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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 studies are 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 internal influence 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 construction site 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 by Marquardt 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. More details 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. Construalability 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 managers 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 analysis and 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 *RII* was 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 Likert-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, as construction 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 analyzed and 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

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

319 <Insert Table 3 here>

320 The Cronbach's Alpha value over 0.8800 indicated a fairly excellent internal consistency
321 among the eight hazards. However, the individual value of H2 related to fall from working at
322 height higher than the overall Cronbach's Alpha value indicated that survey participants from
323 the overall sample tended to perceive H2 differently as they would perceive the occurrence of
324 other hazards. Fall has been identified in the construction industry worldwide (e.g., OSHA,
325 2011; Zhang et al., 2015) as most frequently encountered safety hazard. The statistical results
326 showed the consistency in light of the fall hazard occurrence between employees' perceptions
327 and the empirical data in Table 1. It was also found that fall (i.e., H2) ranked top among the
328 eight hazard scenes, with the lowest item-total correlation coefficient. The overall survey
329 population was then divided into two sub-samples according to their site experience level (i.e.,
330 below or above five-year site experience). Table 4 summarizes the two-sample *t*-test results.

331 <Insert Table 4 here>

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

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 Electrocutation 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 electrocutation 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 poisoning. More experienced
394 employees were found with more confidence in controlling 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 structural
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 poisoning, 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 nowadays the 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 be one 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.

467

468 **Conclusion**

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

- 480 • Both external and internal factors affect construction employees' safety perceptions.
481 External factors included the feature of the hazard itself. For example, those with higher
482 frequency of occurrence were more likely to be perceived by employees with less
483 deviation in terms of their occurrences.
- 484 • Employees with more site experience were more likely to apply their prior scenarios and
485 safety knowledge to form more reliable perceptions towards given safety hazard. This
486 necessitated proper safety training for less experienced employees (e.g., those with less
487 than five years' experience).
- 488 • The main differences of perceptions between more experienced employees and their less
489 experienced peers came from the perception towards the hazard occurrence. In
490 comparison, little difference towards the hazard severity was found between the two
491 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.

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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 poisoning	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

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%

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	<i>RII</i>	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 poisoning	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 <i>t</i> -test results	
	Mean	Standard Deviation	Ranking	Mean	Standard Deviation	Ranking	<i>t</i> value	<i>p</i> 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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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 poisoning	0.5900	0.8475	4.035	0.880	0.807	4

823 Note: overall Cronbach's Alpha value = 0.8620

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Table 6. Comparison of perceptions towards the hazards' severity between newer and more 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	<i>t</i> value	<i>p</i> 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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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 poisoning	0.5539	0.8535	3.443	1.014	0.689	6

Note: overall Cronbach's Alpha value = 0.8638

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876 **Table 8.** Comparison of perceptions towards the hazards’ controllability between newer and
 877 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	<i>t</i> value	<i>p</i> 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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