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Research Article

A Cognitive Failure Model of Construction Workers' Unsafe Behavior

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The construction industry is one of the most dangerous industries globally, and construction workers are the leading cause of safety accidents. Unsafe behavior research focuses on behavioral safety of observable behaviors and the safety culture of organizational behaviors. However, these studies lack a systematic and comprehensive explanation of unsafe behavior. Therefore, this study constructs a cognitive failure model based on cognitive safety theory to explain the mechanisms of construction workers' unsafe behaviors. Five main causes of cognitive link failure were derived from the cognitive process of construction workers' unsafe behaviors: safety vigilance, hazard identification, safety knowledge, safety behavior attitude, and professional skills. Questionnaires were developed based on five cognitive failure factors and validated by structural equation modeling. The results show that the cognitive failure model fits well, and all five cognitive failure factors may lead to construction workers' unsafe behaviors. Among the five cognitive failure factors, safety vigilance is the main cognitive failure factor in obtaining information link; hazard identification is the major cognitive failure factor in understanding information link; and safety behavior attitude is the chief cognitive failure cause for selecting response link. These findings deepen the understanding of construction workers' unsafe behavior mechanisms.

1. Introduction

Construction engineering is one of the most dangerous industries globally because of the workplace's dynamic and most dangerous working conditions [1, 2]. Since 2010, the number of construction accidents and casualties in China has been high and has continued to rise since 2015. There were 442 construction accidents and 554 deaths in 2015 [3] and 773 construction accidents and 904 deaths in 2019 [4], respectively, with 74.88% and 63.17%. Construction workers are the leading cause of safety accidents and the victims of safety accidents. After studying and analyzing 75000 accidents, Heinrich [5] proposed the accident cause theory and suggested that human factors caused 88% of the accidents. After analyzing the accidents in Finland from 1985 to 1990, Salminen and Tallberg [6] found that 84%–94% was work-related deaths, and severe national accidents were caused by the unsafe behavior of the parties. Suraji et al. [7] studied about 500 accident reports and found that workers' unsafe behavior caused 88% of safety accidents. It can be seen that the unsafe behavior of construction workers is the leading cause of safety accidents.

Unsafe behavior can be divided into three research directions: behavioral safety, safety culture, and cognitive safety. Among these, behavioral safety and safety culture are the main research directions. Behavioral safety research believes that people's behavior results from external stimulation, aiming to eliminate unsafe behavior through some measures [8, 9]. Therefore, it is advocated to study observable behavior and ignore consciousness or other psychological activities in research methods. However, the research results are not optimistic, and the intervention measures cannot maintain a sound effect for a long time [10, 11]. Safety culture research believes that people's behavior is affected by organizational culture, focusing on the influencing factors of workers' behavior. Therefore, in terms of research methods, it advocates eliminating workers' unsafe behavior from the organizational level [12–14], ignoring the consideration of individual factors, which result in the lack of explanation for the mechanism of unsafe behavior [15, 16]. Several scholars have introduced cognitive science theory into their research, focused on the internal behavior logic and behavior reasons of behavior subjects, and explored the psychological process of unsafe behavior from stimulation processing response, known as cognitive safety studies. Therefore, cognitive safety research considers unsafe behaviors due to failures in workers' cognitive processes and attempts to understand the microscopic relationship between safety culture and behavioral safety from the cognitive mechanisms.

Cognitive safety research has focused on exploring the relationship between cognitive factors and unsafe behaviors [17–19] or the theoretical framework of unsafe behaviors' cognitive model [20–23]. Among them, the cognitive model of unsafe behavior simulates the cognitive process of workers' unsafe behavior, such as the Furnham's [20] accident source sequence model, Reason's [21] general human error model, and Surry's [22] accident cause model. Among them, Furnham [20] identifies four types of cognitive failures that result from unsafe behavior: (1) not aware of the hazard, (2) not knowing the hazard, (3) choosing unsafe behavior, and (4) inability to avoid the hazard. Surry [22] argues that five cognitive failures cause unsafe behavior, adding a cognitive failure factor to Furnham's model: not knowing how to avoid the hazard. According to the model proposed by Surry [22], Fang et al. [23] believes that the cognitive process could be divided into five links: obtaining information, understanding information, perceiving response, selecting response, and taking action. It can be seen that the cognitive model can explain the mechanisms of unsafe behaviors systematically and comprehensively from an individual cognitive. A cognitive model can elaborate the mechanisms by which internal cognitive factors and external organizational factors lead to construction workers' unsafe behaviors. However, the cognitive model is still in the stage of a theoretical framework and lacks relevant cognitive factors to explain the cognitive model.

This study explores cognitive failure factors in a cognitive model of unsafe behavior based on the study of the relationship between cognitive factors and unsafe behavior and aims to construct a cognitive failure model to explain the causes of workers' unsafe behavior. This study had two main objectives: first, to explain the cognitive process of unsafe behavior from the cognitive failure factors; second, to construct a cognitive failure model to explain the causes of workers' unsafe behavior. Since the cognitive model of unsafe behavior is still the theoretical framework, this study attempts to explore the role of cognitive factors in the cognitive model of unsafe behavior, which not only helps to quantify the cognitive model of unsafe behavior but also strengthens the relationship between cognitive safety research with certain theoretical and practical implications.

2. Literature Review

According to the above analysis, a complete cognitive process should include five cognitive links: obtaining information, understanding information, perceiving response, selecting response, and taking action. Unsafe behavior is the product of the cognitive process, and cognitive failure in any one cognitive link may lead to unsafe behavior. Therefore, cognitive failure factors are also the leading cause of unsafe behavior. According to the cognitive process of unsafe behavior, we conclude that there are five failure factors of cognitive links: safety vigilance, hazard identification, safety knowledge, safety behavior attitude, and professional skills (see Figure 1).

2.1. Safety Vigilance. The first cognitive link is information discovery, where construction workers discover information about hazards present in the work environment by safety vigilance. Deng's [24] studies found that safety vigilance has a positive and positive effect on discovering information link. Workers with higher safety vigilance will actively and consciously search for information about potential hazards in the work environment. However, due to cognitive reluctance [25], construction workers prefer a less safety-vigilance work style, being both unconsciously and passively attracted to hazard information in the work environment. However, this less safety-vigilance way of working can easily ignore potentially dangerous information in the work environment, leading to safety accidents. For example, Kines, [26] study found that workers fall because they were unaware that their workmates had adjusted their work platforms.

2.2. Hazard Identification. The second cognitive link is to understand the information. After discovering the potentially dangerous information in the working environment, the workers will judge the information out of the guarantee of their safety to further determine whether the information is dangerous. However, although some construction workers have found potentially dangerous information, they underestimate the risk of information [27], essential for workers' unsafe behavior. Han et al. [28] found that different construction workers have significant differences in the severity and frequency of accident consequences, and the severity of mechanical injury and vehicle injury has been underestimated. Lombardi et al. [29] study also found that workers underestimate the risk of quickly completing work. If repeated unsafe operations do not cause accidents and injuries, workers will underestimate the risk and think that the probability of accidents caused by unsafe behaviors is low [30].

2.3. Safety Knowledge. After determining the risk of information, enter the perceiving response link. This link requires workers to know which behaviors may cause danger and how to take correct defense measures, which mean workers should have a certain reserve of safety knowledge. However, in practical work, the lack of safety knowledge among workers is common. For example, carpenters think that fall prevention facilities are more dangerous, but they believe that openings without protection are not dangerous [31]. The dump truck driver feels that they can jump out of the car in time if they do

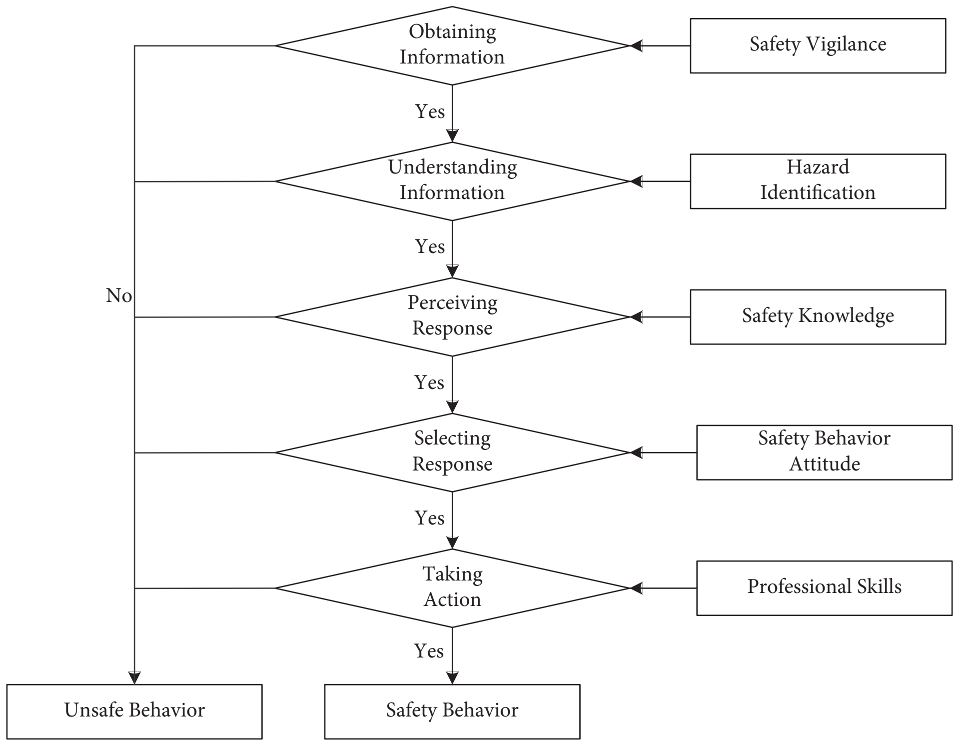

Figure 1: Cognitive failure model.

not wear their seat belts when they overturn [32]. In Abdelhamid and Everett [33] accident cause model, the lack of safety knowledge is considered one of the root causes of workers' unsafe behavior. Due to the lack of safety knowledge, construction workers may not know how to deal with hazards, which results in severe or fatal accidents [34].

2.4. Safety Behavior Attitude. The construction workers are choosing a safe way of working means that they have to pay more physical strength and time. Therefore, when facing high physical fitness operation requirements and tight construction periods, construction workers are more willing to choose time-saving and labor-saving unsafe behaviors to complete the work quickly and easily [35, 36]. For example, carpenters start working because they have no time to wait for safe fall prevention facilities to be in place [31]. Wearing earplugs affects the regular communication of workers, and workers prefer not to use earplugs [37]. In addition, workers' overestimation of self-efficacy is also an important reason affecting workers' behavior. Self-energy efficiency is workers' judgment of their knowledge and ability [38]. Due to overestimating their ability to prevent accidents, workers are likely to choose unsafe behavior. For example, Kines [26] studied 26 falling accidents, two caused by workers overestimating their physical fitness when climbing.

2.5. Professional Skills. The fifth link is the implementation of response and whether construction workers have professional skills is the key to the implementation of response. Construction workers with a high level of professional skills can respond calmly to hazards and reduce the occurrence of unsafe behaviors when faced with unexpected safety events. Deng's et al. [39] study found a significant positive effect of professional skills on construction workers' unsafe behaviors. Ye's et al. [40] study also found that construction workers with high levels of professional skills would actively participate in safety activities and help other workers consciously follow the safety code of conduct, thus reducing the construction workers' unsafe behaviors the probability of occurrence. If construction workers with lower professional skills, even if they choose to behave safely, may not cope because of their lack of professional skills, leading to unsafe behavior.

3. Method

3.1. Questionnaire Design. This study investigated the questionnaire by reading literature and interviewing workers. First, by reading the literature, this paper combed the relevant literature on five cognitive failure factors in recent 20 years and extracted the relevant descriptions of five cognitive failure factors involved in each literature [18, 19, 41–43]. According to the system analysis, the literal meaning was analyzed, and the most commonly used related measurement items are summarized and sorted according to the occurrence frequency. On this basis, this study will further combine worker interviews and expert feedback to construct the initial pool of unsafe behavior questionnaires of construction workers to ensure the content validity of the questionnaire. Second, because the research object of this paper is construction workers, most of them have low educational levels and limited reading ability. The description of the questionnaire items was appropriately modified to ensure that the meaning was clear, easy to understand, and accurate. Finally, three reverse questions were set to reduce the impact of the social expectation effect.

3.2. Content Validity. To analyze the content validity of the questionnaire, it was e-mailed to a panel of experts ($N = 10$) with extensive experience in research topics related to construction safety. Content validity was assessed using a 4-point scale: 1 as not relevant, 2 as somewhat relevant, 3 as relevant, and 4 as highly relevant. In addition, experts were asked to submit their opinions on the items' ambiguity, easiness, and clearness to measure the questionnaire's face validity. Two indicators were used to evaluate quantitative content validity and face validity: content validity ratio (CVR) and content validity index (CVI). The results of content validity analysis show that 20 out of 22 items (90.90%) had good content validity. Among the 22 items, 10 experts had an acceptable CVR of 0.42 or higher [44] and a CVI no lower than the recommended 0.79 [45]. Therefore, 2 items were removed from the questionnaire, and 20 question items were retained (see Appendix and Table 1).

3.3. Presurvey Questionnaire. A questionnaire presurvey study was conducted before the formal questionnaire was distributed. The general questionnaire presurvey sample size is 40–100 [42]. Because the recovery rate and efficiency of filling in the questionnaire on-site are about 80% [24], the number of people determined in the presurvey of this paper is 60. Taking a construction site worker in Urumqi as the survey object, 100 questionnaires were sent out, and 83 questionnaires were recovered, with a recovery rate of 83%. After the questionnaire was collected, the questionnaire was sorted, and the missing, multiple-choice, and regular answer questionnaires were eliminated. Finally, 64 valid data were obtained. The structure and content of the questionnaire were improved according to the effective feedback, and the final version was determined. There are 20 questions in the formal questionnaire, of which 10 questions are measured by the Likert five-level scoring method, and ten questions measure the safety knowledge of construction workers in the form of single choice questions.

3.4. Construct Validity. SPSS version 21.0 was used for exploratory factor analysis (EFA) to explore the construct validity and reliability of the questionnaire in the sample. EFA was performed using principal component analysis (PCA) to analyze the constructs of the initial instruments. The Bartlett test of Sphericity (BTS) and Kaiser–Meyer–Olkin (KMO) sampling adequacy measures were evaluated to ensure that the data were suitable for factor analysis. The data are appropriate when the KMO is greater than 0.8 [16]. BTS evaluation criterion is when the probability of significance is less than 0.01, allowing factor analysis of the data. Cronbach's α coefficient method was used for the reliability test. Cronbach's α should be greater than 0.8, indicating the internal consistency higher of the questionnaire items [17].

3.5. Data Analysis Method. Amos version 21.0 was used for structural equation modeling (SEM) to run the cognitive failure model, and confirmatory factor analysis (CFA) was performed to check the composite reliability (CR) and average variance extracted (AVE). The $\chi 2$/degree freedom (df), goodness of fit index (GFI), adjusted goodness of fit index (AGFI), comparative fit index (CFI), Tacker–Lewis index (TLI), incremental of fit index (IFI), norm fit index (NFI), and root mean square error of approximation (RMSEA) were used to indicate the goodness of fit of the model.

4. Result

4.1. Participants. Three hundred formal questionnaires were distributed, 285 were recovered, and 27 invalid questionnaires were excluded. There are 258 valid questionnaires, and the sample size is between 200 and 300 [17], which is suitable for factor analysis. Descriptive analysis was conducted on the personal information attributes of 258 valid questionnaires, including the age, working years, and education level of on-site workers participating in the questionnaire. As shown in Table 2, 76% of construction workers are between 31 and 50; 88% have more than five years of work experience; 84.1% have a high school or lower education level. The sample data are consistent with the current employment situation in the construction industry, so the sample data are representative.

4.2. Reliability and Validity. Exploratory factor analysis (EFA) was performed using SPSS version 21.0. The results show that the KMO measure of sampling adequacy was 0.870, greater than the recommended 0.7, indicating that the data were suitable for factor analysis. BTS was significant (1683.998, $P < 0.001$), illustrating that correlations exist among the cognitive failure model. Cronbach's α coefficient method was used for the reliability test. The results show that Cronbach's α coefficient is 0.887, greater than the recommended value of 0.7. Cronbach's α coefficients for all factors in Table 3 ranged from 0.726 to 0.888, above the recommended value of 0.70, indicating the questionnaire's good internal consistency.

Amos version 21.0 was used for SEM to check CR and AVE. Convergent validity was assessed based on two criteria: all variables' loading should be greater than 0.70 on its predetermined dimension, and AVE values for all dimensions should be greater than 0.50. Table 3 shows that factor loadings ranged from 0.700 to 0.889, meeting the recommended threshold of 0.70. Similarly, AVE values ranged from 0.582 to 0.763, exceeding the recommended threshold of 0.50. CR scores between 0.735 and 0.891 are above the recommended cutoff of 0.70. Therefore, the cognitive failure model has acceptable internal consistency and convergence effectiveness. The discriminant validity analysis of the cognitive failure model was not conducted because of the high correlation between the five cognitive links in the cognitive process of construction workers' unsafe behaviors.

Table 1: Part 1: formal questionnaire.

Number	Please tick "✓" the corresponding selection box on the right according to your actual situation	Strongly agree	Agree	Not sure	Disagree	Strongly disagree
1	I do not have the extra energy to check the work environment.					
2	I never take the initiative to check the work environment.					
3	I have not paid attention to information about hazards in the work environment.					
4	There is no safety difference between professional operation and unprofessional operation.					
5	The unprofessional operation does not necessarily result in a safety accident.					
6	I prefer to work in a comfortable way to professional operation.					
7	The unprofessional operation can get the work done more efficiently.					
8	I can get the work done efficiently and safely, even in unprofessional operations.					
9	I have the professional skills to get the work done.					
10	I regularly attend professional skills training.					

Table 2: Demographics of participants.

	Number	%
Age (years)		
21–30	48	18.6
31–40	108	41.9
41–50	88	34.1
>50	14	5.4
Working experience (years)		
0–5	31	12.0
6–10	49	19.0
11–15	89	34.5
16–20	54	20.9
>20	35	13.6
Education level		
Primary school and below	52	20.2
Junior middle school	83	32.2
High school	82	31.8
Junior college	18	7.0
Bachelor's degree or above	23	8.9

Table 3: Reliability and convergent validity.

Construct	Indicator	Unstandardized Loading	Standardized loading	t-value	CR	Cronbach's α	AVE
Safety vigilance	N1	1.000	0.855	—	0.891	0.888	0.732
	N2	0.887	0.863	17.214			
	N3	0.837	0.848	16.755			
Hazard identification	C1	1.000	0.858	—	0.866	0.865	0.763
	C2	1.019	0.889	16.903			
Safety knowledge	Q1	1.000	0.832	—	0.742	0.737	0.592
	Q2	0.840	0.701	5.833			
Safety behavior attitude	A1	1.000	0.751	—	0.812	0.813	0.592
	A2	0.911	0.707	10.938			
	A3	1.123	0.844	12.969			
Professional skills	P1	1.000	0.821	—	0.735	0.726	0.582
	P2	0.934	0.700	4.377			

Note: CR: composite reliability; AVE: average variance extracted.

4.3. Measurement Model. Amos version 21.0 was used for the second-order structural equation model. The results are shown in Table 4, and eight commonly used fitness indexes are used to evaluate the goodness of fit of the overall model. It can be seen that all indicators meet the standards and the cognitive failure model fits well. The

Table 4: Estimated values for goodness-of-fit indices.

Fit index	Recommended value	Estimate
χ^2/df	≤3	2.342
GFI	≥0.9	0.935
AGFI	≥0.8	0.897
CFI	≥0.9	0.960
TLI	≥0.9	0.946
NFI	≥0.9	0.933
IFI	≥0.9	0.961
RMSEA	≤0.08	0.072

Note: GFI: goodness-of-fit index; AGFI: adjusted goodness-of-fit index; CFI: comparative fit index; TLI: Tacker–Lewis index; NFI: norm fit index; IFI: Tacker–Lewis index; df: degree of freedom; RMSEA: root mean square error of approximation.

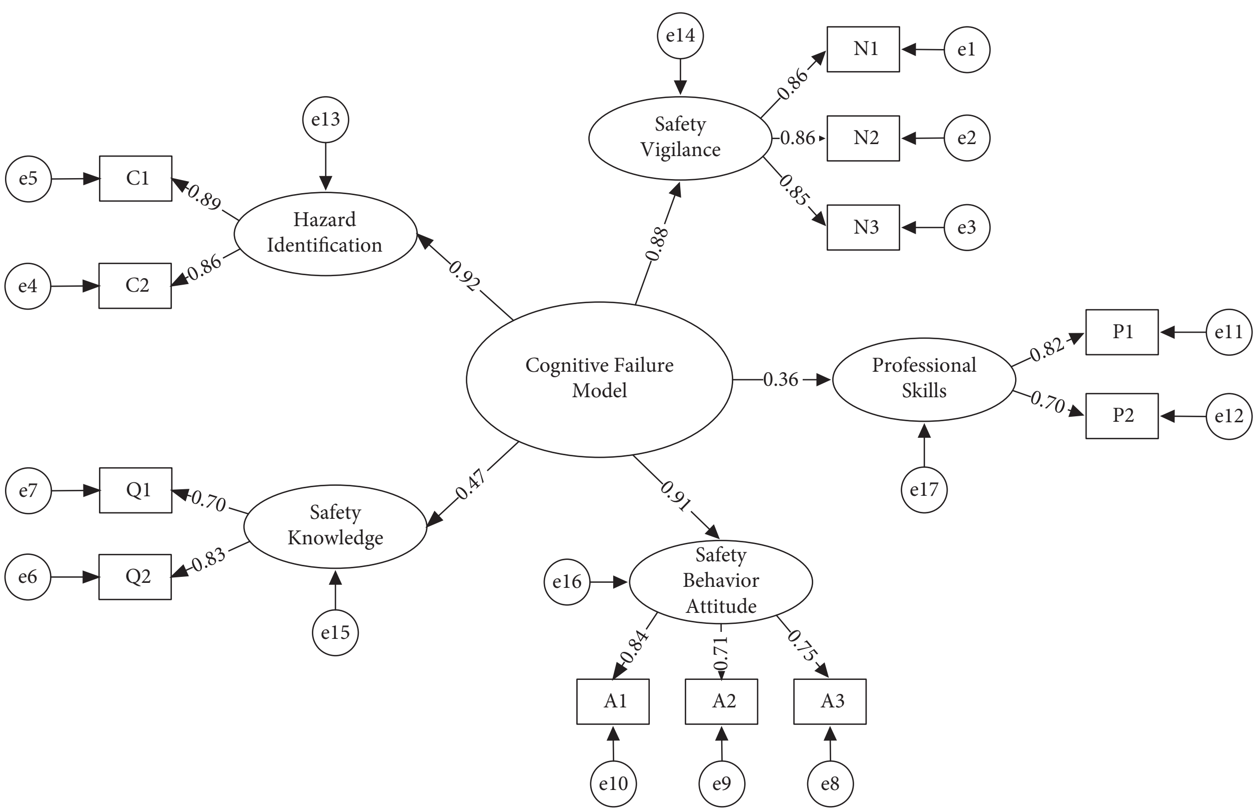

Figure 2: The structural model for the cognitive failure model.

cognitive failure model proposed in this study was supported (see Figure 2).

5. Discussion

Human behavior is the product of cognitive processes, and unsafe behavior is caused by cognitive failure. The cognitive model explains the mechanism of each cognitive link failure. Although this explains the mechanism of unsafe behavior well, the cognitive model is currently a theoretical framework. Based on the research on the relationship between cognitive factors and unsafe behaviors, this paper proposes constructing a cognitive failure model by cognitive factors to explain workers' unsafe behaviors. The proposed cognitive failure model was validated by confirmatory factor analysis, and five cognitive factors were responsible for the failure of the cognitive link. In obtaining information, safety vigilance needs to occupy cognitive resources in cognitive activities. However, building construction is typically a highly physically demanding job. Workers tend not to exhaust their energy because of the physical and mental work required, which means that construction workers are more inclined to adopt a lack of safety vigilance in their work style. Construction workers without safety vigilance often tend to adopt an unconscious and passive approach to searching for information about potential hazards in the work environment. However, this approach can easily miss information about potential hazards in the work environment, leading to cognitive failure to obtain information.

After discovering hazard information, the construction workers will judge the hazard information considering their safety. At this stage, workers with hazard identification ability will develop certain cognitive responses to accurately estimate the danger of hazard information and understand its characteristics. For example, if workers find an unprotected opening, they will realize that the opening is dangerous by estimating the danger of hazard information and should be avoided. Sometimes, the hazard recognition ability breaks down problems due to the complexity of the hazard information until the subproblems can determine the hazard and understand its characteristics. However, construction workers with no hazards identification ability often underestimate the riskiness of hazard information and believe that potential hazard information is safe, which results in a cognitive failure in the understanding information link.

After determining that the information is risky, construction workers will deal with the dangerous information. At this point, long-term memory matches the hazardous information with the knowledge stored in long-term memory. If the knowledge obtained by similarity matching contains no knowledge indicating how to handle hazardous information, or if there is some knowledge that can indicate how to handle hazardous information, but this knowledge is used very infrequently, workers will not know how to handle hazardous information. Although safety knowledge has a certain positive effect on the perceiving reaction link, it is not the main cognitive failure factor. The reason may be that construction workers generally do not have a high level of education, the perceiving reaction link is more inclined to work experience or imitation of other workers' behavior, and safety knowledge is used less frequently.

After the perceiving reaction link, construction workers may get several solutions to deal with hazardous information, including unsafe behaviors. At this point, the construction worker will move on to the next cognitive link, choosing a behavioral solution from several behavioral solutions. The principle of choosing behavioral solutions maximizes construction workers' motivation. This means that workers choose solutions for handling hazard information depending on their attitudes toward safe behavior. If they have negative attitudes toward safe behavior, they may deliberately choose unsafe behaviors to facilitate quick and easy work, which may lead to cognitive failures in selecting responsive links.

After selecting response link, the construction worker will implement the chosen behavioral solution to respond to the hazard information. However, the successful handling of hazard information depends on the professional skills of the construction worker. If construction workers' professional skills level is insufficient, even if they choose safe behavior, there is a risk that operational errors will lead to cognitive failure in taking action links. Unsafe behavior is not clear and uniform definition due to the different understanding, mainly around the "operation error" or "unprofessional operation." However, professional skill is not the main cause of cognitive failure in the taking action link. It is conceivable that the main cause of unsafe behavior is unprofessional operation, which is execution ability. The execution ability is the operational ability to accomplish the intended goal. Construction worker chooses unsafe behavior and completes it by execution ability.

6. Conclusion

Although the cognitive model can explain the mechanism of unsafe behavior well, it is in the theoretical framework. Based on cognitive safety theory, this study constructs a cognitive failure model by cognitive factors to explain the causes of construction workers' unsafe behaviors. CFA validated the cognitive failure model. The results indicates that the cognitive failure model fits well and that five cognitive failure factors could lead to unsafe behaviors. The mechanism of each cognitive link failure was analyzed by five cognitive failure factors, which extended the theoretical framework of the original cognitive model. In addition, since the cognitive links between the cognitive models should be highly correlated, the five cognitive factors should be highly correlated. However, safety knowledge and expertise were not highly correlated with the other three cognitive factors. This indicates that other cognitive failure factors may be the main cause of cognitive failure in the understanding information link and the taking action link. These findings enrich the cognitive safety theory and help understand the mechanisms of construction workers' unsafe behaviors. At the theoretical level, it provides a theoretical basis for the scientific prediction of construction workers' unsafe behavior and promotes multidisciplinary research. At the practice level, managers can further understand the causes of construction workers' unsafe behaviors and take targeted management measures to improve safety management performance.

This study also has some limitations. First, the data sample of this study is construction workers in Urumqi, so the survey data may have certain regional characteristics, which make the scope of application of the research conclusions have certain limitations. Second, workers' work experience, education, and other demographic characteristics may significantly correlate with the five cognitive failure factors, but no further analysis exists. In addition, this study only considered five cognitive failure factors: safety vigilance, hazard identification, safety knowledge, safety behavior attitude, and professional skills, and did not consider other factors that may cause cognitive link failure. Therefore, future studies should expand the scope of data collection and conduct more in-depth research on other cognitive factors. Meanwhile, the relationship between cognitive failure factors and demographic characteristics should be explored.

Appendix

Part 2: Safety Knowledge

(1) Preexisting holes within () can be set up without safety protection facilities.

A. 20 cm B. 30 cm C. 40 cm

(2) The three treasures of building construction safety protection are: safety helmet, safety belt, ().

A. Safety rope B. Safety net C. Touch security

(3) When working directly with electricity, you must () prevent electrocution.

A. Someone to supervise B. Wear insulated shoes, and gloves C. Wear insulated gloves

(4) When the use of machinery is finished and the operator leaves, he or she must ().

A. Inspection of machinery B. Cut the power C. Pay attention to rain protection

(5) You cannot work at heights in () weather.

A. Class 6 windy days and thunderstorm rain B. Winter C. Hot weather above 35 degrees

(6) The adjacent edge of balconies, floors, and roofs should be set up ().

A. Protective railing and safety net B. Protective railing C. Safety net

(7) Safety net use () after the rope strength test must be carried out.

A. 2 months B. 3 months C. 4 months

(8) When working in suspension, the operator should ().

A. Wearing a safety helmet B. Compliance with operating regulations C. Fasten the seat belt

(9) When going up and down the ladder, you must () the ladder and must not hold objects.

A. Left side to B. Right side to C. Face

(10) When entering the construction site, you must wear ().

A. Safety helmet B. Safety belt C. Safety rope

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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