Employees' Safety Perceptions of Site Hazard and Accident Scenes

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Abstract: Despite the improvement of digital technologies (e.g., building information modeling) in enhancing construction safety management, human factor–related issues such as individual perceptions, attitudes, and behavior in safety cannot be downplayed. Existing studies have adopted safety management approaches that address human-factor issues by defining safety climate. From safety climate research, it is evident that certain demographics or subgroup factors can significantly affect safety management. This study aimed to investigate how individual perceptions of safety hazards would be affected by the given hazard's own feature (e.g., probability of occurrence). In addition, the study explored the impacts of subgroup demographic factors (e.g., job position and experience level) on safety perceptions. Eight commonly encountered site hazard/accident scenes were predefined according to their occurrence, severity, and visibility. A site survey approach was adopted to investigate how construction employees from different demographic subgroups rated the degree of danger of the eight predefined scenes. The follow-up statistical analysis revealed that (1) a hazard/accident scene with higher occurrence and lower severity caused a higher variation among employees' opinions in perceiving its degree of danger; (2) entry-level employees tended to evaluate hazards with a higher degree of danger; and (3) compared to early career employees and senior peers, the mid-career professionals tended to perceive a lower degree of danger of a given hazard/accident scene. This study contributed to the body of knowledge in construction safety by investigating the effects of the given hazard/accident's feature (e.g., occurrence) in employees' perceptions, as well as integrating different scenes of safety hazards in the subgroup analysis based on employees' job duties or work trades and their experience levels. Future research is also recommended to address individuals' safety perceptions and demographic factors in safety management. **DOI: 10.1061/(ASCE)CO.1943-7862.0001590.** *© 2018 American Society of Civil Engineers.*

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Introduction

Occurrence of occupational accidents is a major issue in the construction industry (Yılmaz and Kanıt 2018). Aiming to prevent site accidents caused by hazards, researchers in construction safety have often focused on exploring effective safety management programs (e.g., Chen and Jin 2012); building the framework and models of safety climate and culture (e.g., Choudhry et al. 2009; Li et al. 2017); and also predicting and enhancing safety performance (Fang et al. 2015; Xia et al. 2018). Besides these key research areas in construction safety, digital technologies in safety management have gained more applications in recent years (de Melo et al. 2017; Zou et al. 2017; Dong et al. 2018). A review of scholarly works within construction safety reveals that, despite the increasing applications of emerging technologies (e.g., building information modeling) in safety management, human factors still play the key role. Safety performance is highly related to safety culture and safety climate (Choudhry et al. 2009; Molenaar et al. 2009; Li et al. 2017; Martínez-Aires et al. 2018), which is reflected by individuals' perceptions of safety hazards (Chen and Jin 2015). Also, psychological effects have a significant impact on employees' safety behaviors, further affecting the overall safety performance (Wang et al. 2018).

Human factors in construction safety include demographic factors, or subgroup variations, which cannot be ignored in safety management. For example, migration workers face language barriers and communication difficulties (Hare et al. 2013). Other subgroup factors should also be considered when implementing safety training, education, or programs. Without proper training or education, individual perceptions toward hazards might be more subjective as perceptions could be affected by multiple factors (e.g., personal values) according to Slovic (1992). These individual factors in construction safety climate include employees' job position, duties, and work trades. Understanding the differences in how site hazards are perceived by employees with various individual factors is important in effective safety management (Hinze et al. 2013). Safety practices need multiparty commitment involving workers from different job duties or positions, such as site operatives, management personnel, owners, and so on, in order to create a safe work environment (Hinze et al. 2013). Therefore, the subgroup issues in construction safety must be continually explored in order to achieve a safe work environment.

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Some of the gaps in existing research of demographic factors within safety management have been identified as follows: (1) not many studies in safety hazards and accidents have incorporated the nature of these hazards or accidents based on their occurrence, severity, and ease of being noticed on-site; (2) insufficient research has been performed to investigate how the nature of these safety hazards/accidents would affect individuals' safety perceptions; and (3) limited studies have been conducted to explore how subgroup factors (e.g., trades and experience levels) affect safety perceptions of hazard/accident scenes.

Adopting a site questionnaire survey-based approach followed by statistical analysis, this study aimed to (1) categorize eight commonly encountered safety hazards/accidents according to historical safety data and pilot site investigation; (2) develop a valid site survey approach incorporating psychometric paradigm (Slovic 1992) and image-based scenes representing these hazards/accidents; (3) evaluate the overall perception of site employees toward the eight hazard/accident scenes; (4) conduct subgroup analysis of employees' perceptions according to whether or not they were in a management position; and (5) perform further subgroup analysis by dividing employees based on their job duties/trades, as well as their experience levels. This research contributes to the existing studies within human factors in construction safety by integrating the nature of hazards and accidents. Particularly, how the nature of the hazards/accidents affect individual perceptions is studied. The study also provides insights for researchers and practitioners in the field of construction safety management by shedding light on how individual employees' perceptions are affected by their job duties, work trades, and site experience. The current study leads to further research on tracking employees' safety perception and attitude changes following their career path, along with the exploration of effective safety management, which addresses individual differences in terms of career stages and trades.

Literature Review

Safety Hazard/Accidents

OSHA (2011) defined Focus 4 Hazards, which includes falls, electrocution, struck-by, and caught-in or caught-between. Among them, working at height (e.g., working with scaffolding) is one of the primary causes of construction accidents involving injuries or fatalities (Rubio-Romero et al. 2013). Different from postaccident investigation (e.g., Zhou et al. 2012; Kim et al. 2013), multiple studies (e.g., Goh and Chua 2009, 2010; Hallowell and Gambatese 2009; Mitropoulos et al. 2009; Mitropoulos and Namboodiri 2011; Fortunato et al. 2012; Gangolells et al. 2013) have focused on identifying hazards; measuring risks; and, more importantly, preventing unwanted incidents. To minimize risks associated with these hazards and accidents, it has been suggested that safety education, training, or formal safety programs should be enforced for all site participants, including management personnel and workers (Hallowell and Gambatese 2010; Zou and Zhang 2009; Chen and Jin 2012; Esmaeili and Hallowell 2012; Chen and Jin 2013).

Safety Perception and Safety Climate

Hazards or probabilities of risk are perceived by individuals in a somewhat subjective way (Slovic 1992). Workplace safety perception was identified by Chen and Jin (2013), together with safety awareness and attitudes, as well as management involvement (Li et al. 2017), to form part of safety climate. According to Cox and Flin (1998) and NORA (2008), safety climate focuses on workers' perception of the role of safety in the workplace and their attitudes toward safety. Safety climate could be divided into multilevel subclimates based on whether or not employees hold a management position (Grote and Kunzler 2000; Chen and Jin 2012) and even given the different management levels of employees (NORA 2008). Therefore, workers and their supervisors form different subgroup safety climates (Melia et al. 2008). Construction employees from different positions, through their own subgroup safety climate, might have varied safety perceptions, as indicated by Chen and Jin (2015).

Demographic and Subgroup Factors in Construction Safety Perceptions

Safety climate can be divided according to subgroup categories (Schein 1996) and they can be measured by employees' safety perceptions (Zohar 1980; Brown and Homes 1986; Dedobbeleer and Béland 1991; Chen and Jin 2015). Certain demographic factors and their impact on workers' perceptions toward construction site hazards have been studied extensively. For example, del Puerto et al. (2014) found that Latino workers in the US construction industry were more likely to believe that productivity and quality of work were more important than safety. The participants of the study tended to underestimate site dangers, and they had higher rates of injuries and fatalities (del Puerto et al. 2014). Other demographic factors such as workers' age; employer type (e.g., workers from general contractors or subcontractors); and workers from different trades were studied by Chen and Jin (2015), who concluded that older workers tended to have better safety attitudes and overall perceptions compared to their younger peers.

Methodology

The methodology adopted in this study consisted of a jobsite survey and follow-up statistical analysis.

Construction Site Survey

The psychometric paradigm was adopted in this study. According to Slovic (1992), the psychometric paradigm encompasses the theory that probabilistic risk estimated by individuals is subjective because they may be influenced by a wide range of psychological, social, institutional, and cultural factors. The paradigm assumes that, with appropriate survey instruments, these factors and their interrelationships can be quantified and modeled to measure the individuals' responses (Slovic 1992). The psychometric paradigm has been the most influential model in the field of risk, and the cognitive maps of hazards produced by the paradigm could explain how the various risks were perceived (Siegrist et al. 2005). In this study, hazards displayed by eight different scene images were incorporated in the questionnaire-based site survey. Individuals working on construction sites were studied for their perceptions toward the eight safety hazard/accident scenes on-site. Fig. 1 displays these eight images.

These eight safety hazard/accident scenes (i.e., from H1 to H8) illustrated in Fig. 1 were prepared according to three different categories related to their occurrence (i.e., frequent to occasional); severity (i.e., highly dangerous to less dangerous); and visibility (i.e., easily noticed to not obvious on-site).

A pilot study on four local jobsites from Jiangsu, China, was conducted during April and May of 2016. Scenes representing different safety hazards/accidents were shown to site employees in the study. Their feedback was collected to ensure that these image-based scenes with Chinese text descriptions were reasonable, easily understood, and valid to study employees' perceptions toward the

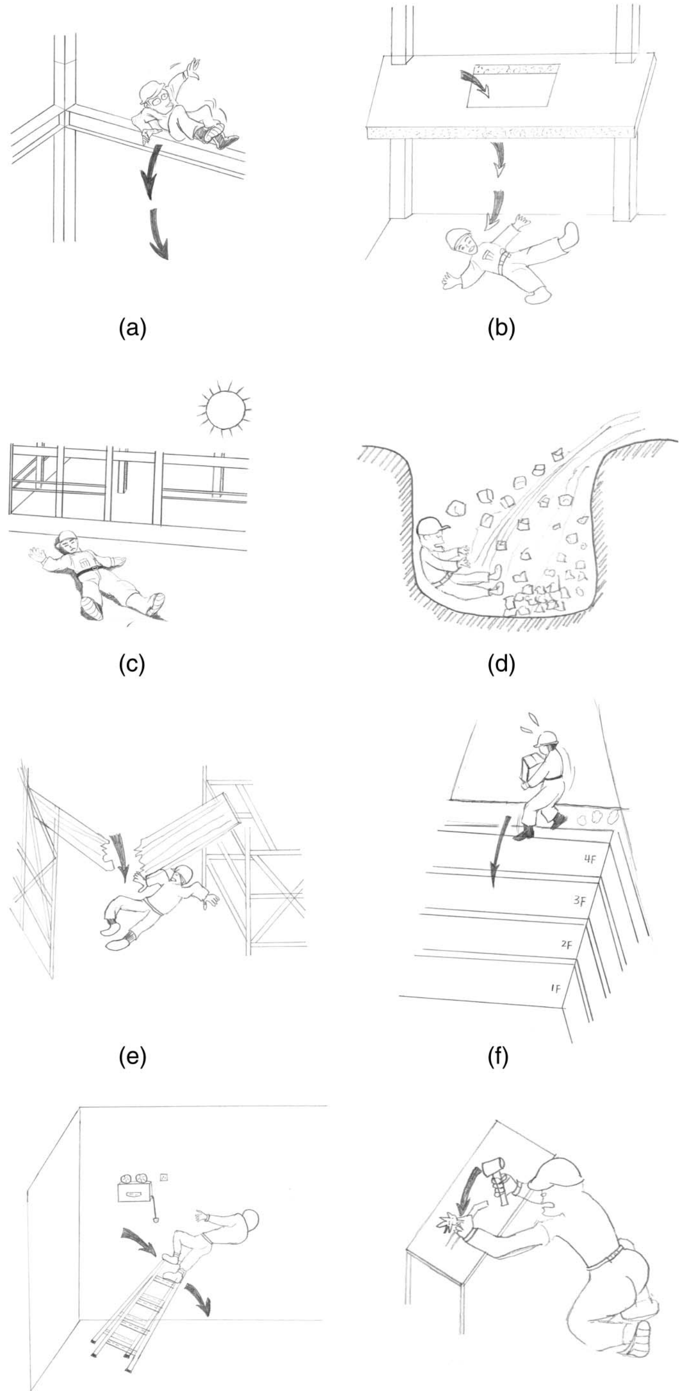

Fig. 1. Eight site hazard/accident scenes in the questionnaire survey: (a) Hazard 1 (H1), loss of body balance and falling from working at height; (b) Hazard 2 (H2), fall from uncovered holes; (c) Hazard 3 (H3), sunburn and heat exhaustion when working in a high temperature; (d) Hazard 4 (H4), collapse of foundation pits; (e) Hazard 5 (H5), failure of temporary working platform; (f) Hazard 6 (H6), fall from scaffolding when working on the fifth floor; (g) Hazard 7 (H7), fall from unstable ladder; and (h) Hazard 8 (H8), struck-by causing hand injury. (Scenes of safety hazards/accidents adapted from Zhang 2009.)

given safety hazards. During the pilot study, employees were also asked to evaluate the visibility of each given scenario. For some scenarios or scenes (e.g., suffocation, choking, and poisoning), site employees either had varied evaluation of their visibilities or claimed little knowledge of them. These types of hazard/accident scenes were then not adopted in the later formal questionnaire survey. Following the pilot study, the eight scenes shown in Fig. 1 were selected for the formal questionnaire survey. The formal site visit and questionnaire survey was conducted in eastern China (specifically, the Shanghai and Jiangsu regions) from May to August in 2016. A total of nine different jobsites were visited for the questionnaire survey. Administering questionnaire surveys to each jobsite was coordinated between the research team and the site manager. All potential survey participants were fully informed of the purpose of the study. The participants were also informed of the anonymity and confidentiality of all data collected. They were also made aware of their right to participate (or decline) on their own accord. Site employees were asked to rank the degree of danger for all eight scenes displayed in Fig. 1 using Likert-scale scores, with 1 being *not dangerous at all regarding the given safety hazard*, 2 meaning *not dangerous*, 3 indicating a neutral attitude, 4 inferring *dangerous*, and 5 referring to *very dangerous*. Survey participants on jobsites were asked about their job roles or trades and experience level measured by years of experience in construction. First impressions were critical to judgments of threats and lasted long in the later stage (Holmes 2016). In this study, survey participants were guided to select the Likert-scale option based on their first impression of each given scene.

Statistical Analysis

Besides the basic statistical values, including the mean and standard deviation used to measure the perceptions of the overall survey population, a Cronbach's alpha analysis (Cronbach 1951; Tavakol and Dennick 2011) was also implemented to test the internal consistency of the survey population's perceptions of the eight scenes. Ranging from 0 to 1, a high Cronbach's alpha value indicates a higher degree of consistency of site individuals' perceptions among the eight scenes. It was stated that an alpha value between 0.70 and 0.95 suggested an acceptable internal consistency among Likert-scale items (Nunnally and Bernstein 1994; Bland and Altman 1997; DeVellis 2003). A higher Cronbach's alpha value in this survey inferred that a site employee who chose a Likert-scale score for one safety hazard/accident scene was more likely to select similar numerical options for other scenes.

The whole sample was then divided into subgroups according to different demographic factors, including job position, duties or work trades, and experience levels. The survey population was initially categorized into management personnel and workers. The two main categories were then further divided into more subgroups according to their management duties (i.e., safety- or non-safety-specialized management) and work trades (e.g., electrical, carpentry, plumbing, and so on). The whole sample could also be divided into subgroups with different experience levels according to their years of work in the construction industry. Several statistical methods were applied in the subgroup analysis, including the two-sample *t*-test and one-way analysis of variance (ANOVA), both of which are parametric methods.

Parametric methods (e.g., ANOVA) have been adopted in previous studies in the field of construction engineering and management (e.g., Aksorn and Hadikusumo 2008; Meliá et al. 2008; Tam 2009; Jin et al. 2017), specifically for Likert-scale items. The superior performance of parametric methods over a nonparametric approach was stated by Sullivan and Artino (2013) in terms of the robustness. Existing studies such as those of Carifio and Perla (2008) and Norman (2010) have shown that parametric methods are robust for survey samples that are either small-sized or not normally distributed. This robustness was further proved by other

Table 1. Safety data analysis

Type of accidents	Number of accidents	Fatality	Severe injuries	Percentage	Severity (fatality or severe injury rate per accident)
Falling from working at height	1,013	1,081	37	53	1.1
Structural collapse	237	454	90	12	2.3
Struck-by	277	289	8	15	1.07
Electrocution	48	50	0	3	1.04
Injuries by manual handling or lifting	166	245	34	9	1.68
Injuries by heavy equipment	109	120	17	6	1.26
Hit by site vehicles	27	30	0	1	1.11
Suffocation, choking, and poisoning	20	37	3	1	2
Total	1,897	—	—	100	—

Source: Data from Division of Safety Supervision, Department of Housing and Urban-Rural Construction (2017).

studies such as those of Tam (2009) and Pearson (1931), where non-normally-distributed data were involved. Compared to these earlier studies, the overall sample size of 155 and subgroup sizes in this research project were considered adequate.

The two-sample t-test was applied to compare the mean value between management personnel and workers for each Likert-scale item. Based on the null hypothesis that management personnel and workers had consistent perceptions toward the given safety hazard/accident scene, a t value and the corresponding p value would be computed to test the hypothesis. Setting the level of significance at 5%, a p value lower than 0.05 would reject the null hypothesis and suggest that there is a significant difference between management personnel and workers in their perceptions. Similar to the two-sample t-test, ANOVA also aimed to test whether subgroups had similar perceptions toward the given safety hazard/accident scene. Based on the similar null hypothesis and the same level of significance, an F value and the corresponding p value were computed to test the null hypothesis. A p value lower than 0.05 indicates that there are different views among subgroups categorized by job duties/trades or experience levels toward the safety hazard/accident scene. Following ANOVA, post-hoc tests were performed to confirm where the differences occurred between subgroups. Two main post-hoc methods were adopted in the statistical analysis, namely, Tukey simultaneous and Fisher individual, both of which were based on 95% confidence intervals.

Results and Findings

Following the safety accidents reported from 2014 to 2017 in China, safety data in terms of number of accidents, fatalities, severe injuries, percentages accounting for total accidents, and severity measurement are summarized in Table 1.

The eight scenes presented in Fig. 1 can be tagged using different combinations of hazard/accident categories according to either Table 1 or the site collected from the pilot study. Table 1 provides the statistical evaluation of occurrence and severity of certain accidents. For example, falling from working at height is a frequent accident; accidents caused by structural collapse (e.g., pit collapse) are highly dangerous due to their high fatality or severe injury rate per accident; struck-by an object may be considered an accident type with lower severity. The visibility of an accident can be determined by feedback collected from the pilot study. For example, H5 shown in Fig. 1 is considered a hazard that is not easily detected due to the suddenness of the working platform failure. In comparison, H7 is perceived as a hazard that can be easily noticed. Table 2 lists the combination of categories assigned to each of the eight scenes.

Table 2. Combination of categorization of eight safety hazard/accident scenes on-site

Hazard	Occurrence	Severity	Visibility
H1	Lower frequency	High severity	Easily noticed
H2	High frequency	High severity	Not easily noticed
H3	High frequency	Low severity	Not easily noticed
H4	Lower frequency	High severity	Not easily noticed
H5	Lower frequency	Low severity	Not easily noticed
H6	High frequency	High severity	Easily noticed
H7	Lower frequency	Low severity	Easily noticed
H8	High frequency	Low severity	Easily noticed

Following the definition of these eight site hazard/accident scenes shown in Fig. 1 and categorizations described in Table 2, the following sections present the findings from the site questionnaire survey in terms of the background information of the survey sample, overall sample analysis in perceptions, analysis of subsamples divided into management personnel and workers, subgroup analysis of survey participants among different trades or job duties, and the subsample analysis according to their experience levels.

Background Information of the Survey Sample

A total of 155 valid responses from 176 questionnaires received from the jobsite survey were used in the sample data analysis. Among the 155 responses, 95 of them were management staff specializing in safety or other management positions (e.g., crew foremen), and the other 60 participants were site workers. The percentages of respondents crossing different positions and trades are shown in Fig. 2. Also displayed in Fig. 2 is the distribution of respondents falling into different categories of experience levels based on their years of working on-site.

It can be seen from Fig. 2 that, demographically, the whole survey sample can be divided into nine different categories in terms of their job duties (safety management or other types of management) or work trades (e.g., scaffolding). Six different subgroups can be identified according to their years of experience in the construction industry.

Overall Sample Analysis

The average and standard deviation of survey respondents' perceptions toward the eight scenes are compared and summarized in Fig. 3.

According to Fig. 3, H1 (i.e., occasional, easily noticed, and highly severe scene) was perceived as most dangerous, followed by H6 (i.e., frequent, easily noticed, and highly severe scene);

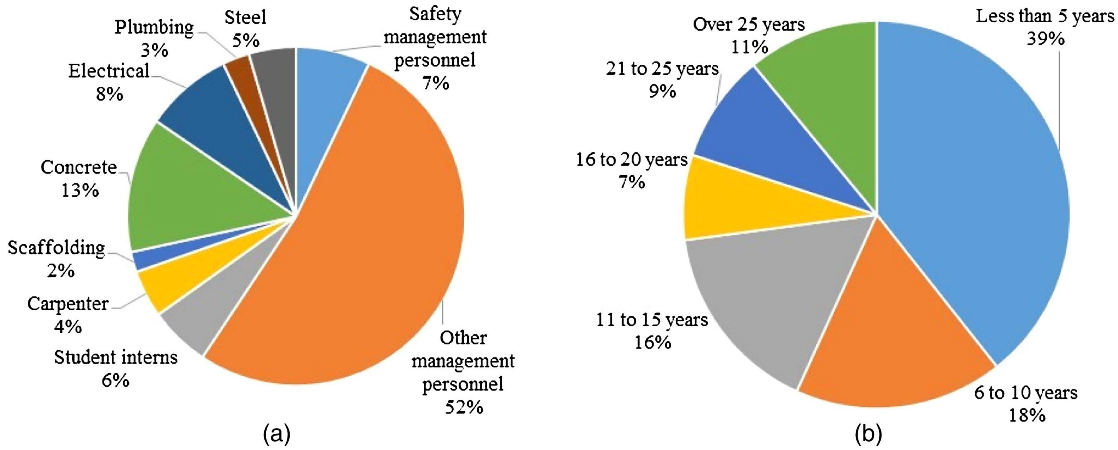

Fig. 2. Background information of survey respondents: (a) percentage of survey participants by position or trade; and (b) percentage of respondents by different experience levels.

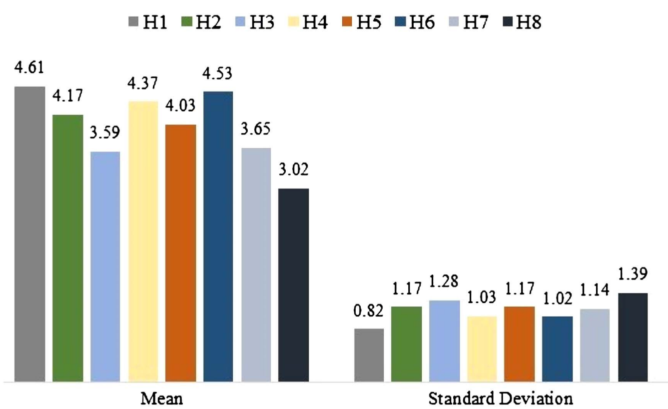

Fig. 3. Basic statistics of the overall survey sample's perceptions toward the given safety hazard.

H4 (i.e., occasional, not easily noticed, and highly severe scene); and then H2 (i.e., frequent, not easily noticed, and highly severe scene). All of these four scenes belonging to the category of being highly severe were found with higher mean scores compared to the remaining four hazards, which fell into the category of lower severity. It is indicated that respondents generally made reasonable judgements on the degree of danger based on the severity levels of the eight scenes. The standard deviation analysis conveyed the information that the highest variation of perceptions was related to H3 and H8, both of which belonged to the category of higher frequency and lower severity. It can be inferred that construction employees tend to have a more varied view on more frequently occurring but less severe accidents. Other hazards with more differing views among respondents (i.e., H2, H5, and H7) also fall into the category of either lower severity or higher frequency.

The Cronbach's alpha analysis was performed to test the internal consistency of the whole survey population's responses to the eight scenes. Table 3 summarizes the test results.

Table 3. Internal consistency analysis of the overall survey sample's perceptions toward the eight safety scenes

Hazard	Item-total correlation	Cronbach's alpha
H1	0.6515	0.8895
H2	0.8049	0.8726
H3	0.7424	0.8788
H4	0.7207	0.8819
H5	0.7829	0.8748
H6	0.5554	0.8953
H7	0.6895	0.8839
H8	0.5700	0.8990

Note: Overall Cronbach's alpha = 0.8977.

The overall Cronbach's alpha value of 0.8977 suggests a high internal consistency of survey participants' perceptions toward the eight scenes. It was indicated that a survey participant who selected a Likert-scale score for one scene was likely to choose similar scores for other scenes. The item-total correlation in Table 3 measures the correlation between the given scene and the remaining seven scenes. H2, with a correlation value of more than 0.800, suggests that respondents' perceptions toward the scene in the categories of high severity, high occurrence, and low visibility have a highly positive correlation with the overall perception of the remaining scenes. In contrast, respondents' perceptions toward H6 and H8 have an item-total correlation of less than 0.600, indicating that respondents' perceptions toward these two hazards representing frequent and easily noticed scenes tend to differ from the remaining scenes. These two scenes receiving differing views from the survey sample can be found from their higher individual Cronbach's alpha values compared to those of the remaining scenes listed in Table 3. H8 with its individual Cronbach's alpha value (i.e., 0.8990) higher than the overall value at 0.8977 infers that it contradicts the overall consistency of the survey sample's perceptions toward these hazard/accident scenes.

Subgroup Analysis between Management Personnel and Workers

The whole survey population was divided into two main subgroups, namely, the management personnel and workers. The former subgroup contained survey participants of either safety managers or other management personnel (e.g., project manager, assistant project manager, and supervisor leading a certain trade of workers, and so on). The latter were workers working on certain trades defined in Fig. 2. Using the two-sample t-test, these two types of site employees' perceptions toward each scene and the overall view are summarized in Table 4.

Three significant differences in the perceptions toward safety scenes between management personnel and workers can be found

Table 4. Two-sample t-test results for subgroup analysis between management personnel and workers

	Management personnel		Trade workers		Statistical comparison	
Safety hazards	Mean	Standard deviation	Mean	Standard deviation	t value	p value
H1	4.726	0.750	4.433	0.909	2.09	0.039[a]
H2	4.330	1.030	3.920	1.340	2.02	0.046[a]
H3	3.650	1.110	3.500	1.510	0.68	0.501
H4	4.450	1.030	4.250	1.020	1.20	0.232
H5	4.110	1.090	3.900	1.300	1.02	0.310
H6	4.580	1.020	4.450	1.030	0.76	0.447
H7	3.800	1.070	3.420	1.230	1.99	0.049[a]
H8	3.120	1.340	2.870	1.460	1.07	0.287
Average	4.095	0.803	3.842	0.947	1.72	0.089

[a]p value lower than 0.05 indicates the significant difference between management personnel and workers.

according to Table 4. Management personnel perceived more danger in the following three hazards in comparison to workers' views: (1) H1, representing the highly severe, occasional, and easily noticed scene; (2) the scene falling into the category of high severity, high frequency, and not being easily noticed; and (3) the scene that is lower in severity but more easily noticed and occasionally occurring. The higher degree of danger perceived by management personnel than workers can be explained by the job nature. According to Feng et al. (2017), management personnel usually have a higher education level and have received more systematic safety training, which leads to a higher sense of safety accountability. Because of the job's nature and duties, management personnel tend to focus on finishing the construction project with zero accidents, while workers are more likely to risk by finishing their work ahead of schedule (Feng et al. 2017).

Subgroup Analysis of Survey Participants among Different Trades or Duties

The management personnel and workers were then further divided according to management duties and work trades according to Fig. 2. Based on ANOVA results, the subgroup analysis is displayed in Table 5.

Two significant differences related to H2 and H7 can be found according to Table 5. Site employees among the nine subgroups had varied views on the scene of falling from uncovered openings, which belongs to the category of high severity, high frequency, and not being easily noticed. Seven out of the nine subgroups all perceived H2 as a highly dangerous scene, with the average score above 4.000, except for carpenters and electrical workers. Management personnel, who might have a more comprehensive coverage of safety knowledge in terms of different types of hazards/accidents, also believed that H2 was highly dangerous. A further post-hoc analysis using both Tukey simultaneous and Fisher individual methods was performed to identify the significant differences of perception between a pair of subgroups. Fig. 4 showcases an example of the Tukey test.

By considering both the Tukey and Fisher methods, it was found that the main difference in the subgroups' perceptions toward H2 came from electrical workers, who perceived H2 with a significantly lower degree of danger. Specifically, according to the Tukey test, other management staff and electrical workers held more significantly different views on H2.

These nine subgroups also had varied views on H7 (i.e., falling from an unstable ladder), which is generally considered as a scene that has a lower degree of danger and lower occurrence and is easily noticed. The majority of subgroups also considered it less dangerous, with their average Likert-score between 3.000 and 4.000, or even below 3.000 among carpenters. The post-hoc analysis using Fisher's individual method revealed significant differences between student interns/other management staff and workers from the concrete and carpentry trades. It could be assumed that carpenters generally had a higher chance of working with ladders and feeling more comfortable with them at work. Therefore, carpenters tended to be more likely to perceive a lower degree of danger of working with ladders. On the other hand, student interns had a much more serious view on H7, with the average score at 4.333. Student interns' overestimation of the danger of working with ladders could be due to the fact that they did not have much site experience compared to the professionals who have been working for years. As inexperienced student interns, they might have received more

Table 5. Subgroup analysis of survey samples divided by job duties or trades

Trades or job duties	Statistical measurement	H1	H2	H3	H4	H5	H6	H7	H8	Average
Safety management personnel ($N = 11$)	Mean	4.929	4.455	3.545	5.000	4.364	4.818	3.455	2.636	4.159
	Standard deviation	0.267	0.934	1.293	0.000	0.924	0.603	1.368	1.286	0.657
Other management personnel ($N = 81$)	Mean	4.691	4.310	3.667	4.381	4.071	4.548	3.845	3.179	4.086
	Standard deviation	0.791	1.041	1.090	1.074	1.106	1.057	1.024	1.346	0.824
Student intern ($N = 9$)	Mean	4.667	4.500	4.167	5.000	5.000	5.000	4.333	3.667	4.542
	Standard deviation	0.516	1.225	1.329	0.000	0.000	0.000	0.816	1.633	0.600
Carpenter ($N = 7$)	Mean	4.571	3.571	3.286	3.857	3.286	4.143	2.571	2.714	3.500
	Standard deviation	0.535	0.976	1.704	1.215	1.496	1.464	0.976	1.496	0.820
Scaffolding workers ($N = 3$)	Mean	4.000	4.000	3.667	4.333	4.333	3.330	4.000	4.667	4.042
	Standard deviation	1.000	1.000	1.155	1.155	1.155	2.080	1.000	0.577	1.003
Concrete workers ($N = 20$)	Mean	4.500	4.000	3.500	4.100	3.750	4.550	3.150	2.850	3.800
	Standard deviation	1.000	1.338	1.504	0.852	1.293	0.686	1.137	1.309	0.820
Electrical workers ($N = 13$)	Mean	4.000	3.154	3.000	4.000	3.462	4.231	3.538	2.077	3.433
	Standard deviation	1.155	1.772	1.871	1.291	1.391	1.301	1.450	1.320	1.235
Plumbing workers ($N = 4$)	Mean	5.000	4.750	3.250	4.750	5.000	5.000	3.750	3.000	4.313
	Standard deviation	0.000	0.500	0.957	0.500	0.000	0.000	1.258	1.633	0.415
Steel workers ($N = 7$)	Mean	4.571	4.429	4.143	4.571	4.000	4.571	3.571	3.000	4.107
	Standard deviation	0.787	0.787	1.215	1.134	1.291	0.787	1.272	1.528	0.897
F value		1.70	2.07	0.79	1.55	1.98	1.17	2.03	1.84	1.70
p value		0.103	0.042[a]	0.610	0.145	0.053	0.321	0.046[a]	0.074	0.103

[a]p value lower than 0.05 indicates significant differences among subgroups toward the given scene.

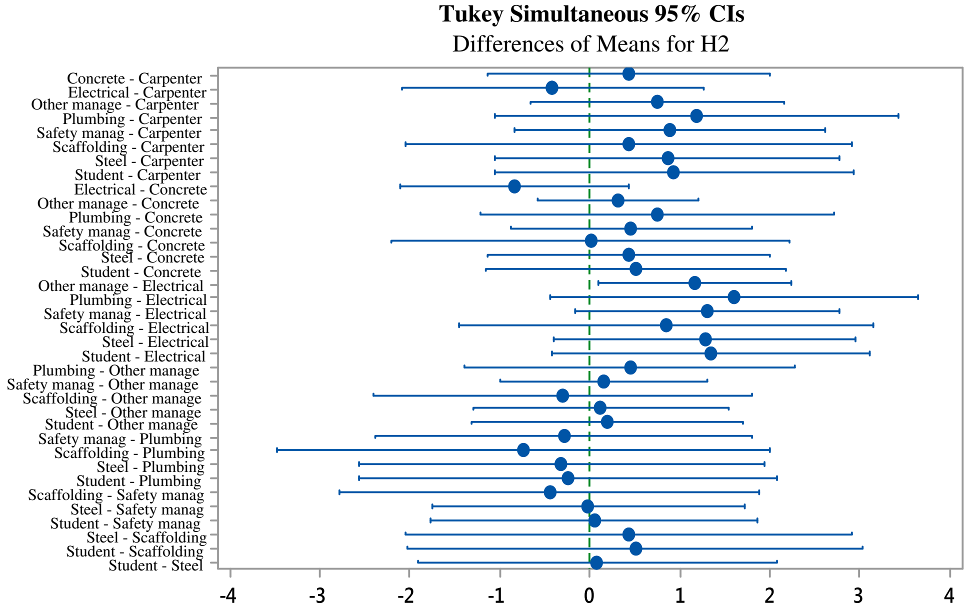

Fig. 4. Tukey test to identify the differences between subgroups for H2. If an interval does not contain zero, the corresponding means are significantly different.

school education emphasizing the importance of site safety and hence tending to preassume that most hazards/accidents are very serious. Furthermore, it can be found from Table 5 that student interns had the highest average Likert-scale score assigned to the eight scenes, inferring that they were prone to consider most hazards with a higher degree of danger. In contrast, it was analyzed by Han et al. (2017) that workers tended to be used to the site hazard after being exposed to more site accidents and gaining more experience, and, as result, they are prone to perceive a lower degree of danger of hazards.

Effect of Experience Levels in Safety Perceptions

Following the finding that student interns had more serious concerns over site safety hazard/accident scenes in the previous section, the effect of experience levels in employees' perceptions toward hazards/accidents was further studied. The whole sample was divided into categories according to respondents' years of construction experience (Fig. 2). The subgroup analysis is summarized in Table 6 based on the ANOVA method.

Table 6 suggests that subgroups from different experience levels had significantly different views on H8 (i.e., struck-by an object). H8 was considered the hazard with the lowest degree of danger by the survey population according to Fig. 3, especially by subgroups with construction experience from 6 to 15 years and 21 to 25 years. Both the Tukey and Fisher test results indicated that senior employees (i.e., over 25 years' experience) and newer employees (i.e., below 5 years' experience) perceived H8 with a significantly higher degree of danger compared to their peers with 11–20 years' experience.

The average Likert-scale scores of the eight scenes were also found with significant variations among the six subgroups, although only one (i.e., H8) out of the eight given scenes was found with significantly different perceptions among survey participants. It is indicated from Table 6 that newer employees with less than 5 years' experience and their peers with more than 25 years' experience tended to be more cautious on safety hazard/accident scenes, with both average Likert-scale scores over 4.000. In contrast, those in their mid-career (i.e., with site experience between 6 and 15 years) were more likely to be risk-takers by underestimating

Table 6. Subgroup analysis of survey samples divided according to site experience

Years of experience	Statistical measurement	H1	H2	H3	H4	H5	H6	H7	H8	Average
Below 5 years ($N = 61$)	Mean	4.738	4.279	3.754	4.459	4.164	4.623	3.869	3.311	4.150
	Standard deviation	0.630	0.985	1.059	1.010	1.019	0.897	0.922	1.272	0.693
6–10 years ($N = 27$)	Mean	4.667	4.148	3.370	4.333	3.815	4.556	3.296	2.370	3.819
	Standard deviation	0.734	1.231	1.275	0.920	1.241	1.050	1.353	1.245	0.838
11–15 years ($N = 25$)	Mean	4.440	3.800	3.080	4.080	3.760	4.080	3.240	2.400	3.610
	Standard deviation	0.917	1.384	1.470	1.222	1.332	1.498	1.300	1.472	1.030
16–20 years ($N = 11$)	Mean	4.727	4.727	4.000	4.636	4.182	4.909	3.818	3.364	4.295
	Standard deviation	0.647	0.647	1.265	0.674	1.328	0.302	1.250	1.362	0.793
21–25 years ($N = 14$)	Mean	4.143	3.714	3.571	4.286	3.714	4.287	3.571	2.929	3.777
	Standard deviation	1.406	1.590	1.604	1.326	1.383	1.139	1.158	1.492	1.190
Above 25 years ($N = 17$)	Mean	4.647	4.353	3.882	4.471	4.412	4.765	4.000	3.765	4.287
	Standard deviation	0.862	1.115	1.317	0.874	1.004	0.437	1.000	1.200	0.775
F value		1.50	1.64	1.59	0.69	1.21	1.76	2.06	**4.15**	**2.54**
p value		0.192	0.153	0.166	0.632	0.306	0.124	0.074	**0.001**[a]	**0.031**[a]

Note: The bold values indicate significant differences of perceptions among subgroups towards the given hazard.
[a]p value lower than 0.05 indicates significant differences among subgroups toward the given scene.

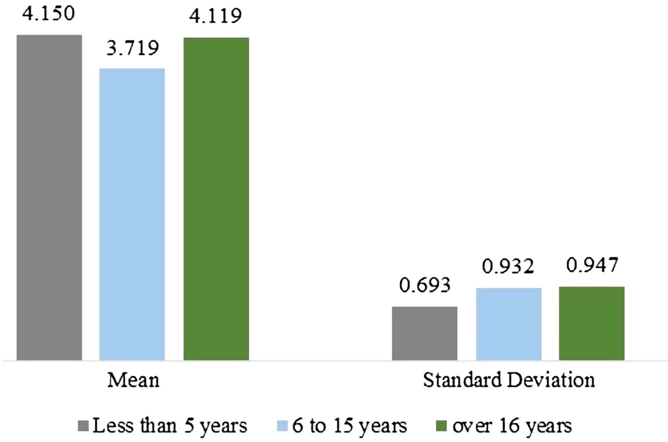

Fig. 5. Comparison of average perceptions among three redefined subgroups.

the danger of hazard/accident scenes. The post-hoc analyses further revealed that the major difference with average perceptions came from the mid-career employees, especially those with 11 to 15 years' experience who were more likely to perceive a lower degree of danger of site hazards.

Employees from the various subgroups (i.e., site experience less than 5 years, between 6 and 15 years, between 16 and 20 years, and more than 25 years) all had lower standard deviations, indicating that they tended to have higher consistency of perceiving safety hazards. Employees with experience between 21 and 25 years had the highest variation of perceptions of the scenes, i.e., according to the standard deviation value of 1.190. Based on the perception variations among these six subgroups, they can be further reduced into three main categories, namely, early career construction employees with less than 5 years of experience, mid-career professionals with site experience between 6 and 15 years, and senior professionals with more than 16 years' experience. The mean values and standard deviations of Likert-scale-based average perceptions toward all the given scenes are displayed in Fig. 5.

The ANOVA test was also performed to analyze the overall perceptions toward the eight scenes among the three different subgroups shown in Fig. 5. All lower standard deviations below 1.000 indicate that survey participants generally held somewhat consistent perceptions within their own subgroups. With the F value at 4.200 and the corresponding p value at 0.017, it is inferred that there were significantly different overall perceptions toward the eight scenes among the three redefined subgroups. Fig. 6 shows the post-hoc test using Fisher's individual method.

Fig. 6 indicates that the main difference among subgroups of different work experience levels came from the mid-career employees. Early career professionals had similar views with their senior peers. Both subgroups had significantly more serious views on the given scenes compared to the mid-career professionals. It can be further assumed that though early career employees had consistent perceptions with their senior peers, the rationale behind that could be different. The former subgroup, due to their lesser site experience, tended to be more careful of their safety behavior, aiming either to prevent injuries or to gain incentives of working safely. The latter group, with more years spent in the industry, was likely to have experienced or witnessed more accidents/incidents, prone to behave more maturely, and less likely to take risks to complete job duties as they might think that they were relatively closer to retirement. Therefore, safety is more important to them compared to rushing to complete work in a riskier way. In comparison, mid-career professionals, with years of site experience but more professional time left compared to their senior peers, tended to perceive a lower degree of danger of hazards or accidents. They might be more ambitious in being more productive and were more likely to take risks in order to complete site jobs.

Discussions

Based on the theory of the psychometric paradigm and the site questionnaire survey-related research method, construction site employees' perceptions toward eight predefined hazard/accident scenes were studied in this research. Guided by Slovic (1992), researchers believed that construction employees' opinions on certain safety scenes were related to their own psychological, social, and

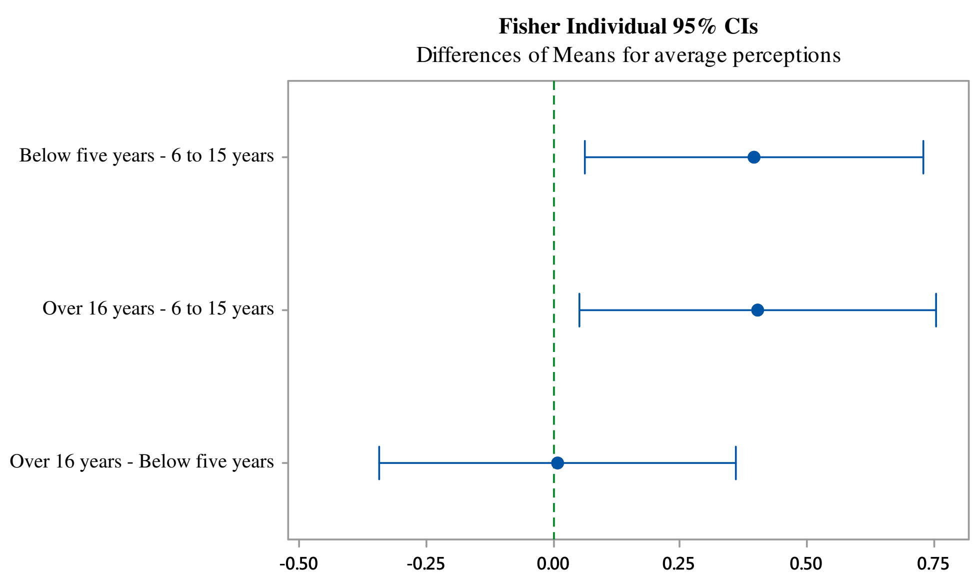

Fig. 6. Fisher individual analysis to identify the main differences between redefined subgroup overall perception toward the eight safety hazard scenes. If an interval does not contain zero, the corresponding means are significantly different.

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cultural factors. Previous studies have focused on subgroup factors' effects in safety perceptions that formed part of the safety climate in construction, such as employees' profession or position (Zohar 1980), worker's trades (Chen and Jin 2015), and employees' experience levels (Chen and Jin 2013). In this study, hypotheses were established regarding whether individuals' perceptions were affected by these subgroup factors. Eight different types of safety hazard/accident scenes were prepared for the site survey to construction employees. These eight scenes belonged to different combinations of safety categories according to their severity, occurrence, and ease of being noticed. Using safety accident data summarized from the Division of Safety Supervision (2017) in China and the feedback from the pilot site study, categories of these eight scenes were determined. For instance, falling from working at height was determined as the scene with higher occurrence compared to pit collapse.

The overall sample analysis revealed that survey respondents generally had reasonable judgment on the degree of danger between more severe scenes (e.g., loss of balance and falling) and less severe scenes (e.g., hand injury due to being struck). Generally, safety hazards/accidents with a lower occurrence are perceived with a higher degree of danger by site employees compared to those with a higher occurrence. The higher occurrence and lower severity of a safety hazard/accident leads to more varied views among construction employees. In contrast, scenes corresponding to hazards/accidents with low occurrence but high severity more easily arouse the concern of construction employees. It is inferred that the nature of a safety scene in terms of occurrence affects an individual's subjective judgment of its degree of danger. Individuals' perceptions toward a certain scene are more consistent when the accident occurs less frequently, especially when it is also highly severe. The internal consistency analysis of the eight scenes demonstrates that the overall perceptions of individuals are highly correlated to the perception toward the scene representing high severity and high occurrence, but low visibility. It is also worth noticing that individuals tend to have different views on frequently occurring and highly visible hazards compared to how they perceive the overall site safety hazards.

The subgroup analysis suggests that, compared to workers, management personnel tend to perceive a few hazard/accident scenes with higher severities. That could be explained by the more education and more comprehensive safety training received by management personnel, who may also have a higher sense of safety accountability. By further dividing the whole survey sample into nine subgroups according to their job duties or work trades, the subgroup analysis revealed that trades or duties affect employees' perceptions toward certain site safety hazard/accident scenes. For example, carpenters and electrical workers perceive falling from uncovered floor holes as much less dangerous compared to other trades (e.g., plumbing). Student interns, with more college education but less site experience, tend to perceive higher severities in these scenes (e.g., falling from unstable ladders). In contrast, full-time professionals, after experiencing more site accidents and gaining more practice, are more likely to perceive a lower degree of danger of the same hazard/accident scene.

This study also divided the whole survey sample into subgroups based on employees' levels of experience measured by number of years spent in construction. Initially, the whole sample was categorized into six different subgroups. Following the initial subsample analysis using ANOVA, three subgroups (i.e., employees in their early career and mid-career, as well as senior employees) were redefined. Mid-career construction employees (i.e., with site experience between 6 and 15 years) are more likely to perceive a lower degree of danger of safety hazards/accidents compared to their early career and senior peers. This could be due to the characteristics of mid-career professionals. Being more experienced in site jobs compared to their entry-level starters and being more ambitious compared to their senior peers, mid-career employees tend to be more optimistic about completing jobs without being injured by perceiving safety hazards/accidents with lower degrees of danger. As perceptions have a direct effect on human behaviors (Dijksterhuis and Bargh 2001), mid-career professionals' underestimation of safety hazard/accident scenes could lead to unsafe behaviors. Therefore, it is suggested that safety orientation, training, and education should be emphasized not only for entry-level or early career employees, but also for employees in their mid-career phase. Effective approaches to reinforce the safety awareness and accountability of mid-career employees can be further studied in the future, such as using a holistic approach incorporating case studies of safety accidents belonging to the category of high severity and low occurrence, designing for safety in the preconstruction stage (Weinstein et al. 2005), adopting digital technologies for automated construction safety checking (Lu et al. 2015), and so on.

Conclusion

Incorporating the theory of the psychometric paradigm, this research aimed to evaluate construction site employees' safety perceptions of eight designed hazard/accident scenes. The study firstly adopted the whole survey sample in evaluating site employees' perceptions toward these eight scenes and later divided the survey sample into subgroups according to their job position, trades, and experience levels. Through the site survey, followed by multiple statistical analysis methods in this research, several findings and corresponding recommendations guiding future research are provided below:

- Construction employees have more varied views on hazard/accident scenes with higher occurrence and lower severity, and their opinions of the scenes with lower occurrence but higher severity tend to be more consistent. It was indicated that the occurrence of a hazard/accident scene affects employees' perceptions of the given hazard/accident. Furthermore, it was suggested that using a scene with low occurrence, high severity, and low visibility can be more effective in safety training and education.
- Scenes easily noticed and more frequently occurring are more likely to be perceived differently by construction employees than other types of scenes. Evaluation of employees' safety perception should also consider the nature of the hazard or accident.
- Student interns tend to view safety hazards/accidents with a higher degree of danger. After entering the job market and gaining more experience in construction safety, they may become used to witnessing and handling site safety issues. As a result, they are more likely to perceive a lower degree of danger of safety hazards. Future research could target tracking the career path of entry-level construction employees to study how their safety attitudes, safety perceptions, and safety behaviors change as they develop professionally. Corresponding strategies addressing the continuous safety training and education following employees' career path can be proposed.
- Safety education and training should consider subgroup differences between management personnel and workers, as well as workers from different trades. It is suggested that while safety policies should be consistently implemented to all site employees, demographic or subgroup factors should also be addressed, especially to those subgroups that tend to perceive a lower degree of danger of safety hazards.

- The issue regarding the safety perceptions of mid-career site employees was also addressed in this study. As mid-career professionals might perceive a lower degree of danger of safety hazards (possibly leading to unsafe behaviors), it is recommended that safety awareness and safety education be reinforced to employees in their mid-careers.

This research focused on human factors in construction safety management in two main aspects. Firstly, this study investigated the variation of construction employees' perceptions caused by the features of the hazard/accident scene (i.e., occurrence, severity, and visibility). Secondly, it explored the effects of demographic factors (i.e., job positions, duties or trades, and experience levels) in the safety perceptions of site hazard/accident scenes with different levels of severity, occurrence, and ease of noticing. By adopting influencing factors involving both hazards' features and construction employees' demographic subgroups, this study contributed to the body of knowledge in the construction safety climate by investigating how employees' perceptions toward hazards would be affected by these factors. Though the site investigation was conducted in China, the findings could be applied to a wider context, across different regions or countries. Future work will continue exploring more demographic factors in safety management, such as employees' educational background, gender, age, and so on. Further work in the field of construction safety management, as suggested, can focus on exploring effective safety training methods targeting non-early-career construction employees, especially those in their mid-career stage.

Data Availability Statement

Data generated or analyzed during the study are available from the corresponding author by request. Information about the *Journal*'s data-sharing policy can be found here: http://ascelibrary.org/doi/10.1061/(ASCE)CO.1943-7862.0001263.

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