were higher, hazard recognition performance was relatively higher for projects that adopted high-engagement training. For example, when training transfer levels were the highest (i.e., score of 30), 73% of hazards were recognized with high-engagement training; whereas, only 55% of hazards were identified when low-engagement training was adopted. In other words, even with comparable training transfer levels, hazard recognition performance varied up to 18% between the two training approaches.

Finally, the range of training transfer levels for which the interaction effect was significant was estimated using Equation 3.5. The analysis revealed that a training transfer level of 21.62 demarcated the regions of significance for the relationship between training and hazard recognition performance. For ease of interpretation, MODPROBE also provides the conditional effect and its corresponding significance of various training transfer levels based on the range of the raw data. The results are presented in Table 3.6. As can be seen, when training transfer levels were below 21.62 the conditional effect of training transfer on the relationship between training and hazard recognition was not significant. In other words, when training transfer levels were low, the difference in hazard recognition between the two training

methods was not statistically significant. However, for training transfer values above 21.62, the conditional effect was statistically significant.



**Figure III.2.** Visual representation of interaction results

### Implications of Analysis Findings

Past studies in construction safety training have focused on identifying and developing effective training practices (Demirkesen and Arditi 2015; Sacks et al. 2013). The assumption in these studies is that effective and engaging training programs can substantially improve safety performance.

The findings of this study, however, challenges this simplistic assumption. Specifically, this study suggests that effective safety training is *necessary* but not *sufficient* to maximize desirable safety outcomes. The results of the study show that training transfer elements must

be adopted along with effective and engaging training practices to maximize hazard recognition and related outcomes.

The analysis of empirical data showed that the adoption of training transfer elements significantly strengthens the relationship between training efforts and training outcomes. In other words, training transfer elements support the transfer of safety skill and behavior – acquired through training efforts – to the workplace. When safety skill and behavior are successfully transferred to the workplace, hazard recognition and related safety outcomes can be expected to improve.

Further, when training transfer levels are low, adopting more engaging and expensive training methods may not yield additional benefits over traditional low-engaging training methods. Therefore, employers seeking to improve project-level hazard recognition and safety performance through effective training interventions must also focus on improving training transfer levels to yield maximum benefits.

**Table III.6.** Probing interaction results

<b>Training Transfer levels</b>	<b>Conditional Effect (<math>\beta_1+\beta_3 TT</math>)</b>	<b>Std. Dev.</b>	<b><i>t</i>-value</b>	<b><i>p</i>-value</b>
9.00	-11.11	11.49	-0.97	0.34
11.10	-8.22	9.93	-0.83	0.41
13.20	-5.33	8.42	-0.63	0.53
15.30	-2.44	6.97	-0.35	0.73
17.40	0.44	5.62	0.08	0.94
19.50	3.33	4.47	0.74	0.46
21.62	6.24	3.72	1.68	0.10
22.65	7.66	3.58	2.14	<0.10
24.75	10.55	3.85	2.74	<0.05
26.85	13.44	4.72	2.85	<0.01
28.95	16.32	5.92	2.76	<0.01
30.00	17.77	6.60	2.69	<0.01

## **STUDY LIMITATIONS**

Despite its strength, the study has several limitations that future research may address. The most significant limitation of this study is the assumption that one worker was representative of each project. For example, the hazard recognition performance of one worker, instead of a cohort of workers, was assessed to represent the project-level performance. This was done because the researchers had to make a tradeoff between conducting an in-depth analysis of a few case projects versus studying a larger cohort of projects. For the purpose of inferential hypothesis testing, the researchers chose to gather data from 51 case projects representing diverse project types, scope, and location.

The second limitation pertains to the use of case images for gathering hazard recognition performance. The case images only capture a snapshot of construction operations and do not represent the true dynamic nature of construction environments. Nevertheless, measuring hazard recognition performance using case images allowed the researchers to assess the relative performance of workers across different projects using a standardized procedure. Further, past research has revealed that a strong correlation exists between performance assessed using case images and in real field conditions (Albert et al. 2013).

Finally, the construct of training transfer was limited to only the six most influential training transfer elements to reduce potential bias during data collection in the present study. Future work will focus on evaluating the impact of all factors on the relationship between training and safety training outcomes.

## CONCLUSION

Proper hazard recognition and management are essential to improving construction safety performance. However, past research has revealed that a large proportion of hazards remain unrecognized and unmanaged during construction operations (Albert et al. 2013; Bahn 2013; Carter and Smith 2006). When hazards remain unrecognized and unmanaged, the likelihood of accidents and injuries dramatically increases.

To improve hazard recognition and safety performance, employers adopt a wide variety of safety training programs. However, training program design weaknesses and industry challenges have limited the impact of training on improving hazard recognition and safety performance (Bunch 2007; Wilkins 2011). To address these challenges, a large body of construction research has focused on developing robust and high-engaging training programs (Albert et al. 2014; Li et al. 2012; Sacks et al. 2013).

While much effort has been devoted to improving training practices, the issue of training transfer has largely been ignored in the construction context. This is alarming because past research suggests that only 10 to 15% of training investments translate into tangible benefits, while the rest reduces to wasted resources (Baldwin and Ford 1994; Cromwell and Kolb 2004).

In this study, 11 core training transfer elements that facilitate the efficient transfer of hazard recognition and safety training was identified. The elements included workplace factors such as supervisor and peer support and worker characteristics such as motivation and aptitude. Some of these factors were also identified in past research as relevant to training transfer in other industries (Blume et al. 2010; Grossman and Salas 2011). Among the identified factors,

upper management commitment and supervisor support and expectations were assessed as being the most influential elements for transfer of training.

Analysis of empirical data gathered from 51 case projects showed that hazard recognition performance improved when training transfer levels were higher. However, the correlation between training transfer and hazard recognition performance was stronger when high-engagement training approaches were adopted instead of low-engaging training methods.

The results of this research challenge the traditional assumption that effective training by itself can lead to improvements in training outcomes such as hazard recognition and safety performance. The findings of this study suggest that effective and high-engagement training methods are necessary, but not sufficient to improve hazard recognition performance. Specifically, the results revealed that the interaction effect of high-engagement training and high training transfer levels will result in better hazard recognition.

This study represents the first research effort to assess the role of training transfer in the construction context. It is expected that the research findings will be beneficial to construction professionals seeking to improve hazard recognition and safety performance. Future research efforts will focus on identifying additional factors that impact hazard recognition performance. This is especially important given that the selected mathematical model (Model I) in this study explained only 32.7% of the variability in hazard recognition performance. A deeper understanding of factors that impact hazard recognition is essential to improving construction safety performance. Future studies will also focus on assessing the impact of training methods and training transfer levels on lagging indicators of safety performance such as injury rates.

## REFERENCES

- Albert, A., Hallowell, M. R., Kleiner, B., Chen, A., Golparvar-Fard, M. (2014). "Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality." *J. Constr. Eng. Manage.*, 140(7), 04014024.
- Albert, A., Hallowell, M. R., Kleiner, B. M. (2013). "Enhancing Construction Hazard Recognition and Communication with Energy-Based Cognitive Mnemonics and Safety Meeting Maturity Model: Multiple Baseline Study." *J. Constr. Eng. Manage.*, 140(2), 04013042.
- Bahn, S. (2013). "Workplace Hazard Identification and Management: The Case of an Underground Mining Operation." *Saf. Sci.*, 57, 129-137.
- Baldwin, T. T., and Ford, J. K. (1994). "Transfer of Training: A Review and Directions for Future Research." *The Training and Development Sourcebook*, 180-207.
- Behm, M., and Schneller, A. (2012). "Application of the Loughborough Construction Accident Causation Model: A Framework for Organizational Learning." *Constr. Manage. Econ.*, (ahead-of-print), 1-16.
- Blume, B. D., Ford, J. K., Baldwin, T. T., Huang, J. L. (2010). "Transfer of Training: A Meta-Analytic Review." *Journal of Management*, 36(4), 1065-1105.
- Borys, D. (2012). "The Role of Safe Work Method Statements in the Australian Construction Industry." *Saf. Sci.*, 50(2), 210-220.

Brahm, F., and Singer, M. (2013). "Is More Engaging Safety Training always Better in Reducing Accidents? Evidence of Self-Selection from Chilean Panel Data." *J. Saf. Res.*, 47, 85-92.

Bunch, K. J. (2007). "Training Failure as a Consequence of Organizational Culture." *Human Resource Development Review*, 6(2), 142-163.

Bureau of Labor Statistics (BLS). "National census of fatal occupational injuries in 2014." <<http://www.bls.gov/news.release/cfoi.nr0.htm>> October 2015).

Bureau of Labor Statistics (BLS). "Injuries, illness, and fatalities." <<http://www.bls.gov/iif/>> December 2014).

Burke, M. J., Sarpy, S. A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R. O., Islam, G. (2006). "Relative Effectiveness of Worker Safety and Health Training Methods." *Am. J. Public Health*, 96(2), 315-324.

Burslem, D., Pinard, M., Hartley, S. (2005). *Biotic Interactions in the Tropics: Their Role in the Maintenance of Species Diversity*, Cambridge University Press, Cambridge.

Carter, G., and Smith, S. (2006). "Safety Hazard Identification on Construction Projects." *J. Constr. Eng. Manage.*, 132(2), 197-205.

Choudhry, R. M., Aslam, M. A., Hinze, J. W., Arain, F. M. (2014). "Cost and Schedule Risk Analysis of Bridge Construction in Pakistan: Establishing Risk Guidelines." *J. Constr. Eng. Manage.*, 140(7), 04014020.

Choudhry, R. M., and Fang, D. (2008). "Why Operatives Engage in Unsafe Work Behavior: Investigating Factors on Construction Sites." *Saf. Sci.*, 46(4), 566-584.

Cohen, A., Colligan, M. J., Sinclair, R., Newman, J., Schuler, R. (1998). *Assessing Occupational Safety and Health Training: A literature review*, National Institute for Occupational Safety and Health, Ohio.

Cromwell, S. E., and Kolb, J. A. (2004). "An Examination of Work-Environment Support Factors Affecting Transfer of Supervisory Skills Training to the Workplace." *Human Resource Development Quarterly*, 15(4), 449.

Demirkesen, S., and Arditi, D. (2015). "Construction Safety Personnel's Perceptions of Safety Training Practices." *Int. J. Project Manage.*, 33(5), 1160-1169.

Donovan, P., and Darcy, D. P. (2011). "Learning Transfer: The Views of Practitioners in Ireland." *International Journal of Training and Development*, 15(2), 121-139.

Goh, Y. M., and Chua, D. (2009). "Case-Based Reasoning Approach to Construction Safety Hazard Identification: Adaptation and Utilization." *J. Constr. Eng. Manage.*, 136(2), 170-178.

Goldenhar, L. M., Moran, S. K., Colligan, M. (2001). "Health and Safety Training in a Sample of Open-Shop Construction Companies." *J. Saf. Res.*, 32(2), 237-252.

Grossman, R., and Salas, E. (2011). "The Transfer of Training: What really Matters." *International Journal of Training and Development*, 15(2), 103-120.

Gündüz, M., Nielsen, Y., Özdemir, M. (2012). "Quantification of Delay Factors using the Relative Importance Index Method for Construction Projects in Turkey." *J. Manage. Eng.*, 29(2), 133-139.

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., Duff, A. R. (2005). "Contributing Factors in Construction Accidents." *Appl. Ergon.*, 36(4), 401-415.

Hayes, A. F., and Matthes, J. (2009). "Computational Procedures for Probing Interactions in OLS and Logistic Regression: SPSS and SAS Implementations." *Behavior Research Methods*, 41(3), 924-936.

Hinze, J., and Gambatese, J. (2003). "Factors that Influence Safety Performance of Specialty Contractors." *J. Constr. Eng. Manage.*, 129(2), 159-164.

Jarkas, A. M., and Bitar, C. G. (2011). "Factors Affecting Construction Labor Productivity in Kuwait." *J. Constr. Eng. Manage.*, 138(7), 811-820.

Jha, K. N. (2011). *Construction Project Management: Theory and Practice*, Pearson Education India.

Langford, J., and McDonagh, D. (2003). *Focus Groups: Supporting Effective Product Development*, CRC press, New York.

Lewis-Beck, Michael S., Bryman, Alan., Liao, Tim Futing, (2004). *The Sage Encyclopedia of Social Science Research Methods*, Sage, Thousand Oaks, Calif.

Li, H., Chan, G., Skitmore, M. (2012). "Visualizing Safety Assessment by Integrating the use of Game Technology." *Autom. Constr.*, 22, 498-505.

Lingard, H. (2013). "Occupational Health and Safety in the Construction Industry." *Constr. Manage. Econ.*, 31(6), 505-514.

Lingard, H. (2002). "The Effect of First Aid Training on Australian Construction Workers' Occupational Health and Safety Motivation and Risk Control Behavior." *J. Saf. Res.*, 33(2), 209-230.

Mitropoulos, P., Abdelhamid, T. S., Howell, G. A. (2005). "Systems Model of Construction Accident Causation." *J. Constr. Eng. Manage.*, 131(7), 816-825.

Mitropoulos, P., and Namboodiri, M. (2011). "New Method for Measuring the Safety Risk of Construction Activities: Task Demand Assessment." *J. Constr. Eng. Manage.*, 137(1), 30-38.

Occupational Safety and Health Administration. (2010). *OSHA Training Standards Policy Statement*, OSHA, Washington.

Rajendran, S., and Gambatese, J. A. (2009). "Development and Initial Validation of Sustainable Construction Safety and Health Rating System." *J. Constr. Eng. Manage.*, 135(10), 1067-1075.

Robson, L. S. (2010). *A Systematic Review of the Effectiveness of Training & Education for the Protection of Workers*, Institute for Work & Health, Toronto.

Rozenfeld, O., Sacks, R., Rosenfeld, Y., Baum, H. (2010). "Construction Job Safety Analysis." *Saf. Sci.*, 48(4), 491-498.

Ruttenberg, R. (2013). *The Economic and Social Benefits of OSHA-10 Training in the Building and Construction Trades*, The center for construction research and training (CPWR), Maryland.

Sacks, R., Perlman, A., Barak, R. (2013). "Construction Safety Training using Immersive Virtual Reality." *Constr. Manage. Econ.*, 31(9), 1005-1017.

Spiller, S. A., Fitzsimons, G. J., Lynch Jr, J. G., McClelland, G. H. (2013). "Spotlights, Floodlights, and the Magic Number Zero: Simple Effects Tests in Moderated Regression." *J. Market. Res.*, 50(2), 277-288.

Suraji, A., Duff, A. R., Peckitt, S. J. (2001). "Development of Causal Model of Construction Accident Causation." *J. Constr. Eng. Manage.*, 127(4), 337-344.

Vittinghoff, E., Glidden, D. V., Shiboski, S. C., McCulloch, C. E. (2012). *Regression Methods in Biostatistics: Linear, Logistic, Survival, and Repeated Measures Models*, Springer, New York.

Wang, Y., Goodrum, P. M., Haas, C. T., Glover, R. W. (2008). "Craft Training Issues in American Industrial and Commercial Construction." *J. Constr. Eng. Manage.*, 134(10), 795-803.

Wilkins, J. R. (2011). "Construction Workers' Perceptions of Health and Safety Training Programmes." *Constr. Manage. Econ.*, 29(10), 1017-1026.

Winchester, H. P. (1999). "Interviews and Questionnaires as Mixed Methods in Population Geography: The Case of Lone Fathers in Newcastle, Australia." *The Professional Geographer*, 51(1), 60-67.

Withrow, B. L. (2014). *Research Methods in Crime and Justice*, Routledge, New York.

Zou, P. X., and Zhang, G. (2009). "Comparative Study on the Perception of Construction Safety Risks in China and Australia." *J. Constr. Eng. Manage.*, 135(7), 620-627.

Zou, P. X., and Sunindijo, R.Y. (2015). *Strategic Safety Management in Construction and Engineering Electronic Resource]*, Wiley, Hoboken.

**CHAPTER IV: EFFECT OF DISTRACTION (STUDY III)**

## **ABSTRACT**

Both hazard recognition and safety risk perception are fundamental to effective safety management. When construction hazards remain unrecognized, or the associated safety risk remains unperceived, the likelihood of injuries increase. Unfortunately, recent studies have shown that a large number of construction hazards remain unrecognized in typical workplaces. Likewise, past research has demonstrated that safety risk is widely underestimated within construction. Therefore, to improve safety performance, a proper understanding of factors that influence hazard recognition and safety risk perception is vital. Towards achieving this goal, the objective of the current study was to evaluate the effect of distractions – which are ubiquitous in construction environments – on the hazard recognition performance and safety risk perception of workers. The study goals were accomplished through an experimental effort involving 70 construction workers representing various specialty trades. In this study, the participating workers were randomly assigned to a distracted or an undistracted condition; and their hazard recognition performance and safety risk perception levels were measured using construction case images captured from real projects. The study findings revealed that the distracted workers recognized a smaller proportion of hazards compared to the undistracted workers. However, there were no significant differences in the level of perceived safety risk between the two groups. A closer examination of the data revealed that the safety risk perception levels for the undistracted workers were positively related to their hazard recognition performance. In other words, when undistracted workers recognized a larger proportion of hazards, they also perceived higher levels of safety risk. However, no such relationship was observed for the distracted workers – suggesting that the perceived risk was unrelated to or non-dependent on their hazard recognition performance. The findings of the

study suggest that workplace distractions can adversely affect hazard recognition performance, and the ability of workers to assess the associated safety risk. The current study represents the first empirical effort investigating the effect of workplace distraction on construction hazard recognition and safety risk perception.

## **INTRODUCTION**

Unacceptable injury rates continue to be a global issue in the construction industry. The numbers of fatal and non-fatal injuries in construction have consistently been among the highest – across industries and regions (International Labor Organization 2016). Most nations including the United States, the United Kingdom, and Australia have recognized construction as a high-risk industry – that is responsible for a disproportionate number of injuries (Occupational Safety and Health Administration 2016; Health and Safety Executive 2016; Safe Work Australia 2016).

In the United States, construction workplaces reported over 900 fatal and 200,000 non-fatal injuries in 2015 (Bureau of Labor Statistics 2016). These injuries cause substantial pain and distress among workers and their families, and in some cases destroy careers and livelihoods (Zou and Sunindijo 2015). In addition, the annual cost of these injuries exceed \$48 billion – adversely affecting profitability, reputation, and the financial sustainability of construction businesses (Ahmed et al. 2006).

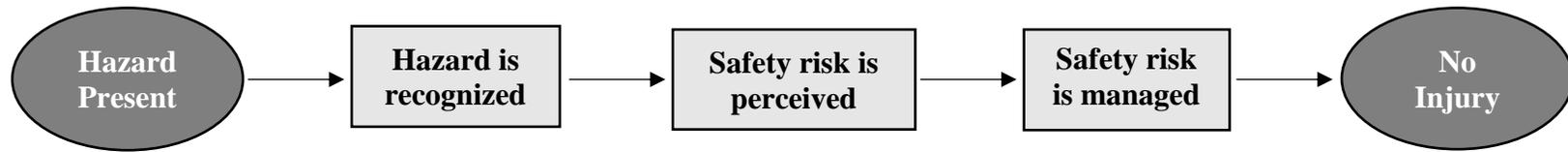
To prevent such injuries, much of construction safety research has focused on identifying and examining common injury causal factors (e.g., Abdelhamid and Everett 2000; Mitropoulos et al. 2005; Rajendran and Gambatese 2009). Among others, poor hazard recognition and the underestimation of safety risk have been identified as principal contributors

in a disproportionate number of injuries (Carter and Smith 2006; Namian et al. 2016a; Zuluaga et al. 2016; Tixier et al. 2014).

To demonstrate the importance of hazard recognition and safety risk perception, a simple conceptual safety management model adopted from Albert et al. (2014a) is presented in Figure 4.1. As can be seen, when construction hazards are properly recognized, and the associated safety risk is perceived and managed, the likelihood of injuries decrease. On the other hand, when safety hazards remain unrecognized, or the associated safety risk is not perceived, catastrophic injuries can follow.

Unfortunately, recent findings suggest that a large number of construction hazards remain unrecognized in typical construction environments (Albert et al. 2014b; Bahn 2013; Carter and Smith 2006). Likewise, evidence suggests that safety risk is widely underestimated or inaccurately perceived in the construction industry (Shin et al. 2014). In fact, past research has shown that over 42% of construction injuries are associated with worker-related factors including poor hazard recognition and the inaccurate assessment of safety risks (Haslam et al. 2005).

Therefore, to reduce workplace injuries, a proper understanding of factors that impact hazard recognition and safety risk perception is necessary. However, there has been limited research in this area – particularly in the construction context.



**Figure IV.1.** Conceptual safety management model

To begin addressing this knowledge gap, the objective of the current research was to evaluate the effect of distraction on hazard recognition and the safety risk perception of workers. More specifically, the hypotheses that distractions can adversely affect hazard recognition and safety risk perception was tested. In addition, the effect of distraction on the relationship between hazard recognition and safety risk perception was evaluated in the post-hoc phase of the study.

Although a number of studies have examined the effect of distraction in other domains such as transportation, aviation, and medicine (Rivera-Rodriguez and Karsh 2010; Young and Salmon 2012), only anecdotal and theoretical propositions (e.g., Hinze's distraction theory) are available in the construction literature (Hinze 1997). The current study represents the first attempt to test these propositions using an experimental approach.

## **BACKGROUND**

### **Hazard Recognition**

Hazard Recognition is arguably the most fundamental element of any safety management program. When safety hazards remain unrecognized, the likelihood of hazard exposure increases – which in turn increases the likelihood of catastrophic workplace safety incidents (Albert et al. 2014a; Carter and Smith 2006).

To prevent such safety incidents, the construction industry has traditionally adopted a number of hazard recognition methods. Examples of these methods include job-hazard analyses (JHA), pre-task safety meetings, safety checklists (Rozenfeld et al. 2010; Zou and Zhang 2009) and others.

Despite their usefulness, some important limitations of these methods have led to sub-optimal hazard recognition performance. For example, job-hazard analyses and pre-task safety meetings are predictive methods that require workers to predict future working conditions and expected safety hazards (Rozenfeld et al. 2010). However, a large body of research has demonstrated that even experienced and skilled workers struggle with making accurate predictions in dynamic and sometimes unpredictable environments (Fleming 2009). Other weaknesses of these methods include their inability to capture hazards that are imposed by adjacent work crews, those that emerge from unrelated work activities, and hazards resulting from dynamic workplace changes (Rozenfeld et al. 2010).

On the other hand, retrospective methods such as safety checklists are developed largely based on lessons learned from past safety incidents – to prevent future reoccurrences (Goh and Chua 2009). These methods require workers to examine the work environment for a list of pre-defined safety hazards known to have caused harm or injury in the past. Although useful, the most significant limitation of retrospective methods is that the pre-defined list of safety hazards may not be comprehensive of all possible hazards in dynamic work environments. In fact, Fleming (2009) argues that safety checklists may give a false sense of security to workers after the pre-defined set of safety hazards are addressed – even if additional hazards that are not part of the checklist may remain unrecognized.

In recent years, a number of emerging and specialized technologies have been proposed to improve and support hazard recognition. For example, recent research has proposed proximity sensors to detect struck-by potential (Park et al. 2015), inertial measurement sensors to detect trip and fall hazards (Kim et al. 2016; Yang et al. 2016), and worker localization systems to control unsafe behavior and hazardous area intrusions (Lee et al. 2011; Park et al.

2015). Others have proposed new frameworks to capture and visualize safety hazards (Awolusi and Marks 2016; Shen and Marks 2015b). Although promising, the proposed technologies are often designed to only capture specific hazard types (e.g., fall and stuck-by potential) and have not become mainstream within the construction industry. In most cases, construction workplaces continue to rely on the ability of workers to recognize and manage construction hazards.

Partly because of such limitations, recent research has demonstrated that a large number of construction hazards remain unrecognized in construction environments. For example, studies from the United States showed that over 40% of workplace hazards remain unrecognized in typical projects (Albert et al. 2014a). Similarly, case studies from the United Kingdom revealed that up to 33% of hazards remain unrecognized in projects that were examined (Carter and Smith 2006). More shockingly, a study from Australia found that novice workers fail to recognize more than 57% of hazards in work representative environments (Bahn 2013). Recent studies have unveiled several upstream and field-level barriers that impede thorough hazard recognition at the work interface (Jeelani et al. 2016; Namian et al. 2016).

These unrecognized hazards can potentially lead to catastrophic and tragic workplace safety incidents. Therefore, research into factors that are likely to influence hazard recognition performance is fundamental to improving construction safety performance.

## **Safety Risk Perception**

Apart from hazard recognition, the accurate perception of safety risk is fundamental to effective safety management. When safety risk is accurately perceived, workers are more likely to adopt responsive safety measures to prevent injuries (Arezes and Miguel 2008). On the other hand, when safety risk is underestimated or inaccurately perceived, safe decisions are unlikely to logically follow – and the likelihood of workplace injuries increase (Taylor and Snyder 2017).

Apart from safety risk management, the underestimation of safety risk is also highly correlated with risk-taking behavior (Patel and Jha 2014; Tixier et al. 2014). For example, experienced workers that regularly use ladders to work at heights (e.g., ironworkers and painters) may become desensitized to the associated safety risk, even when fall potential is recognized as a relevant hazard (Perlman et al. 2014). Other commonly observed risk-taking behaviors that stem from the underestimation or the inaccurate perception of safety risk include the non-usage of personal protective equipment (PPE), entering restricted work areas, operating equipment at unsafe speeds, and the removal of equipment safety features (Bohm and Harris 2010; Chi et al. 2012; Choudhry and Fang 2008). Such risk-taking behaviors are extremely common in construction workplaces and account for over 70% of workplace safety incidents (Haslam et al. 2005).

Although only a few studies have empirically investigated risk-taking behavior, several studies have examined factors that influence safety risk perception. For example, when workers regularly adopt risky behavior without experiencing any negative outcomes (e.g., injury), their risk perception levels decline with time – which can further instigate risk-taking behavior (Geller 2001). On the other hand, workers that have experienced an injury tend to

perceive relatively higher levels of safety risk – making them less likely to indulge in risk-taking behaviors (Shin et al. 2014).

Other factors that may impact safety risk perception include personal factors such as experience, knowledge, and the emotional states of workers (Tixier et al. 2014); and workplace factors such as safety climate and social norms (Lopez del Puerto et al. 2013). However, research into the effects of transitory workplace factors that occur during work (e.g., productivity pressures, workplace distractions) is still in its infancy. Because the underestimation and the inaccurate perception of safety risk are widespread issues in construction, a thorough understanding of factors that influence safety risk perception is necessary.

### **Distraction**

A large body of research has discussed the adverse effects of distractions – particularly on safety outcomes. However, much of this research has been conducted outside the construction context. For example, highway research has shown that distracted drivers are more likely to lose control over their vehicles, overlook roadway safety signage, and be involved in catastrophic accidents and crashes (Young and Salmon 2012). Similarly, distracted medical professionals are more prone to making fatal medical errors including the administration of incorrect drugs, adoption of improper infection control measures, and be inattentive to clinically important information (Rivera-Rodriguez and Karsh 2010). Other sectors with similar evidence on the effects of distractions include mining, aviation, and manufacturing (Chang et al. 2016).

In these studies, distraction is generally defined as any diversion of attention from safely performing the primary task (e.g., driving) (Regan et al. 2011). For example, drivers may be distracted by a cellphone conversation (Young and Salmon 2012), or physicians may be distracted by an irrelevant alarm from medical devices (Rivera-Rodriguez and Karsh 2010). Such distractions are known to impair performance in the primary task and can lead to disastrous outcomes (e.g., accidents). This is because the human brain possesses only a limited amount of attentional resource (Kahneman 1973). When this limited attentional resource is depleted or is diverted to a distractor, performance in the primary task that requires attention often deteriorates (Weisberg and Reeves 2013; Wickens and Horry, 2008).

Although empirical investigations on the effect of distraction have not been conducted in the construction context, anecdotal evidence suggests that distractions can have adverse effects. For example, Hinze's distraction theory suggests that workers that are distracted by productivity demands are more likely to overlook safety hazards (Hinze 1997). Others have suggested that distractions can lead to human errors, violations, and omissions with serious safety implications (Mitropoulos et al. 2005; Rasmussen 1997). Because distractions are ubiquitous in dynamic construction environments, empirical investigations on the effect of distraction are vital.

## **RESEARCH OBJECTIVES AND HYPOTHESIS DEVELOPMENT**

To improve construction safety performance, an understanding of factors that are predictive of hazard recognition and safety risk perception is necessary. Among other factors, researchers have hypothesized that distractions can adversely affect workplace safety outcomes. However,

these propositions remain largely untested in the construction context. To address this research gap, this study focused on testing the following hypotheses:

***Hypothesis 1:*** Distracted workers will recognize a smaller proportion of construction hazards compared to undistracted workers.

***Hypothesis 2:*** Distracted workers will perceive lower levels of safety risk (i.e., safety risk perception) compared to undistracted workers.

## **RESEARCH APPROACH**

The research objectives were accomplished in three separate and complementary stages. In the first stage, visual stimuli to induce distraction for the experiment were selected. In the next stage, the research participants were recruited from three independent projects in North Carolina. In the final stage, the experimental study to assess the effect of distraction was conducted. The following sections describe the research methods in detail:

### **Stage I: Selection of visual stimuli to induce distraction**

In the past, researchers have used various methods to induce distraction among study participants. For example, researchers have asked drivers to perform mental arithmetic calculations during driving operations (Ersal et al. 2010); students have been exposed to visual stimuli presented as video clips (e.g., television) during study sessions (Pool et al. 2003); and working professionals have been exposed to auditory stimuli (e.g., music) while at work (Furnham and Bradley 1997).

Because hazard recognition largely involves the visual examination of the workplace to identify relevant hazards, visual distractors are expected to cause higher levels of

impairment (as suggested by the Multiple Resource Theory, Wickens 2002). Moreover, visual distractors are prevalent in construction where dynamic operations and rapid changes are common. For the purposes of this study, visual stimuli in the form of video clips were used because of its superiority in capturing attention and inducing distraction – compared to other forms of visual stimuli such as static images (Chattington et al. 2010).

While comparing potential distractors for the study, video clips depicting construction operations were first considered to enhance internal validity. However, a preliminary examination of a few construction-related video clips highlighted an important problem. The video clips themselves contained several safety hazards that could potentially confound the hazard recognition performance measure. Therefore, the decision was made to use video clips that were unrelated to construction operations and free from construction hazards – but could nonetheless divert attention from the primary task (i.e., hazard recognition). Based on evidence from past research that even task-irreverent stimuli can draw from the limited pool of attentional resources available, the use of videos without construction hazards is reasonable (Weisberg and Reeves 2013).

A review of the literature was conducted to identify visual distractors used in previous research – particularly in the field of psychology, education, and medicine. The review suggested that visual stimuli pertaining to sports, nature, art, and animations were commonly used (e.g., Al-Khotani et al. 2016; Yoo et al. 2011). However, a database of the visual stimuli (i.e., video clips) used in the previous studies was not readily available. Therefore, a search for video clips of the same nature was conducted using the YouTube database.

Because the objective was to divert attention and thus induce distraction, popular video clips with over 200,000 views were first examined. The video clips were evaluated by the

experimenters for its suitability for the current research purpose while the audio content was muted. After reviewing over 100 video clips, 25 potential video clips were selected for further assessment. Special care was taken to ensure that the video clips did not depict any violent or risky operations (e.g., unsafe driving) that could inherently affect safety risk perception levels.

For each of the 25 video clips, a 60-second segment was selected excluding portions that were less distracting (e.g., opening title and closing credits). Next, a preliminary study was conducted with six graduate students to select the most distracting video clips. In this preliminary study, the students participated in a hazard recognition activity similar to the approach used in our experiment – as will be discussed in the subsequent sections. At the end of the activity, the students rated each video clip for the induced distraction level using a 7-point Likert scale ranging from 1 (*not at all distracting*) to 7 (*extremely distracting*). The ratings were subjective self-reported distraction levels experienced by the students during the hazard recognition activity. A final set of 16 video clips were selected based on participants' ratings of distractibility. The content of the selected video clips included sports (i.e., basketball game), aerial videography (i.e., view of mountain ranges), animations (i.e., time lapse of a flower blooming), wildlife (i.e., dolphins), and others.

## **Stage II: Recruitment of study participants**

The study participants were recruited from a convenient sample of three construction projects located in North Carolina. The scope of work in these projects included the construction of a large commercial hotel (\$4.5 Million), renovation of an athletic facility (\$35 Million), and the construction of several apartment complexes (\$35 Million). All of the projects were at least 50% complete during the initial visit for data collection. The workers in each of the projects

received safety training and toolbox talks on a regular basis that covered material provided and recommended by the Occupational Safety and Health Administration (OSHA) and beyond.

After the demographic details of the projects were gathered from the site leadership, the researchers were given access to recruiting study participants from the projects directly. The workers were randomly approached in the break-rooms where the experimental study was conducted. Because the research required the recruitment of a sufficient number of workers for hypotheses testing, the workers were recruited one-at-a-time over a 12 month period. This method ensured minimal work disruptions, the efficient use of the limited resources available to the researchers, and the ability to recruit workers representing diverse specialty trades that arrive at different stages of the project.

Overall, 70 workers representing more than 20 subcontractors were recruited for participation in the study. The participating workers represented various specialty trades and production workers including electricians (26%), piping and plumbing contractors (18%), mechanical contractors (16%), laborers and helpers (10%) and others (30%). The inclusion of a variety of workers representing diverse trades ensures the advancement of knowledge that is more generalizable to the construction industry. On average, the participating workers had over 12 years of construction experience in various states within the United States.

### **Stage III: Experimental Data Collection**

As mentioned earlier, the experiment was conducted in the break-rooms of the participating projects. The break-rooms provided an efficient location to easily gain access to workers, but also limited external distractions from construction operations. To further reduce external distractions, the experiments were conducted during regular work hours – when non-

participating workers are less likely to remain in the break-room. In most cases (>85%), the workers participated in the study in the morning between 8 am and lunch break.

To reliably test the hypotheses, the independent measures design – also known as the between-groups design – was adopted. The choice was made to adopt the independent measures design over the alternate repeated measures (or within-groups) design to control for any order effects that may result because of the length of the experiment (Smith et al. 2008). More specifically, there was concern that fatigue, boredom or disinterest may possibly confound the measures of hazard recognition and safety risk perception if the repeated measures design was adopted – which may have possibly required more than 30 minutes of participation from each worker as opposed to less than 20 minutes with the independent measures approach.

After the experimental procedure was discussed with the participating workers independently, they were randomly assigned to either a distracted or an undistracted condition. More specifically, the participants were assigned to both groups based on a random assignment plan produced by a random number generator for experimental research. Such an approach for random assignment maximizes the probability that potential confounding variables – those that are known (e.g., age, experience, etc.) and others that may be unknown (e.g., intelligence, safety knowledge, etc.) – are equivalently distributed across the comparison groups to minimize bias (Johnson and Christensen 2008). In other words, randomization facilitates the formation of comparison groups that are equivalent in all aspect – except for the manipulated variable such as distraction (Graphpad 2017). In addition, care was taken to ensure that workers in both the conditions experienced the same conditions except for the distracted or undistracted condition.

After the random assignment, the undistracted group included 29% electricians, 23% piping and plumbing contractors, 14% mechanical contractors, 11% laborers and helpers, and 23% others. On the other hand, the distracted group included 23% electricians, 14% piping and plumbing contractors, 17% mechanical contractors, 9% laborers and helpers, and 37% others. Workers in both conditions participated in the hazard recognition task and provided their safety risk perception ratings as described below.

### ***Measuring Hazard Recognition Performance***

To measure hazard recognition performance, a preselected set of 16 construction case images captured from real projects in the United States were used. The case images were gathered in a previous research effort by a panel of 17 construction safety professionals (Albert et al. 2014a). The case images presented diverse construction operations including excavation, grinding, welding, cutting, crane rigging, equipment operation, and others.

After the case images were gathered, the expert panel pre-identified the safety hazards in each case image through brainstorming sessions. Each case image depicted at least eight safety hazards of varying types including gravity (e.g., trip potential), motion (e.g., work adjacent to moving equipment), electricity (e.g., power lines), temperature (e.g., ignition source), and others.

In the current study, each participant completed the hazard recognition activity with four construction case images that were randomly selected from the pool of 16 case images. Because it is common practice for different trades to work alongside each other, workers are often exposed to hazards imposed by other trades. For example, it is not uncommon for electricians to be exposed to hazards imposed by an excavation contractor. Therefore, the

assignment of the case images was not based on the trade focus of the participating worker. In addition, four case images were used in the current study to minimize any bias based on performance in a particular case image. Such an approach, for example, reduced bias that may be introduced if an electrician only experiences case images depicting electrical work – where his performance may be superior. The study assumed that the performance of a participating worker across the four case images was more representative of the worker’s overall performance.

For each case image, the workers were provided with up to 60 seconds to recognize all hazards. After the 60 second limit, the construction case images were not viewable for both groups. This ensured that the distracted workers remained in the distracted condition throughout the activity – since the length of each distracting visual stimuli was 60 seconds.

The case images were presented to the workers on a 14” laptop computer monitor. For the workers assigned to the distracted condition, the construction case images were presented along with a distracting video clip. However, for workers in the undistracted condition, only the construction case images were presented.

More specifically, for workers in the distracted condition, the left half of the screen presented the case images, and the right half of the screen presented the distracting visual stimuli. For each construction case image presented (i.e., four for each worker), a video clip was randomly selected from among the videos selected in stage I as the visual distractor.

For each case image, the hazard recognition performance of the worker was calculated as the proportion of hazard identified as shown in Equation 4.1. The overall hazard recognition performance of each worker ( $HR_i$ ) was calculated as the average performance across the four construction case images.

$$HR_{ij} = \frac{HR_{worker}}{HR_{total}} \quad (4.1)$$

Where  $HR_{ij}$  is the proportion of hazards identified by worker  $i$  in case image  $j$ ;  $HR_{worker}$  is the total number of hazards identified by worker  $i$  in a specific construction case image  $j$ ; and  $HR_{total}$  represents the total number of unique hazards identified by the expert panel and all participating worker for the same case image.

### ***Measuring Safety Risk Perception***

Safety risk perception is generally defined as one's subjective assessment of the likely frequency and severity of adverse outcomes (e.g., injury) for a given scenario (Fung et al. 2010). Accordingly, past research has measured safety risk perception by presenting workers with a particular work scenario and gathering their judgment on the likely frequency and severity of potential safety incidents (e.g., Zhao et al. 2016). Using this information, an individual's safety risk perception for a particular work scenario can be quantified as the product of the frequency and severity of expected safety incidents as presented in Equation 2. This approach has successfully been used and validated in a number of previous studies (e.g., Hallowell and Gambatase 2009).

$$\text{Safety Risk} = \text{Frequency of incidents} \times \text{Severity of incidents} \quad (4.2)$$

Where frequency of incidents (e.g., injury frequency) is usually measured as the no. of incidents within a specific time period (e.g., # of injuries / worker-hour), and the severity of incidents is representative of the magnitude or seriousness of the undesirable safety outcome (e.g., treatment medical cost).

To gather the safety risk perception in the current study, the survey instrument presented in Figure 4.2 was used. Specifically, based on the scenario depicted in the case images, the workers were asked to indicate the expected injury frequency for each of the severity levels or injury outcomes. To ensure a uniform understanding of the survey instrument among the study participants, the definitions of the injury outcomes as presented in Table 4.1 were provided. In most cases, the participating workers completed the safety risk perception activity for each case image in less than 30 seconds irrespective of the assigned condition.

**Injury Frequency**

	<b>Every week (~ 40 w-hr)</b>	<b>Every month (~ 167 w-hr)</b>	<b>Every year (~ 2k w-hr)</b>	<b>Every ten years (~ 20k w-hr)</b>
<b>Discomfort/Pain</b>				
<b>First aid</b>				
<b>Medical Case</b>				
<b>Lost work time</b>				
<b>Permanent disablement or fatality</b>				

**Figure IV.2.** Safety risk reception measurement instrument

**Table IV.1.** Injury outcome description

<b>Injury Outcomes</b>	<b>Description</b>
<b>Discomfort / Pain</b>	Incidents that result in temporary or persistent pain, but do not prevent workers from performing work in normal capacity
<b>First Aid</b>	Incidents that require treatment for cases such as minor cuts, scratches, and sprains; where the worker is able to return to work immediately following treatment.
<b>Medical Case</b>	Injuries or illnesses that require care or treatment from medical professionals beyond first aid; where the worker is able to return to regular work under normal capacity.
<b>Lost Work Time</b>	Injuries or illnesses that restrict workers from returning to work on the following day.
<b>Permanent Disability or Fatality</b>	Injuries or illnesses that result in permanent disablement or death of worker

**Table IV.2.** Safety risk perception values

Frequency Severity	Severity score	Every week (~ 40 w-hr)	Every month (~ 167 w-hr)	Every year (~ 2k w-hr)	Every ten years (> 20k w-hr)
<b>Discomfort/Pain</b>	2.5	0.06	0.01	$1.25 \times 10^{-3}$	$1.25 \times 10^{-4}$
<b>First aid</b>	5.5	0.14	0.03	$2.75 \times 10^{-3}$	$2.75 \times 10^{-4}$
<b>Medical Case</b>	7	0.18	0.04	$3.50 \times 10^{-3}$	$3.50 \times 10^{-4}$
<b>Lost work time</b>	8	0.20	0.05	$4.0 \times 10^{-3}$	$4.0 \times 10^{-4}$
<b>Disablement/fatality</b>	9.5	0.24	0.06	$4.7 \times 10^{-3}$	$4.75 \times 10^{-4}$

After the data were gathered, the severity scale proposed by Hallowell (2008) as shown in the left column of Table 4.2 was adopted to calculate the safety risk perception levels. The safety risk perception values corresponding to the combination of each frequency and severity levels (i.e., using Equation 2) is presented in the remaining columns of Table 4.2. For example, if a medical case injury (i.e., severity score of 7) is expected to occur every month (i.e., the frequency of 1/167 worker-hours), the corresponding safety risk perception value will be 0.04 as shown in Table 4.2.

Using the values shown in Table 4.2, the aggregate safety risk perception score for each case image was calculated for each worker. For example, if a worker indicates that discomfort or pain is likely to occur once every week, first aid incidents are likely to occur once every month, and the remaining injury outcomes are likely to occur once every year, the corresponding safety risk perception score for the case image will be 0.1023 (i.e.,  $0.06 + 0.03 + 3.5 \times 10^{-3} + 4 \times 10^{-3} + 4.75 \times 10^{-3}$ ).

After the safety risk perception scores for each worker corresponding to each case image was calculated, the scores were standardized using Equation 3. This standardization process provided two important advantages. First, it provided an efficient way to compare safety risk perception levels among the participating workers. For example, a positive standardized score would suggest that the particular worker rated the safety risk to be higher than the average worker. Likewise, a negative score would indicate that the worker perceived a lower level of safety risk than average for a particular case image. If a standardized score of zero is observed, it would indicate that the safety risk perceived by the particular worker is equal to the average safety risk rating provided by all participating workers for that particular image.

$$SRP_{ij} = \frac{RP_{ij} - \overline{RP}_j}{\sigma_j} \quad (4.3)$$

Where  $SRP_{ij}$  is the standardized safety risk perception score for worker  $i$  for case image  $j$ ;  $RP_{ij}$  is the raw safety risk perception score for worker  $i$  for case image;  $\overline{RP}_j$  is the mean safety risk perception score for case image  $j$  for all participating workers; and  $\sigma_j$  is the standard deviation of the safety risk perception scores for case image  $j$  from all participating workers

The standardized score also enables the comparison of safety risk perception scores across independent case images when the underlying safety risk may be different. For example, a case image involving excavation work for utility installation adjacent to an active highway may be inherently riskier than other standard work scenarios. In such cases, the standardization process facilitates the interpretation of the safety risk perception scores in terms of the number of standard deviations above or below the mean irrespective of the underlying risk in a case image. For example, if a particular worker rates the aggregate safety risk depicted in a particular case image to be equal to 0.35, and the average rating of all the workers were 0.1 for the same case image with a standard deviation of 0.22, then the resulting standardized score would be equal to 1.14. The interpretation of this number would be that the particular worker's safety risk perception score was 1.14 standard deviations above the mean of all workers.

After the standardized scores were calculated, the overall safety risk perception score was calculated as the average standardized score across the four case. This score depicted whether a worker – across the four case images – perceived safety risk to be relatively higher or lower compared to all participating workers.

## DATA ANALYSIS AND DISCUSSIONS

The experimental effort yielded a unique hazard recognition score and a standardized safety risk perception (henceforth called safety risk perception for simplicity) score for each of the 70 participants. Among these, 35 represented data gathered from workers assigned to the undistracted condition, and the remaining 35 represented data gathered from workers assigned to the distracted condition. The two groups were not significantly different in terms of age or experience (i.e., no. of years in the construction industry) – which provided evidence that the random assignment of the study participants was successful in producing equivalent groups.

As discussed earlier, the objective was to test the hypotheses that the hazard recognition and safety risk perception scores for both the groups will be different. More specifically, the hypotheses predicted that the workers assigned to the distracted condition (1) will recognize a smaller proportion of hazards, and (2) will perceive lower levels of safety risk.

To test the hypotheses, two-sample tests for independent measures were adopted. To choose the appropriate two-sample test, the hazard recognition and safety risk perception scores were first tested for normality. The results indicated that the hazard recognition data was normally distributed based on the skewness (undistracted group:  $\gamma = 0.45$ ,  $p$ -value = 0.24; distracted group:  $\gamma = 0.52$ ,  $p$ -value = 0.18) and the kurtosis criteria (undistracted group:  $g = 0.086$ ,  $p$ -value > 0.10; distracted group:  $g = -0.33$ ,  $p$ -value > 0.10). However, for safety risk perception, the distracted group violated the skewness criteria (distracted group:  $\gamma = 0.829$ ,  $p$ -value = 0.04; undistracted group:  $\gamma = -0.021$ ,  $p$ -value = 0.95), and the undistracted group violated the kurtosis criteria (undistracted group:  $g = -1.250$ ,  $p$ -value < 0.02; distracted group:  $g = -0.246$ ,  $p$ -value > 0.10). Accordingly, the two-sample student's  $t$ -test was adopted to test

hypothesis 1 and the non-parametric equivalent Mann-Whitney *U*-test was used to test hypothesis 2.

Table 4.3 presents the descriptive statistics including the means and standard deviations for workers in both the conditions. The results revealed that workers in the undistracted condition ( $M = 42.71\%$ ) recognized a larger proportion of hazards than the workers in the distracted condition ( $M = 35.52\%$ ). Therefore, the difference in hazard recognition performance between the two groups exceeded 7%. In addition, the results of the *t*-test suggested that this difference was statistically significant (i.e.,  $p\text{-value} < 0.05$ ). Therefore, the data provided support for hypothesis 1, suggesting that distraction can indeed adversely affect hazard recognition performance.

However, the comparison of the safety risk perception scores between the two groups did not provide support for hypothesis 2. Contrary to the expectations, the descriptive statistics suggested that the undistracted workers perceived lower levels of safety risk compared to the distracted workers. However, the results of the Mann-Whitney *U*-test suggested that the difference between the two groups were not statically significant. Therefore, based on the findings, no significant difference was found in the safety risk perception of both the groups.

**Table IV.3.** Analysis results (Hypotheses 1 & 2)

<b>Experimental Condition</b>	<b>Hazard recognition performance</b>					<b>Safety risk perception</b>			
	<i>n</i>	<i>M (Mn)</i>	<i>SD</i>	$\Delta$	<i>p</i> -value	<i>M (Mn)</i>	<i>SD</i>	$\Delta$	<i>p</i> -value
<b>Undistracted</b>	35	42.71% (40.41%)	10.20%	7.19%	0.003**	-0.14	0.49	0.23	0.53
<b>Distracted</b>	35	35.52% (34.24%)	9.59%			0.22	0.87		
<b>Overall</b>	70	39.11% (38.41%)	10.48%		-	0.00	0.70	-	-

Note: n = number of projects; *M (Mn)* = mean (median); *SD* = standard deviation;  $\Delta$  = effect size.

\*\* significant level: *p*-value < 0.01

In summary, hypothesis 1 was supported which predicted that the undistracted workers will recognize a larger proportion of hazards compared to the distracted workers. However, hypothesis 2 was not supported, and the analysis findings suggested that the safety risk perception levels were not different (i.e., comparable) for the distracted and the undistracted workers. Apart from the primary hypotheses results, a significant correlation was not observed between experience (i.e., number of years in construction) and hazard recognition or safety risk perception in the current study ( $p$ -value  $> 0.05$ ). Similarly, other known variables such as participant age, participating project, or time of data collection were not positively correlated with either hazard recognition or safety risk perception ( $p$ -value  $> 0.05$ ).

### **POST HOC DATA ANALYSIS**

The purpose of the study was to evaluate the effect of distraction on two leading indicators of safety performance: (1) hazard recognition and (2) safety risk perception. As discussed in the previous section, the findings suggested that distraction adversely affected hazard recognition performance, but not safety risk perception levels. This finding is surprising because previous research has suggested that workers who do not recognize safety hazards, will also be unable to perceive the associated safety risk (Carter and Smith 2006).

Because a clear explanation for this surprising finding was not available, additional posthoc analyses were conducted. More specifically, additional investigation was conducted to assess whether a relationship existed between the hazard recognition performance and the safety risk perception for workers in the two groups independently. Accordingly, the following hypothesis was tested:

**Hypothesis 3:** Safety risk perception levels will be positively related to the proportion of hazards recognized by the undistracted and the distracted workers.

To test the hypothesis, the data was first separated into two groups. The first group included the data for workers that were assigned to the undistracted condition, and the second group included the remaining data pertaining to workers that were assigned to the distracted condition.

For both groups, regression analysis was performed independently using the mathematical model presented in Equation 4.4.

$$RP_i = \beta_0 + \beta_1 \cdot HR_i + \varepsilon \quad (4.4)$$

Where,  $RP_i$  is the safety risk perception (i.e., standardized) of worker  $i$ ;  $HR_i$  is the hazard recognition performance of worker  $i$ ;  $\beta_0$  is the intercept of the regression line at  $HR = 0$ ;  $\beta_1$  is the slope of the regression line representing the strength of the relationship between hazard recognition ( $HR$ ) and safety risk perception ( $RP$ );  $\varepsilon$  is the error term that represents the unexplained variability of the data.

The model parameters were estimated by regressing the hazard recognition scores over the safety risk perception scores. Because the error variance was not normally distributed, the bootstrapping method was adopted to generate confidence intervals. The bootstrapping approach is a resampling method that does not rely on the assumption of normality of error variance or homoscedasticity and is well suited for data with irregular distributions (Mooney et al. 1993). For the current analysis, 1000 resamples were used for the bootstrapping technique with a slightly liberal alpha level ( $\alpha = 0.1$ ) to account for the relatively small sample size as recommended by Burslem et al. (2005).

The results of the analysis are presented in Table 4.4. As can be seen, the hazard recognition coefficient for the undistracted group ( $\beta_1 = 0.018$ ) was positive, suggesting that the safety risk perception levels increased with a corresponding increase in hazard recognition performance. More specifically, for every unit increase in hazard recognition performance (i.e. .1%), the safety risk perception score increased by 0.018 units. The corresponding  $p$ -value and the confidence interval suggested that the relationship between hazard recognition and safety risk perception was statistically significant. In other words, the perceived level of safety risk was dependent on the proportion of hazards recognized by the workers in the undistracted condition.

**Table IV.4.** Post hoc analysis results (Hypothesis 3)

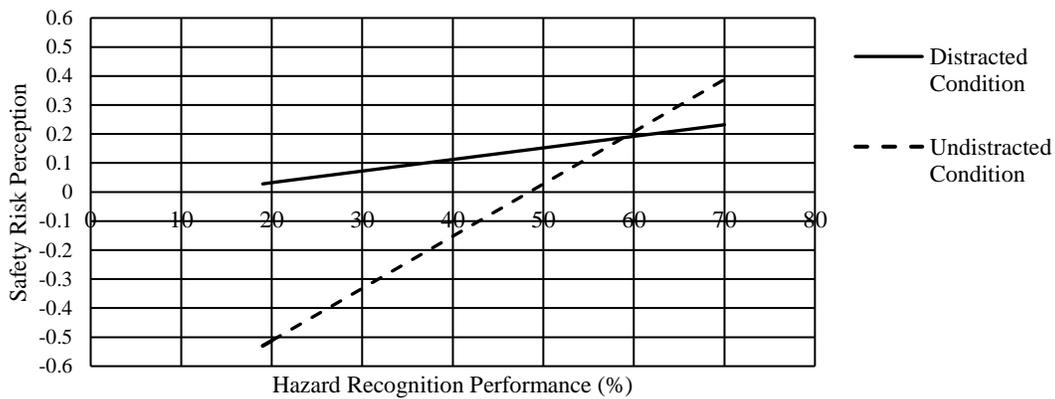
<b>Condition</b>	<b>Predictors</b>	<b>Coefficient</b>	<b>Std. Error</b>	<b><i>p</i>-value</b>	<b>LLCI</b>	<b>ULCI</b>	<b><i>r</i><sup>2</sup></b>
<b>Undistracted</b>	<b>Constant (<math>\beta_0</math>)</b>	-0.872	0.310	0.006	-1.398	-0.380	0.117
	<b>Hazard Recognition (<math>\beta_1</math>)</b>	0.018	0.007	0.017**	0.007	0.031	
<b>Distracted</b>	<b>Constant (<math>\beta_0</math>)</b>	-0.048	0.466	0.914	-0.915	0.658	0.003
	<b>Hazard Recognition (<math>\beta_1</math>)</b>	0.004	0.014	0.741	-0.016	0.030	

LLCI & ULCI - Lower and upper limit confidence intervals

\*\* significance level: *p*-value < 0.10

For workers in the distracted condition, although a positive relation was found between hazard recognition and safety risk perception ( $\beta_1 = 0.004$ ), the relationship was not statistically significant. Therefore, the findings suggested that the safety risk perception levels were not dependent on the hazard recognition performance for workers in the distracted condition. In other words, hazard recognition performance was not a significant predictor of safety risk perception in the presence of a distraction.

To compare the trends more closely, both regression equations estimated using the method of least squares (i.e., best-fit lines) were plotted in the form of a chart as shown in Figure 4.3. As can be seen, the undistracted group demonstrated a strong and positive relationship between hazard recognition and safety risk perception ( $r = .342$ ). However, the distracted group's safety risk perception levels did not vary substantially with changes in hazard recognition performance ( $r = .055$ ).



**Figure IV.3.** Safety risk reception measurement instrument

According to the chart, the distracted workers surprisingly perceived higher levels of safety risk compared to the undistracted workers when hazard recognition levels were less than 59%. However, as per the results of the hypotheses tests, hazard recognition was not a significant predictor of safety risk perception for workers in the distracted condition. Therefore, the results suggest that the higher levels of perceived safety risk may be unrelated to the underlying hazards – but may have been induced by other external factors that may be potentially related to workers being in the distracted state.

One plausible explanation for this pattern is that the presence of multiple and concurrent stimuli (i.e., hazard stimuli and distracting stimuli) may have caused cognitive overload – where workers were not able to rationally quantify the risk associated with the underlying safety hazards (Shahar 2009). The relatively higher standard error (i.e., variability) associated with the relationship between hazard recognition and safety risk perception (i.e., for the distracted workers) offers some additional support for this explanation. In fact, the standard error was two times higher for the distracted workers than the undistracted workers. Another potential explanation is that distraction may have impaired situational awareness (Strayer and Fisher 2015). Situational awareness is the ability to process and understand important information and infer related consequences. Because distraction may have impaired situational awareness, workers may have been unable to properly assess safety risk levels.

Irrespective of the underlying reason for the higher levels of perceived risk, when the perceived safety risk is not dependent on the underlying hazards, safe work practices that avoid hazard exposure are unlikely to follow in practice. Because safety risk perception was unrelated to the hazard recognition performance for the distracted workers, the findings suggest

that distraction can adversely affect the ability of workers to assess the safety risk associated with recognized hazards.

## **IMPLICATIONS OF STUDY FINDINGS**

The current study represents the first effort to empirically investigate the effect of distraction on two leading indicators of safety performance – hazard recognition and safety risk perception. The findings of the study have important theoretical and practical implications for construction safety as discussed below:

First, the study results provide empirical evidence suggesting that workplace distractions can lead to adverse safety outcomes. More specifically, the current study found evidence suggesting that workplace distractions that consume attentional resources can lead to lower hazard recognition levels. In addition, even when workers recognize workplace hazards, distractions may impair the ability of workers to effectively quantify the associated safety risk. Because both hazard recognition and safety risk perception are essential prerequisites to effective safety management, workplace distractions may undesirably increase injury likelihood.

Second, the research findings highlight the importance of reducing workplace distraction – whenever possible – to improve workplace safety. This has important implications for employers and contractors as they evaluate and introduce new technologies within construction such as remote sensing (Ramezaniapour et al. 2014). For example, contractors and researchers are actively investigating technologies such as Unmanned Aerial Vehicles (UAVs) for project progress monitoring, topographical surveying, safety inspections, and even material transportation (Irizarry and Costa 2016). While these technologies offer breakthrough

opportunities, practitioners must be cognizant of its effects as a potential distractor (Tatum and Liu 2017). Similar concerns with UAVs have been expressed in the literature concerning distracted drivers, pedestrian safety, and recreational sports (e.g., Kim et al. 2017). Other emerging technologies that may also need careful monitoring include augmented and mixed reality headsets, wearable sensor technologies, and smart mobile robots.

Finally, contractors may consider potential interventions to minimize workplace distractions and associated outcomes. For example, employers may educate workers on the adverse effects of distractions, and encourage the reduction of unnecessary distraction from mobile devices and portable tablet devices while at work. Employers may also consider scheduling high-risk work tasks when distraction levels are expected to be low – or when only a few concurrent tasks are scheduled. Employers may also take active steps to reduce employer-induced distractions such as imposed productivity pressures that divert attention from safety issues in the workplace. Although eliminating attention-diverting distractions may not be completely feasible, minimizing them are expected to yield safety benefits.

## **STUDY LIMITATIONS AND FUTURE RESEARCH RECOMMENDATIONS**

Despite the strengths and contributions of this study, there are important limitations that shall be addressed in future research. The most important limitation of the current study is the method that was used to induce distraction. More specifically, as discussed earlier, the decision was made to use video-clips that were unrelated to construction operations to induce distraction. This decision was made to preserve the reliability of the hazard recognition and safety risk perception measures – because the use of construction-related distractors would present additional hazards – apart from the ones in the case images that were used to measure

performance. Given that past research suggests that attention drawing distractions – irrespective of type – operate in the same manner by consuming from the limited pool of attentional resource, the substitution was reasonable (Weisberg and Reeves 2013). Future observational studies may be conducted in real construction environments to examine the effect of more representative distractions.

Second, both hazard recognition and safety risk perception were measured using static construction case images. Although the case images were captured from real projects, they do not capture the true dynamic nature of construction operations. Nonetheless, the approach provided a standard and reliable approach to measure and compare performance between the two groups for the purposes of this study. Moreover, past research has found a strong correlation between the performance of workers in construction case images and actual workplaces (Albert et al. 2014b).

Third, in the current study, data were gathered from multiple workers representing diverse trades and different subcontractors. However, all the study participants were recruited from only three projects in North Carolina – which may limit the generalizability of the study findings. Nonetheless, most workers had previous employment in other states within the United States. Moreover, there is no evidence suggesting that workers in North Carolina are systematically different from workers in other regions in the United States.

Finally, because safety risk perception is a subjective measure rather than an absolute measure, like previous studies, the current study assumed that higher levels of perceived safety risk are desirable (e.g., Tixier et al. 2014). This assumption has been made because previous efforts have found a strong positive correlation between safety risk perception levels and the adoption of safe work practices (Taylor and Snyder 2017). In addition, previous findings have

shown that workers who perceive higher levels of safety risk are less likely to adopt risk-taking behavior (Tixier et al. 2014). However, the current research findings present an important problem that must be tackled in future research. More specifically, the findings suggested that the workers in the distracted condition perceived higher levels of safety risk than the undistracted workers when hazard recognition levels were less than 59%. However, this finding is surprising because the results suggest that the perceived safety risk was unrelated to the underlying safety hazards present in the case images – and may be related to the distraction itself. Future research must investigate the effect of this increase in safety risk perception – even when the underlying hazards may remain unrecognized – on workplace behavior and safety outcomes.

## **CONCLUSION**

Both hazard recognition and the perception of safety risk are fundamental to the prevention of workplace injuries. When workplace hazards remain unrecognized, or the associated safety risk is unperceived, the likelihood of injuries increase (Carter and Smith 2006). Unfortunately, recent research has found that a large number of construction hazards remain unrecognized in typical construction environments (Albert et al. 2014a; Bahn 2013; Carter and Smith 2006). Similarly, evidence suggests that safety risk is widely underestimated or inaccurately perceived in construction – leading workers to adopt risk-taking behavior (Shin et al. 2014). Therefore, to reduce the likelihood of construction injuries, a proper understanding of factors that influence both hazard recognition and safety risk perception is fundamental.

Towards this goal, the current study focused on evaluating the effect of distraction on the ability of workers to recognize safety hazards and perceive the associated safety risk. The

study involved an experimental effort where 70 workers were recruited and randomly assigned to a distracted or an undistracted condition – and their performance was measured using construction case images. The study found that the distracted group recognized fewer hazards than the undistracted group. However, there were no differences in the level of perceived safety risk between the two groups.

A closer examination of the data revealed a positive relationship between hazard recognition and safety risk perception for the workers in the undistracted group. More specifically, when the undistracted workers recognized a larger proportion of hazards, their safety risk perception levels were higher. However, no particular pattern was observed for workers assigned to the distracted group – suggesting that the safety risk perception scores were not dependent on the recognized hazards.

Overall, the findings suggested that distractions can adversely affect the hazard recognition performance of workers, and may impede their ability to quantify the associated safety risk rationally. Therefore, employers must actively consider interventions to reduce workplace distractions whenever possible to improve workplace safety. The findings of this research will be useful to practitioners and researchers seeking to understand and mitigate adverse effects of workplace distractions.

## REFERENCES

- Abdelhamid, T. S., and Everett, J. G. (2000). "Identifying Root Causes of Construction Accidents." *J. Constr. Eng. Manage.*, 126(1), 52-60.
- Ahmed, S. M., Azhar, S., Forbes, L. H. (2006). "Costs of Injuries/Illnesses and Fatalities in Construction and their Impact on the Construction Economy." CIB W99 International Conference on Global Unity for Safety and Health in Construction, Beijing, China.
- Albert, A., Hallowell, M. R., Kleiner, B. M. (2014a). "Experimental Field Testing of a Real-Time Construction Hazard Identification and Transmission Technique." *Constr. Manage. Econ.*, 32(10), 1000-1016.
- Albert, A., Hallowell, M. R., Kleiner, B., Chen, A., Golparvar-Fard, M. (2014b). "Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality." *J. Constr. Eng. Manage.*, 140(7), 04014024.
- Al-Khotani, A., Bello, L. A., Christidis, N. (2016). "Effects of Audiovisual Distraction on children's Behaviour during Dental Treatment: A Randomized Controlled Clinical Trial." *Acta Odontol. Scand.*, 74(6), 494-501.
- Arezes, P. M., and Miguel, A. S. (2008). "Risk Perception and Safety Behaviour: A Study in an Occupational Environment." *Saf. Sci.*, 46(6), 900-907.
- Awolusi, I. G., and Marks, E. D. (2016). "Safety Activity Analysis Framework to Evaluate Safety Performance in Construction." *J. Constr. Eng. Manage.*, 143(3), 05016022.

Bahn, S. (2013). "Workplace Hazard Identification and Management: The Case of an Underground Mining Operation." *Saf. Sci.*, 57, 129-137.

Bohm, J., and Harris, D. (2010). "Risk Perception and Risk-Taking Behavior of Construction Site Dumper Drivers." *Int. J. Occup. Saf. Ergonomics*, 16(1), 55-67.

Bureau of Labor Statistics (BLS). (2016). "Injuries, illnesses, and fatalities." <<https://www.bls.gov/news.release/osh.toc.htm>> September 13, 2017).

Burslem, D., Pinard, M., Hartley, S. (2005). *Biotic Interactions in the Tropics: Their Role in the Maintenance of Species Diversity*, Cambridge University Press, Cambridge, U.K.

Carter, G., and Smith, S. (2006). "Safety Hazard Identification on Construction Projects." *J. Constr. Eng. Manage.*, 132(2), 197-205.

Chang, Y., Yang, H., Hsiao, Y. (2016). "Human Risk Factors Associated with Pilots in Runway Excursions." *Accident Analysis & Prevention*, 94, 227-237.

Chattington, M., Reed, N., Basacik, D., Flint, A., Parkes, A. (2010). *Investigating Driver Distraction: The Effects of Video and Static Advertising*, Transportation Research Lab., London.

Chi, S., Han, S., Kim, D. Y. (2012). "Relationship between Unsafe Working Conditions and Workers' Behavior and Impact of Working Conditions on Injury Severity in US Construction Industry." *J. Constr. Eng. Manage.*, 139(7), 826-838.

Choudhry, R. M., and Fang, D. (2008). "Why Operatives Engage in Unsafe Work Behavior: Investigating Factors on Construction Sites." *Saf. Sci.*, 46(4), 566-584.

Ersal, T., Fuller, H. J., Tsimhoni, O., Stein, J. L., Fathy, H. K. (2010). "Model-Based Analysis and Classification of Driver Distraction under Secondary Tasks." *IEEE Transactions on Intelligent Transportation Systems*, 11(3), 692-701.

Fleming, M. A. (2009). "Hazard Recognition Techniques." *By Design, ASSE*, 9(3), 15-18.

Fung, I. W., Tam, V. W., Lo, T. Y., Lu, L. L. (2010). "Developing a Risk Assessment Model for Construction Safety." *Int. J. Project Manage.*, 28(6), 593-600.

Furnham, A., and Bradley, A. (1997). "Music while You Work: The Differential Distraction of Background Music on the Cognitive Test Performance of Introverts and Extraverts." *Applied Cognitive Psychology*, 11(5), 445-455.

Geller, E. S. (2001). *Working Safe: How to Help People Actively Care for Health and Safety*, CRC Press, Boca Raton, FL.

Goh, Y. M., and Chua, D. (2009). "Case-Based Reasoning Approach to Construction Safety Hazard Identification: Adaptation and Utilization." *J. Constr. Eng. Manage.*, 136(2), 170-178.

Graphpad (2017). "Randomly assign subjects to treatment groups." <  
<https://www.graphpad.com/quickcalcs/randomize1>> Jan. 15, 2017).

Hallowell, M. R., and Gambatese, J. A. (2009). "Activity-Based Safety Risk Quantification for Concrete Formwork Construction." *J. Constr. Eng. Manage.*, 135(10), 990-998.

Hallowell, M. R. (2008). *A Formal Model for Construction Safety and Health Risk Management*, Oregon State University, Ph.D. thesis, Oregon State Univ., Corvallis, Oregon.

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., Duff, A. R. (2005). "Contributing Factors in Construction Accidents." *Appl. Ergon.*, 36(4), 401-415.

Health and Safety Executive. (2016). "Health and safety in the construction industry." <<http://www.hse.gov.uk/statistics/industry/construction/construction.pdf?pdf=construction>> (September 13, 2017).

Hinze, J. (1997). "The distractions theory of accident causation." CIB Rep., A.A. Balkema, Rotterdam, Netherlands.

International Labor Organization. (2016). "Safety, health and welfare on construction sites; A training manual." < [http://www.ilo.org/wcmsp5/groups/public/---ed\\_protect/---protrav/---safework/documents/instructionalmaterial/wcms\\_110237.pdf](http://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/instructionalmaterial/wcms_110237.pdf)> (September 13, 2017).

Irizarry, J., and Costa, D. B. (2016). "Exploratory Study of Potential Applications of Unmanned Aerial Systems for Construction Management Tasks." *J. Manage. Eng.*, 32(3), 05016001.

Jeelani, I., Albert, A., Gambatese, J. A. (2016). "Why do Construction Hazards Remain Unrecognized at the Work Interface?" *J. Constr. Eng. Manage.*, 143(5), 04016128.

Johnson, B., and Christensen, L. (2008). *Educational Research: Quantitative, Qualitative, and Mixed Approaches*, Sage, California.

Kahneman, D. (1973). *Attention and Effort*, Prentice Hall. New Jersey.

Kim, K., Uyeno, R., Pant, P., Yamashita, E., Ghimire, J. (2017). *Drones and Traffic Safety: Preliminary Risk Assessment*, Transportation Research Board, Washington DC.

Kim, H., Ahn, C. R., Yang, K. (2016). "Identifying Safety Hazards using Collective Bodily Responses of Workers." *J. Constr. Eng. Manage.*, 143(2), 04016090.

Lee, H., Lee, K., Park, M., Baek, Y., Lee, S. (2011). "RFID-Based Real-Time Locating System for Construction Safety Management." *J. Comput. Civ. Eng.*, 26(3), 366-377.

Lopez del Puerto, C., Clevenger, C. M., Boremann, K., Gilkey, D. P. (2013). "Exploratory Study to Identify Perceptions of Safety and Risk among Residential Latino Construction Workers as Distinct from Commercial and Heavy Civil Construction Workers." *J. Constr. Eng. Manage.*, 140(2), 04013048.

Mitropoulos, P., Abdelhamid, T. S., Howell, G. A. (2005). "Systems Model of Construction Accident Causation." *J. Constr. Eng. Manage.*, 131(7), 816-825.

Mooney, C. Z., Duval, R. D., Duval, R. (1993). *Bootstrapping: A Nonparametric Approach to Statistical Inference*, Sage Publications, California.

Namian, M., Albert, A., Zuluaga, C. M., Behm, M. (2016a). "Role of Safety Training: Impact on Hazard Recognition and Safety Risk Perception." *J. Constr. Eng. Manage.*, 142(12), 04016073.

Namian, M., Albert, A., Zuluaga, C. M., Jaselskis, E. J. (2016b). "Improving Hazard-Recognition Performance and Safety Training Outcomes: Integrating Strategies for Training Transfer." *J. Constr. Eng. Manage.*, 142(10), 04016048.

Occupational Safety and Health Administration (OSHA). (2016). "Construction industry." <<https://www.osha.gov/doc/>> September 13, 2017).

Park, J., Kim, K., Cho, Y. K. (2016). "Framework of Automated Construction-Safety Monitoring using Cloud-Enabled BIM and BLE Mobile Tracking Sensors." *J. Constr. Eng. Manage.*, 143(2), 05016019.

Park, J., Marks, E., Cho, Y. K., Suryanto, W. (2015). "Performance Test of Wireless Technologies for Personnel and Equipment Proximity Sensing in Work Zones." *J. Constr. Eng. Manage.*, 142(1), 04015049.

Patel, D., and Jha, K. (2016). "Evaluation of construction projects based on the safe work behavior of co-employees through a neural network model." *Saf. Sci.*, 89, 240–248.

Perlman, A., Sacks, R., Barak, R. (2014). "Hazard Recognition and Risk Perception in Construction." *Saf. Sci.*, 64, 22-31.

Pool, M. M., Koolstra, C. M., Voort, T. H. (2003). "The Impact of Background Radio and Television on High School Students' Homework Performance." *J. Commun.*, 53(1), 74-87.

Rajendran, S., and Gambatese, J. A. (2009). "Development and Initial Validation of Sustainable Construction Safety and Health Rating System." *J. Constr. Eng. Manage.*, 135(10), 1067-1075.

Ramezani-pour, A. A., Moodi, F., Namian, M., Doostmohammadi, M. (2014). "Application of Expert System in Sewer Network Management." *Amirkabir Journal of Science & Research (Civil & Environmental Engineering) (AJSR.CEE)*, 47(1), 43-45.

Rasmussen, J. (1997). "Risk Management in a Dynamic Society: A Modelling Problem." *Saf. Sci.*, 27(2), 183-213.

- Regan, M. A., Hallett, C., Gordon, C. P. (2011). "Driver Distraction and Driver Inattention: Definition, Relationship and Taxonomy." *Accident Analysis & Prevention*, 43(5), 1771-1781.
- Rivera-Rodriguez, A. J., and Karsh, B. T. (2010). "Interruptions and Distractions in Healthcare: Review and Reappraisal." *Qual. Saf. Health. Care.*, 19(4), 304-312.
- Rozenfeld, O., Sacks, R., Rosenfeld, Y., Baum, H. (2010). "Construction Job Safety Analysis." *Saf. Sci.*, 48(4), 491-498.
- Safe Work Australia (2016). "Work health and safety perceptions: Construction industry." <<https://www.safeworkaustralia.gov.au/construction>> September 13, 2017).
- Shahar, A. (2009). "Self-Reported Driving Behaviors as a Function of Trait Anxiety." *Accident Analysis & Prevention*, 41(2), 241-245.
- Shen, X., and Marks, E. (2015). "Near-Miss Information Visualization Tool in BIM for Construction Safety." *J. Constr. Eng. Manage.*, 142(4), 04015100.
- Shin, M., Lee, H., Park, M., Moon, M., Han, S. (2014). "A System Dynamics Approach for Modeling Construction Workers' Safety Attitudes and Behaviors." *Accident Analysis & Prevention*, 68, 95-105.
- Smith, L. F., Gratz, Z. S., Bousquet, S. G. (2008). *The Art and Practice of Statistics*, Cengage Learning, California.
- Strayer, D. L. and Fisher, D. L. (2015). "SPIDER: A Framework for Understanding Driver Distraction." *Human Factors*, 58(1), 5-12.

Tatum, M. C., and Liu, J. (2017). "Unmanned aerial vehicles in the construction industry." *Proc., 53rd ASC Annual International Conference Proceedings*, Mississippi.

Taylor, W. D., and Snyder, L. A. (2017). "The Influence of Risk Perception on Safety: A Laboratory Study." *Saf. Sci.*, 95, 116-124.

Tixier, A. J., Hallowell, M. R., Albert, A., van Boven, L., Kleiner, B. M. (2014). "Psychological Antecedents of Risk-Taking Behavior in Construction." *J. Constr. Eng. Manage.*, 140(11), 04014052.

Weisberg, R. W., and Reeves, L. M. (2013). *Cognition: From Memory to Creativity*, John Wiley & Sons, New Jersey. Wickens, C. D. (2002). "Multiple Resources and Performance Prediction." *Theoretical Issues in Ergonomics Science*, 3(2), 159-177.

Wickens, C. D. & Horrey, W. J. (2008). "Models of Attention, Distraction, and Highway Hazard Avoidance." In M. A. Regan, J. D. Lee, & K. L. Young (Eds.) *Driver Distraction: Theory, Effects and Mitigation* (chapter 5, pp.57-69). Boca Raton, FL: CRC Press.

Wickens, C. D. (2002). "Multiple resources and performance prediction." *Theoretical Issues in Ergonomics Science*, 3(2), 159–177.

Yang, K., Ahn, C. R., Vuran, M. C., Aria, S. S. (2016). "Semi-Supervised Near-Miss Fall Detection for Ironworkers with a Wearable Inertial Measurement Unit." *Autom. Constr.*, 68, 194-202.

Yoo, H., Kim, S., Hur, H., Kim, H. (2011). "The Effects of an Animation Distraction Intervention on Pain Response of Preschool Children during Venipuncture." *Applied Nursing Research*, 24(2), 94-100.

Young, K. L., and Salmon, P. M. (2012). "Examining the Relationship between Driver Distraction and Driving Errors: A Discussion of Theory, Studies and Methods." *Saf. Sci.*, 50(2), 165-174.

Zhao, D., McCoy, A. P., Kleiner, B. M., Mills, T. H., Lingard, H. (2016). "Stakeholder Perceptions of Risk in Construction." *Saf. Sci.*, 82, 111-119.

Zou, P., and Sunindijo, R.Y. (2015). *Strategic Safety Management in Construction and Engineering*, Wiley, Hoboken.

Zou, P. X., and Zhang, G. (2009). "Comparative Study on the Perception of Construction Safety Risks in China and Australia." *J. Constr. Eng. Manage.*, 135(7), 620-627.

Zuluaga, C. M., Namian, M., and Albert, A. (2016). "Impact of Training Methods on Hazard Recognition and Risk Perception in Construction." *Construction Research Congress 2016*.

## **CHAPTER V: CONCLUSIONS AND FUTURE WORK**

## **INTRODUCTION**

Despite recent improvements in safety management practices, unacceptable numbers of fatal and non-fatal construction injuries continue to be reported. In the United States, the number of fatal construction injuries increased by 27 percent between 2011 and 2015 (BLS 2016; BLS 2013). In addition, more than 200,000 non-fatal occupational injuries were reported in construction in 2014 (BLS 2015). These accidents have severe tangible and intangible costs to workers, employers, and broadly to the society (Ikpe et al. 2012). Ahmed et al. (2006) have quantified the cost of construction-related injuries in the United States to exceed \$48 billion every year.

To prevent construction accidents and injuries, proper hazard recognition and safety risk perception are vital. In fact, both hazard recognition and the perception of safety risk are key elements for a successful safety management program. However, poor hazard recognition and safety risk underestimation are widely reported in construction literature from over the world. When hazards remain unrecognized, or the associated risk is underestimated, the likelihood of injuries dramatically increases.

However, studies have revealed that construction workers fail to identify a large proportion of hazards in workplaces (Albert et al. 2014; Bahn 2013; Carter and Smith 2006). Similarly, previous studies have demonstrated that workers typically underestimate the safety risks associated with hazards (Helander 1991; Salvendy, 2012; Shin et al. 2014). Therefore, a proper understanding of factors that adversely affect hazard recognition performance is a fundamental step to improving safety performance. To address this problem, three key factors (training methods, training transfer elements, and workplace distractions) that were

hypothesized to influence hazard recognition and safety risk perception were examined in three studies.

To improve safety performance, employers adopt a wide variety of training programs; however, the desirable levels of performance have not been achieved. In fact, past research suggests that less than 10–15% of training expenditures translate into true tangible benefits. Besides, while much effort has been devoted to improving training practices, the issue of training transfer has largely been ignored in the construction context. This is alarming for safety researchers and construction practitioners because a large proportion of safety efforts does not translate into tangible benefits (Baldwin and Ford 1994; Cromwell and Kolb 2004).

Apart from training, distractions can also lead to human errors, violations, and omissions with serious safety implications (Mitropoulos et al. 2005; Rasmussen 1997; Namian et al. 2017; Namian et al. 2018). Because distractions are ubiquitous in dynamic construction environments, empirical investigations on the effect of distraction are vital.

Accordingly, in Study I and II, safety training methods (i.e., high-engagement and low-engagement) and training transfer elements were investigated respectively. To achieve the goals, empirical data were obtained from 51 active construction projects located across the United States.

In addition, in Study III, a novel experiment was designed and conducted in which 70 construction workers from three construction projects located in North Carolina participated over a period of 12-months. The primary results and implications of the current research (specific details are provided in the subsequent section) can be used by the construction practitioners and researchers to adopt more effective strategies to enhance construction safety performance.

## **THEORETICAL AND PRACTICAL RESEARCH CONTRIBUTIONS**

In Study I of the research, our findings showed that high-engagement training is associated with higher levels of hazard recognition and safety risk perception compared to low-engagement training method. In addition, the research suggests that projects offering high-engagement training can expect higher hazard recognition levels; which will also improve project-level risk perception levels. The findings of the study will help practicing professionals adopt, design, and implement better training approaches. This research also provides the description of high-engagement training methods including criteria such as training that is: 1) trainee-centric; 2) requires active participation; 3) discussions are encouraged; 4) high level of interaction among workers and the facilitator; 5) feedback provided; 6) on-site or off-site that construction practitioners can adopt..

Moreover, in Study II, this research found 11 core training transfer elements that facilitate the efficient transfer of hazard recognition and safety training. The elements included workplace factors, such as supervisor and peer support, and worker characteristics, such as motivation and aptitude. Among the identified factors, upper management commitment and supervisor support and expectations were assessed as being the most influential elements for transfer of training. Accordingly, construction employers can invest their resources in adopting the identified training transfer elements to maximize safety training outcomes.

Finally, the findings of Study III suggested that distractions can adversely affect the hazard recognition performance of workers, and may impede their ability to rationally quantify the associated safety risk. Therefore, employers must actively consider interventions to reduce workplace distractions whenever possible to improve workplace safety outcomes. The findings

of this research will be useful to practitioners and researchers seeking to understand and mitigate adverse effects of workplace distractions.

## **FUTURE RESEARCH**

Future research must focus on identifying and evaluating other factors that impact hazard recognition and safety risk perception of workers. Further, future studies must focus on evaluating the impact of safety training, hazard recognition, and safety risk perception on lagging indicators of safety performance such as recordable injury rates. A deeper understanding of factors that impact hazard recognition and safety risk perception is essential to improving construction safety performance.

Given the unique, complex, and dynamic nature of construction workplaces, distraction is a universally present in such environments. According to Hinze's distractions theory, workers are more prone to be involved in an accident while they are distracted. Distracted workers compromise safety to keep their regular performance from being interrupted (Hinze 1997). Similar to the past research, the findings of Study III indicated that workers identify fewer hazards when they are distracted. However, in the study, the level of distraction was not measured assuming that all participants were distracted equally. In fact, an identical distractor might cause different levels of distraction which vary from person to person. Therefore, new methods to measure distraction at the personal level will be useful to adopt proactive safety measures.

In addition, the research findings from Study III presented an important problem that must be tackled in future research. More specifically, the findings suggested that the workers in the distracted condition perceived higher levels of safety risk than the undistracted workers

when hazard recognition levels were less than 59%. However, this finding is surprising because the results suggest that the perceived safety risk was unrelated to the underlying safety hazards present in the case images – and may be related to the distraction itself. Future research must investigate the effect of this increase in safety risk perception – even when the underlying hazards may remain unrecognized – on workplace behavior and safety outcomes.

## REFERENCES

- Ahmed, S. M., Azhar, S., Forbes, L. H. (2006). "Costs of Injuries/Illnesses and Fatalities in Construction and their Impact on the Construction Economy." CIB W99 International Conference on Global Unity for Safety and Health in Construction, Beijing, China.
- Albert, A., Hallowell, M. R., Kleiner, B., Chen, A., Golparvar-Fard, M. (2014). "Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality." *J. Constr. Eng. Manage.*, 140(7), 04014024.
- Bahn, S. (2013). "Workplace Hazard Identification and Management: The Case of an Underground Mining Operation." *Saf. Sci.*, 57, 129-137.
- Bureau of Labor Statistics (BLS). "Revisions to the 2011 Census of Fatal Occupational Injuries (CFOI) counts." <[www.bls.gov/iif/oshwc/cfoi/cfoi\\_revised11.pdf](http://www.bls.gov/iif/oshwc/cfoi/cfoi_revised11.pdf)> 2013).
- Bureau of Labor Statistics (BLS). "2014 Census of Fatal Occupational Injuries (revised data)." <<http://www.bls.gov/iif/oshcfoi1.htm#2014>> 2015).
- Bureau of Labor Statistics (BLS). "2015 Census of Fatal Occupational Injuries (revised data)." <<https://www.bls.gov/news.release/cfoi.t04.htm>> 2016).
- Carter, G., and Smith, S. (2006). "Safety Hazard Identification on Construction Projects." *J. Constr. Eng. Manage.*, 132(2), 197-205.
- Ikpe, E., Hammon, F., and Oloke, D. (2012). "Cost-Benefit Analysis for Accident Prevention in Construction Projects." *J. Constr. Eng. Manage.*, 138(8), 991–998.

Helander, M. G. (1991). "Safety hazards and motivation for safe work in the construction industry." *International Journal of Industrial Ergonomics*, 8(3), 205–223.

Namian, M., Albert, A., Feng, J. (2018). " Effect of Distraction on Hazard Recognition and Safety Risk Perception." *J. Constr. Eng. Manage.*, (In press).

Namian, M., Albert, A., Feng, J. (2018). "Effect of Distraction on Hazard Recognition and Safety Performance." *Construction Research Congress 2018*.

Salvendy, G. ed. (2012). *Handbook of Human Factors and Ergonomics*. Wiley, New Jersey.

Shin, M., Lee, H., Park, M., Moon, M., Han, S. (2014). "A System Dynamics Approach for Modeling Construction Workers' Safety Attitudes and Behaviors." *Accident Analysis & Prevention*, 68, 95-105.

## INTEGRATED REFERENCES

Abdelhamid, T. S., and Everett, J. G. (2000). "Identifying Root Causes of Construction Accidents." *J. Constr. Eng. Manage.*, 126(1), 52-60.

Ahmed, S. M., Azhar, S., Forbes, L. H. (2006). "Costs of Injuries/Illnesses and Fatalities in Construction and their Impact on the Construction Economy." *CIB W99" Jian Zhu an Quan Yu Jian Kang De Quan Qiu He Zuo" Guo Ji Hui Yi Lun Wen Ji*, 363.

Albert, A., Hallowell, M. R., Kleiner, B. M. (2013). "Enhancing Construction Hazard Recognition and Communication with Energy-Based Cognitive Mnemonics and Safety Meeting Maturity Model: Multiple Baseline Study." *J. Constr. Eng. Manage.*, 140(2), 04013042.

Albert, A., Hallowell, M. R., Kleiner, B. M. (2014a). "Experimental Field Testing of a Real-Time Construction Hazard Identification and Transmission Technique." *Constr. Manage. Econ.*, 32(10), 1000-1016.

Albert, A., Hallowell, M. R., Kleiner, B., Chen, A., Golparvar-Fard, M. (2014b). "Enhancing Construction Hazard Recognition with High-Fidelity Augmented Virtuality." *J. Constr. Eng. Manage.*, 140(7), 04014024.

Al-Khotani, A., Bello, L. A., Christidis, N. (2016). "Effects of Audiovisual Distraction on children's Behaviour during Dental Treatment: A Randomized Controlled Clinical Trial." *Acta Odontol. Scand.*, 74(6), 494-501.

Arezes, P. M., and Miguel, A. S. (2008). "Risk Perception and Safety Behaviour: A Study in an Occupational Environment." *Saf. Sci.*, 46(6), 900-907.

Awolusi, I. G., and Marks, E. D. (2016). "Safety Activity Analysis Framework to Evaluate Safety Performance in Construction." *J. Constr. Eng. Manage.*, 143(3), 05016022.

Bahn, S. (2013). "Workplace Hazard Identification and Management: The Case of an Underground Mining Operation." *Saf. Sci.*, 57, 129-137.

Baldwin, T. T., and Ford, J. K. (1994). "Transfer of Training: A Review and Directions for Future Research." *The Training and Development Sourcebook*, 180-207.

Behm, M., and Schneller, A. (2012). "Application of the Loughborough Construction Accident Causation Model: A Framework for Organizational Learning." *Constr. Manage. Econ.*, (ahead-of-print), 1-16.

Blume, B. D., Ford, J. K., Baldwin, T. T., Huang, J. L. (2010). "Transfer of Training: A Meta-Analytic Review." *Journal of Management*, 36(4), 1065-1105.

Bohm, J., and Harris, D. (2010). "Risk Perception and Risk-Taking Behavior of Construction Site Dumper Drivers." *Int. J. Occup. Saf. Ergonomics*, 16(1), 55-67.

Borys, D. (2012). "The Role of Safe Work Method Statements in the Australian Construction Industry." *Saf. Sci.*, 50(2), 210-220.

Brahm, F., and Singer, M. (2013). "Is More Engaging Safety Training always Better in Reducing Accidents? Evidence of Self-Selection from Chilean Panel Data." *J. Saf. Res.*, 47, 85-92.

Bunch, K. J. (2007). "Training Failure as a Consequence of Organizational Culture." *Human Resource Development Review*, 6(2), 142-163.

Bureau of Labor Statistics (BLS). "Injuries, illness, and fatalities." <<http://www.bls.gov/iif/>> December 2014).

Bureau of Labor Statistics (BLS). "National census of fatal occupational injuries in 2014." <<http://www.bls.gov/news.release/cfoi.nr0.htm>> October 2015).

Bureau of Labor Statistics (BLS). (2016). "Injuries, illnesses, and fatalities." <<https://www.bls.gov/news.release/osh.toc.htm>> September 13, 2017).

Burke, M. J., Salvador, R. O., Smith-Crowe, K., Chan-Serafin, S., Smith, A., Sonesh, S. (2011). "The Dread Factor: How Hazards and Safety Training Influence Learning and Performance." *J. Appl. Psychol.*, 96(1), 46.

Burke, M. J., Sarpy, S. A., Smith-Crowe, K., Chan-Serafin, S., Salvador, R. O., Islam, G. (2006). "Relative Effectiveness of Worker Safety and Health Training Methods." *Am. J. Public Health*, 96(2), 315-324.

Burslem, D., Pinard, M., Hartley, S. (2005). *Biotic Interactions in the Tropics: Their Role in the Maintenance of Species Diversity*, Cambridge University Press, Cambridge, U.K.

Carter, G., and Smith, S. (2006). "Safety Hazard Identification on Construction Projects." *J. Constr. Eng. Manage.*, 132(2), 197-205.

Chang, Y., Yang, H., Hsiao, Y. (2016). "Human Risk Factors Associated with Pilots in Runway Excursions." *Accident Analysis & Prevention*, 94, 227-237.

Chattington, M., Reed, N., Basacik, D., Flint, A., Parkes, A. (2010). *Investigating Driver Distraction: The Effects of Video and Static Advertising*, Transportation Research Lab., London.

Chi, S., Han, S., Kim, D. Y. (2012). "Relationship between Unsafe Working Conditions and Workers' Behavior and Impact of Working Conditions on Injury Severity in US Construction Industry." *J. Constr. Eng. Manage.*, 139(7), 826-838.

Choudhry, R. M., and Fang, D. (2008). "Why Operatives Engage in Unsafe Work Behavior: Investigating Factors on Construction Sites." *Saf. Sci.*, 46(4), 566-584.

Choudhry, R. M., Aslam, M. A., Hinze, J. W., Arain, F. M. (2014). "Cost and Schedule Risk Analysis of Bridge Construction in Pakistan: Establishing Risk Guidelines." *J. Constr. Eng. Manage.*, 140(7), 04014020.

Cohen, A., Colligan, M. J., Sinclair, R., Newman, J., Schuler, R. (1998). *Assessing Occupational Safety and Health Training: A literature review*, National Institute for Occupational Safety and Health, Ohio.

Cromwell, S. E., and Kolb, J. A. (2004). "An Examination of Work-Environment Support Factors Affecting Transfer of Supervisory Skills Training to the Workplace." *Human Resource Development Quarterly*, 15(4), 449.

Demirkesen, S., and Arditi, D. (2015). "Construction Safety Personnel's Perceptions of Safety Training Practices." *Int. J. Project Manage.*, 33(5), 1160-1169.

Dong, X. S., Fujimoto, A., Ringen, K., Stafford, E., Platner, J. W., Gittleman, J. L., Wang, X. (2011). "Injury Underreporting among Small Establishments in the Construction Industry." *Am. J. Ind. Med.*, 54(5), 339-349.

Donovan, P., and Darcy, D. P. (2011). "Learning Transfer: The Views of Practitioners in Ireland." *International Journal of Training and Development*, 15(2), 121-139.

Ersal, T., Fuller, H. J., Tsimhoni, O., Stein, J. L., Fathy, H. K. (2010). "Model-Based Analysis and Classification of Driver Distraction under Secondary Tasks." *IEEE Transactions on Intelligent Transportation Systems*, 11(3), 692-701.

Fang, D., Zhao, C., and Zhang, M. (2016). "A Cognitive Model of Construction Workers' Unsafe Behaviors." *Journal of Construction Engineering and Management*, 142(9), 04016039.

Fleming, M. A. (2009). "Hazard Recognition Techniques." *By Design, ASSE*, 9(3), 15-18.

Fung, I. W., Tam, V. W., Lo, T. Y., Lu, L. L. (2010). "Developing a Risk Assessment Model for Construction Safety." *Int. J. Project Manage.*, 28(6), 593-600.

Furnham, A., and Bradley, A. (1997). "Music while You Work: The Differential Distraction of Background Music on the Cognitive Test Performance of Introverts and Extraverts." *Applied Cognitive Psychology*, 11(5), 445-455.

Geller, E. S. (2001). *Working Safe: How to Help People Actively Care for Health and Safety*, CRC Press, Boca Raton, FL.

Ghiasvand, E., Ramezaniapour, A., Ramezaniapour, A., Namian, M., Slami, R., and Gharechaei, M. (2015). "Effect of grinding method and particle size distribution on early-age properties of blended cements." *Advances in Cement Research*, 27(4), 201–213.

Goh, Y. M., and Chua, D. (2009). "Case-Based Reasoning Approach to Construction Safety Hazard Identification: Adaptation and Utilization." *J. Constr. Eng. Manage.*, 136(2), 170-178.

Goldenhar, L. M., Moran, S. K., Colligan, M. (2001). "Health and Safety Training in a Sample of Open-Shop Construction Companies." *J. Saf. Res.*, 32(2), 237-252.

Graphpad (2017). "Randomly assign subjects to treatment groups." <<https://www.graphpad.com/quickcalcs/randomize1>> Jan. 15, 2017).

Grossman, R., and Salas, E. (2011). "The Transfer of Training: What really Matters." *International Journal of Training and Development*, 15(2), 103-120.

Gündüz, M., Nielsen, Y., Özdemir, M. (2012). "Quantification of Delay Factors using the Relative Importance Index Method for Construction Projects in Turkey." *J. Manage. Eng.*, 29(2), 133-139.

Hallowell, M. (2010). "Safety Risk Perception in Construction Companies in the Pacific Northwest of the USA." *Constr. Manage. Econ.*, 28(4), 403-413.

Hallowell, M. R. (2008). *A Formal Model for Construction Safety and Health Risk Management*, Oregon State University, Ph.D. thesis, Oregon State Univ., Corvallis, Oregon.

Hallowell, M. R., and Gambatese, J. A. (2009). "Activity-Based Safety Risk Quantification for Concrete Formwork Construction." *J. Constr. Eng. Manage.*, 135(10), 990-998.

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., Duff, A. R. (2005). "Contributing Factors in Construction Accidents." *Appl. Ergon.*, 36(4), 401-415.

Hayes, A. F., and Matthes, J. (2009). "Computational Procedures for Probing Interactions in OLS and Logistic Regression: SPSS and SAS Implementations." *Behavior Research Methods*, 41(3), 924-936.

Health and Safety Executive. (2016). "Health and safety in the construction industry." <<http://www.hse.gov.uk/statistics/industry/construction/construction.pdf?pdf=construction>> September 13, 2017).

Hinze, J. (1997). "The distractions theory of accident causation." CIB Rep., A.A. Balkema, Rotterdam, Netherlands.

Hinze, J., and Gambatese, J. (2003). "Factors that Influence Safety Performance of Specialty Contractors." *J. Constr. Eng. Manage.*, 129(2), 159-164.

International Labor Organization. (2016). "Safety, health and welfare on construction sites; A training manual." < [http://www.ilo.org/wcmsp5/groups/public/---ed\\_protect/---protrav/---safework/documents/instructionalmaterial/wcms\\_110237.pdf](http://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/instructionalmaterial/wcms_110237.pdf)> September 13, 2017).

Irizarry, J., and Costa, D. B. (2016). "Exploratory Study of Potential Applications of Unmanned Aerial Systems for Construction Management Tasks." *J. Manage. Eng.*, 32(3), 05016001.

Jarkas, A. M., and Bitar, C. G. (2011). "Factors Affecting Construction Labor Productivity in Kuwait." *J. Constr. Eng. Manage.*, 138(7), 811-820.

Jeelani, I., Albert, A., Gambatese, J. A. (2016). "Why do Construction Hazards Remain Unrecognized at the Work Interface?" *J. Constr. Eng. Manage.*, 143(5), 04016128.

Jha, K. N. (2011). *Construction Project Management: Theory and Practice*, Pearson Education India.

Jiang, Z., Fang, D., Zhang, M. (2014). "Understanding the Causation of Construction Workers' Unsafe Behaviors Based on System Dynamics Modeling." *J. Manage. Eng.*, 04014099.

Johnson, B., and Christensen, L. (2008). *Educational Research: Quantitative, Qualitative, and Mixed Approaches*, Sage, California.

Kahneman, D. (1973). *Attention and Effort*, Prentice Hall. New Jersey.

Kim, H., Ahn, C. R., Yang, K. (2016). "Identifying Safety Hazards using Collective Bodily Responses of Workers." *J. Constr. Eng. Manage.*, 143(2), 04016090.

Kim, K., Uyeno, R., Pant, P., Yamashita, E., Ghimire, J. (2017). *Drones and Traffic Safety: Preliminary Risk Assessment*, Transportation Research Board, Washington DC.

Langford, J., and McDonagh, D. (2003). *Focus Groups: Supporting Effective Product Development*, CRC press, New York.

Lee, H., Lee, K., Park, M., Baek, Y., Lee, S. (2011). "RFID-Based Real-Time Locating System for Construction Safety Management." *J. Comput. Civ. Eng.*, 26(3), 366-377.

Lewis-Beck, Michael S., Bryman, Alan., Liao, Tim Futing, (2004). *The Sage Encyclopedia of Social Science Research Methods*, Sage, Thousand Oaks, Calif.

Li, H., Chan, G., Skitmore, M. (2012). "Visualizing Safety Assessment by Integrating the use of Game Technology." *Autom. Constr.*, 22, 498-505.

Lingard, H. (2002). "The Effect of First Aid Training on Australian Construction Workers' Occupational Health and Safety Motivation and Risk Control Behavior." *J. Saf. Res.*, 33(2), 209-230.

Lingard, H. (2013). "Occupational Health and Safety in the Construction Industry." *Constr. Manage. Econ.*, 31(6), 505-514.

Lingard, H., Pink, S., Harley, J., Edirisinghe, R. (2015). "Looking and Learning: Using Participatory Video to Improve Health and Safety in the Construction Industry." *Constr. Manage. Econ.*, 33(9), 740-751.

Lopez del Puerto, C., Clevenger, C. M., Boremann, K., Gilkey, D. P. (2013). "Exploratory Study to Identify Perceptions of Safety and Risk among Residential Latino Construction Workers as Distinct from Commercial and Heavy Civil Construction Workers." *J. Constr. Eng. Manage.*, 140(2), 04013048.

Mitropoulos, P., Abdelhamid, T. S., Howell, G. A. (2005). "Systems Model of Construction Accident Causation." *J. Constr. Eng. Manage.*, 131(7), 816-825.

Mitropoulos, P., and Namboodiri, M. (2011). "New Method for Measuring the Safety Risk of Construction Activities: Task Demand Assessment." *J. Constr. Eng. Manage.*, 137(1), 30-38.

Mooney, C. Z., Duval, R. D., Duval, R. (1993). *Bootstrapping: A Nonparametric Approach to Statistical Inference*, Sage Publications, California.

Namian, M., Albert, A., Zuluaga, C. M., Behm, M. (2016a). "Role of Safety Training: Impact on Hazard Recognition and Safety Risk Perception." *J. Constr. Eng. Manage.*, 142(12), 04016073.

Namian, M., Albert, A., Zuluaga, C. M., Jaselskis, E. J. (2016b). "Improving Hazard-Recognition Performance and Safety Training Outcomes: Integrating Strategies for Training Transfer." *J. Constr. Eng. Manage.*, 142(10), 04016048.

Namian, M., Albert, A., Feng, J. (2017). "Effect of Distraction on Hazard Recognition and Safety Risk Perception." *J. Constr. Eng. Manage.*, (In press).

Namian, M., Albert, A., Feng, J. (2018). "Effect of Distraction on Hazard Recognition and Safety Performance." *Construction Research Congress 2018*.

Namian, M., Zuluaga, C. M., and Albert, A. (2016c). "Critical Factors That Impact Construction Workers' Hazard Recognition Performance." *Construction Research Congress 2016*.

National Institute of Occupational Safety and Health (NIOSH). "Fatality assessment and control (FACE) program." <<http://www.cdc.gov/niosh/face/default.html>> October 2015).

Occupational Safety and Health Administration (OSHA). (2016). "Construction industry." <<https://www.osha.gov/doc/>> September 13, 2017).

Occupational Safety and Health Administration. (2010). *OSHA Training Standards Policy Statement*, OSHA, Washington.

Park, J., Kim, K., Cho, Y. K. (2016). "Framework of Automated Construction-Safety Monitoring using Cloud-Enabled BIM and BLE Mobile Tracking Sensors." *J. Constr. Eng. Manage.*, 143(2), 05016019.

Park, J., Marks, E., Cho, Y. K., Suryanto, W. (2015). "Performance Test of Wireless Technologies for Personnel and Equipment Proximity Sensing in Work Zones." *J. Constr. Eng. Manage.*, 142(1), 04015049.

Patel, D., and Jha, K. (2016). "Evaluation of construction projects based on the safe work behavior of co-employees through a neural network model." *Saf. Sci.*, 89, 240–248.

Perlman, A., Sacks, R., Barak, R. (2014). "Hazard Recognition and Risk Perception in Construction." *Saf. Sci.*, 64, 22-31.

Pool, M. M., Koolstra, C. M., Voort, T. H. (2003). "The Impact of Background Radio and Television on High School Students' Homework Performance." *J. Commun.*, 53(1), 74-87.

Rajendran, S., and Gambatese, J. A. (2009). "Development and Initial Validation of Sustainable Construction Safety and Health Rating System." *J. Constr. Eng. Manage.*, 135(10), 1067-1075.

Ramezani-pour, A. A., Moodi, F., Namian, M., Doostmohammadi, M. (2014). "Application of Expert System in Sewer Network Management." *Amirkabir Journal of Science & Research (Civil & Environmental Engineering) (AJSR.CEE)*, 47(1), 43-45.

Rasmussen, J. (1997). "Risk Management in a Dynamic Society: A Modelling Problem." *Saf. Sci.*, 27(2), 183-213.

Regan, M. A., Hallett, C., Gordon, C. P. (2011). "Driver Distraction and Driver Inattention: Definition, Relationship and Taxonomy." *Accident Analysis & Prevention*, 43(5), 1771-1781.

Rivera-Rodriguez, A. J., and Karsh, B. T. (2010). "Interruptions and Distractions in Healthcare: Review and Reappraisal." *Qual. Saf. Health. Care.*, 19(4), 304-312.

Robson, L. S. (2010). *A Systematic Review of the Effectiveness of Training & Education for the Protection of Workers*, Institute for Work & Health, Toronto.

Robson, L. S., Stephenson, C. M., Schulte, P. A., Amick III, B. C., Irvin, E. L., Eggerth, D. E., Chan, S., Bielecky, A. R., Wang, A. M., Heidotting, T. L. (2012). "A Systematic Review of the Effectiveness of Occupational Health and Safety Training." *Scand. J. Work Environ. Health*, 193-208.

Rozenfeld, O., Sacks, R., Rosenfeld, Y., Baum, H. (2010). "Construction Job Safety Analysis." *Saf. Sci.*, 48(4), 491-498.

Ruttenberg, R. (2013). *The Economic and Social Benefits of OSHA-10 Training in the Building and Construction Trades*, The center for construction research and training (CPWR), Maryland.

Sacks, R., Perlman, A., Barak, R. (2013). "Construction Safety Training using Immersive Virtual Reality." *Constr. Manage. Econ.*, 31(9), 1005-1017.

Safe Work Australia (2016). "Work health and safety perceptions: Construction industry." <<https://www.safeworkaustralia.gov.au/construction>> September 13, 2017).

Shahar, A. (2009). "Self-Reported Driving Behaviors as a Function of Trait Anxiety." *Accident Analysis & Prevention*, 41(2), 241-245.

Shen, X., and Marks, E. (2015). "Near-Miss Information Visualization Tool in BIM for Construction Safety." *J. Constr. Eng. Manage.*, 142(4), 04015100.

Shin, M., Lee, H., Park, M., Moon, M., Han, S. (2014). "A System Dynamics Approach for Modeling Construction Workers' Safety Attitudes and Behaviors." *Accident Analysis & Prevention*, 68, 95-105.

Smith, L. F., Gratz, Z. S., Bousquet, S. G. (2008). *The Art and Practice of Statistics*, Cengage Learning, California.

Spiller, S. A., Fitzsimons, G. J., Lynch Jr, J. G., McClelland, G. H. (2013). "Spotlights, Floodlights, and the Magic Number Zero: Simple Effects Tests in Moderated Regression." *J. Market. Res.*, 50(2), 277-288.

Strayer, D. L. and Fisher, D. L. (2015). "SPIDER: A Framework for Understanding Driver Distraction." *Human Factors*, 58(1), 5-12.

Suraji, A., Duff, A. R., Peckitt, S. J. (2001). "Development of Causal Model of Construction Accident Causation." *J. Constr. Eng. Manage.*, 127(4), 337-344.

Tatum, M. C., and Liu, J. (2017). "Unmanned aerial vehicles in the construction industry." *Proc., 53rd ASC Annual International Conference Proceedings*, Mississippi.

Taylor, W. D., and Snyder, L. A. (2017). "The Influence of Risk Perception on Safety: A Laboratory Study." *Saf. Sci.*, 95, 116-124.

Tixier, A. J., Hallowell, M. R., Albert, A., van Boven, L., Kleiner, B. M. (2014). "Psychological Antecedents of Risk-Taking Behavior in Construction." *J. Constr. Eng. Manage.*, 140(11), 04014052.

Vittinghoff, E., Glidden, D. V., Shiboski, S. C., McCulloch, C. E. (2012). *Regression Methods in Biostatistics: Linear, Logistic, Survival, and Repeated Measures Models*, Springer, New York.

Wang, Y., Goodrum, P. M., Haas, C. T., Glover, R. W. (2008). "Craft Training Issues in American Industrial and Commercial Construction." *J. Constr. Eng. Manage.*, 134(10), 795-803.

Wang, Y., Goodrum, P. M., Haas, C., Glover, R., Vazari, S. (2010). "Analysis of the Benefits and Costs of Construction Craft Training in the United States Based on Expert Perceptions and Industry Data." *Constr. Manage. Econ.*, 28(12), 1269-1285.

Weidman, J., Dickerson, D. E., Koebel, C. T. (2015). "Intervention to Improve Purchasing Decision-Maker Perceptions of Ventilated Tools." *J. Constr. Eng. Manage.*, 141(6), 04015007.

Weisberg, R. W., and Reeves, L. M. (2013). *Cognition: From Memory to Creativity*, John Wiley & Sons, New Jersey. Wickens, C. D. (2002). "Multiple Resources and Performance Prediction." *Theoretical Issues in Ergonomics Science*, 3(2), 159-177.

Wickens, C. D. & Horrey, W. J. (2008). "Models of Attention, Distraction, and Highway Hazard Avoidance." In M. A. Regan, J. D. Lee, & K. L. Young (Eds.) *Driver Distraction: Theory, Effects and Mitigation* (chapter 5, pp.57-69). Boca Raton, FL: CRC Press.

Wickens, C. D. (2002). "Multiple resources and performance prediction." *Theoretical Issues in Ergonomics Science*, 3(2), 159–177.

Wilkins, J. R. (2011). "Construction Workers' Perceptions of Health and Safety Training Programmes." *Constr. Manage. Econ.*, 29(10), 1017-1026.

Winchester, H. P. (1999). "Interviews and Questionnaires as Mixed Methods in Population Geography: The Case of Lone Fathers in Newcastle, Australia." *The Professional Geographer*, 51(1), 60-67.

Withrow, B. L. (2014). *Research Methods in Crime and Justice*, Routledge, New York.

Yang, K., Ahn, C. R., Vuran, M. C., Aria, S. S. (2016). "Semi-Supervised Near-Miss Fall Detection for Ironworkers with a Wearable Inertial Measurement Unit." *Autom. Constr.*, 68, 194-202.

Yoo, H., Kim, S., Hur, H., Kim, H. (2011). "The Effects of an Animation Distraction Intervention on Pain Response of Preschool Children during Venipuncture." *Applied Nursing Research*, 24(2), 94-100.

Young, K. L., and Salmon, P.M. (2012). "Examining the Relationship between Driver Distraction and Driving Errors: A Discussion of Theory, Studies and Methods." *Saf. Sci.*, 50(2), 165-174.

Zhang, M., and Fang, D. (2013). "A Cognitive Analysis of Why Chinese Scaffolders do Not use Safety Harnesses in Construction." *Constr. Manage. Econ.*, 31(3), 207-222.

Zhang, P., Lingard, H., Blismas, N., Wakefield, R., Kleiner, B. (2014). "Work-Health and Safety-Risk Perceptions of Construction-Industry Stakeholders using Photograph-Based Q Methodology." *J. Constr. Eng. Manage.*,.

Zhao, D., McCoy, A. P., Kleiner, B. M., Mills, T. H., Lingard, H. (2016). "Stakeholder Perceptions of Risk in Construction." *Saf. Sci.*, 82, 111-119.

Zou, P. (2015). *Strategic Safety Management in Construction and Engineering Electronic Resource*], Wiley, Hoboken.

Zou, P. X., and Sunindijo, R.Y. (2015). *Strategic Safety Management in Construction and Engineering Electronic Resource*], Wiley, Hoboken.

Zou, P. X., and Zhang, G. (2009). "Comparative Study on the Perception of Construction Safety Risks in China and Australia." *J. Constr. Eng. Manage.*, 135(7), 620-627.

Zou, P., and Sunindijo, R.Y. (2015). *Strategic Safety Management in Construction and Engineering*, Wiley, Hoboken.

Zuluaga, C. M., Namian, M., and Albert, A. (2016). "Impact of Training Methods on Hazard Recognition and Risk Perception in Construction." *Construction Research Congress 2016*.