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Focus on the fatal-four: Implications for construction hazard recognition

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ABSTRACT

Much effort has been devoted to improving hazard recognition in the construction industry. One such effort is the training outreach program pioneered and promoted by the Occupational Safety and Health Administration (OSHA) – commonly known as the *Construction Focus Four* or the *Construction Fatal Four* program. This program which is integrated in much of the training efforts offered in the construction industry seeks to promote hazard recognition and management by focusing on the four leading causes of fatal incidents – namely falls, caught-in/between, struck-by, and electrocution (i.e., fatal-four) hazards. Given the emphasis of these hazards in most training efforts, the objective of the current research was to explore if there are any performance disparities among workers in recognizing hazards that fall under the fatal-four and the non-fatal-four hazard categories. To accomplish this research goal, more than 280 workers were recruited from 57 construction workplaces in the United States to participate in a hazard recognition activity. The results of the study reveal that workers fail to recognize a disproportionate number of safety hazards in both the fatal-four and the non-fatal-four hazard categories. However, workers are relatively more proficient in recognizing hazards in the fatal-four hazard category than the non-fatal-four hazard category. More specifically, on average, the participating workers roughly recognized 57% of the fatal-four safety hazards while only recognizing 18% of the non-fatal-four safety hazards. Collectively, these findings suggest that apart from focusing on the fatal-four hazards, training efforts must also focus on the non-fatal-four safety hazards – given the relative poor performance.

1. Introduction

High injury rates are a persistent issue in the construction industry. Most nations, including the United States, the United Kingdom, Australia, and others consistently report an unacceptable number of safety incidents from construction workplaces (Bureau of Labor Statistics, 2018; Health and Safety Executive; Safe Work Australia, 2018). For example, in the United States, in 2017, the construction industry reported more than 970 fatal and 200,000 non-fatal incidents (Bureau of Labor Statistics, 2018). These injuries and illnesses cause much pain to workers and their families, while also leading to losses and injury claims that exceed $49 billion every year (Ahmed et al. 2006).

One reason for these high injury rates is the prevalence of poor hazard recognition in the construction industry. When workers fail to recognize and manage relevant safety hazards, the likelihood of unintended hazard exposure, injuries, and catastrophic safety incidents increases (Carter and Smith 2006; Jeelani et al. 2016). Unfortunately, recent investigations suggest that workers may fail to recognize up to 57% of safety hazards in typical work environments (Albert et al. 2017; Bahn 2013; Carter and Smith 2006; Jeelani et al. 2019; Perlman et al. 2014).

To address this persistent issue, researchers, employers, and regulatory bodies have invested much effort into developing and disseminating promising interventions. One of the most influential interventions has been the *Construction Focus Four* program – more popularly known as the *Construction Fatal Four* program – pioneered and promoted by the Occupational Safety and Health Administration. (OSHA). This program seeks to improve hazard recognition and reduce injury rates by increasing the attention devoted to the most common causes of fatal incidents – namely falls, caught-in/between, struck-by, and electrocution hazards (OSHA 2011).

Apart from being integrated into the official training material of OSHA (e.g., OSHA 10-hour or 30-hour training programs), the *Construction Focus Four* program has been adopted in much of the training efforts undertaken within the construction industry. For example, hazards associated with falls, caught-in/between, struck-by, and electrocution are regularly integrated into the training efforts of employers, apprenticeship programs, and trade unions (Taylor 2015; Williams Jr et al., 2010). The *Construction Focus Four* program elements are also commonly discussed as part of tool-box meetings initiated and led by workers themselves.

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Despite the widespread adoption of the *Construction Focus Four* program, the problem of poor hazard recognition continues to be a universal issue. Therefore, it is useful to examine the issue of hazard recognition more closely to evaluate if meaningful patterns exist among hazards that are generally recognized and those that remain largely unrecognized.

Given that the widespread *Construction Focus Four* program particularly targets falls, caught-in/between, struck-by, and electrocution incidents (i.e., the four leading causes of fatalities), the current investigation focused on examining whether there are disparities in hazard recognition performance when considering the fatal-four and the non-fatal-four safety hazards. Such an effort can provide valuable insights into the direction that the construction industry must take to tackle the issue of poor hazard recognition and safety performance. For example, the findings of such an effort can identify particular problem areas or provide information that is useful to develop new strategic and industry-level initiatives. Finally, the effort can also provide preliminary evidence with regards to the success of the *Construction Focus Four* program pioneered and promoted by the Occupational Safety and Health Administration.

2. Literature review

2.1. Hazard recognition in construction workplaces

Construction workplaces present a wide variety of safety hazards that must be recognized and managed. However, recent investigations suggest that construction workers fail to recognize an unacceptable number of safety hazards. For example, efforts examining performance in the United States found that construction workers may fail to recognize over 50% of work-related safety hazards (Albert et al., 2017; Jeelani et al., 2019). Likewise, investigations from the United Kingdom reported that up to 33.5% of safety hazards may remain unrecognized and unassessed (Carter and Smith, 2006). In the same manner, investigations from Australia and Israel suggested that workers may fail to recognize up to 57% of safety hazards in realistic work environments (Bahn, 2013; Perlman et al., 2014). These unrecognized safety hazards can cause unintentional hazard exposure which can increase the risk of injury and catastrophic safety incidents.

Because of the importance of hazard recognition in injury prevention, various practices have been adopted to promote hazard recognition levels in the construction industry. For example, pre-task safety meetings and job safety analyses are widely adopted in the industry to facilitate hazard recognition and management (Albrechtsen et al., 2019; Rozenfeld et al., 2010). Despite their ability to foster hazard recognition and management, recent research has unveiled fundamental weaknesses associated with these methods (Fleming, 2009; Jeelani et al., 2016; Rozenfeld et al., 2010). Among others, the most prominent weakness is the presupposition that workers are by nature able to identify safety hazards that are associated with planned activities (Fleming, 2009). However, empirical findings suggest that workers fail to recognize a disproportionate number of safety hazards even when such formal practices are adopted (Albert et al., 2013; Bahn, 2013; Carter and Smith, 2006; Perlman et al., 2014).

Another widely adopted approach is training programs that focus on transferring safety knowledge that is necessary for effective hazard recognition and management (Taylor, 2015; Wilkins, 2011). While useful, the adoption of training programs have also not resulted in desirable levels of performance (Haslam et al., 2005; Namian et al., 2016). In fact, past research has unveiled systemic weaknesses with how training is designed and delivered (Demirkesen and Arditi, 2015; Haslam et al., 2005; Wilkins, 2011). For example, past research has demonstrated that much of the training efforts are not efficiently designed to transfer essential safety knowledge to adult learners (Li et al., 2012; Namian et al., 2016; Wilkins, 2011). While efforts are focusing on addressing some of these identified challenges (e.g., Bhandari and Hallowell, 2017; Jeelaniet al., 2016), there is a dearth of research examining if the content that is embedded in training programs are sufficient to achieve desirable levels of performance. An examination of the hazard types that are generally recognized and those that largely remain unrecognized will be useful to inform future industry-level training and outreach efforts.

2.2. Construction fatal four program

With the goal of reducing injury rates, the Occupational Safety and Health Administration (OSHA) tracks injury patterns reported from construction workplaces every year. These findings consistently identify *falls* as a leading cause of fatal incidents (OSHA, 2017). For example, of the more than 13,000 fatal incidents reported between 2003 and 2015, more than 34% (i.e., more than 4500) resulted from falls (Bureau of Labor Statistics, 2018). These incidents involved falls from roofs, ladders, scaffolding, and other surfaces. Other leading causes of fatal injuries include struck-by incidents, caught-in/between incidents, and electrical incidents; which account for 18%, 9%, and 8% of all the reported fatal incidents respectively (Bureau of Labor Statistics, 2018). Together, the four leading causes of safety incidents were responsible for approximately 70% of all reported fatalities between 2003 and 2015.

To strategically target these injuries, the Occupational Safety and Health Administration (OSHA) pioneered and promoted the *Construction Fatal Four* or the *Construction Focus Four* program (OSHA, 2011). The objective of this strategic initiative has been to increase the attention devoted to the four most common causes of fatal incidents – namely falls, caught-in/between, struck-by, and electrical injuries.

The Occupational Safety and Health Administration (OSHA) accomplished this goal by developing and widely disseminating training material relevant to the fatal-four hazards throughout the construction industry. The dissemination was promoted in a number of ways. For example, OSHA authorized trainers are required to integrate the material on the fatal-four hazards in their OSHA 10-hour and 30-hour training efforts (OSHA, 2011). These training efforts (e.g., OSHA 10-hour) have also been prescribed as a mandatory pre-requisite to participation in various state-sponsored projects in states that include Connecticut, Massachusetts, Nevada, and others (e.g., Connecticut Department of Labor, 2009; Massachusetts Office of Labor and Workforce Development, 2008).

In addition, the Occupational Safety and Health Administration (OSHA) has made much of its training material on the fatal-four hazards freely available to employers, industry trainers, and the general public for active adoption and dissemination (OSHA, 2011). Because of such efforts, resources on the fatal-four safety hazards are integrated into much of the training efforts in the industry – whether administered by OSHA authorized trainers, employers, trade unions, or through apprenticeship programs (Schoenfisch et al., 2017; Taylor, 2015; Williams Jr et al., 2010).

Given these efforts, it is useful to examine how workers perform when considering the fatal-four safety hazards and the non-fatal-four safety hazards. Such an effort can provide useful information to inform future industry-level endeavors as the industry continues to grapple with the issue of high injury rates.

3. Research objectives and study rationale

As already discussed, much of the training provided in the United States construction industry has largely focused on the fatal-four safety hazards. In comparison, relatively less attention has been devoted to hazards that fall under the non-fatal-four hazard category. While the rationale for this imbalance may be justifiable given the goals of emphasizing the most common causes of fatal incidents, it is useful to evaluate if any disparity in performance exists when considering performance under the fatal-four and the non-fatal-four safety hazard categories. Accordingly, the goal of the study was to assess if construction workers are more proficient in recognizing hazards that fall under one of the two categories.

If workers are more proficient in recognizing safety hazards that fall under the fatal-four hazard category, this may provide preliminary evidence to suggest that the *Construction Focus Four* program has been – at least – partly successful in achieving its intended goals. If this is the case, and if workers demonstrate desirable levels of hazard recognition in the fatal-four hazard category, this may suggest that the industry could potentially switch at least some of its attention to the non-fatal four hazard category. However, given that the fatal-four safety hazards continue to account for the vast majority of the safety incidents, this may also suggest that the industry may need to devote attention to factors beyond hazard recognition such as the underestimation of safety risk and risk-taking behavior in the presence of the fatal-four safety hazards.

On the other hand, (1) if workers are more proficient in recognizing safety hazards in the non-fatal four hazard category or (2) if there are no significant differences in performance between the two hazard categories, this may signify that a more aggressive effort to pursue the goals of the *Construction Focus Four* program is needed. In fact, such a finding may suggest that the efforts of the *Construction Focus Four* program have not sufficiently diffused into the construction industry. If this is the case, then the industry may need to seek more innovative and strategic initiatives to boost the diffusion of the *Construction Focus Four* program efforts.

It is important to note that although the objectives of the *Construction Focus Four* program was to devote additional attention to the most common causes of fatal incidents – which includes falls, caught-in/between, struck-by, and electrocution – the program does not necessarily distinguish between hazards that may possibly result in fatal or non-fatal incidents (e.g., disabling incidents, medical cases, first-aid incident, etc.). For example, hazards such as slips and trips that can occur from housekeeping issues are also emphasized within the scope of the *Construction Focus Four* program – although these hazards are associated with a larger number of non-fatal incidents in injury reports (OSHA, 2011). Accordingly, the current research effort also does not distinguish between hazards that may cause fatalities or other incident types. Regardless of the likely outcome, the study examined relative performance in the two hazard categories as per the formalized program.

4. Research methods

To accomplish the research objective, a hazard recognition activity was first planned using 16 construction case images. The case images were gathered during a previous research effort where real construction workplaces in the United States were visited, and photographs representing a variety of construction operations were captured (Construction Industry Institute, 2014). The case images included operations such as excavation, trenching, crane lifting, crane rigging, welding, grinding, cutting, drilling, stud welding, and the erection of structural elements.

After the case images were gathered, the case images were examined by a panel of 17 construction industry safety professionals with an accumulated experience of over 300 years in the construction industry. The expert panel pre-identified relevant safety hazards depicted in each of the case images. Each of the construction case images included at least five safety hazards. An example case image along with the pre-identified safety hazards is presented in Fig. 1.

In the current research study, the research team recruited a convenience sample of 57 construction crews representing independent projects (i.e., 57 projects) in the United States to participate in the research effort. Each of the participating crews included at least four workers with an overall participation from 287 workers. The projects undertaken by the participating crews included commercial (~37%), infrastructure (~19%), industrial (~16%), educational (~11%), and residential work (~14%). The participating workers were involved in a variety of construction operations including site preparation, plumbing and piping, carpentry, welding and cutting, electrical utility work, and others. The age of the participants ranged from 19 to 65 years and their experience in the construction industry ranged between 1 and 40 years. The site leadership of each of the participating projects also confirmed that training covering topics related to falls, caught-in/between, struck-by, and electrical injuries are offered to the workers in their workplace either by workplace representatives or authorized third party entities.

During a visit to the participating workplaces, demographic data from the site-leadership was first gathered. Next, the participating workers were engaged in the planned hazard recognition activity. The activity involved the administration of a random set of two construction case images from the initial 16 to each of the participating workers representing the crews. The workers were then tasked with reporting all safety hazards represented in the case images verbally – which were cataloged by the researchers.

After the data collection effort, the set of *unique hazards* present in each of the case images – that included hazards identified by (1) the previous expert panel and (2) the workers of the current study were reexamined.

The reexamination was conducted by a panel of four safety professionals along with the researchers during a focus-group session. The safety professionals possessed a cumulative experience of over 107 years in the construction industry. The purpose of the reexamination was to distinguish each of the unique hazards in the case images as either falling under the fatal-four or the non-fatal-four hazard categories. The assessments were made in accordance with the description of the fatal-four safety hazards and relevant examples made available by OSHA through the *Construction Fatal Four* or the *Construction Focus Four* program webpage. Examples also presented in Table 1 were reviewed to guide and facilitate the decision-making process.

Of the total 120 hazards represented in the 16 case images, the effort identified a total of 75 hazards as falling in the fatal-four hazard category and the remaining 45 as falling in the non-fatal-four hazard category across the 16 case images – with consensus among the expert panelist. Based on this gathered data, the performance of the workers in both the hazard categories was computed as described in the following section.

5. Data pre-processing

Since certain case images included a very few non-fatal-four safety hazards (i.e., mean number of non-fatal four hazards in the case images = 2.8) and one of the case images did not include any non-fatal-four safety hazards, the analysis for this study was conducted at the crew level. This ensured that a sufficient number of the non-fatal-four safety hazards were present in the examined case images to reliably assess relative performance when considering the fatal-four and the non-fatal four hazard categories. In other words, the analysis was conducted at the crew level to address the relative under-representation of the non-fatal safety hazards in each of the examined case images.

As a first step, the total number of the fatal-four and the non-fatal-four safety hazards recognized by all the participating workers in a crew across the examined case images were computed independently. Next, the total number of unique safety hazards in the fatal-four and the non-fatal-four hazard categories – identified by the expert panel of the previous study and the workers of the current study – across each of the examined case images (i.e., by the crew) were independently computed. Finally, this information was used to calculate the relative performance of the participating workers when considering the fatal-four and the non-fatal four safety hazards as shown in Equation 1 and 2. Accordingly, the hazard recognition score in the fatal-four and the non-fatal-four hazard categories could potentially range from 0% where the workers in a crew do not recognize any of the safety hazards in the

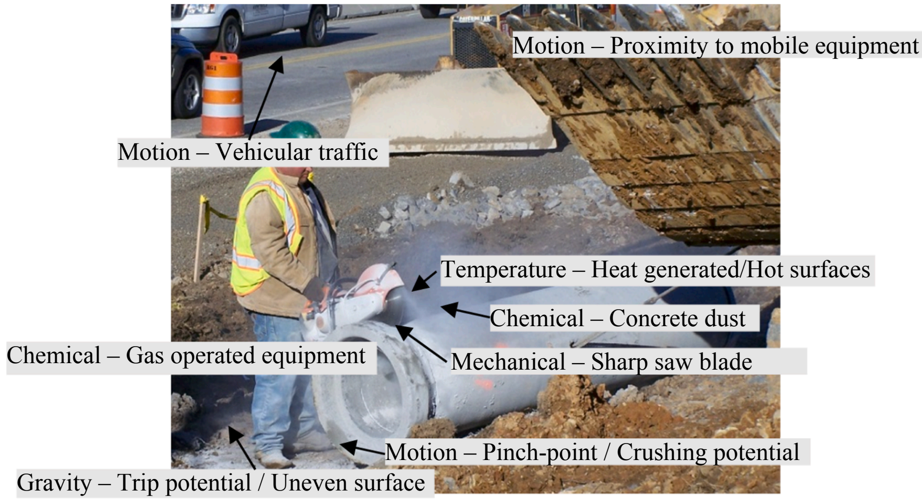

Fig. 1. Example of captured case image along with safety hazards.

Table 1
Examples of hazards in the fatal-four and the non-fatal-four categories.

Hazard Type	Examples
Fatal-Four	– Falls from ladders, scaffolds, and staging – Falls through floor openings or edges – Trip potential from material on the floor – Cave-in of soil into an excavation or trench – Pinch-point potential while handling material – Struck-by potential from proximate heavy equipment – Struck-by potential from falling objects – Contact with power lines or energized cables - Electric shock from power tools or other equipment
Non-fatal-Four	– Potential for burns from sparks generated during hot-work (e.g., welding) – Exposure to concrete dust, silica, or saw dust (i.e., inhalation potential) – Exposure to chemicals, gasses, and carcinogens – Awkward body posture, overexertion, and ergonomic hazards – Exposure to harmful fumes and vapors – Struck-against potential from protruding structural members – Laceration potential from striking sharp objects – Potential exposure to hot surfaces or substances

examined case images to 100% where the workers in a crew recognize all of the safety hazards in the examined case images.

$$HR_{Fatal-four} = \frac{HR_{Fatal-fourrecognized}}{HR_{Totalfatal-four}} \times 100 \quad (1)$$

$$HR_{Non-fatal-four} = \frac{HR_{Non-fatal-fourrecognized}}{HR_{Totalnon-fatal-four}} \times 100 \quad (2)$$

where $HR_{Fatal-four}$ is the percentage of the fatal-four safety hazards recognized by workers in a crew among the examined case images; $HR_{Non-fatal-four}$ is the percentage of the non-fatal-four safety hazards recognized by workers in a crew among the examined case images; $HR_{Fatal-fourrecognized}$ is the number of the fatal-four safety hazards recognized by workers in a crew among the examined case images, $HR_{Non-fatal-fourrecognized}$ is the number of the non-fatal-four safety hazards recognized by workers in a crew among the examined case images; $HR_{Totalfatal-four}$is the total number of the fatal-four safety hazards identified by the expert panel of the previous study and the workers of the current study in each of the case images examined by the workers in the crew; and $HR_{Non-fatal-fourrecognized}$ is the total number of the non-fatal-four safety hazards identified by the expert panel of the previous study and the workers of the current study in each of the case images examined by the workers in the crew.

6. Data analysis and results

The data pre-processing effort yielded a unique hazard recognition score for each of the participating crews (i.e., 57 nos.) in the fatal-four and the non-fatal-four hazard categories. The two scores corresponding to each of the participating crews were used to assess if any difference in performance existed when considering the fatal-four and the non-fatal-four hazard categories.

A two-sample paired test was selected to perform the data analysis (i.e., performance in fatal-four vs. non-fatal four hazard categories). To choose between the parametric and the nonparametric alternatives, the normality of the data in the two hazard categories were first independently tested using the skewness and kurtosis test. Although the kurtosis test found that the data in both the hazard categories were independently mesokurtic (i.e., met the assumption of normality), the skewness test suggested that the data in the non-fatal-four hazard category was slighly positively skewed. Therefore, the *Wilcoxon signed ranks test* was selected for the data analysis.

The descriptive analysis and the results of the *Wilcoxon signed ranks test* are presented in Table 2. As can be seen, on average, the participating workers (i.e., across the crews) recognized more than 56% (Median = 58.62%) of the safety hazards in the fatal-four hazard category. However, only roughly 18% (Median = 17.39%) of the non-fatal-four safety hazards were recognized by the participating workers across the crews. This difference in performance exceeded 38%. Not surprisingly, the associated *z*-statistic and *p*-value unequivocally suggested that the participating workers were much more proficient in recognizing the fatal-four safety hazards than the non-fatal-four safety hazards.

Table 2
Performance disparities in the fatal-four and the non-fatal-four hazard categories.

	Mean	Median	Std. Dev.	Minimum	Maximum	*z*-statistic	*p*-value
Fatal-Four-hazards	56.65%	58.62%	17.17%	29.17%	93.55%	6.567	< 0.01
Non-Fatal-four hazards	18.06%	17.39%	10.17%	3.45%	43.75%		

7. Implications of study findings

The research findings have important implications for the construction industry. First, the study suggests that workers are more proficient in recognizing the fatal-four safety hazards than the non-fatal-four safety hazards. This difference in performance may be at least partly attributable to the efforts of the Occupational Safety and Health Administration (OSHA) in pioneering and widely promoting the *Construction Focus Four* program. In addition, the difference in performance may also be partly attributable to the training and outreach efforts in the industry that has largely focused on the fatal-four safety hazards – whether led by employers, trade unions, or authorized trainers. These findings provide preliminary evidence of the value of such targeted and industry-wide interventions to promote occupational safety and health – although causal inferences cannot be made due to the non-experimental nature of the effort.

Second, although superior performance was found in the fatal-four hazard category, a large number of the fatal-four hazards still remained unrecognized in the current study. In fact, on average, more than 40% of the fatal-four safety hazards remained unrecognized in the hazard recognition activity. Although workers in certain crews recognized up to roughly 93% of the hazards in the fatal-four hazard category, more than 38% of the crews recognized less than 50% of these hazards. This finding suggests that the focus on the fatal-four safety hazards must be maintained in the industry given the significant room for better performance. In fact, the industry may need to seek additional efforts to improve the diffusion and dissemination of the *Construction Focus Four* program within the construction industry. Apart from industry-wide efforts, construction professionals may also want to actively adopt interventions to tackle unrecognized fatal-four safety hazards in their own workplaces. This has increasingly become important, particularly in nations such as Australia, where industrial manslaughter laws are becoming more relevant. These laws can hold construction employers, executives, and the site-leadership criminally responsible for fatal incidents where negligence or failure to adopt proactive injury prevention measures can be demonstrated (Dekker, 2011; Johnson, 2008; Lawrenson and Braithwaite, 2018).

Third, workers in the participating crews recognized less than 20% of the non-fatal-four safety hazards. This is quite problematic given that the non-fatal-four safety hazards can also impose significant safety risk and economic burden. For example, given that the fatal-four hazards are responsible for approximately 70% of all fatal injuries (i.e., > 9200 cases) as discussed earlier, the remaining 30% of the injuries – which translates to roughly 4000 fatalities between 2003 and 2015 – can be attributed to hazards that are not considered to fall under the fatal-four hazard category as defined by *OSHA's Focus Four* Program (Bureau of Labor Statistics, 2018). These hazards include ignition sources used in hot work such as welding, cutting and brazing operations; exposure to poisonous gasses, fumes, and vapors; and others. Moreover, evidence suggests that more than 20,000 injuries requiring days-away-from-work are reported annually due to factors such as overexertion and ergonomic safety hazards – which are not emphasized as part of the *Construction Focus Four program* (i.e., hazards in the non-fatal-four category) (BLS, 2018). These injuries are alone responsible for claims that exceed millions of dollars in the construction industry every year (Bhattacharya, 2014; Dunning et al., 2010; Wang et al., 2015). Likewise, a review of the injury reports maintained by the Bureau of Labor Statistics (2018) also suggests that a disproportionate number of safety injuries and illnesses can be attributed to the non-fatal-four hazard sources that cause burns, chemical exposure, lacerations, and others. Accordingly, it is imperative for the industry to devote additional attention to the non-fatal-four safety hazards to achieve desirable levels of safety performance.

Finally, given that the fatal-four safety hazards continue to account for the vast majority of the fatal incidents in the industry (Bureau of Labor Statistics, 2018), apart from efforts to improve hazard recognition in the fatal-four hazard category, efforts must also focus on addressing other issues including the underestimation of safety risk and the prevalence of risk-taking behavior in the presence of these hazards. While much research has been undertaken in these areas (e.g., Bohm and Harris, 2010; Choudhry and Fang, 2008; Man et al., 2017), there is a dearth of industry-level efforts undertaken to address these important challenges. The site leadership and the management must also develop a climate that fosters the transfer of learning from training experiences (e.g., training focusing on the fatal-four hazards) to the workplace (Namian et al., 2016). If the management does not visibly demonstrate their commitment to workplace safety or encourage workers to ignore workplace hazards to achieve higher production goals, the benefits of offering such training experiences can be negated. In such work environments, workers are more likely to indulge in risk-taking behaviors which can result in injuries and fatalities (Ale et al., 2008; Choudhry and Fang, 2008).

8. Study strengths and limitations

One of the primary strengths of the study in the paired-design adopted to effectively compare relative performance in the fatal-four and the non-fatal-four hazard categories. Because the performance of the workers in a crew were compared against their own performance in the two hazard categories, the approach effectively controlled for potential confounders such as differences in project types, locations, and experience of the crew members from affecting the research findings (Gravetter and Forzano, 2018). Apart from this primary strength, the within-group (i.e., workers in the same crew) statistical comparisons and the exclusion of potential confounders offered superior statistical power to make reliable comparisons and inferences (Murphy et al., 2014).

One of the primary limitations of the study is the use of case images that may not sufficiently capture the true dynamic nature of construction operations. However, past research has demonstrated a strong correlation between performance captured using construction case images and performance captured in real workplaces (Albert et al., 2013). While the adopted methods offered a standardized and safe approach to assess and compare performance, future efforts may focus on replicating the study efforts as workers observe active construction operations.

Finally, given the non-experimental nature of the present study, any causal inference regarding the effect of the *Construction Focus Four* program cannot be made. However, because a true experimental effort is largely not feasible given the wide dissemination of the *Construction Focus Four* program among the construction workforce, the results of the study provide preliminary evidence of the disparity in performance in the two hazard categories – which may at least partly be attributable to the *Construction Focus Four* program.

9. Conclusion

Countless efforts have been undertaken to promote hazard recognition and injury prevention in the construction industry (e.g., Jeelani et al., 2016; OSHA, 2011; Rozenfeld et al., 2010). Among others, the *Construction Focus Four* program has been widely promoted and disseminated by the Occupational Safety and Health Administration (OSHA, 2011). This program seeks to increase the attention devoted to the most common causes of fatal incidents – including falls, caught-in/between, struck-by, and electrocution hazards – to improve workplace safety performance. As a result, most training and outreach efforts offered in the industry by authorized trainers, employers, and trade unions have also largely focused on these safety hazards (Schoenfisch et al., 2017; Taylor, 2015).

Given this emphasis on the fatal-four safety hazards, the reported study focused on evaluating if any disparity in performance exists among workers when considering hazard recognition in the fatal-four and the non-fatal four hazard categories. The research objectives were accomplished by recruiting 287 workers representing 57 crews and engaging the workers in a hazard recognition activity.

The results of the study demonstrated that workers are more proficient in recognizing hazards in the fatal-four than the non-fatal-four hazard category. While causal inferences cannot be made given the non-experimental nature of the study, the disparity in performance may at least partly be attributeable to the widespread dissemination of the *Construction Focus Four* program.

However, the study also demonstrated that a large number of safety hazards continues to remain unrecognized in both the fatal-four and the non-fatal four hazard categories. Therefore, while the construction industry must continue their emphasis of hazards represented in the *Construction Focus Four* program, attention must also be devoted to the non-fatal-four safety hazards which are also associated with undesirable incidents and economic losses. The results of the study will be useful to policymakers, researchers, and industry leaders seeking to improve safety in the construction industry.

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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. In: Proc., Int. Conf. on Global Unity for Safety and Health in Construction, 363–371. Tsinghua University Press, Beijing.

Ale, B.J., Bellamy, L.J., Baksteen, H., Damen, M., Goossens, L.H., Hale, A.R., Mud, M., Oh, J., Papazoglou, I.A., Whiston, J., 2008. Accidents in the construction industry in the Netherlands: an analysis of accident reports using storybuilder. Reliab. Eng. Syst. Saf. 93 (10), 1523–1533.

Albert, A., Hallowell, M.R., Skaggs, M., Kleiner, B., 2017. Empirical measurement and improvement of hazard recognition skill. Saf. Sci. 93 (1), 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.

Albrechtsen, E., Solberg, I., Svensli, E., 2019. The application and benefits of job safety analysis. Saf. Sci. 113 (1), 425–437.

Bahn, S., 2013. Workplace hazard identification and management: the case of an underground mining operation. Saf. Sci. 57 (1), 129–137.

Bhandari, S., Hallowell, M.R., 2017. Emotional engagement in safety training: impact of naturalistic injury simulations on the emotional state of construction workers. J. Constr. Eng. Manage. 143 (12), 04017090.

Bhattacharya, A., 2014. Costs of occupational musculoskeletal disorders (MSDs) in the United States. Int. J. Ind. Ergonomics 44 (3), 448–454.

Bohm, J., 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). (2018). "Injuries, illnesses, and fatalities. https://www.bls.gov/iif/ (January, 2018).

Carter, G., Smith, S., 2006. Safety hazard identification on construction projects. J. Constr. Eng. Manage. 132 (2), 197–205.

Choudhry, R.M., Fang, D., 2008. Why operatives engage in unsafe work behavior: investigating factors on construction sites. Saf. Sci. 46 (4), 566–584.

Connecticut Department of Labor (CTDOL). (2009). The 10-hour OSHA construction safety and health course, program or training. https://www.ctdol.state.ct.us/wgwkstnd/InfoBull051109-ConstSafety.pdf (January, 2018).

Construction Industry Institute, 2014. "Strategies for Improving Hazard Recognition – RR293-11" https://www.construction-institute.org/topic-summaries/rt-201-300/strategies-for-hse-hazard-recognition (January, 2018).

Dekker, S., 2011. The criminalization of human error in aviation and healthcare: a review. Saf. Sci. 49 (2), 121–127.

Demirkesen, S., Arditi, D., 2015. Construction safety personnel's perceptions of safety training practices. Int. J. Project Manage. 33 (5), 1160–1169.

Dunning, K.K., Davis, K.G., Cook, C., Kotowski, S.E., Hamrick, C., Jewell, G., Lockey, J., 2010. Costs by industry and diagnosis among musculoskeletal claims in a state workers compensation system: 1999–2004. Am. J. Ind. Med. 53 (3), 276–284.

Fleming, M.A., 2009. Hazard recognition techniques. By Design, ASSE 9 (3), 15–18.

Gravetter, F.J., Forzano, L.B., 2018. Research Methods for the Behavioral Sciences. Cengage Learning, Belmont, CA.

Haslam, R.A., Hide, S.A., Gibb, A.G., Gyi, D.E., Pavitt, T., Atkinson, S., Duff, A., 2005. Contributing factors in construction accidents. Appl. Ergon. 36 (4), 401–415.

Health and Safety Executive. (2018). "Health and safety in the construction industry. http://www.hse.gov.uk/construction/ (October, 2018).

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., 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., Han, K., Azevedo, R., 2019. Are visual search patterns predictive of hazard recognition performance? empirical investigation using eye-tracking technology. J. Constr. Eng. Manage. 145 (1), 04018115.

Johnson, C.W., 2008. Ten contentions of corporate manslaughter legislation: public policy and the legal response to workplace accidents. Saf. Sci. 46 (3), 349–370.

Massachusetts Office of Labor and Workforce Development, 2008. An act relative to the health and safety on public construction projects. https://www.mass.gov/files/documents/2016/08/ru/osha10-advisory.pdf (January, 2018).

Lawrenson, A.J., Braithwaite, G.R., 2018. Regulation or criminalisation: what determines legal standards of safety culture in commercial aviation? Saf. Sci. 102, 251–262.

Li, H., Chan, G., Skitmore, M., 2012. Visualizing safety assessment by integrating the use of game technology. Autom. Constr. 22 (1), 498–505.

Man, S., Chan, A.H., Wong, H., 2017. Risk-taking behaviors of Hong Kong Construction workers – a thematic study. Saf. Sci. 98 (1), 25–36.

Murphy, K.R., Myors, B., Wolach, A., 2014. Statistical Power Analysis: A Simple and General Model for Traditional and Modern Hypothesis Tests. Routledge, New York.

Namian, M., Albert, A., Zuluaga, C.M., Behm, M., 2016. 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., 2016. 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), 2017. Commonly used statistics https://www.osha.gov/oshstats/commonstats.html (December, 2018).

Occupational Safety and Health Administration (OSHA), 2011. Outreach training program. https://www.osha.gov/dte/outreach/construction/focus_four/ (December, 2018).

Perlman, A., Sacks, R., Barak, R., 2014. Hazard recognition and risk perception in construction. Saf. Sci. 64 (1), 22–31.

Rozenfeld, O., Sacks, R., Rosenfeld, Y., Baum, H., 2010. Construction job safety analysis. Saf. Sci. 48 (4), 491–498.

Safe Work Australia, 2018. Work-related injury fatalities - Key WHS Statistics Australia 2018. https://www.safeworkaustralia.gov.au/book/work-related-injury-fatalities-key-whs-statistics-australia-2018 (October, 2018).

Schoenfisch, A.L., Lipscomb, H., Sinyai, C., Adams, D., 2017. Effectiveness of OSHA Outreach Training on Carpenters' work-related Injury Rates, Washington State 2000–2008. Am. J. Ind. Med. 60 (1), 45–57.

Taylor, E.L., 2015. Safety benefits of mandatory OSHA 10 h training. Saf. Sci. 77 (1), 66–71.

Wang, D., Dai, F., Ning, X., 2015. Risk assessment of work-related musculoskeletal disorders in construction: state-of-the-art review. J. Constr. Eng. Manage. 141 (6), 04015008.

Wilkins, J.R., 2011. Construction workers' perceptions of health and safety training programmes. Constr. Manage. Econ. 29 (10), 1017–1026.

Williams Jr, Q., Ochsner, M., Marshall, E., Kimmel, L., Martino, C., 2010. The impact of a peer-led participatory health and safety training program for latino day laborers in construction. J. Saf. Res. 41 (3), 253–261.