Research Report

Training the next generation of Construction Engineers and Managers

Job-Site Safety Institute

NC State

Construction Safety Laboratory

Developing Hazard Recognition Skill among the Next-Generation of Construction Engineers and Managers

ABSTRACT

Globally, a large number of safety hazards remain unrecognized in construction workplaces. These unrecognized safety hazards are also likely to remain unmanaged and can potentially cascade into unexpected safety incidents. Therefore, the development of hazards recognition skill – particularly among the next-generation of construction engineers and managers – is vital for injury prevention and safe work-operations. To foster the development of such skill, the current investigation examined the effect of administering a hazard recognition intervention to students seeking to enter the construction workforce. First, prior to introducing the intervention, the pre-intervention hazard recognition skill of the participating students was measured. Next, the intervention that included a number of program elements was introduced. The program elements included (1) visual cues to promote systematic hazard recognition, (2) personalized hazard recognition performance feedback, (3) visual demonstration of common hazard recognition search weaknesses, and (4) diagnosis of hazard search weaknesses using metacognitive prompts. Finally, the post-intervention skill demonstrated by the student participants were measured and compared against their pre-intervention performance. The results suggest that the intervention was effective in improving the hazard recognition skill demonstrated by the next generation of construction engineers and managers. The observed effect was particularly prominent among those that demonstrated relatively lower levels of skill in the pre-intervention phase. The research also unveiled particular impediments to hazards recognition that the participants experienced. The findings of this research can be leveraged to better prepare the next generation of construction engineers and managers to tackle the safety challenges in the construction industry.

Keywords: Construction safety, Safety management, Hazard identification, Hazard recognition, Injury prevention, Occupational Safety

INTRODUCTION

The construction industry continues to report an unacceptable number of safety incidents. For example, construction workplaces in the United States have consistently reported the highest number of fatalities since 2012 (Bureau of Labor Statistics 2017). Likewise, more than 200,000 non-fatal injuries are reported every year (Bureau of Labor Statistics 2017). These injuries not only cause substantial suffering among workers and their loved ones, but also results in annual costs that exceed $48 billion (Ahmed et al. 2006; Zou and Sunindijo 2015).

To reduce these adverse outcomes, decades of research has focused on identifying industry best practices for injury prevention (Hinze et al. 2013; Saurin et al. 2008). Among others, the importance of effective hazard recognition is widely accepted across the research and professional community (Albert et al. 2017; Carter and Smith 2006; Perlman et al. 2014). For example, if safety hazards are not recognized, they are also likely to remain unmanaged; which can translate into unexpected injuries and illnesses (Jeelani et al. 2016).

Therefore, to reduce the likelihood of injuries and illnesses, construction professionals must possess the necessary skills to sufficiently recognize and manage safety hazards. Unfortunately, a large body of evidence suggests that construction professionals – including engineers, managers, and supervisors – that are currently employed in the industry do not possess the necessary hazard recognition skill (Fleming 2009; Perlman et al. 2014; Toole 2005).

To address these issues, the purpose of this study was to evaluate the efficacy of an intervention in improving the hazard recognition skill of students seeking to enter the construction workforce. Because these students represent the next generation of construction engineers and managers, improving their hazard recognition skill can have profound benefits. In addition, the research intended to understand why certain safety hazards may remain unrecognized during hazard recognition operations.

BACKGROUND

Hazard Recognition in the construction industry

Most safety management efforts focus on managing hazards that are recognized as shown in Figure 1. Therefore, if safety hazards are not recognized, they are also likely to remain unmanaged (Jeelani et al. 2016). These unrecognized and unmanaged safety hazards can potentially translate into unexpected safety outcomes including injuries and illnesses (Albert et al. 2017; Carter and Smith 2006; Perlman et al. 2014).

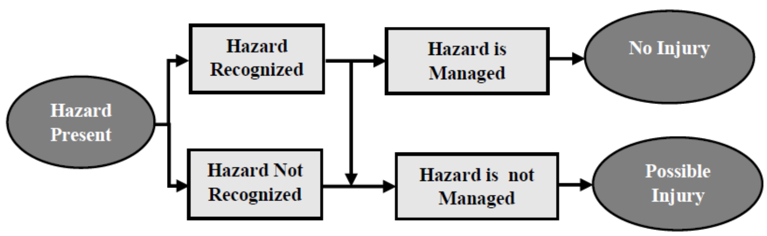

Figure 1: Role of hazard recognition in injury prevention

Unfortunately, existing research suggests that a large number of safety hazards are not recognized in construction workplaces. For example, research from the United States estimates that over 40% of safety hazards may remain unrecognized in typical construction workplaces (Albert et al. 2013). Likewise, research from the United Kingdom and Australia suggests that up to 57% of safety hazards may remain unrecognized (Bahn 2013; Carter and Smith 2006). In fact, poor hazard recognition has been identified as a global challenge within the construction industry (Fleming 2009; Jeelani et al. 2016; Perlman et al. 2014).

Past research has also found causal evidence linking poor hazard recognition and injury occurrences. For example, investigations suggest that more than 70% of workplace injuries can be attributed to human factors – including poor hazard recognition and management skill (Carter and Smith 2006; Choudhry and Fang 2008; Haslam et al. 2005). Likewise, causal relationships have been established between poor hazard recognition and risk-taking behavior in construction workplaces (Bohm and Harris 2010; Choudhry and Fang 2008).

Therefore, research focusing on improving hazard recognition levels in the construction industry is necessary to improve safety performance levels. Such efforts can dramatically reduce construction injury rates and promote the safety and the wellbeing of the construction workforce.

Role of the Next-Generation of Construction Engineers and Managers.

Construction engineers and managers play a pivotal role in maintaining safety in construction workplaces. Among other roles, they are expected to lead safety management efforts, cultivate a positive safety climate, and make crucial safety decisions (Abudayyeh et al. 2006; Aksorn and Hadikusumo 2008). Their duties also include scheduling and planning high-risk work tasks, identifying and managing resources for safe operations, and protecting field-workers from undesirable hazard exposure (Arditi et al. 2009; Clevenger et al. 2017; Toole 2002). In fact, construction engineers and managers, based on the Occupational Safety and Health Administration's (OSHA) general duty clause (29 U.S.C. § 654, 5(a)1), are expected to ensure the safety and the well-being of the workforce – on behalf of their employers (Toole and Gambatese 2002).

In recent years, construction engineers and managers are also being involved in the design stage – where they serve as consultants to the designers. More specifically, they review preliminary design specifications and recommend revisions to enhance safety, productivity, and constructability (Atkinson and Westall 2010; Lingard et al. 2014; Weinstein et al. 2005). This emerging best practice is known by different names including Prevention through Design (Ptd), Construction Hazard Prevention through Design (CHPtD), Design for Construction Safety (DCS), and Safety through Design (StD) (Behm 2005; Toole and Gambatese 2008). This practice is becoming particularly popular with the introduction of more collaborative project delivery methods such as the Integrated Project Delivery (IPD) method – where contractors are engaged earlier in the project cycle to enhance safety and planning (Zhang et al. 2013).

Given the important role of construction engineers and managers in safety management, their ability to recognize safety hazards is fundamental. Not surprisingly, a recent study involving 45 employers and industry experts revealed that the primary competency employers seek in the next-generation of construction engineers and managers is their ability to manage construction safety challenges (Clevenger et al. 2017). Unfortunately, current evidence suggests that traditional construction professionals – including construction engineers, managers, and superintendents – lack sufficient hazard recognition skill (Carter and Smith 2006; Fleming 2009; Perlman et al. 2014). Therefore, efforts to foster the development of such skill can yield substantial safety benefits.

RESEARCH OBJECTIVES

The study had two primary objectives. The first objective involved examining the efficacy of an intervention in improving the hazard recognition skill demonstrated by the next generation of construction engineers and managers. The second objective was to gain an understanding of why these future construction engineers and managers fail to recognize certain safety hazards (i.e., impediments to hazard recognition). The approach adopted to accomplish these objectives are discussed in more detail in the research methods section. The next section introduces the intervention that was tested in the current study.

INTERVENTION DESCRIPTION

The intervention included a number of program elements that were identified in a number of previous studies which were customized for the purpose of the current investigation (Albert et al. 2013; Dunlosky and Metcalfe 2008; Dzeng et al. 2016; Jeelani et al. 2016; Perera et al. 2008). The individual program elements are discussed below:

Visual Cues to Promote Systematic Hazard Recognition

Typical hazard recognition efforts often involve visually examining the construction work environment to identify potential hazards that can cause harm (Hadikusumo and Rowlinson 2002). During such efforts, construction personnel generally do not rely on a particular strategy or approach to aid their visual examination process. In most cases, they randomly examine the work environment with the assumption that safety hazards – if present – will automatically capture their attention (Jeelani et al. 2016).

However, recent investigations have shown that such unguided visual examinations can result in superficial search operations that can yield poor hazard recognition levels (Nickles et al. 2003). For example, evidence suggests that workers often prematurely terminate their hazard recognition process after a few generic safety hazards such as trips, falls and struck-by potential are identified – even if additional safety hazards may still remain unrecognized (Fleming 2009; Jeelani et al. 2016). Likewise, individuals may also devote attention to only particular work areas – such as the area where the primary task is being undertaken – while ignoring other relevant work areas (Dzeng et al. 2016; Jeelani et al. 2016).

In comparison to such unguided approaches, systematic and guided search efforts have yielded better results in various domains including the military, mining, and construction (Albert et al. 2013; Nickles et al. 2003). As part of this program element, the plan was to provide the student participants with a list of visual cues based on the Haddon's energy release theory – to guide the hazard recognition process. According to this theory, any undesirable or unwanted exposure to any energy source can potentially cause workplace injuries or illnesses (Haddon 1973). Therefore, the students were provided with a catalog of 10 energy sources, as shown in Figure 2, along with relevant examples to guide their hazard recognition process. For example, hazards that fall under the gravity category include falling objects or working at heights. Similarly, power lines and energized equipment will fall under the electrical category. More examples of safety hazards corresponding to each of the energy sources can be found in Albert et al. (2013).

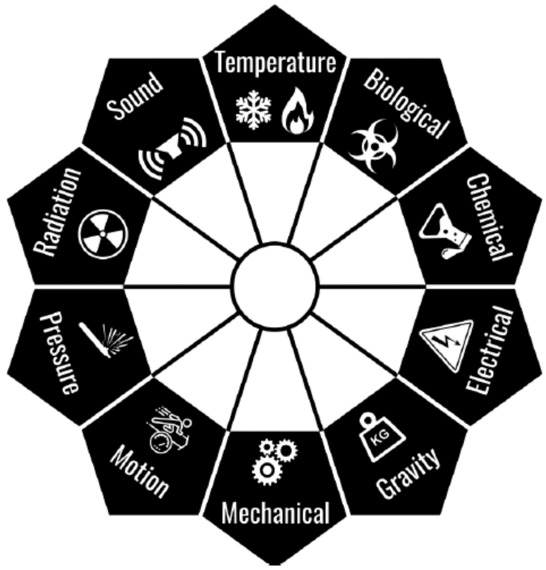

Figure 2: Energy sources used to serve as visual cues.

Hazard Recognition Performance Feedback

The importance of personalized feedback in learning and skill development has been highlighted in a large body of literature (e.g., Lyster and Saito 2010). For example, when feedback is provided, individuals better understand what is expected of them and what desirable-performance looks like (Perera et al. 2008). When individuals do not meet the desired levels of performance, such feedback can provide an opportunity to take corrective and remedial action (Benn et al. 2009). On the other hand, individuals who already demonstrate desirable levels of performance are often motivated to maintain their performance-levels due to the positive reinforcement (Locke et al. 1981; Mouratidis et al. 2008).

Unfortunately, in construction workplaces, feedback on hazard recognition performance is rarely offered. In most cases, feedback on poor hazard recognition performance is only obtained when an incident is experienced – when remedial actions cannot undo the undesirable event. More importantly, because injuries are relatively infrequent when compared to the number of near-misses and safety violations in construction workplaces, learning from such feedback is generally insufficient (Cambraia et al. 2010; Yorio and Moore 2018).

To foster the development of hazard recognition skill in the current study, the decision was made to engage the next generation of construction engineers and managers in a hazard recognition activity where their performance is measured prior to the intervention. Subsequently, the plan was to provide feedback on the hazards that were successfully recognized and those that remained unrecognized as part of the intervention.

Visual Demonstration of Common Hazard Recognition Search Weaknesses

As already mentioned, most hazard recognition efforts involve the visual examination of the construction workplace to identify relevant safety hazards. Therefore, how an individual examines the workplace can affect performance levels and whether particular hazards are recognized (Dzeng et al. 2016; Jeelani et al. 2018).

The visual examination process that an individual adopts is often affected by a number of mental and subconscious factors that include previous experiences, training, and knowledge (Dzeng et al. 2016). However, such subconscious mental processes are largely inaccessible to the individuals themselves and to researchers for more careful investigation.

One recently used approach to gain some understanding of these mental and visual search processes has been the use of eye-tracking devices. These are devices that can capture the search processes adopted by individuals by tracking eye-movement data during any visual search operation (Holmqvist et al. 2011). The capabilities of this technology have been used in various applications including understanding how radiologists examine radiographs to identify tissue abnormalities and how security personnel scan passenger baggage at an airport terminal to identify contraband items (Cain et al. 2013; Manning et al. 2004). Several of these efforts have identified various search weaknesses that result in poor search performance.

In the current study, demonstrations of commonly identified visual search weaknesses in the context of construction hazard recognition were included as part of the intervention. These demonstrations were captured from a pilot effort using the EyeTech VT3 eye-tracker. An example demonstration is presented in Figure 3. As can be seen, the image presents a case of *selective attention* where an individual devoted much of their attention to the primary task being undertaken while participating in a hazard recognition activity. Consequently, safety hazards around the activity (e.g., Gravity – trip potential from electrical cables or uneven surfaces) that are relevant were not identified during the hazard recognition operation.

Another example is presented in Figure 4. Here, as can be seen, attention was devoted or distributed more widely across the work area in the image in the right compared to the one in the left. As a result, the individual that demonstrated the search pattern in the right image identified a larger number of safety hazards during the hazard recognition activity for the same work scenario. It is important to note that eye-tracking devices were not used as part of the current effort; only demonstrations captured as part of previous pilot effort was adopted to illustrate search weaknesses.

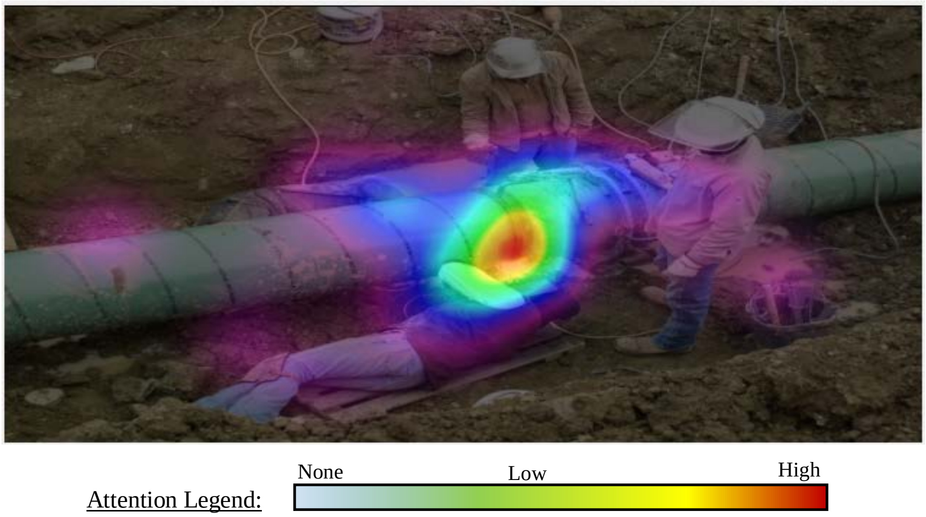

Figure 3: Demonstration of selective attention captured using eye-tracking devices

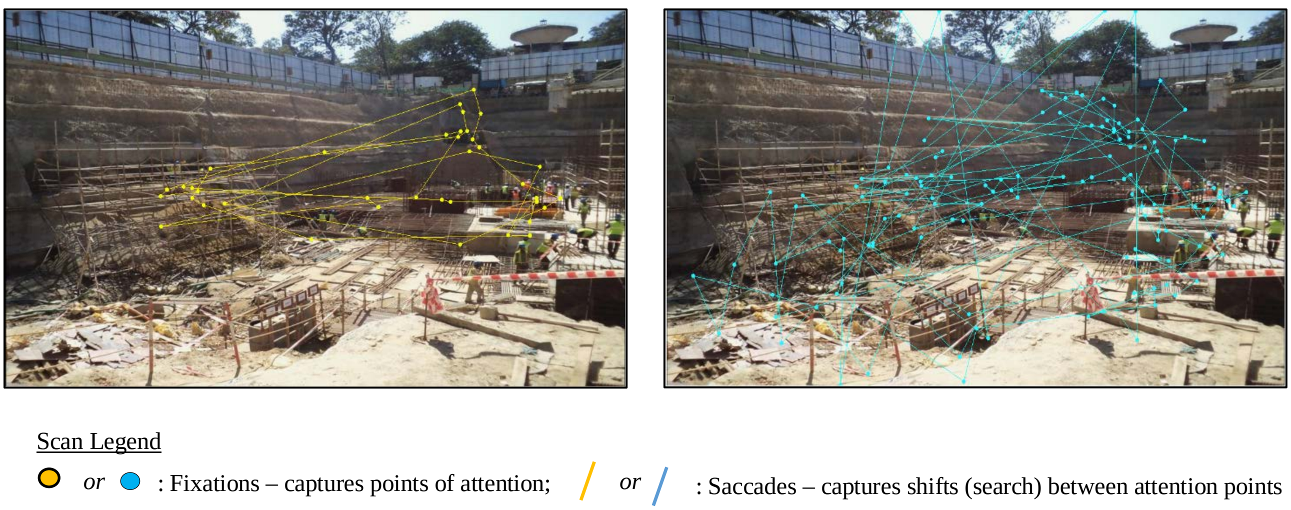

Figure 4: Demonstration of the distribution of attention captured using eye-tracking devices

Other errors that were demonstrated included *detection errors* and *search errors*. A detection error occurs when an individual allocates attention on a hazard or hazard stimuli, but fails to detect the hazard or hazard stimuli (i.e., does not report it as a hazard). An example can be seen in Figure 3 where the individual clearly devoted attention to the welding operation – but failed to report the fumes generated during the operation as a safety hazard. On the other hand, a search error occurs when an individual does not recognize a safety hazard simply because the individual did not allocate attention on a particular hazard or hazard stimuli (e.g., exposure to electricity from the electrical cables as shown in Figure 3).

The above-discussed search weaknesses were demonstrated using a number of images depicting various construction operations including grinding, pipe-laying, stud welding, excavation operations, and others. The objective of using these demonstrations was to communicate search patterns that can lead to poor performance and to encourage deliberate self-regulation among the participants to avoid the demonstrated search weaknesses.

Diagnosis of Hazard Search Weaknesses using Metacognitive Prompts

Past research has unveiled a number of reasons why construction personnel fail to recognize safety hazards (Jeelani et al. 2016). For example, as already discussed earlier, they may prematurely terminate the hazard recognition process after a few generic, and well-known safety hazards such as trip potential and pinch-point likelihood are identified (Fleming 2009). Others may fail to recognize certain hazards types – such as those that may not result in an immediate injury, illness, or adverse outcome – such as exposure to welding fumes and carcinogens (Zohar and Erev 2006). In fact, a recent effort focusing on understanding why construction hazards remain unrecognized unveiled 13 underlying impediments or factors that can lead to unrecognized safety hazards (Jeelani et al. 2016).

As part of this intervention, it was decided that the 13 impediments or factors that were identified as part of the previous effort will be provided to the participants (see Figure 5) along with discussions and illustrations. Apart from understanding the underlying reasons that contribute to unrecognized hazards, the purpose of providing these factors was to trigger metacognition. Metacognition is a process where individuals reflect on their own performance to identify underlying reasons that contributed to their poor or good performance (Dunlosky and Metcalfe 2008). Accordingly, the plan was to provide the 13 impediments as shown in Figure 5 to the study participants, and task them with self-diagnosing why they failed to identify each of the unrecognized safety hazards. It is also important to note that a particular safety hazard may remain unrecognized because of one or more factors as shown in Figure 5. Therefore, the participants can choose multiple factors for each unrecognized safety hazard.

Directions: In your opinion, why did you not recognize specific safety hazards during the hazard recognition activity?

	← **Hazard 1 to Hazard n** →			
	Hazard 1	Hazard 2	………	Hazard n
1. Operational unfamiliarity with construction tools and equipment: I was not familiar with the operations and the operational features of the equipment or tool to recognize the associated safety hazard.				
2. Hazard that is secondary or unassociated with the primary task: The hazard was not relevant to the primary task being carried out which I focused on. So, I missed this hazard.				
3. Hazards perceived to impose low levels of safety risk: The risk associated with the hazard was very low to be regarded as dangerous. So, I disregarded this as being a hazard.				
4. Premature termination of hazard recognition: After identifying several hazards, I thought I identified all of them, so stopped looking for more.				
5. Low prevalence or unexpected hazards: This hazard is quite rare for the work tasks being carried out and the workplace conditions. So, I missed this.				
6. Visually unperceivable / Obscure hazards: The hazard was not visually perceivable (e.g., hot surfaces, gasses) or was obscure within the workplace for me to recognize.				
7. Unexpected and unknown potential hazard set: I was not sure what hazards I could expect, or I needed to look for. So, I missed this hazard.				
8. Selective attention or Inattention: I did not pay attention to this type or category of hazard, or I just did not pay attention to this hazard.				
9. Multiple hazards associated with a single source or task: I thought I had already identified the hazard(s) associated with this source or task. But it turns out that the source or task was associated with other hazards as well.				
10. Task unfamiliarity: I wasn't aware of the potential hazards associated with the ongoing tasks or operations.				
11. Latent or stored energy hazards The construction hazard was latent or did not impose any immediate danger. However, it is true that a trigger or unexpected release of the stored energy can cause potential injury or illness.				
12. Hazard source detection failure: I wasn't able to identify the source of the hazard (e.g., material, tool, equipment, task, object, etc.). So I wasn't sure what the associated hazard was in this case.				
13. Hazards without immediate outcome onset: This hazard can cause injury or illness in the long term. But the outcome onset is not immediate. So I did not recognize this hazard.				

Figure 5: Diagnostic tool to identify impediments to hazard recognition

As part of the intervention, the plan was to ask the participants to examine the performance feedback that was provided (as discussed in the Hazard Recognition Performance Feedback section), and identify impediments or factors that contributed to why particular hazards remained unrecognized by completing the table shown in Figure 5 for each unrecognized safety hazard.

Subsequently, they were asked to self-reflect on strategies and remedial actions that they could adopt to overcome the identified weaknesses. For example, if a participant identified that the reason why they did not recognize a particular hazard was that they prematurely terminated the hazard recognition effort, they could decide to be more cautious and spend additional time to improve performance in subsequent efforts.

RESEARCH METHODS

The research objectives were accomplished by recruiting 22 graduate students who were expected to join the construction workforce within the next 18 months. The students were all enrolled in the Construction Engineering and Management (CEM) program in the Department of Civil, Construction, and Environmental Engineering at North Carolina State University. Most of the participating students possessed less than one year of previous experience in the construction industry.

After the recruitment, the study was conducted in three sequential stages. The first stage focused on assessing the pre-intervention hazard recognition skill of the participants. This was followed by the introduction of the intervention in the second stage. Finally, the post-intervention skill level was assessed to estimate intervention effects.

Such an experimental approach where the same participant is tested in the pre-intervention and post-intervention phase (i.e., repeated measures) offers a number of advantages. For example, because comparisons and inferences, concerning the effectiveness of the intervention, can be made by comparing the performance of the same participant in the pre-intervention and post-intervention phase – the experimental approach effectively eliminates issues related to the differences between individuals (Gravetter and Wallnau 2016). This issue is common in other experimental approaches where the performance of a group of individuals that received the intervention is compared against another group that did not receive the intervention. In addition, such an approach that eliminates the effect of extraneous variables offers the ability to make stronger causal claims with smaller sample sizes because of the increase in statistical power (Gravetter and Wallnau 2016). The following sections describe the three individual stages in detail.

Stage I: Measurement of Pre-intervention Hazard Recognition Skill

To measure the pre-intervention skill, the participants were asked to participate in a hazard recognition activity. The activity was conducted using 16 construction case images selected from an initial pool of over 100 case images depicting diverse work operations. Example work operations included excavation, pipe-cutting, welding, crane rigging and others. The case images were captured as part of a previous effort from real workplaces in the United States with the assistance of industry representatives (Albert et al. 2013). After the case images were gathered, 17 safety professionals representing the Construction Industry Institute (CII) member organizations examined each of the case images and pre-identified the safety hazards present using brainstorming sessions. An example case image with the pre-identified hazards is presented as Figure 6 for illustration.

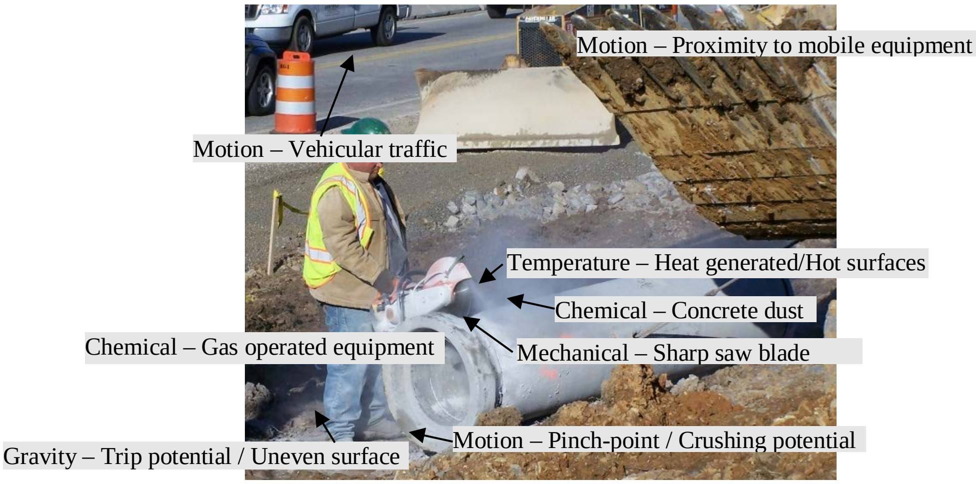

Figure 6: Example case image along with pre-identified safety hazards

As part of the current study, a unique random set of four construction case images were selected from the initial set of 16 and presented to each study participants during the hazard recognition activity. The participants were tasked with examining the images and identifying all safety hazards in writing. Using the responses, the pre-intervention hazard recognition performance for each participant, corresponding to each case image, was computed using Equation 1.

$$Hazard\ Recogntiion\ performance = \frac{No.of\ hazard\ recognized}{Total\ number\ of\ hazards\ present}$$

As can be seen, the measure captured the relative proportion of hazards a particular participant recognized in a given case image relative to the total number of hazards that were present. The total number of hazards, for the purposes of this study, was defined as the total number of unique safety hazards that the safety professionals and the participants of the current study identified. Therefore, the measure of the hazard recognition performance for each case image would range between 0% and 100%.

Based on the performance of the participants in each of the four case images, the demonstrated hazard recognition skill was measured as the average performance across the images. Accordingly, a unique hazard recognition skill score was computed for each of the study participants.

Stage II Introduction of the Intervention and Identifying Impediments to Hazard Recognition

After the pre-intervention assessment of the hazard recognition skill, the intervention was introduced to the study participants. First, the students were introduced to the *visual cues to promote systematic hazard recognition* element. This involved exposure to the ten energy sources as discussed earlier along with the PowerPoint presentation of illustrative case image depicting hazards corresponding to each of the energy sources.

Next, the *hazard recognition performance feedback* was provided using the same case images the particular participants examined as part of the pre-intervention stage. More specifically, the same case images along with the pre-identified safety hazards as illustrated in Figure 6 were provided to each of the participants in a separate sheet. The participants were encouraged to compare their performance against the pre-identified safety hazards as part of the feedback process.

Following this, the *visual demonstration of the common hazard recognition search weakness* was introduced and discussed as mentioned earlier. Finally, the *metacognitive prompts*, as presented in Figure 6, were shared with the participants and they were encouraged to diagnose their demonstrated weaknesses and self-reflect on strategies that they can adopt to overcome the weaknesses. The responses from the self-diagnosis process were also gathered to identify the most commonly reported impediments to hazard recognition – to accomplish the second objective of the study.

Stage III Measurement of Post-intervention Hazard Recognition Skill

At the conclusion of the intervention, a new hazard recognition activity following the same procedure adopted for the pre-intervention stage was conducted. This involved randomly selecting a new set of four construction case images and repeating the same procedure for the post-intervention assessment. Care was taken to ensure that the study participants were examining case images that were different from those examined in the pre-intervention stage for which feedback was already provided. Based on their performance in each of the case images, the demonstrated hazard recognition skill was again computed as was done in the pre-intervention stage. The process yielded a new set of hazard recognition skill scores for each of the 22 participants for comparison against the pre-intervention skill – to accomplish the first objective of the study.

In addition, as performed in Stage II, the participants were once again provided feedback on their hazard recognition performance, and they were asked to indicate again why particular hazards may have remained unrecognized using the table in Figure 5. Comparing this data against the data captured in Stage II would provide information on the impediments that remained after experiencing the intervention.

DATA ANALYSIS, RESULTS AND DISCUSSIONS

Objective I: Effectiveness of the Intervention in Improving Hazard Recognition skill

As discussed, the repeated-measures approach provided a hazard recognition skill score for each of the 22 study participants in the pre-intervention and the post-intervention phase. The descriptive statistics of the scores are presented in Table 1.

Table 1: Effect of the intervention of hazard recognition skill

Conditions	Mean	Standard Deviation	*t*-test statistic	*p*-value
Pre-intervention Hazard Recognition Skill	39.95%	8.12%	-8.96	<0.05
Post-intervention Hazard Recognition Skill	58.05%	8.01%		

As can be seen, overall the study participants, on average, recognized less than 40% of the safety hazards in the pre-intervention phase. However, after experiencing the intervention, they were able to identify over 58% of the safety hazards on average. Therefore the average observed improvement in the hazard recognition skill exceeded 18% across the study participants.

To test whether the observed difference is statistically significant, first, the normality of the data was tested using the Anderson-Darling test. The results suggested that the assumption of normality can be assumed for both the pre-intervention and post-intervention data. Next, the two-sample dependent *t*-test was conducted with an alpha level of 0.05. The results of the test are also included in Table 1. As can be seen, the *p*-value associated with the *t*-test statistic is less than the selected alpha level of 0.05. Therefore, the results suggest that the difference in performance is statistically significant. Therefore, there is sufficient evidence to conclude that the introduction of the intervention caused a significant improvement in the hazard recognition skill among the next-generation of construction engineers and managers.

Additional analysis was conducted to evaluate whether there were differential effects among the study participants. In other words, there was interested in evaluating whether certain participants demonstrated higher levels of improvement than others. Because participants whose performance were relatively lower in the pre-intervention phase had a much larger room for improvement, the analysis focused on evaluating whether these individuals demonstrated higher levels of improvement. In other words, there was interest in testing if there were higher gains in skill among those that were relatively poorer in recognizing safety hazards in the pre-intervention phase. For example, the analysis focused on evaluating whether an individual who identified only 30% of the safety hazards in the pre-intervention phase is likely to show higher levels of improvement than another individual who may have identified 50% of the safety hazards in the pre-intervention phase.

To test whether such a differential effect existed, the regression model presented as Equation 2 was estimated. As can be seen, the regression coefficient β_1 is the coefficient that is of the most interest in the analysis as it captures the differential effect across the study participants. More specifically, if the participants who demonstrated lower levels of skill in the pre-intervention phase demonstrated higher levels of improvement than the others, then the value of β_1 will be negative and statistically significant. In other words, as the pre-intervention hazard recognition skill level increases across the participants, the demonstrated improvement will decrease.

$$\Delta HR = \beta_0 + \beta_1 HR_{pre} + \varepsilon$$

Where, ΔHR is the demonstrated improvement in the hazard recognition skill, HR_{pre} is the hazard recognition skill demonstrated in the pre-intervention phase (i.e., measures across four construction case images), β_0 is the intercept is the intercept of the regression model, β_1 represents the slope between the relationship between the pre-intervention hazard recognition skill (HR_{pre}) and the demonstrated improvement (ΔHR), and ε is the error term in the mathematical regression model.

The results of the estimation of the regression model are presented in Table 2. As can be seen, the coefficient (β_1) associated with the improvement in hazard recognition skill is negative. This suggests that as the pre-intervention hazard recognition skill increased across the study participants, the observed improvement in the hazard recognition skill decreased. For example, according to the results in Table 2, a participant who demonstrates a pre-intervention hazard recognition skill of 30% is expected to demonstrate an improvement of 25% [i.e., 45.831 – 0.694 (30%)]. However, another participant who demonstrates a pre-intervention skill of 50% is expected to only demonstrate an improvement of approximately 11% [i.e., 45.831 – 0.694 (50%)]. Therefore, in summary, although the introduction of the intervention improved the demonstrated hazard recognition skill across the study participants, the effect was particularly stronger among those that demonstrated poorer performance in the pre-intervention phase.

Table 2: Differential effect of the intervention on the study participants

Predictors	Coefficient	Std. Error	t-value	p-value	LLCI	ULCI	r^2
Constant (β_0)	45.831	8.532	5.372	<0.05	28.034	63.628	0.354
ΔHR (β_1)	-0.694	0.209	-3.314	0.003	-1.131	-0.257	

Note: LLCI & ULCI = Lower and upper limit confidence intervals, respectively

Objective II: Experienced Impediments to Recognizing Safety Hazards

Table 3 summarizes the results of the metacognitive activity where the participants identified why they might not have identified particular safety hazards. As can be seen, prior to the introduction of the intervention, the most common reason reported for not recognizing particular safety hazards was the *premature termination of hazard recognition* (i.e., 17.07%). As discussed earlier, this is a phenomenon where individuals terminate the hazard recognition process after a few generic and mundane safety hazards are identified – even if additional safety hazards may still remain unrecognized. This was closely followed by *selective attention or inattention*, which was also responsible for close to 17% of the unrecognized safety hazards. As discussed in Jeelani et al. (2016), *selective attention or inattention* occurs when individuals allocate attention to only certain hazards that may be in close proximity to workers or are adjacent to the primary task being undertaken. In other cases, individuals may also selectively allocate attention only to certain hazard types or categories such as *gravity hazards* that includes debris on the floor (i.e., trip potential), leading edges (i.e., fall potential), and falling material.

Table 3: Impediments to hazard recognition

Factors	Pre-intervention		Post-intervention		Change / Difference	
	No. of hazards	Percentage	No. of hazards	Percentage	No. of Hazards	Percentage
Operational unfamiliarity with construction tools and equipment	57	5.50%	49	13.14%	8	14.04%
Hazard that are secondary or unassociated with the primary task	63	6.08%	18	4.83%	45	71.43%
Hazards perceived to impose low levels of safety risk	114	10.99%	70	18.77%	44	38.60%
Premature termination of hazard recognition	177	17.07%	23	6.17%	154	87.01%
Low prevalence or unexpected hazards	27	2.60%	17	4.56%	10	37.04%
Unknown potential hazard set	127	12.25%	26	6.97%	101	79.53%
Visually unperceivable / Obscure hazards	73	7.04%	32	8.58%	41	56.16%
Selective attention or Inattention	176	16.97%	43	11.53%	133	75.57%
Task unfamiliarity	63	6.08%	41	10.99%	22	34.92%
Hazard source detection failure	26	2.51%	14	3.75%	12	46.15%
Multiple hazards associated with single source or task	35	3.38%	12	3.22%	23	65.71%
Hazards without immediate outcome onset	64	6.17%	21	5.63%	43	67.19%
Latent or stored energy hazards	35	3.38%	7	1.88%	28	80.00%

After the intervention was introduced, the most commonly identified impediment was *Hazards perceived to impose low levels of safety risk*. This is a phenomenon when individuals do not report a particular safety hazard when they perceive that the risk imposed by the safety hazard is minimal. This was closely followed by *operational unfamiliarity with construction tools and equipment* – which occurs when individuals do not identify hazards because of their unfamiliarity with the operation or operational features of certain tools or pieces of equipment. For example, when an individual is not aware of whether a particular equipment (e.g., chainsaw, hand saw, etc.) is operated using gas, electricity, or battery, they may fail to accurately identify the associated safety hazards.

Examining the change in performance after the intervention was introduced suggests that the highest impact of the intervention was on the *premature termination of hazard recognition*. More specifically, the frequency with which the participants reported *premature termination of hazard recognition* as an impediment to hazard recognition reduced by over 87%. This was followed by the intervention's effect on *latent or stored energy hazards*. This includes hazards such as pressurized piping – that do not appear to impose any imminent danger – but can result in catastrophic incidents if the latent or stored energy is unexpectedly released (e.g., rupture of pressurized piping). Another common example of a latent or stored energy hazard is the cave-in potential of an excavation that can occur with little or no observable warning.

The intervention had the least effect on hazards that were not identified due to the *operational unfamiliarity with construction tools and equipment* and *task unfamiliarity*. This may be because the intervention was not particularly designed to target the unfamiliarity among the participants with particular construction tasks, pieces of equipment, or tools. Supplementing the current intervention elements with a description of common tasks, pieces of equipment, and tools may address this shortcoming of the current intervention.

STUDY CONTRIBUTIONS AND PRACTICAL IMPLICATIONS

The current study makes a number of important contributions to literature and practice. First, the research successfully demonstrated that the discussed intervention can be adopted to improve hazard recognition skill among the next generation of construction engineers and managers. Accordingly, educators and trainers can adopt such interventions to better prepare individuals to tackle the safety challenges experienced in the construction industry. Such efforts will not only address the skill requirements of the industry (Clevenger et al. 2017; Toole 2002), but can also lead to superior hazard recognition levels and a dramatic reduction in the number of injuries.

Second, while the intervention caused an improvement in the hazard recognition skill across all the study participants, the intervention was particularly effective for those that demonstrated inferior levels of hazard recognition in the pre-intervention phase. Therefore, while the intervention is broadly relevant to all future construction engineers and managers, it can be particularly useful to those that have little experience with construction hazard recognition.

Third, the research unveiled common impediments to hazard recognition experienced by the next generation of construction engineers and managers. Among others, the *premature termination of hazard recognition* was the most common. Fortunately, the intervention dramatically reduced the number of safety hazards that remained unrecognized corresponding to each impediment in the post-intervention phase. Therefore, the intervention successfully targeted each of the impediments to hazard recognition that the participants demonstrated.

Fourth, the research also quantified the relative effect of the intervention on the various impediments to hazard recognition. More specifically, the intervention had the highest impact on reducing hazards that remained unrecognized because of the *premature termination of the hazard recognition*. The intervention also had a large effect on *latent and stored energy hazards*. However, the intervention had the least effect on *operational unfamiliarity with construction tools and equipment* and *task unfamiliarity*. This important finding suggests that the presented intervention can potentially be further improved by introducing additional elements that assist with gaining more familiarity with construction tasks, tools, and pieces of equipment. This is a potential area for future research given that more than 40% of the safety hazards still remained unrecognized, on average, in the current study – after the intervention was introduced. However, it should also be noted that the participants recognized up to 72% of safety hazards in the current study.

LIMITATIONS AND POTENTIAL FUTURE EFFORTS

While the research makes valuable contributions, there are few limitations that may be addressed in future research. First, in the current study, the hazard recognition skill was measured using construction case images rather than in real construction workplaces. This was done because it was unrealistic to transport the student participants to real construction workplaces where they could be potentially exposed to safety hazards. In addition, the use of the construction case images provided a standardized approach to measure hazard recognition skill and to offer feedback based on the pre-identified list of safety hazards. It is also important to note that previous efforts suggest that there is a strong correlation between performance measurements captured using construction case images and in real workplaces (Albert et al. 2013). Nonetheless, future efforts could be undertaken in real construction workplaces after sufficient safety precautionary measures are adopted, and a suitable experimental plan is developed.

Second, the study participants were all recruited from the student body enrolled in the construction engineering and management program in one institute. Although the participants were sufficient to make meaningful statistical inferences, future efforts could focus on a larger cohort of students from across the nation. Not only will such efforts yield more generalizable results, but will also foster the development of hazard recognition skill more widely across the next generation of construction engineers and managers.

Finally, as already discussed, while the intervention significantly improved the hazard recognition skill of the study participants, the research revealed that the intervention did not sufficiently address the lack of familiarity with tasks, tools, and pieces of equipment. Future research could explore the addition of other intervention elements to further improve the effectiveness of the discussed intervention.

CONCLUSION

Past research has established that a large number of safety hazards remain unrecognized in construction workplaces (Albert et al. 2013; Bahn 2013; Carter and Smith 2006; Perlman et al. 2014). These unrecognized safety hazards are also likely to remain unmanaged and can potentially cascade into unexpected safety incidents (Jeelani et al. 2016). Therefore, effective hazard recognition skill is fundamental to effective safety management and injury prevention.

To improve performance, the current research focused on testing an intervention targeted at improving the hazard recognition skill among the next generation of construction engineers and managers. The intervention included a number of program elements such as: visual cues to promote systematic hazard recognition, personalized hazard recognition performance feedback, visual demonstration of common hazard recognition search weaknesses, and diagnosis of hazard search weaknesses using metacognitive prompts.

After measuring the pre-intervention hazard recognition skill of the study participants, the intervention was introduced. The post-intervention assessment suggested that the intervention successfully improved the hazard recognition skill demonstrated by the study participants. In addition, the intervention was effective in addressing a number of common impediments to effective hazard recognition.

The results of the study can be used to equip the next generation of construction engineers and managers with the necessary skill to effectively recognize safety hazards. Such efforts can dramatically improve safety performance and reduce injury likelihood in the construction industry. The results of the study will be of interest to construction educators, professional trainers, and safety researchers.

REFERENCES

Abudayyeh, O., Fredericks, T. K., Butt, S. E., Shaar, A. (2006). "An Investigation of Management's Commitment to Construction Safety." *Int. J. Project Manage.*, 24(2), 167-174.

Ahmed, S. M., Azhar, S., and Forbes, L. H. (2006). "Costs of injuries/ illnesses and fatalities in construction and their impact on the construction economy." *Int. Conf. on Global Unity for Safety and Health in Construction*, Tsinghua University Press, Beijing.

Aksorn, T., and Hadikusumo, B. (2008). "Critical Success Factors Influencing Safety Program Performance in Thai Construction Projects." *Saf. Sci.*, 46(4), 709-727.

Albert, A., Hallowell, M. R., Skaggs, M., Kleiner, B. (2017). "Empirical Measurement and Improvement of Hazard Recognition Skill." *Saf. Sci.*, 93, 1-8.

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.

Arditi, D., Ongkasuwan, D., Committee on Management Practices in Construction (MPIC) of the ASCE Construction Institute. (2009). "Duties and Responsibilities of Construction Managers: Perceptions of Parties Involved in Construction." *J. Constr. Eng. Manage.*, 135(12), 1370-1374.

Atkinson, A. R., and Westall, R. (2010). "The Relationship between Integrated Design and Construction and Safety on Construction Projects." *Constr. Manage. Econ.*, 28(9), 1007-1017.

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

Behm, M. (2005). "Linking Construction Fatalities to the Design for Construction Safety Concept." *Saf. Sci.*, 43(8), 589-611.

Benn, J., Koutantji, M., Wallace, L., Spurgeon, P., Rejman, M., Healey, A., Vincent, C. (2009). "Feedback from Incident Reporting: Information and Action to Improve Patient Safety." *Qual. Saf. Health. Care.*, 18(1), 11-21.

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). (2017). "Injuries, illnesses, and fatalities." <https://www.bls.gov/iif/> January, 2018).

Cain, M. S., Adamo, S. H., Mitroff, S. R. (2013). "A Taxonomy of Errors in Multiple-Target Visual Search." *Visual Cognition*, 21(7), 899-921.

Cambraia, F. B., Saurin, T. A., Formoso, C. T. (2010). "Identification, Analysis and Dissemination of Information on Near Misses: A Case Study in the Construction Industry." *Saf. Sci.*, 48(1), 91-99.

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

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.

Clevenger, C. M., Brothers, H., Abdallah, M., Wolf, K. (2017). "Initial Assessment of a Newly Launched Interdisciplinary Construction Engineering Management Graduate Program." *J. Prof. Issues Eng. Educ. Pract.*, 143(3), 04017001.

Dunlosky, J., and Metcalfe, J. (2008). *Metacognition,* Sage Publications, California.

Dzeng, R., Lin, C., Fang, Y. (2016). "Using Eye-Tracker to Compare Search Patterns between Experienced and Novice Workers for Site Hazard Identification." *Saf. Sci.*, 82, 56-67.

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

Gravetter, F. J., and Wallnau, L. B. (2016). *Statistics for the Behavioral Sciences,* Cengage Learning, MA.

Haddon, W. (1973). "Energy Damage and the Ten Countermeasure Strategies." *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 15(4), 355-366.

Hadikusumo, B., and Rowlinson, S. (2002). "Integration of Virtually Real Construction Model and Design-for-Safety-Process Database." *Autom. Constr.*, 11(5), 501-509.

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., Hallowell, M., Baud, K. (2013). "Construction-Safety Best Practices and Relationships to Safety Performance." *J. Constr. Eng. Manage.*, 139(10), 04013006.

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., Van de Weijer, J. (2011). *Eye Tracking: A Comprehensive Guide to Methods and Measures,* OUP Oxford, NY.

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.

Jeelani, I., Albert, A., Azevedo, R., Jaselskis, E. J. (2016). "Development and Testing of a Personalized Hazard-Recognition Training Intervention." *J. Constr. Eng. Manage.*, 143(5), 04016120.

Jeelani, I., Albert, A., Han, K. (2018). "Are visual search patterns predictive of hazard recognition performance? Empirical investigation using eye-tracking technology?" *J. Constr. Eng. Manage.*, in-press.

Lingard, H., Pirzadeh, P., Blismas, N., Wakefield, R., Kleiner, B. (2014). "Exploring the Link between Early Constructor Involvement in Project Decision-Making and the Efficacy of Health and Safety Risk Control." *Constr. Manage. Econ.*, 32(9), 918-931.

Lyster, R., and Saito, K. (2010). "Oral Feedback in Classroom SLA: A Meta-Analysis." *Studies in Second Language Acquisition,* 32(2), 265-302.

Locke, E. A., Shaw, K. N., Saari, L. M., Latham, G. P. (1981). "Goal Setting and Task Performance: 1969–1980." *Psychol. Bull.*, 90(1), 125.

Manning, D. J., Ethell, S., Donovan, T. (2004). "Detection or Decision Errors? Missed Lung Cancer from the Posteroanterior Chest Radiograph." *Br. J. Radiol.*, 77(915), 231-235.

Mouratidis, A., Vansteenkiste, M., Lens, W., Sideridis, G. (2008). "The Motivating Role of Positive Feedback in Sport and Physical Education: Evidence for a Motivational Model." *Journal of Sport and Exercise Psychology*, 30(2), 240-268.

Nickles, G. M., Melloy, B. J., Gramopadhye, A. K. (2003). "A Comparison of Three Levels of Training Designed to Promote Systematic Search Behavior in Visual Inspection." *Int. J. Ind. Ergonomics*, 32(5), 331-339.

Perera, J., Lee, N., Win, K., Perera, J., Wijesuriya, L. (2008). "Formative Feedback to Students: The Mismatch between Faculty Perceptions and Student Expectations." *Med. Teach.*, 30(4), 395-399.

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

Saurin, T. A., Formoso, C. T., Cambraia, F. B. (2008). "An Analysis of Construction Safety Best Practices from a Cognitive Systems Engineering Perspective." *Saf. Sci.*, 46(8), 1169-1183.

Toole, T. M., and Gambatese, J. (2008). "The Trajectories of Prevention through Design in Construction." *J. Saf. Res.*, 39(2), 225-230.

Toole, T. M. (2005). "Increasing Engineers' Role in Construction Safety: Opportunities and Barriers." *J. Prof. Issues Eng. Educ. Pract.*, 131(3), 199-207.

Toole, T. M. (2002). "Construction Site Safety Roles." *J. Constr. Eng. Manage.*, 128(3), 203-210.

Toole, T. M., and Gambatese, J. A. (2002). "Primer on Federal Occupational Safety and Health Administration Standards." *Pract. Periodical Struct. Des. Constr.*, 7(2), 56-60.

Weinstein, M., Gambatese, J., Hecker, S. (2005). "Can Design Improve Construction Safety?: Assessing the Impact of a Collaborative Safety-in-Design Process." *J. Constr. Eng. Manage.*, 131(10), 1125-1134.

Yorio, P. L., and Moore, S. M. (2018). "Examining Factors that Influence the Existence of Heinrich's Safety Triangle using Site-Specific H&S Data from More than 25,000 Establishments." *Risk Analysis*, 38(4), 839-852.

Zhang, S., Teizer, J., Lee, J., Eastman, C. M., Venugopal, M. (2013). "Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules." *Autom. Constr.*, 29, 183-195.

Zohar, D., and Erev, I. (2006). "On the Difficulty of Promoting Workers' Safety Behaviour: Overcoming the Underweighting of Routine Risks." *International Journal of Risk Assessment and Management*, 7(2), 122-136.

Zou, P. X., and Sunindijo, R. Y. (2015). *Strategic Safety Management in Construction and Engineering*, John Wiley & Sons, NY.