Defining and Testing a Safety Cognition Framework Incorporating Safety Hazard Perception

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7   **Defining and Testing a Safety Cognition Framework Incorporating Safety Hazard**

8   **Perception**

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11   **Abstract**

12   There has been insufficient research focusing on checking the reliability of construction

13   employees' hazard perceptions by comparing them to the empirical safety data. There have

14   also been limited studies focusing on how site employees' perceptions could be affected by

15   multiple external and internal influence factors such as worker's experience levels. This study

16   firstly developed a theoretical safety cognitionframework addressing site employees'

17   perceptions towards hazards. Empirical data from China's construction safety report were

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18 collected to quantify and define eight common safety hazard or accident scenes. Following

19 the empirical data analysis, these eight hazards were ranked in terms of their occurrence,

20 severity, and controllability. Based on a total of 201 valid questionnaires received in China's

21 construction industry, site employees' perceptions towards these eight hazards were analyzed,

22 ranked, and compared to the empirical ranking. Major findings included but were not limited

23 to: (1) hazards with higher occurrence tended to be perceived with less deviation; (2) more

24 experienced employees were more likely to apply their prior scenarios and safety knowledge

25 in perceiving given hazards and further to hold more reliable perceptions; (3) prior scenarios

26 might also create biased perceptions in the case of electrocution. The current study

27 contributed to the knowledge in safety climate by proposing and testing the framework

28 incorporating safety perceptions. Continued from this study, further research could be

29 performed to explore more subgroup factors' effects on workers' perceptions, as well as how

30 to design an effective safety training program to correct their biased perceptions.

31 **Keywords:**Safety cognition; Safety hazards; Safety perception; Construction Safety; Safety

32 climate

33 **Introduction**

34   Construction is considered one of the most risky industries in terms of safety performance

35 (Lingard and Rowlinson, 2015). The employment in the construction industry accounted only

36 for 4% of all workforce on nonfarm payrolls, but accounted for over 17% of fatal injuries

37 crossing all industries in the U.S. (U.S. Bureau of Labor Statistics., 2013a; 2013b). About 2.9%

38 of construction workers in UK are injured each year, and the rate is significantly higher than

39 the average value across all industries (Swingewood and Burd, 2018). Organizations (e.g.,

40 main contractors) should lead and promote the culture that supports safety and health, which

41 involves a risk-based thinking as well as the participation and consultation of workers

42 (Swingewood and Burd, 2018). Construction risks could come from site hazards, and workers'

43 risk perception towards certain safety hazards is not separated from safety culture. OSHA

44 (2011) defined four types of most commonly occurring accidents, namely fall, struck-by,

45 caught-in-between, and electrocution. There have been multiple studies (e.g., Guo et al., 2017;

46 Asilian-Mahabadi et al., 2018; Wang et al., 2018) on workers' safety behavior and safety

47 education on preventing these accidents/incidents from happening. Based on these existing

48 studies, more research could be performed in investigating the perceptions of workers and

49 other site employees' towards these commonly encountering hazards or accidents.

50 Specifically, more studiesare needed to investigate how the feature of the hazard or accident

51 (e.g., its frequency of occurrence) would affect site employees' safety hazard perception, as

52 well as how the site employees' subgroup factors (e.g., site experience level) would impact

53 safety perceptions (Han et al., 2019a).

54 Li et al. (2017) identified workers' self-perception of safety (e.g., workers' believes in

55 controlling their own safety onsite) as one of the main dimensions of safety climate. However,

56 there has been limited assessment and evaluation of workers' safety perceptions against the

57 empirical data to evaluate the reliability of their perceptions and whether certain training is

58 needed to modify that perception, especially towards commonly encountered site hazards

59 (e.g., fall).Safety perceptions have direct effects on workers' safety behavior. It should also

60 be noticed that construction employees' perceptions could be affected by several potential

61 external and internalinfluence factors, such as the building trades and job positions (Chen and

62 Jin, 2015), the local cultural context (Zou and Zhang, 2009), and demographic factors (Han et

63 al., 2019b). There is a need to understand the perceptions of site employees in order to

64 provide proper safety training or education programs with the goal of promoting a positive

65 safety climate on-site. Understanding how employees' perceptions could be affected by these

66 defined influence factors also enables safety educators to decide how to correct biased safety

67 perceptions.

68   Besides the need to study employees' safety perceptions against empirical data, there is

69   also a need to continue the study of subgroup factors linked to safety cognition which would

70   affect employees' perceptions and behaviors in construction safety (Jin et al., 2019). So far

71   there has been limited research further linking employees' safety perceptions towards site

72   hazards to their internal safety cognition pattern.Aiming to address these research gaps of

73   construction employees' safety perceptions towards site hazards, this study was designed

74   with these objectives: (1) to define a theoretical cognition framework incorporating the

75   external and internal factors that affect site employees' safety perceptions within the context

76   of safety culture; (2) to identify the typical safety hazards based on empirical safety accident

77   data; (3) to investigate site employees' safety hazard perceptions by comparing them to the

78   empirical data; (4) to further discuss how the feature of these hazards would affect employees'

79   safety perceptions; and (5) to discuss how the safety cognition patterns, as internal indicators,

80   would affect site employees' hazard perception. This research adopted a comprehensive

81   research methodology, including theoretical cognition framework establishment,

82   questionnaire survey approach to site employees in China's construction industry, statistical

83   analysis involving ranking method, and finally an in-depth qualitative discussion. The study

84   contributed to the body of knowledge in safety perception of construction employees by

85   addressing the reliability of hazard perceptions, as well as investigating how employees'

86   perceptions were affected by the hazard feature as well as their own safety cognition. Safety

87   hazard perception in this study was measured in terms of the given hazard's occurrence,

88   severity, and controllability.

89   **Literature review**

90   *Safety climate and safety culture*

91   The workplace safety perception is part of safety climate, which reflects site employees'

92   perception regarding the role of safety (Cox and Cox, 1991). Li et al. (2017) studied the

93 safety climate in the level of construction team which consisted of workers and foremen.

94 Workers' attitudes to hazards, risks and possibility of injury, capability to identify safety

95 hazards, as well as belief in their own ability to control personal safety onsite were listed by

96 Li et al. (2017) as key indicators for safety climate within construction teams. Safety climate

97 is included in the safety culture, which involves both implicit and explicit social cognitions

98 (Marquardt et al., 2012). Both safety climate and safety culture impact safety performance

99 (Choudhry et al., 2009; Newaz et al., 2018). Both of them are multi-level depending on site

100 employees' job positions (Grote and Kunzler, 2000; Chen and Jin, 2012). Chen and Jin (2015)

101 further identified on construction sites' safety climate from employees with and without

102 management roles, as well as workers from various building trades (e.g., mechanical).

103   Safety climate can be measured by site employees' safety perceptions (Zohar, 1980;

104 Brown and Homes, 1986). Employees' safety perceptions are formed by their own patterns of

105 safety cognition when exposed to hazards (Liu, 2018). Implicit memory influences and has a

106 significant role in unconscious cognition when making judgements (Jacoby and Witherspoon,

107 1982; Jacoby et al., 1992). Cognition directly affects human behavior (Liao et al., 2017).

108 Safety cognition for construction personnel is critical to improve safety performance in

109 construction (Chen et al., 2011).

110   *Subgroup factors among constructionsite employees*

111   Studies on construction safety climate have largely focused on workers' safety perception

112 (Melia et al., 2008), attitudes (Chen and Jin, 2013), safety behaviour (Jin and Chen, 2013),

113 and further how they were linked to safety performance (Molenaar et al., 2009). As safety

114 climate could be divided according to subgroup categories (Schein, 1996), more studies have

115 focused on subgroup or demographic factors of workers and their safety issues. For example,

116 Korkmaz and Park (2018) found that foreign workers did not have the same safety beliefs or

117 commitments towards safety management compared to domestic workers in Korea. It was

118 further suggested that an improved safety education was needed to improve foreign workers'

119 safety perceptions (Korkmaz and Park, 2018). Similarly, del Puerto et al. (2013) identified

120 that Hispanic workers in the U.S. construction industry tended to hold the belief that

121 productivity and work quality is more important than safety. Besides these demographic

122 factors, other internal factors also had some significant influences on site employees' safety

123 perceptions. For example, Han et al. (2019a) found that construction site employees in their

124 mid-career (i.e., with more than five years' site experience) were more likely to

125 underestimate the severity of site hazards compared to their entry-level peers. It was further

126 indicated of the importance of proper safety training in correcting site employees' biased

127 perceptions.

128 **Theoretical background**

129   This empirical study of construction employees' safety perceptions towards given site

130 hazard/scenarios started from the defined theoretical cognition framework illustrated in Fig.1.

131 The framework was set in the context of safety culture which was defined byMarquardt et al.

132 (2012) with three different layers of social cognition. As indicated by Marquardt et al. (2012),

133 explicit attitudes towards certain safety hazards could be deemed as part of safety climate.

134   \<Insert Fig.1 here\>

135   The core structure of safety cognition within safety culture model shown in Fig.1 is based

136 on multiple theories proposed from earlier research including Schein (1992), Guyldenmund

137 (2000), Rowatt et al. (2005), Parker et al.(2006), and Marquardt et al. (2012). Other previous

138 studies are also reflected in Fig.1. For example, appraisal of work hazards forms part of

139 safety climate (Mohamed, 2002; Saunders et al., 2017). According to Fig.1, multiple factors

140 affect workers' individual perceptions towards certain given site hazard scenarios, including

141 both internal and external factors. These inter-related factors are illustrated in Fig.1. For

142 example, prior similar scenarios of safety accidents, either from workers own witness or

143 secondary experience from peers would form their own safety knowledge. Safety knowledge,

144 prior scenarios, and workers' own basic assumptions (Marquardt et al., 2012) work as

145 internal factors that stimulate their perceptions towards certain site hazards (e.g., fall from

146 working at height). Other internal factors include demographic issues such as workers' age

147 and gender (Han et al., 2019b), as well as workers' years of working experience (Han et al.,

148 2019a). External factors such as features of hazards (i.e., occurrence, severity, and

149 controllability) described by Han et al. (2019a) could also affect individual perceptions. Fig.1

150 also reveals the role of safety training in correcting employees' biased or deviated hazard

151 perceptions. The process of how workers perceive site hazards can be described in Fig.2.

152   <Insert Fig.2 here>

153   Both Fig.1 and Fig.2 indicate that prior scenarios in construction safety would affect

154 workers' judgement or perceptions when exposed to certain site hazards. The prior scenarios

155 form workers' implicit cognition in safety culture, which then affects workers' basic

156 assumption towards site hazards. Prior scenarios also form workers' knowledge in safety

157 cognition. There were three main types of safety cognition defined by Liu (2018), namely

158 safety cognition based on prior scenarios, safety knowledge, and basic assumption as shown

159 in Fig.3.

160   <Insert Fig.3 here>

161   Based on Fig.1, Fig.2, and Fig.3, the main research tasks performed in this study are

162 illustrated in Fig.4.

163   <Insert Fig.4 here>

164   In this research, construction employees' perceptions towards certain given safety hazards

165 are compared to the empirical data to explore the deviation between site employees'

166 perceptions and the reported safety accident data. The three main safety cognition patterns

167 illustrated in Fig.3 are discussed of their effects in workers' perceptions towards certain given

168 hazards. The effect of employees' experience level on safety perceptions is also investigated

169 leading to further discussions of how safety training could be implemented effectively to

170 employees by considering these internal influence factors (e.g., site experience).Fig.4 also

171 indicates that employees' experience is reflected through their cognition pattern.

172 **Methodology**

173 Following the theoretical background and research tasks illustrated from Fig.1 to Fig.4, the

174 overall methodology of this study is demonstrated in Fig.5.

175 <Insert Fig.5 here>

176 According to Fig.5, this study was based on a four-step approach, namely collecting the

177 empirical data of safety accidents/hazards, site investigation through questionnaire survey to

178 construction employees, follow-up statistical analysis, and the in-depth discussion of safety

179 cognition illustrated in Fig.2 and Fig.3. The statistical methods included both descriptive way

180 (e.g., ranking method) and inferential method to allow comparisons of: (1) the empirical

181 safety data and employees' perception-based data related to safety accidents, and (2) the

182 comparison of perceptions between more experienced employees and their less experienced

183 peers towards given safety accident/hazard scenes. More detailed descriptions of research

184 steps can be found below.

185 *Empirical safety accident data*

186 According to Fig.1, the consistency between workers' perceptions and empirical data

187 regarding safety hazards would allow the further decisions in safety management on whether

188 training is needed to correct biased perceptions. Researchers in this study started from the

189 empirical data of eight most commonly encountered accidents in China's construction sites

190 released by Division of Safety Supervision (2017). Researchers ranked the eight different

191 types of hazards according to their occurrence, severity, and risk controllability as shown in

192 Table 1. Moredetails of the eight defined hazards are provided in Table 1.

193   <Insert Table 1 here>

194   Each accident in Table 1 is calculated of its percentage accounting for the total number of

195   accidents reported from 2014 to 2017 in Chinese construction industry. The rankings inter of

196   occurrence and severity among the eight hazards were based on their percentages and fatality

197   rate. The risk score (RS) of each accident is then measured in this study by multiplying the

198   percentage by the fatality rate (Wu et al., 2019). For example, the RS of falling from working

199   at height would be 0.567. The risk controllability ranking of each corresponding hazard

200   leading to the accident is determined in the reverse order of its RS (i.e. a hazard with higher

201   RS would be ranked lower in its controllability).

202   Following the data analysis of the eight most typical accidents, two main research

203   questions were proposed: (1) were there deviations or inconsistencies regarding the

204   occurrence, severity, and controllability for the eight hazard/accident scenes between site

205   employees' perceptions and the empirical data summarized in Table 1? (2) would site

206   employees' perceptions be affected by their internal factors such as work experience level as

207   indicated in Fig.1? The follow-up research adopted site investigationto construction

208   employees' in China.

209   *Questionnaire survey*

210   According to Marquardt et al. (2012), employees' attitudes could be measured by multi-

211   item self-report scales within safety culture. A questionnaire survey, as a typical approach in

212   the study of safety climate and safety culture (Choudhry et al., 2007; Chen and Jin, 2015),

213   was adopted as the research method to collect hazard perceptions from site employees. The

214   questionnaire survey was comprised of two main parts. The first part focused on site

215   employee's demographic information, including their site position (e.g., crew foremen or

216   workers), their building trades (e.g., plumbing), and their years of site experience. The second

217   part was a Likert-scale question consisting of the eight hazard or accident scenes defined in

218   Table 1. Following the questionnaire formatting procedure described in the study of Han et al.

219   (2019a) by considering the lower education level completed by most Chinese construction

220   workers, corresponding hazard or accident scenes as shown in Fig.6 were provided to

221   potential survey participants from construction employees.

222   <Insert Fig.6 here>

223   For each picture shown in Fig.6, potential survey participants would be asked to rank its

224   occurrence,   severity,   and   controllability.Construability   was   defined   as   employees'

225   perceptions of their own capability of holding the given site hazard under control. They were

226   asked the standard questions which were designed to be easily understood by site employees.

227   These three questions were asked for each given hazard/accident scene in the Likert-scale

228   format, including: (1) "how often do you think this hazard happens on-site?"(1: least often; 2:

229   not very often; 3: neutral; 4: quite often; 5: most often); (2) "how dangerous do you think if

230   this hazard happens on-site?" (1: not dangerous at all; 2: not very dangerous; 3: neutral; 4:

231   quite dangerous; 5: very dangerous); and(3) "how confident do you perceive yourself on

232   holding this hazard under control on-site?" (1: I am totally unable to control it; 2: I am less

233   likely to hold it under my control; 3: neutral; 4: I have some level of confidence to hold it in

234   control; 5: I am very capable of controlling it);

235   The initial questionnaire underwent the pilot study by being peer reviewed by two site

236   mangers and crew members in Zhenjiang China during August 2017. The questionnaire was

237   then finalized in September 2017 to ensure that questions were all clear to potential

238   participants. The formal sampling of survey participants from construction sites followed the

239   un-biased sampling procedure suggested by Li et al. (2018).During October and December

240   2017, the finalized questionnaire was sent through construction site visits in south-eastern

241   part of China (e.g., Jiangsu Province and Shanghai Metropolitan regions). Construction

242   employees recruited for the questionnaire survey during site visits were first explained of the

243   research purpose and the anonymous nature of the survey by the research team consisting of

244   research students and academic staff. Coordinated by site managers, they were also given the

245   guide that they could either decline the survey request or accept to start the survey by

246   providing the answers to their best knowledge. They were also made aware that they could

247   drop the survey in the middle of filling the questionnaire.

248   *Statistical analysisand in-depth qualitative discussion*

249   A follow-up statistical analysis was conducted to analyze site employees' perceptions

250   towards the occurrence, severity, and controllability of each given hazard scene. Besides

251   mean and standard deviation as the prescriptive measurements, statistical methods applied in

252   the survey data analysis also included Relative Importance Index (*RII*), Cronbach's Alpha

253   analysis (Cronbach, 1951), and two-sample *t*-test, the latter two of which were considered

254   inferential statistical methods according to Web Center for Social Research Methods (2006).

255   The RIIwas used to rank the eight hazard scenes in terms of either occurrence, severity, or

256   controllability. It was calculated following the same equation suggested by Tam (2009) and

257   Eadie et al. (2013). Ranging from 0 to 1, a higher RII value would indicate a higher ranking

258   or a higher degree of significance of the given hazard scene.

259   Cronbach's Alpha, an internal consistency measurement proposed by (Cronbach, 1951),

260   was adopted in this research to analyze site employees' perceptions among the eight hazard

261   scenes. The Cronbach's Alpha value ranges from 0 to 1, and a higher value indicates that a

262   site employee who selects one Liker-scale score to one hazard scene would be more likely to

263   assign a similar score to another scene. It was suggested by Nunnally and Bernstein (1994) as

264   well as Bland and Altman (1997) that a Cronbach's Alpha value between 0.70 and 0.95

265   would be acceptable. Besides the overall Cronbach's Alpha value, there was an individual

266   value corresponding to each hazard scene. An individual Cronbach's Alpha value lower than

267   the overall one indicates that the given hazard scene contributes to the internal consistency.

268   Otherwise, a higher individual Cronbach's Alpha value than the overall value means that site

269   employees tended to held a different perception towards this given hazard/accident scene as

270   they would perceive other hazard scenes. There is also an item-total correlation

271   corresponding to each individual Cronbach's Alpha value, measuring the correlation between

272   survey participants' perceptions towards this given hazard scene and their perceptions

273   towards the remaining hazards.

274   The overall site employees sample was then divided into two subsamples between those

275   having less than five years' site experience and the other with more than five-year

276   experience.The rationale of defining five years' site experience as the cut-off point for

277   subgroup comparison was based on the earlier study by Han et al. (2019a) investigating

278   construction site employees' perceptions towards the danger of common site hazards. It was

279   discovered that employees with less than five years' experience tended to perceive a higher

280   degree of danger compared to their peers in the mid-career stages. The five-year threshold

281   was also confirmed during the pilot study, asconstruction management personnel agreed that

282   site employees with more than five years' experience could be considered as the subgroup of

283   "being more experienced".The two-sample t-test was adopted as the parametric method to

284   study the effect of site experience on employees' safety perception towards the given hazard

285   scene. The superior robustness of parametric methods over non-parametric approach was

286   demonstrated by Sullivan and Artino (2013).Other studies such as Carifio and Perla (2008)

287   and Norman (2010) showed that parametric methods are robust for small-sized or non-

288   normally distributed survey samples. The two sample t-test in this study was based on the 5%

289   level of significance, and the null hypothesis that site experience below or above five years

290   did not have significant effects on employees' perceptions towards the given hazard or

291   accident scene. A p value would be computed corresponding to the t value towards each

292   hazard scene. A p value lower than 0.05 would decline the null hypothesis and suggest the

293   alternative hypothesis that employees held significantly different perceptions towards the

294   given hazard scene.

295   Since employees' perceptions towards each hazard were further categorized as occurrence,

296   severity, and controllability, the ranking deviation for each hazard between employees'

297   perception and the empirical ranking from Table 1 would be calculated and compared in

298   order to identify which hazards cause more deviations. Further qualitative discussions were

299   provided to discuss the possible causes of the deviation of employees' perceptions from the

300   empirical data, leading to suggestions to minimize employee's perception bias through

301   effective safety training.

302   Similar to the survey sample in Li et al. (2018), construction teams consisting of crew

303   leader and workers were the main survey population. By the end of December 2017, a total of

304   *201* valid responses were collected from totally *290* questionnaires completed through jobsite

305   survey. Among the *201* responses, *85%* were workers from multiple building trades including

306   steel and concrete. The remaining *15%* were foremen or other site personnel with certain

307   management roles. Around *60%* of survey participants had over five years of site experience.

308   The detailed sample attributes are summarized in Table 2.

309   <Insert Table 2 here>

310   **Results**

311   Site employees' perceptions towards the occurrence, severity, and risk controllability of

312   each of the eight hazards were statistically analyzedand compared to the empirical data

313   according to Division of Safety Supervision (2017).

314   *Statistical analysis of site employees' perceptions towards hazards' occurrence*

315   Following the statistical methods described in Section 4, site employees' perceptions

316   towards the eight hazards were analyzed in terms of occurrence as shown in Tables 3. The

mean value and standard deviation in Table 3 were computed based on the five-point Likert-scale.

<center><Insert Table 3 here></center>

The Cronbach's Alpha value over 0.8800 indicated a fairly excellentinternal consistency among the eight hazards. However, the individual value of H2 related to fall from working at height higher than the overall Cronbach's Alpha value indicated that survey participants from the overall sample tended to perceive H2 differently as they would perceive the occurrence of other hazards. Fall has been identified in the construction industry worldwide (e.g., OSHA, 2011; Zhang et al., 2015) as most frequently encountered safety hazard.The statistical results showed the consistency in light of the fall hazard occurrence between employees' perceptions and the empirical data in Table 1. It was also found that fall (i.e., H2) ranked top among the eight hazard scenes, with the lowest item-total correlation coefficient. The overall survey population was then divided into two sub-samples according to their site experience level (i.e., below or above five-year site experience). Table 4 summarizes the two-sample t-test results.

<center><Insert Table 4 here></center>

According to Table 4, all the eight hazards received significantly different perceptions between less-experienced and more experienced employees in terms of the hazard occurrence. It is seen in Table 4 that those with more than five years' site experience perceived all the eight hazards with higher occurrence. Nevertheless, the two subsamples identified the same three top-ranked hazards (i.e., fall, struck-by, and injuries caused by heavy equipment) with highest occurrence. Among the top-ranked three hazards, two of them (i.e., fall and struck-by) were consistent with the empirical ranking in Table 1. Fig.7 further compares the rankings in terms of occurrence to each hazard scene among the empirical data, the overall sample, subsample with those having more than five-year experience, and subsample with less than five years' experience. Except fall and struck-by which received more consistent perceptions

342   from subsamples, other hazards were perceived more differently, either between subsamples,

343   or between the empirical data and employee perceptions.

344   <Insert Fig.7 here>

345   Employees with more than five-year site experience tended to have less deviated

346   perceptions from the empirical data. For example, they held generally reliable perception of

347   viewing structural collapse as one of the frequently occurring accidents, while the less

348   experienced employees tended to significantly underestimate the occurrence of structural

349   collapse. Other hazards perceived by less experienced employees with significant deviations

350   included H7 related to site vehicles and H8 related to suffocation or poising.

351   *Statistical analysis of site employees' perceptions towards hazards' severity*

352   For the same eight defined hazards or accident scenes, the same statistical methods were

353   applied. The overall Cronbach's Alpha value at 0.8620 displayed in Table 5 indicated an

354   excellent internal consistency.

355   <Insert Table 5 here>

356   The individual Cronbach's Alpha value for H1 indicated that employees' perceptions

357   towards structural collapse tended to differ as they would perceive other hazards.

358   Electrocution was ranked as the most severe hazard, while hit by site vehicles were perceived

359   least severe. The subgroup difference is summarized in Table 6, based on the two-sample *t*-

360   test.

361   <Insert Table 6 here>

362   Compared to the occurrence, where all hazards were found with significant differences,

363   only one hazard (i.e., H4) was perceived differently between less experienced employees and

364   their more experienced peers. Those with less than five-year experience perceived

365   electrocution significantly more severe. The rankings between samples are further

366   summarized in Fig.7.

367   <Insert Fig.7 here>

368   It is seen in Fig.7 that H4 (i.e., electrocution) is significantly overestimated of its severity

369 by both subsamples. The other significantly overestimated hazard was fall, due to the fact that

370 fall could occur in different scenarios. For example, employees working at height could fall

371 from a platform lower than 3 meters, or from five-story height. The variety of scenarios in the

372 fall hazard created a varied perception among employees, and hence causing the significant

373 deviation from the empirical ranking. Hazards including H6 and H7 were underestimated by

374 employees in terms of their severities, possibly due to the fact that heavy equipment and site

375 vehicles were most commonly seen in their daily work, and they had received relatively more

376 safety training handling heavy equipment and site vehicles. The familiarity could cause

377 employees' underestimate of risks towards site hazards.

378 *Statistical analysis of site employees' perceptions towards hazards' controllability*

379   The last category of hazard perception focused on the controllability. As summarized in

380 Table 7, there is an excellent internal consistency based on the overall Cronbach's Alpha

381 value at 0.8638.

382   <Insert Table 7 here>

383   The individual Cronbach's Alpha value for H1 higher than the overall one indicated that

384 employees held a differed view towards the controllability of structural collapse. Generally

385 consistent to the risk controllability ranking in Table 1, structural collapse was identified as

386 one of the least controllable hazard. Electrocution, although perceived with the highest degree

387 of severity by the overall sample, was also ranked as the most controllable hazard. The

388 subgroup analysis is summarized in Table 8.

389   <Insert Table 8 here>

390   Five out of the eight hazards were perceived by employees with significant differences in

391 in terms of their controllability. Those more experienced employees held a more positive

392   view of holding these hazards under control: structural collapse, struck-by, injureis by heavy

393   equipment, hit by site vehicles, and suffocation, choking, or poising. More experienced

394   employees were found with more confidence in controling hazards.The deviation analysis

395   based on rankings is summarized in Fig.9.

396   <Insert Fig.9 here>

397   Fig.9 indicates that compared to their senior peers, less experienced workers tended to

398   have a larger deviation of hazard perception in terms of controlability. Especially for structual

399   collapse and fall, less experienced employees tended to overestimate their capacities to

400   control.

401   ***Overall deviation between the empirical data and site employees' safety perceptions***

402   The overall deviations bewteen subsamples, as well as between employee perceptions and

403   the empirical data are summarized in Fig.10.

404   <Insert Fig.10 here>

405   It is seen in Fig.10 that employees with more than five-year site experience held less

406   deviated perceptions from the empirical data. In contrast, those less experienced employees

407   tended to have more biased perceptions towards all of these eight commonly encountered

408   hazards, especially in H1, where those more experienced employees had significantly more

409   reliable perceptions. Those hazards with higher accumulated ranking deviations from the

410   overall sample included H1 related to structural collapse, H2 related to fall, H4 related to

411   electrocution, and H8 related to suffocation, choking, or poising, which of which had the

412   same accumulated deviation of ranking at 10. For H2 (i.e., fall hazards), the deviated

413   perceptions for both subgroups came from the severity and controllability. Instead, the

414   perception of fall occurrence was highly consistent among subgroups without deviation from

415   the empirical data.

416   **Discussion**

417   Both external and internal factors could affect employees' hazard perceptions. External

418   factors included the feature of the hazard itself in terms of occurrence, severity, and

419   controllability which would affect construction employees' perceptions towards the given

420   hazard, further causing the deviation between individual perceptions and the reality. Internal

421   factors included but were not limited to worker's site experience, as well as other

422   demographic factors (e.g., gender).

423   The perception analysis of the survey sample revealed that among the eight defined hazard

424   scenes, fall could be easily identified by the survey sample in this study as the most

425   frequently occurring site accident.In this study, fall and struck-by related hazards, which were

426   defined by Han et al. (2019a) as hazards with higher occurrence, were also perceived by the

427   survey sample as hazards with top occurrences.In contrast, hazards with lower occurrence,

428   such as structural collapse, were perceived by less experienced employees with significant

429   deviation. It is therefore suggested that effective safety training should consider employees'

430   experience level, as well as categorizing the features of hazards.

431   Implicit cognition reflects how the past experience affects the performance even though

432   the earlier experience is not remembered, as past experience could mediate the feelings,

433   thoughts, and actions towards social objects (Greenwald and Banaji, 1995). Electrocution,

434   which was least severe hazard, was ranked by the overall sample as the most severe one

435   among the eight defined hazards. This could be due to the fact that electrocution used to be a

436   highly occurring accident due to poor electrical safety setup in China's construction sites. A

437   follow-up discussion with these surveyed employees revealed that most of them had been

438   told by their senior peers or others of the stories of fatalities caused by electrocution on-site.

439   According to Fig.1,the prior scenarios, either from their own witnesses, or from story-telling

440   by others, would affect their safety perceptions and form part of their safety knowledge of

441   pre-assuming that electrocution is extremely dangerous, even though nowadaysthe anti-

442 electrocution facility had been significantly improved. Variety in the scenario itself, such as

443 fall, could link employees' past experience from working in different heights. This variety

444 within a scenario would then cause deviation of individual perceptions from the empirical

445 data in reality. Other scenarios, such as working with heavy equipment and site vehicles, due

446 to employees' familiarity with them, tended to be perceived with lower severities.

447 Significant differences in hazard perceptions were found between more experienced

448 employees and their less experienced counterparts. More experienced construction employees

449 were more likely to have developed their safety cognition, which was reflected through their

450 perceptions towards site hazards.In this study, it was indicated that safety knowledge

451 developed within the subgroup of more experienced employees was found mostly reliable in

452 perceiving safety hazards. This research revealed that site employees with more than five-

453 year experience held less deviated perceptions towards site hazards from the empirical data.

454 This further suggested that prior safety scenarios or established safety knowledge could

455 beone reliable source for construction employees to form their correct perceptions. Instead,

456 less experienced employees, with fewer safety scenarios from their past career or non-

457 verbalized knowledge (Smith, 1990; 1994), could catch the latest safety knowledge through

458 alternative multiple ways, such as virtual and augmented reality applications (Li et al., 2018),

459 which could be incorporated as part of effective safety training.

460 According to Fig.2 and Fig.3, construction employees formed their hazard perceptions by

461 using their own safety knowledge, prior scenarios, or basic assumption. For more

462 experienced workers, they were more likely to apply their previous scenarios to match the

463 current hazard scene to form their perceptions leading to decision making. Less experienced

464 employees were more likely to perceive risks according to their basic assumption with

465 limited safety knowledge or prior scenarios to apply. As a result, hazard perceptions of less

466 experienced employees might be more biased and deviate more from the empirical data.

Conclusion

This study defined a theoretical safety cognition framework by addressing construction employees' safety perceptions towards given site hazards within the context of safety culture. The initially defined framework was then applied through site investigations in China's construction industry. Firstly, the empirical safety accident data were collected and analyzed in terms of the occurrence, severity, and controllability. Eight hazard or accident scenes (e.g., fall) were defined through the empirical data analysis. Afterwards, site questionnaire survey was conducted to crew members to collect their perceptions towards the eight hazards/accidents. Employees' perceptions of the eight hazards were ranked and compared to the empirical data. Further, this study investigated the differences between more experienced employees and their less experienced peers in perceiving these hazards. The main findings are summarized below:

- Both external and internal factors affect construction employees' safety perceptions. External factors included the feature of the hazard itself. For example, those with higher frequency of occurrence were more likely to be perceived by employees with less deviation in terms of their occurrences.

- Employees with more site experiencewere more likely to apply their prior scenarios and safety knowledge to formmore reliable perceptions towards given safety hazard. This necessitatedproper safety training for less experienced employees (e.g., those with less than five years' experience).

- The main differences of perceptions between more experienced employees and their less experienced peers came from the perception towards the hazard occurrence. In comparison, little difference towards the hazard severity was found between the two subsamples.

492   •   More experienced employees held more positive views of controlling site hazards with

493   their prior scenarios and developed safety knowledge.

494   •   Although in most cases, gaining experience would help employees develop a less biased

495   hazard perception. Employees' prior scenarios could create biased perceptions towards

496   the severity of certain hazards (e.g., electrocution). It was therefore suggested that

497   experienced workers should also be updated of the latest site condition and safety

498   scenarios.

499   This research contributes to the body of knowledge in safety culture and safety climate by

500 introducing the theoretical cognition framework incorporating construction employees'

501 hazard perceptions with both external and internal influence factors included and tested

502 through site investigations. Site experience level was identified as one internal factor

503 affecting employees' hazard perceptions. This internal factor divides safety climate into sub-

504 climates, and leads to further studies in sub-safety-climate, specifically, how employees from

505 different sub-safety-climate groups could work together to create a positive overall safety

506 climate by minimizing the perception deviations.

507   The current study was limited to construction employees' safety perceptions towards

508 defined hazards in China, and the experience level was considered the sole variable in

509 studying the variations between site employees. Future studies could extend the defined

510 theoretical framework into other countries' context, and to explore the safety perceptions of

511 immigration or ethnic minority workers. More studies are also needed to how to adopt

512 effective safety education to correct employees' biased perceptions.

513 **Data Availability Statement**

514   Data generated or analyzed during the study are available from the corresponding author

515 by request.

516 **Acknowledgement**

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683   **Table 1.** Safety data analysis

Type of accidents	Number of accidents	Fatality	Severe injuries	Percentage	Fatality rate per accident	Ranking		
						Occurrence	Severity	Risk controllability
Structural collapse	237	454	90	12%	1.92	3	1	7
Falling from working at height	1013	1081	37	53%	1.07	1	6	8
Struck-by	277	289	8	15%	1.04	2	7	6
Electrocution	48	50	0	3%	1.04	6	8	3
Injuries by manual handling or lifting	166	245	34	9%	1.48	4	3	5
Injuries by heavy equipment	109	120	17	6%	1.10	5	4	4
Hit by site vehicles	27	30	0	1%	1.11	7	5	1
Suffocation, choking, or poising	20	37	3	1%	1.85	8	2	2

684   Note: data in Table 1 were summarized according to accident reports from Division of Safety Supervision (2017)

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Table 2. Sample attributes of the survey population

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Gender		Job position		Site experience level		Trade		
Male	Female	Workers	Management personnel	Less than five years	More than five years	Concrete	Steel/iron	Others*
66%	34%	85%	15%	40%	60%	26%	23%	51%

719 Note: other trades include plumbing, electrical, carpentry, and scaffolding, etc.
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Table 3. Statistical analysis of the eight safety hazards measured by occurrence

Hazards	Item-total Correlation	Cronbach's Alpha*	Mean	Standard Deviation	RII	Ranking
H1: (i.e., related to structural collapse)	0.6169	0.8719	3.393	1.179	0.679	8
H2: (i.e. causing falling from working at height)	**0.4184**	**0.8882**	3.851	0.926	0.770	1
H3: struck-by	0.7179	0.8612	3.617	1.019	0.723	3
H4: Electrocution	0.7223	0.8601	3.468	1.208	0.694	5
H5: injuries by manual handling or lifting	0.7121	0.8612	3.423	1.120	0.685	7
H6: injuries by heavy equipment	0.7417	0.8591	3.622	1.003	0.724	2
H7: hit by site vehicles	0.6205	0.8707	3.453	1.053	0.691	6
H8: suffocation, choking, or poising	0.6480	0.8680	3.473	1.030	0.695	4

763   Note: overall Cronbach's Alpha value = *0.8825*

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Table 4. Comparison of perceptions towards the hazards' occurrence between newer and more experienced site employees

Hazards	Employees over five-year site experience			Employees with less than five years' site experience			Two-sample t-test results	
	Mean	Standard Deviation	Ranking	Mean	Standard Deviation	Ranking	t value	p value
H1	3.790	1.000	2	2.800	1.180	8	**6.13**	**0.000***
H2	3.992	0.861	1	3.638	0.984	1	**2.62**	**0.010***
H3	3.760	0.966	3	3.400	1.060	3	**2.44**	**0.016***
H4	3.710	1.110	6	3.100	1.260	5	**3.52**	**0.001***
H5	3.730	1.020	5	2.960	1.120	7	**4.92**	**0.000***
H6	3.760	1.080	3	3.413	0.837	2	**2.56**	**0.011***
H7	3.669	0.986	7	3.130	1.070	4	**3.64**	**0.000***
H8	3.600	1.030	8	3.270	1.010	6	**2.24**	**0.026***

*:ap value lower than 0.05 indicates significant differences between subgroup workers with different level of site experience. The same rule applies to follow-up tables involving two-sample t-test.

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822   **Table 5.** Statistical analysis of the eight safety hazards measured by severity

Hazards	Item-total Correlation	Cronbach's Alpha*	Mean	Standard Deviation	*RII*	Ranking
H1: (i.e., related to structural collapse)	**0.4225**	**0.8690**	4.030	1.072	0.806	5
H2: (i.e. causing falling from working at height)	0.5854	0.8479	4.154	0.895	0.831	2
H3: struck-by	0.7134	0.8333	3.876	0.943	0.775	6
H4: Electrocution	0.6825	0.8377	4.179	0.882	0.836	1
H5: injuries by manual handling or lifting	0.7042	0.8366	4.080	0.827	0.816	3
H6: injuries by heavy equipment	0.6428	0.8416	3.751	1.067	0.750	7
H7: hit by site vehicles	0.5968	0.8471	3.662	1.042	0.732	8
H8: suffocation, choking, or poising	0.5900	0.8475	4.035	0.880	0.807	4

823   Note: overall Cronbach's Alpha value = *0.8620*

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839 **Table 6.** Comparison of perceptions towards the hazards' severity between newer and more

840 experienced site employees

Hazards	Employees with more than five-year site experience			Employees with less than five years' site experience			Two-sample t-test results	
	Mean	Standard Deviation	Ranking	Mean	Standard Deviation	Ranking	*t* value	*p* value
H1	4.070	1.020	2	3.980	1.150	5	0.58	0.566
H2	4.198	0.891	1	4.088	0.903	3	0.86	0.393
H3	3.835	0.960	6	3.938	0.919	6	-0.76	0.447
H4	4.066	0.946	3	4.350	0.748	1	**-2.37**	**0.019***
H5	4.058	0.849	4	4.112	0.795	2	-0.46	0.643
H6	3.830	1.140	7	3.625	0.946	7	1.42	0.158
H7	3.777	0.979	8	3.490	1.110	8	1.89	0.061
H8	4.050	0.893	5	4.013	0.864	4	0.29	0.769

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858 **Table 7.** Statistical analysis of the eight safety hazards measured by risk controllability

Hazards	Item-total Correlation	Cronbach's Alpha	Mean	Standard Deviation	*RII*	Ranking
H1: (i.e., related to structural collapse)	**0.4540**	**0.8684**	3.055	1.242	0.611	8
H2: (i.e. causing falling from working at height)	0.6287	0.8462	3.622	0.947	0.724	2
H3: struck-by	0.7208	0.8354	3.443	1.033	0.689	7
H4: Electrocution	0.6274	0.8459	3.682	1.191	0.736	1
H5: injuries by manual handling or lifting	0.6135	0.8471	3.448	1.090	0.690	5
H6: injuries by heavy equipment	0.7199	0.8355	3.587	1.031	0.717	4
H7: hit by site vehicles	0.6350	0.8449	3.622	1.018	0.724	3
H8: suffocation, choking, or poising	0.5539	0.8535	3.443	1.014	0.689	6

859 Note: overall Cronbach's Alpha value = *0.8638*

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Table 8. Comparison of perceptions towards the hazards' controllability between newer and

more experienced site employees

Hazards	Employees above five-year site experience			Employees with less than five years' site experience			Two-sample t-test results	
	Mean	Standard Deviation	Ranking	Mean	Standard Deviation	Ranking	*t* value	*p* value
H1	3.300	1.180	8	2.690	1.250	3	**3.46**	**0.001***
H2	3.537	0.931	6	3.750	0.961	1	-1.56	0.122
H3	3.640	1.060	4	3.138	0.924	8	**3.60**	**0.000***
H4	3.660	1.160	3	3.710	1.240	2	-0.29	0.769
H5	3.450	1.100	7	3.450	1.090	4	-0.02	0.981
H6	3.810	0.994	1	3.250	1.000	6	**3.89**	**0.000***
H7	3.802	0.900	2	3.350	1.130	5	**3.01**	**0.003***
H8	3.612	0.995	5	3.188	0.110	7	**2.96**	**0.004***

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