Working together
www.rcis.ro

Revista de Cercetare si Interventie sociala

ISSN: 1583-3410 (print), ISSN: 1584-5397 (electronic)

COGNITIVE MECHANISM AND INTERVENTION STRATEGIES OF COAL MINERS' UNSAFE BEHAVIORS: EVIDENCE FROM CHINA

Lifen FANG, Zaixu ZHANG, Haihong GUO

Revista de cercetare și intervenție socială, 2018, vol. 61, pp. 7-31

The online version of this article can be found at:
www.rcis.ro, *www.doaj.org* and *www.scopus.com*

Published by:
Expert Projects Publishing House

expert projects
publishing

On behalf of:
„Alexandru Ioan Cuza" University,
Department of Sociology and Social Work
and
HoltIS Association
REVISTA DE CERCETARE SI INTERVENTIE SOCIALA
is indexed by Clarivate Analytics (Web of Science)
Social Sciences Citation Index
(Sociology and Social Work Domains)

Cognitive Mechanism and Intervention Strategies of Coal Miners' Unsafe Behaviors: Evidence from China

Lifen FANG[1], Zaixu ZHANG[2], Haihong GUO[3]

Abstract

Coal mine safety is an important part of safety management for a risk society and the unsafe behaviors of coal miners are major sources of hidden dangers. A considerable number of studies on coal miners' unsafe behaviors have been done based on behavioral science. However, few studies have been conducted from the perspective of cognition. This study explored the cognitive mechanism of coal miners' unsafe behaviors and proposed corresponding intervention strategies. A conceptual model of coal miners' unsafe behaviors was constructed after the analysis on the cognitive failure mechanism of unsafe behaviors, and an empirical test was carried out in Zhaizhen coal mine of China. Results show the necessity of exploring the causes of coal miners' unsafe behaviors from the perspective of cognitive failure. Among all the identified causes, the combined influence of personal causes is the most profound and the degree of influence of environmental causes, organization management, and behavioral attributes are decreased in turn. Unsafe behaviors can be restrained by optimizing the employment mechanism, improving the level of mechanization of underground mining, arranging the job division and operation schedule reasonably, and improving safety training mechanism and safety culture. Moreover, the safety of coal miner' operation behaviors can be ensured by improving safety management capability of managers, strengthening site management and safety protection, and improving the safety management system and incentive mechanism. This study provides significant reference for behavioral intervention to reduce coal miners' unsafe behaviors in an effort to avoid the unsafe factors in risk society.

Keywords: coal miner, unsafe behaviors, cognitive mechanism, cause, intervention strategy

[1] China University of Petroleum, School of Economics and Management, Qingdao, CHINA. Email: zjjhflf@163.com (Corresponding Author)
[2] China University of Petroleum, School of Economics and Management, Qingdao, CHINA. Email: zzx1766@126.com
[3] China University of Petroleum, School of Economics and Management, Qingdao, CHINA. Email: 254155838@qq.com

Introduction

Safety is a significant issue of common concern in current society and is an indispensable prerequisite for all kinds of social activities, such as daily life, production process, scientific experiments, and economic operation. Thus, people's demands for safety, have increased gradually with the development of society and civilization. Coal mining is an important mainstay for the social and economic development in China, and the continuous improvement of the level of safety management and production technology of the coal industry has reduced the safety production accidents in coal mines to a certain extent. However, the frequent occurrences of various safety accidents continue to restrict the sound development of the coal industry of China and have serious negative impact on regional social stability, economic development, and people's life. According to the analysis of coal mine accident cases of China in the "Coal accidents and expert review," 97.67% of the analyzed accidents were due to human errors (Wang, & Li, 2002). The results of a comprehensive study of 30 years' major accidents (1980–2010) in China's coal mines showed that the accidents involving human error account for 96.5% (Li, 2016). These human accidents are caused mainly by coal miners' unsafe behaviors. Accordingly, coal miners' unsafe behaviors are the key factors in coal mine accidents, thus restricting the improvement of coal mine safety production considerably and increasing the unsafe factors of risk society. Therefore, safety management is important to effectively control and avoid coal miners' unsafe behaviors.

Identifying the formation mechanism and specific causes of unsafe behaviors, then proposing feasible intervention strategies are effective ways to control and intervene in the unsafe behaviors. Present studies on coal miners' unsafe behaviors mostly focus on the formation mechanism, control method, and intervention strategies. Scholars have studied the causes of unsafe behaviors and their mechanism of action based on behavioral and cognitive science (Paul, 2013; Li, 2016). The influencing factors of unsafe behaviors have been analyzed from different aspects and formation models of unsafe behaviors like Surry Model and KAA (Knowledge, Ability, and Action) Unsafe Behavior Mode have been proposed (Surry, 1969; Cao, Li, & Song, 2007). Based on the analysis of the formation mechanism and causes, unsafe behaviors have been controlled and intervened from the internal and external influencing factors. Essentially, the formation process of coal miners' behaviors is a cognitive psychological process, and unsafe behaviors are induced by the failure of this process. However, few studies have been conducted on the formation process and mechanism of cognitive failures that lead to the coal miners' unsafe behaviors. Such situation makes the research on the essential mechanism and causes of unsafe behaviors non-exhaustive and incomplete, which highlights the lack of effective intervention paths and strategies. All these factors give rise to the limitations of the cause identification and intervention activities of unsafe behaviors in underground coal mines.

From the view of the essential process of behavior, this study aims to explore the cognitive mechanism of coal miners' unsafe behaviors and proposes feasible intervention strategies. The results provide support for intervention for coal miners' unsafe behaviors from the perspective of cognitive psychology, thereby reducing the negative impacts of unsafe factors of coal mines on the society.

State of the art

Present studies on the formation mechanism, causes, and influencing factors of coal miners' unsafe behaviors are relatively systematic, and intervention methods and strategies of unsafe behaviors have played a certain role in the practice of coal mine safety production. Research based on behavioral science aims to identify the causes of unsafe behaviors mainly from three aspects of human flaws, human ability, and external influencing factors. Paul, Zhang, and Curcuruto studied the effect of psychological factors and attitudes of coal miners to unsafe behaviors (Paul, 2013; Zhang, & Deng, 2015; Curcuruto, Conchie, Mariani, & Violante, 2015). Deficiencies in safety knowledge and awareness as well as improper safety habits of coal miners are important factors that cause unsafe behaviors. For example, Kjersti Bergheim and Liu Shuangyue pointed out improving the professional quality and safe behavior ability of employees was an important measure to eliminate unsafe behaviors (Bergheim, Nielsen, Mearns, & Eid, 2015; Liu, Chen, Zhou, Peng, & Fang, 2013). Some scholars found organizational and social environment factors of coal miners played an important role in their unsafe behaviors, including safety climate, culture, management system, and investment (Mullen, 2004; Babette, 2015; Li, & Yang, 2018). These studies have started from the influencing factors of unsafe behaviors to explore their causes, but no further research has been done on the problems of the essential formation process and mechanism of coal miners' unsafe behaviors.

Research based on cognitive science pays more attention to the essential formation mechanism of behavior, and the possible causes of unsafe behaviors have been found in the study of information processing stages. The Surry model was established by analyzing the causes of accidents from the perspective of information process from information perception to behavioral output (Surry, 1969). Cao Qingren constructed The KAA Unsafe Behavior Mode of Coal Miners based on cognitive psychology (Cao, Li, & Song, 2007). An integrative model of organizational safety behaviors was also proposed based on social cognition theory and safety culture, and after that, the influencing factors of safe behaviors was indicated (Cui, Fan, Fu, & Zhu, 2013). Furnham and Kines studied individual workers' cognitive and behavioral processes based on the cognitive process theory (Furnham, 1994; Kines, 2003). Through the exploration of the problems in the cognitive process, Lombardi and Verma analyzed the causes and influencing factors of unsafe behaviors from the perspective of human cognition (Lombardi,

Verma, Brennan, & Perry, 2009). However, these studies mostly focus on the qualitative clarification of the information processing process of unsafe behaviors, and the failure causes of the information processing stages of coal miners have not been studied systematically. These studies have failed to explain the essential mechanism problems of the formation of unsafe behaviors, such as "How do the influencing factors of cognitive process lead to the failure of coal miners' information processing?" and "What is the relationship between cognitive failure and unsafe behaviors?" The lack of studies focusing on these questions affects directly the accurate identification of the causes of unsafe behaviors in underground coal mines, which in turn limits the control effect of unsafe behaviors.

Therefore, aiming at the deficiencies of present research and based on the information-processing theory of cognitive psychology, this study ascribes unsafe behaviors to the failure of cognitive information processing and explores the formation mechanism of unsafe behaviors from the essential process of behaviors. The causes of coal miners' unsafe behaviors are revealed by analyzing the failure causes of all information processing stages. Thus, corresponding intervention strategies are proposed to obtain the intervention basis and paths of coal miners' unsafe behaviors.

The remainder of this study is organized as follows. Based on research of the cognitive mechanism of unsafe behaviors, a conceptual model of the causes of coal miners' unsafe behaviors is constructed after the analysis of the failure causes of information processing stages, and the method of empirical test is designed. The rationality of cause analysis method and the validity of identified causes are analyzed, and the corresponding intervention strategies are proposed. Finally, conclusions and limitations are presented in Section 5.

Methodology

Cognitive mechanism of unsafe behaviors

Cognitive information processing. Information-processing theory views cognitive process as the processing of external information and the response to changes and characteristics of objective things (Liang, 2014). Allen Newell and Herbert A. Simon, representatives of information-processing theory, analogized the cognitive process to computer information processing system, which can realize the receiving, storage, processing, extraction, replication, and transmission of external information to conduct reaction behaviors. This study aims to explore coal miners' unsafe behaviors by analyzing the psychological and behavioral processes of human interactions with operating systems. An information processing model proposed by Wickens typically expresses the information processing of operation behaviors and provides a matching framework for this study. Hence, the following analysis is based on this model.

Accordingly, the information processing of behaviors is divided into five stages: information reception, information understanding, solutions thinking, response selection, and response execution, as shown in *Figure 1* (Christopher, Wickens, Hollands, & Raja, 2014).

Figure 1. Five information processing stages

Failure mode of cognitive information processing of unsafe behaviors. According to information-processing theory, behavior is the output after the brain processes external information and the failure at any information processing stage can give rise to the failure of the entire information processing process. Consequently, the wrong response can be given. That is, the coal miners' unsafe behaviors are the results of the deviation from safety behaviors caused by the failure of information processing. Effective reception of information, correct understanding of information, effective thinking of solutions, correct selection of response, and proper execution of response are the preconditions to implement safe operation behaviors by coal miners. Thus, noneffective reception and misunderstanding of information as well as wrong solutions and response selection and execution can cause the failure of information processing. As a result, unsafe behaviors can happen. *Figure 2* describes the failure mode of information processing stages.

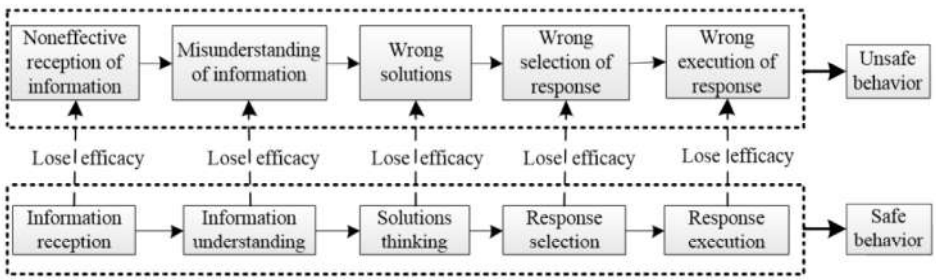

Figure 2. Failure mode of cognitive information processing

Construction of the conceptual model of the causes of coal miners' unsafe behaviors

Based on the earlier discussion, partial or full failure mechanism at any stage of information processing can lead to unsafe behaviors. Therefore, the causes of unsafe behaviors can be identified by analyzing the failure causes that occur at information processing stages.

Failure causes at the information reception stage

Impact of attentional resources. Attentional resources are finite and new information might not get enough attention resources if too many tasks happen at the same time (Herbert, 2010). According to Seegmiller, blind vision is the result of the lack of attention to new information that enters the visual system (Seegmiller, Watson, & Strayer, 2011). Physical and psychological fatigues lessen the coal miners' attention on information (Christopher, Wickens, Hollands, & Raja, 2014). Thus, effective use of attentional resources of the coal miner is mainly restricted by three aspects. 1) Multi-path attentional resource requirements: The underground environment of a coal mine is complex and dangerous, which requires more attention from coal miners. 2) Body fatigue: Coal miners are in the condition requiring long working hours and high load, respectively. 3) Psychological fatigue: Work in underground coal mine is repetitive and mechanical. The bad and dangerous operating environment makes coal miners prone to psychological fatigue.

Failure of signal detection. According to signal detection theory, the stronger the information signal is, the more sensitive the receiver's response is. The richer the receiver's knowledge, skills, and experience are, the more receptive the receiver is (Swets, 1998). The greater the intensity of information signal is, the more sensitive the receiver is (Swets, 1998). Considering internal and external factors, failure causes of signal detection are as follows:

– *Physical environment*. 1) Temperature: High and low temperatures affect the sensitivity of people, and the temperatures of working areas in most coal mines are beyond the range of comfortable work for the human body (Cai, & Brown, 2017; Zhao, 2014). 2) Humidity: The humidity in underground coal mines is generally higher than 85% (Wang, Xu, Zhang, & Liang, 2010), which affects the sensitivity of the sensory system of coal miners. 3) Noise: The loud noise of the production area in the underground coal mine greatly affects the auditory, nerve, and psychology of coal miners (Murray-Johnson, Witte, Patel, Orrego, Zuckerman, Maxfield, & Thimons, 2004). 4) Illumination: Poor lighting conditions in the underground coal mines are not conducive to the detection of safety hazard information (Ni, 2013). 5) Hazardous gas: Poisonous and harmful gases, such as CH_4, CO, and H_2S, can do harm to coal miners (Wu, & Xing, 2014).

– *Personal causes*. 1) Lack of knowledge: Coal miners are generally undereducated and have low safety and professional knowledge. 2) Lack of technical skills: The proportion of people with high technical skills in coal mines is lower than that of managers and ordinary workers (He, & Song, 2012; Chen, Qi, Long, & Zhang 2012). 3) Lack of work experience: Coal miners with longer working hours and more accident experiences are more sensitive to environmental information in the underground, while the working life of front-line coal miners in coal mines is relatively short. 4) Lack of safety awareness: Coal miners with higher safety awareness are more likely to receive important safety information perceived during operation (Cao, Li, Liu, Sun, & Zhang 2012). 5) Body fatigue: Physical and psychological fatigues reduce the sensitivity of the sensory organs of coal miners.

Due to the lack of specific regulations and incentive measures, coal miners are extremely prone to neglect information that is not related to production tasks in the operation process. Meanwhile, most safety accidents in coal mines are sudden and much unsafe information is not easy to be detected for its invisibility, low probability, and weak signal.

Unverified information. Due to the interference of many factors, coal miners easily tend to omit the verification of environmental information on site, which causes the failure of information reception. Lack of the habit of on-site safety inspection also easily makes coal miners' operation behaviors inconsistent with on-site needs. According to statistical analysis of coal mine accidents, habitual violation of coal miners account for about 90% of unsafe behavior accidents (Zhang, 2014). Meanwhile, mental shortcut results in doing things the easy way, which leads coal miners to rely directly on experiences stored in long-term memory. Thus, actions are done without verifying on-site information, which makes action decisions biased (Herbert, 2010; Kahneman, & Klein 2009). That is, coal miners can easily ignore environmental changes and system biases, and confidently take the information from their long-term memory as environmental information. Consequently, the response behaviors might be inconsistent with the actual environmental needs.

Failure causes at the information understanding stage

Failure causes of information extraction from long-time memory. The information stage requires coal miners to extract the highest matching and mostly frequency used information from long-term memory (Reason, 1990). Failure of information extraction may lead to information misunderstanding. When the required information is deficient, not commonly used, and incorrect, coal miners would not be able to extract such information to match in-process information, which leads to the failure of information understanding. On the one hand, rich

work experience and high technical skills can better instruct coal miners to apply the existing knowledge correctly; on the other hand, lack of work experience and technical skills can affect the effective use of knowledge by coal miners, which alters accuracy of information understanding.

Impact of working memory and attentional resources. The information understanding stage is accomplished in the working memory, whose major function is attention control. Passage of time declines working memory and limits its capacity (Tang, Shui, Sun, & Dai, 2012; Burgess, & Hitch, 2006; Kane, & Engle, 2002). Professional knowledge, technical skills, and work experience can improve the capacity of working memory. Thus, limitations of coal miners in relevant knowledge, technical skills, and work experience affect their correct understanding of information. Meanwhile, the energy and capacity of attentional resources affect the information understanding stage as well (Oppenheimer, & Kelso, 2015).

Failure causes at the solutions thinking stage. Based on the information understanding stage, this stage produces response behaviors through using information from long-term memory and external environment (Liang, 2014). The failure causes of information extraction from long-time memory have been analyzed in the above discussion. The inspection failure of external environment information mainly includes failure in information understanding and reception. The former causes belong to the information understanding stage. The latter contains the causes at the information reception stage, as well as the impact of information providers, which include the behaviors and suggestions of managers and workmates (Tong, Li, & Li, 2015).

The solutions thinking stage is done in the working memory and controlled by attentional resources. Thus, the lack of working memory and attention resources affect comprehensiveness and rationality of solutions thinking (Tang, Shui, Sun, & Dai, 2012). Besides, mental shortcut, lack of safety awareness, improper safety habits, and overconfidence can make coal miners directly adopt previous work experience as response solutions and omit the solution thinking stage. They would come up with solutions directly without the verification of the on-site environment information, and thus, deviate from the required action decision (Herbert, 2010; Kahneman, & Klein, 2009).

Failure causes at the response selection stage. The information processing of response selection stage needs to extract information from long-term memory and ensure accuracy of behavior selection through the verification of related external environment information. Information sources at this stage are the same as the information understanding stage, and thus, the causes of information understanding stage also affect the response selection stage. At the same time, response selection is influenced by individual psychological motivation (Franken, 2006). Based on expectancy-value theory, the result of individual behavior selection is determined by individual expectation of the possibilities of behavioral success and the value

of behavior. Individual expectation of the possibilities of behavioral success is influenced by self-efficacy, consciousness of behavioral difficulty, individual goal, and self-schema (Franken, 2006; Wigfield, & Eccles, 2000). The value of behavior is composed of capturing value, intrinsic value, utility value, and behavioral cost (Franken, 2006; Wigfield, & Eccles, 2000). Accordingly, the failure causes of coal miners' response selection are as follows:

- *Personal causes*. Self-efficacy: Coal miners overestimate the safety of unsafe behaviors and underestimate their risks. Self-schema: Coal miners' subjective initiatives of implementation of safe behaviors are deficient. Individual demand: Coal miners lack the demand for safety.
- *Behavioral attributes*. Behavioral difficulty: Unsafe behaviors are easier to carry out than the safe ones. Behavioral outcome: Coal miners are unaware of the significance of safe behaviors. Behavioral cost: Safe behaviors require more time, physical strength, or other costs of coal miners. Behavioral performance: The appraisal mechanism of individual behavioral performance is imperfect.
- *External influence*. Work environment: The corresponding safety facilities are not provided in the work environment. Organizational management: The safety regulations are imperfect. Impact of other people: The management behaviors of managers are not correct, and workmates provide unsafe behaviors and incorrect suggestions.

Failure causes at the response execution stage. The response selection is implemented at the response execution stage under the control of attentional resources, which is transmitted to the effector organs in the form of instructions. This stage directly receives the information processing results of the previous stages, and the finiteness of attentional resources limits the effective implementation of response selection. Therefore, attentional resources are the main controlling factor of this stage.

Based on the above analysis of the causes of unsafe behaviors at each stage, all causes are divided into four categories that are personal, environmental, organization management, and behavioral attributes according to different attributes of causes. A conceptual model of coal miners' unsafe behaviors is proposed, as shown in *Figure 3*.

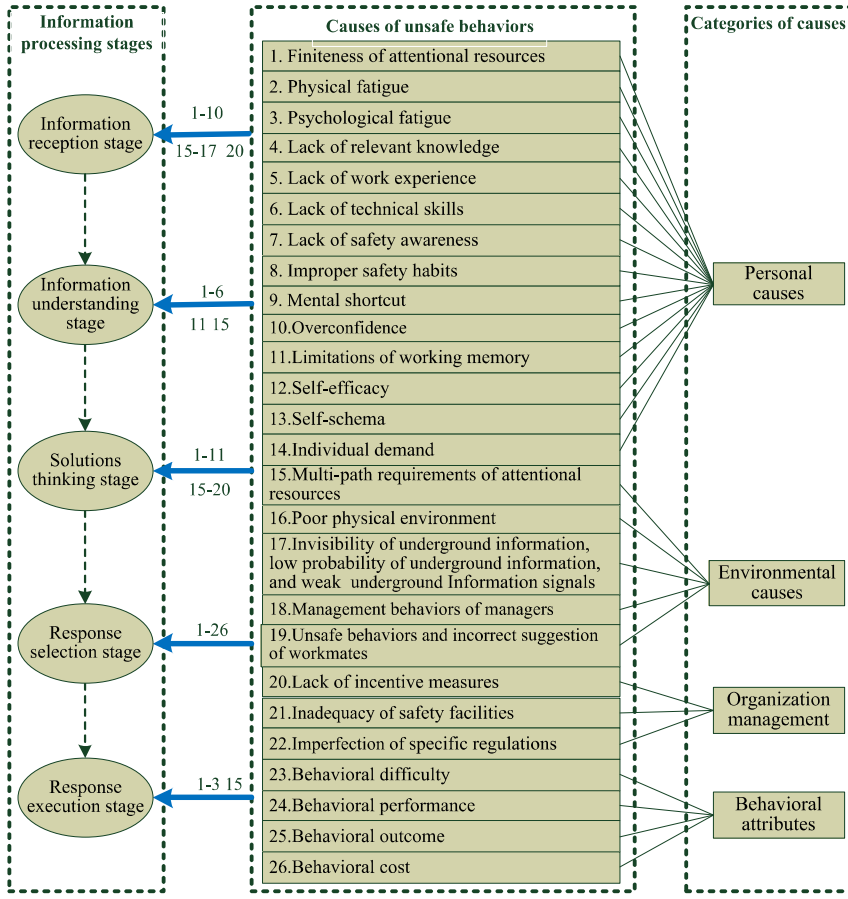

Figure 3. Conceptual model of the causes of coal miners' unsafe behaviors

Method design of empirical test

The empirical test of this study was carried out in the Zhaizhen coal mine, which is a large-scale mine of the Xinwen Mining Group in Shandong Province, China. The productivity of the mine is two million tons per year and the mine has been awarded the "National Safety Quality Standardization Coal Mine." Thus, the site can well reflect the general state of coal mine safety production and safety management in China. The empirical test was conducted from May to August 2016, when the coal production and driving force were at high levels. During this period, the mine was in a normal production state and the frequency of occurrence of unsafe behaviors was high. Thus, the statistics in this study are representative and typical.

The test adopted the combination of on-site investigation and safety inspection of Zhaizhen coal mine. Behavior observation was adopted to find out the frequent and common unsafe behaviors. The executors of these unsafe behaviors were interviewed to verify the rationality of the cause analysis method used in this study. Combined with safety inspection that aims to inspect illegal operations and commands as well as violations of labor disciplines, the violators were interviewed to investigate their psychological processes and contents using a questionnaire survey. The questionnaire embodied the causes identified in this study and aimed to verify the validity of these causes.

Method of rationality test

Based on the analysis of the cognitive mechanism of unsafe behaviors and the proposed conceptual model, the psychological processes and responses of coal miners that produced unsafe behaviors were explored through investigation interview. The interviews aimed to identify the causes of unsafe behaviors. The on-site investigation interview was conducted in five information processing stages. The rationality of the cause analysis method in this study can then be verified. *Figure 4* shows the specific implementation process and content of the investigation.

Method of validity test

According to the results of the safety inspection of the Zhaizhen coal mine, a questionnaire survey of causes was conducted on the executors of these unsafe behaviors. The data obtained from the questionnaire were analyzed statistically to realize a quantitative analysis of the causes of unsafe behaviors.

Reliability analysis of questionnaire. Reliability analysis aims to examine the consistency, stability, and reliability of the questionnaire results. Cronbach's coefficient alpha is the most commonly used reliability analysis method for questionnaires. Hence, in this study, it was used to measure the reliability and stability of the questionnaire results. According to the results, which were analyzed by SPSS Statistics 22.0 statistical software, the value of Cronbach's coefficient alpha of this questionnaire was 0.714, which was between 0.7 and 0.8. That is, the questionnaire had considerable reliability, and the content of this questionnaire was comparatively consistent with the investigation of the causes.

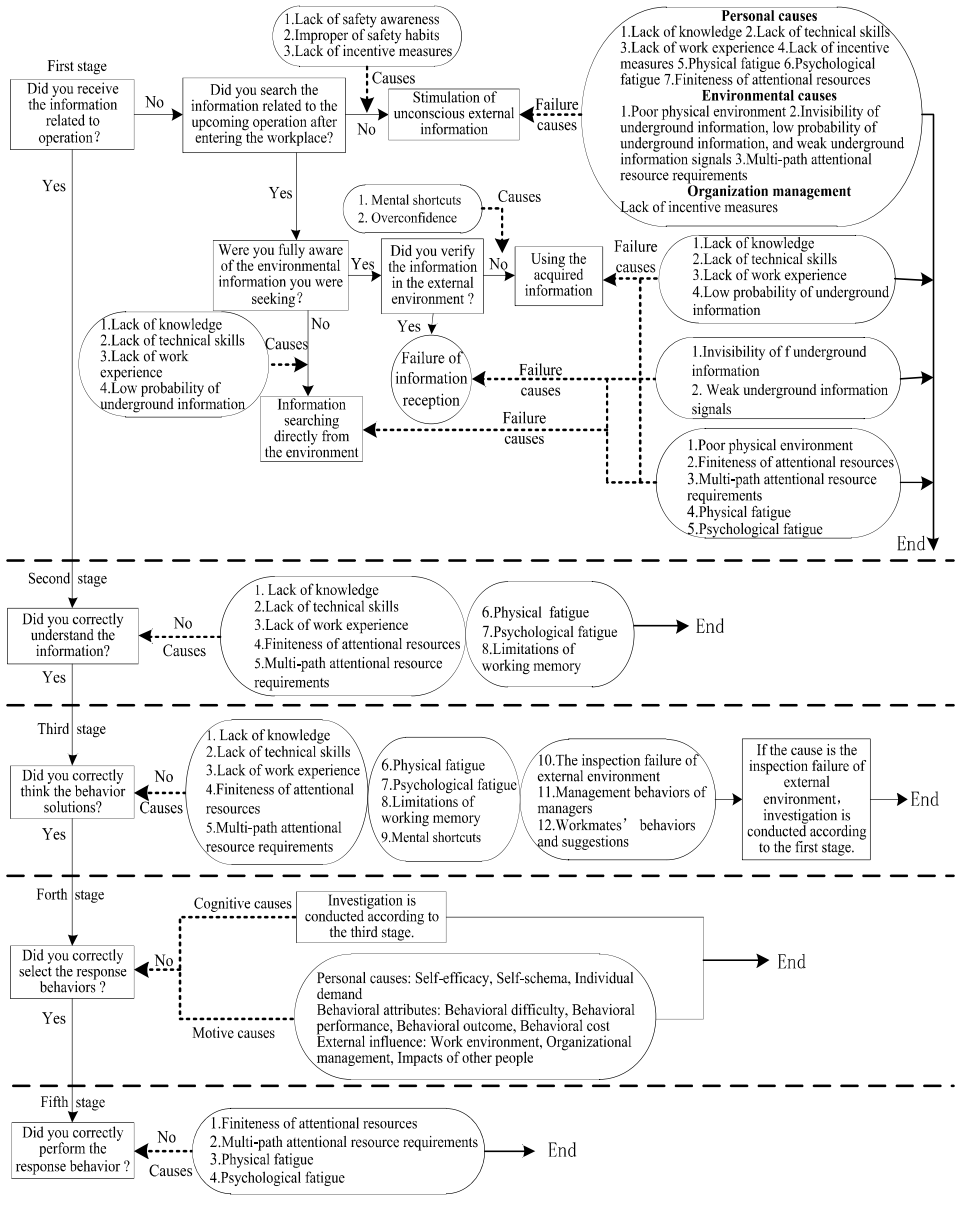

Figure 4. Implementation process and content of the on-site investigation of the causes of coal miners' unsafe behaviors

Validity analysis of questionnaire. This study adopted expert evaluation method to analyze the content validity index of questionnaire items (I-CVI). Six coal mine safety management experts with senior titles were invited (three professors, one researcher, one senior professor, and one senior engineer). Based on the index calculation method of (I-CVI) (Shi, Mo, & Sun, 2012), questions in the questionnaire were evaluated according to strong correlation, correlation, weak correlation, and no correlation. To avoid the consistency of random selection, the adjusted kappa value (K^*) was adopted to revise such consistency (Polit, Beck, & Owen, 2007). The probability value (P_C) was calculated according to Formula (1), which showed that A of all experts (n) agreed correlation. Then, the value of K^* was calculated according to Formula (2).

$$P_C = \left[\frac{n!}{A!(n-A)}\right] \times 0.5^n \tag{1}$$

$$K^* = \frac{(I\text{-}CVI) - P_C}{1 - P_C} \tag{2}$$

In the Formula (2), I-CVI refers to the ratio of the number of experts who selected strong correlation and correlation to all experts (n).

According to the evaluation form of I-CVI (Polit, Beck, & Owen, 2007), the I-CVI index and K^* of this questionnaire were calculated, and the values were greater than 0.74, which attained excellent level. That is, the content validity index of this questionnaire was comparatively high and content validity was good.

Result Analysis and Discussion

Analysis of rationality test

Based on the statistical analysis of the results of on-site investigation, eight unsafe behaviors had relatively high frequency of occurrence (more than 15%). Suitable respondents were selected from the executors of these unsafe behaviors for the investigation, which was implemented according to the process and content of investigation in *Figure 4*. The investigation results are shown in *Table 1*.

Table 1. Investigation results of the causes of unsafe behaviors

Unsafe behaviors	Description of the situation	Hazard	Respondents	Investigation results
i. Coal miners descended into the mine without cap lamps, self-rescuers, safety caps, and tied hatband.	Safety cap was not tied to the hatband.	The unfixed safety cap is unable to protect the head effectively.	Roadway digger	Due to the lack of safety awareness, the coal miner did not effectively receive dangerous information in the external environment. (Failure of information reception stage)
			Electrocar driver	Due to the lack of safety awareness, the coal miner underestimated the dangers of the environment and the role of safety caps. (Failure of response selection stage)
ii. Equipment was not checked, and the records not filled.	The checking of winch was formalistic, and the broken wire was not detected.	The wire is weak and can be easily broken, which leads to sliding down accident.	Winch driver	Due to the lack of safety awareness, the coal miners ignored the importance of safety confirmation, and did not consciously search on dangerous information from the operation environment. (Failure of information reception stage)
	Equipment was not checked, and the slip chain of scraper-trough conveyer was not detected.	The broken chain can easily hurt people.	Scraper-trough conveyer driver	

iii. Safety confirmation was not conducted before operation.	Safety confirmation was not conducted before adding the belt and roller to the head of the belt conveyor	The hidden danger on-site is not confirmed in time, which can easily hurt people.	Mechanics	Due to mental shortcut and overconfidence, previous work experiences were adopted without the verification of on-site environment information. (Failure of response selection stage)
	Safety confirmation was not conducted before handling the broken chain.			
iv. After the support was removed, the feed liquid handle was not returned to zero position or non-use limiter.	After the support was removed, the feed liquid handle was not at zero position.	The support hydraulic system works by itself, as the liquid inlet and return pipes are not closed, it can lead to hurtful accident.	Hydraulic timbermen	In the operation, the coal miner was in poor mental condition and lacked concentration. After finishing the operation, he forgot to put the feed liquid handle back to zero position. (Failure of response execution stage)
	After the support was removed, the feed liquid handle did not return the non-use limiter.	The feed liquid handle is skewed for people walking around and prone to gangue fall.		The coal miner thought the normal operation was finished, and there was no need to use the limiter to avoid the trouble in the next operation and improve operation efficiency. (Failure of response selection stage)

v. The operation site had dangerous rocks and hanging gangue, which when not removed in time would put the coal miner below in a dangerous situation.	The coal miner continued work below dangerous rocks, which were not removed in time.	The surrounding rock can fall and injure people.	Holers	Due to the lack of safety awareness, the coal miner did not check the potentially dangerous information from the operation environment. (Failure of information reception stage)
	The hanging gangue was not removed in time, and the coal miner continued work below.			Due to the lack of safety awareness, the coal miner ignored the detected hanging gangue and did not remove it in time. (Failure of solutions thinking stage)
vi. After the operation of the dig loader, the dig bucket was not moved to the front.	After the operation of the dig loader, the dig bucket was not returned to the front of machine.	When the dig loader starts again, the dig bucket and wire rope are not easy to control and can shake, consequently hurting people.	Dig loader drivers	The coal miner thought the normal operation was finished; hence, he simplified the operation process and did not follow the corresponding procedures. (Failure of response selection stage)
				The coal miner thought omitting the procedure of moving the dig bucket to the front of machine was a small hazard, and improving work efficiency, saving homework time, and getting off work early could be realized. (Failure of response selection stage)

vii. Using the support bolt lifting equipment and hanging sliders without permission.	Supporting bolt and hanging sliders were conducted without permission.	Roof bolt is easy to crack, which can lead to roof failure and hurt people.	Dig loader drivers	The coal miners knew that the operating behavior violated safety operation procedure. However, because of the mental shortcut and workmate's unsafe behavior, they selected unsafe operation behavior. (Failure of response selection stage)
viii. Before and after the blasting, or during the carting of gangue, water was not sprinkled to falling dust, or water sprinkling was unqualified.	Before and after the blasting, water was not sprinkled to fall dust.	The dust concentration in the site is too high, which can lead to explosion accident.	Dust prevention workers	Due to the lack of safety knowledge, the coal miner thought that the blasting was finished and eliminating the procedure of water sprinkling had small hazard. (Failure of solutions thinking stage)
	During the carting of gangue, water sprinkling was unqualified.			The coal miner underestimated the dangers of dust and unsafe behavior. (Failure of response selection stage)

As shown in *Table 1*, the causes of all investigated unsafe behaviors were obtained in this investigation, and coal miners generally reflected that these five stages could embody their psychological processes. That is, starting from the process of cognitive information processing, the causes of coal miners' unsafe behaviors can be found out by looking at the failure stages of information processing and their causes. Hence, the study is scientific, and is a reasonable exploration of the causes of unsafe behaviors from the perspective of cognitive failure.

Analysis of validity test

According to the results of the safety inspection of the Zhaizhen coal mine, the different teams of five major aspects (mining, digging, machine, transportation, and ventilation) were selected to conduct the questionnaire survey. A total of 400 questionnaires were distributed, and 347 questionnaires were returned in which 317 were valid. The recovery rate was 86.75% and the efficient recovery rate was

91.35%. SPSS Statistics 22.0 was used to analyze the survey results, which showed the mean of each cause was between 2.7 and 3.62, and there was only one cause whose mean was below 3. The standard deviation of each cause was between 0.714 and 1.146, and the data were concentrated on the mean. The above results showed the causes were well recognized by the coal miners. The investigation results of all information processing stages are shown in *Figure 5* and the sequence number of causes in *Figure 5* corresponds to the conceptual model in *Figure 3*.

Figure 5. Investigation results of all information processing stages

Information reception stage. As shown in *Figure 5*, multi-path requirements of attentional resources, lack of relevant knowledge, improper safety habits, and lack of work experience and technical skills had a great influence on the information reception stage. In addition, physical and psychological fatigues caused coal miners to deviate from normal state of perception, and the external environmental factors restrained coal miners' perception of information. Mental shortcut, overconfidence of coal miners, and lack of incentive measures affected their effective reception of information.

Information understanding stage. The lack of relevant knowledge and work experience and physical fatigue were the main causes of failure of information understanding stage. Coal miners' correct understanding of information depended on relevant knowledge in long-term memory and their accumulated work experience. At the same time, a normal working state of body was the prerequisite for coal miners to understand information accurately, and thus, physical fatigue could reduce accuracy of information understanding. Lack of technical skills, psychological fatigue, multi-path requirements of attentional resources, limitations of working memory, and attentional resources also influenced the correct understanding of information to a certain extent.

Solutions thinking stage. At the solutions thinking stage, the limitations of working memory, improper safety habits, lack of relevant knowledge and technical skills, invisibility of underground information, low probability of underground information, weak underground information signals, multi-path requirements of attentional resources, lack of work experience, and poor physical environment were the most critical factors. This stage relied on knowledge, accumulated experience, and technical skills stored in long-term memory, and it also depended on the external environment information to verify the accuracy of response behavior. Such situation caused significant demands for working memory and attentional resources. The wrong management behaviors of managers and imperfect incentive measures failed to motivate coal miners to complete information processing. Lack of safety awareness, overconfidence, and mental shortcuts led coal miners to omit verification of environmental information. Physical and psychological fatigues also caused coal miners to deviate from normal thinking state.

Response selection stage. The unsafe behaviors and incorrect suggestions of workmates, behavioral outcome, finiteness of attentional resources, poor physical environment, self-efficacy, physical fatigue, limitations of working memory, mental shortcuts, management behaviors of managers, behavioral performance, and imperfection of specific regulations had great effects on the selection of unsafe behaviors. As the response selection stage required choosing response behavior from the information processing results, coal miners received information (behavior and advice) from workmates at first time, and then the behavioral outcomes and self-assessment were evaluated. The incorrectness of the managers' behaviors and

the imperfection of specific regulations could increase the coal miners' violation of regulations. Besides, the response selection stage depended on relevant external information, which made coal miners require more attentional resources and working memory. The physical fatigue and poor physical environment made it easier for coal miners to produce mental shortcuts.

At the same time, because of the lack of safety awareness and negative self-schema, coal miners were more inclined to choose behaviors less costly in strength, thinking and time to satisfy individual demands. Without the good safety habit of prior confirmation, coal miners selected the response behavior with overconfidence, which resulted in unsafe behaviors that did not meet on-site needs. The limitations of work experience, technical skills, and related knowledge caused coal miners to be more likely to select unsafe behavior, which is easy to enforce. The multi-path requirements of attentional resources and psychological fatigue affected the concentration of coal miners. Invisibility of underground information, low probability of underground information, and weak underground information signals affected their comprehensive inspection of the outside environment. The inadequacy of safety facilities and lack of incentive measures made coal miners more likely coal miners to violate the rules.

Response execution stage. According to the statistical results in *Figure 5*, the finiteness of attentional resources had the most significant impact on the response execution stage. The multi-path requirements of attentional resources occupied the attention resources when the implementation of safe behavior was conducted. Hence, this cause had a significant influence on unsafe behaviors. Physical fatigue and mental shortcut had effects on the response execution because they affected the effective utilization of attentional resources.

Analysis of intervention strategies

Figure 6 shows the statistical results of the combined influence of each cause on unsafe behaviors. Through the analysis of the degree of combined influence, the order of the degree of influence of the four types of causes from large to small was personal causes, environmental causes, organization management, and behavioral attributes.

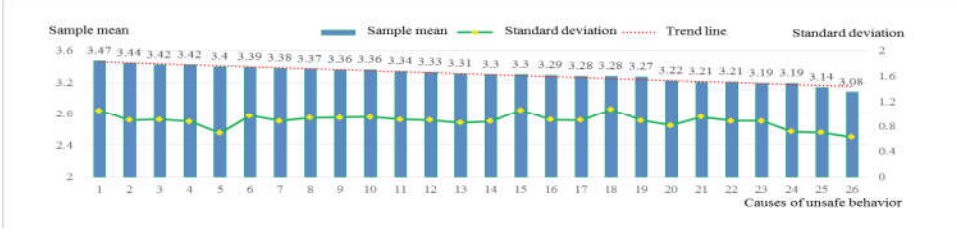

*Figure 6. S*tatistical results of combined influence of causes on unsafe behaviors

Coal miners' personal causes had the largest degree of combined influence. Among these personal causes, lack of knowledge, work experience, and technical skills were the most prominent, and had a considerable effect on the effective reception of information, correct understanding of information, and thinking of corresponding solutions. The physical fatigue of coal miners directly or indirectly had a certain degree of influence on all the information processing stages. Therefore, to reduce difficulty of coal work and fatigue of coal miners, coal mine enterprises need to optimize employment mechanism, improve the level of mechanization of underground mining, arrange the job division and operation schedule reasonably, and improve the proportion of coal miners with rich experience and professional knowledge in frontline positions. Improving safety training mechanism and safety culture can strengthen the related safety knowledge and technical skills of coal miners to improve their ability to work safely and develop their own safety operation habit. At the same time, the above measures can further improve safety awareness and working memory capacity of coal miners, thereby restraining the unsafe behaviors with the efforts of coal miners themselves.

The combined influence of environmental causes on coal miners' unsafe behaviors was profound. Thereinto, the multi-path requirements of attentional resources, management behaviors of managers, invisibility of underground information, low probability of underground information, weak underground information signals, and poor physical environment were the causes that had significant influence on all information processing stages. Therefore, in a poor working environment, coal mine enterprises need to strengthen the safety input of mine cooling, dehumidification, dust prevention, and control of toxic and harmful gas, and to improve lighting conditions in the working area and the safety management capability of managers. In addition, coal mine enterprises should also improve the protection and environment in underground coal mine and reduce the occupation of attentional resources by non-essential operations. At the same time, improving the site management and dangerous information warning system and reducing the hidden space of dangerous information on- site can further ensure the safe operation of coal miners.

Defects in organization management could result in the production of unsafe behaviors, and the behavioral attributes as the reference of behavioral value further affected the coal miners' selection of response behaviors. Under the conditions of imperfect regulations, inadequacy of safety facilities, and lack of incentive measures, coal miners selected behaviors more conducive to their benefits, and thus the complex safe behaviors were replaced by less costly unsafe behaviors with high behavioral performance. Therefore, coal mine enterprises need to improve safety management system, incentive mechanism, and safety production technology and equipment, to further satisfy the physical and psychological needs of coal miners. Then, a positive safety production status of coal miners can be motivated and the atmosphere and habits of safe operation in the group can be formed to promote mutual supervision and motivation among coal miners.

Conclusion

To explore the formation mechanism and intervention paths of coal miners' unsafe behaviors from the perspective of cognition, a concept model of the causes of coal miners' unsafe behaviors was constructed. The model was based on research on the failure mechanism of the information processing of coal miners' operation behaviors, the rationality of the cause analysis method, and the validity of these identified causes from data obtained from respondents from the Zhaizhen coal mine. The main conclusions are as follows:

Exploring the causes of unsafe behaviors from the perspective of cognitive failure is scientific and reasonable. The identified causes have different influences on the information processing stages. The multi-path requirements of attentional resources, lack of relevant knowledge, improper safety habits, and lack of work experience and technical skills have a considerable influence on the information reception stage. Lack of relevant knowledge and work experience and body fatigue are the main causes of the failure at the information understanding stage. For the solutions thinking stage, the limitations of working memory, improper safety habits, lack of relevant knowledge and technical skills, invisibility of underground information, low probability of underground information, weak underground information signals, multi-path requirements of attentional resources, lack of work experience, and poor physical environment are the most critical factors. Unsafe behaviors and incorrect suggestions of workmates, behavioral outcomes, finiteness of attentional resources, poor physical environment, self-efficacy, body fatigue, limitations of working memory, mental shortcuts, management behaviors of managers, behavioral performance, and imperfections of specific regulations all have significant effects on the selection of unsafe behaviors. The finiteness of attentional resources has the greatest impact on the response execution stage.

From the perspective of the combined influence on unsafe behaviors, the influence of coal miners' personal causes is the most profound followed by environmental causes. The influences of organization management and behavioral attributes on unsafe behaviors are relatively small. Coal mine enterprises need to optimize their employment mechanism, improve the level of mechanization of underground mining, reasonably arrange the job division and operation schedule, and improve safety training mechanism and safety culture to restrain unsafe behaviors from the perspective of coal miners themselves. In addition, the safety behaviors of coal miners can be ensured well by improving the safety management capability of managers, strengthening site management and safety protection, and improving the safety management system and incentive mechanism.

This study can obtain the theoretical foundation of intervention for coal miners' unsafe behaviors to a certain extent. While the production environment of coal mines is influenced by many factors, such as society, nature, and humanity and because the analysis results of unsafe behaviors in different visions are different, identified

causes of unsafe behaviors based on cognitive psychology do not necessarily include all causes. However, this limitation does not affect the exploration of the psychological activity of the formation process of coal miners' unsafe behaviors from the perspective of information processing and analysis of the intervention paths. In future research, comprehensive consideration of various factors needs to be conducted to provide more effective and comprehensive intervention strategies of coal miners' unsafe behaviors.

Acknowledgements

The study was supported by the Social Science Research Subject of Dongying (DYSK2017-29).

References

Babette, B. (2015). Behaving safely under pressure: The effects of job demands, resources, and safety climate on employee physical and psychosocial safety behavior. *Journal of Safety Research, 55*, 63-72.

Bergheim, K., Nielsen, M.B., Mearns, K., & Eid, J. (2015). The relationship between psychological capital, job satisfaction, and safety perceptions in the maritime industry. *Safety science*, *74*, 27-36.

Burgess, N., & Hitch, G.J. (2006). A revised model of short-term memory and long-term learning of verbal sequences. *Journal of Memory and Language, 55*(4), 627-652.

Cai, M., & Brown, E.T. (2017). Challenges in the Mining and Utilization of Deep Mineral Resources. *Engineering, 3*(4), 432-433.

Cao, Q.G., Li, K., Liu, Y.J., Sun, Q.H., & Zhang, J. (2012). Risk management and workers' safety behavior control in coal mine. *Safety science*, *50*(4), 909-913.

Cao, Q.R., Li, S., & Song, X.F. (2007). Study on the KAA unsafe behavior mode of coal mine employees. *China Safety Science Journal. 17*(12), 19-25.

Chen, H., Qi, H., Long, R., & Zhang, M. (2012). Research on 10-year tendency of China coal mine accidents and the characteristics of human factors. *Safety Science, 50*(4), 745-750.

Christopher, D., Wickens, J.D., Hollands, S.B., & Raja, P. (2014). *Engineering Psychology & Human Performance*. Beijing: China Machine Press.

Cui, L., Fan, D., Fu, G., & Zhu, C.J. (2013). An integrative model of organizational safety behavior. *Journal of safety research, 45*, 37-46.

Curcuruto, M., Conchie, S.M., Mariani, M.G., & Violante, F.S. (2015). The role of prosocial and proactive safety behaviors in predicting safety performance. *Safety Science, 80*, 317–323.

Franken, R.E. (2006). *Human Motivation.* San Francisco: Wadsworth Publishing.

Furnham, A. (1994). *Personality at work.* London: Routledge.

He, X., & Song, L. (2012). Status and future tasks of coal mining safety in China. *Safety Science, 50*(4), 894-898.

Herbert, W. (2010). *On second thought.* New York: Random House.

Kahneman, D., & Klein, G. (2009). Conditions for intuitive expertise: a failure to disagree. *American psychologist, 64*(6), 515.

Kane, M.J., & Engle, R.W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic bulletin & review, 9*(4), 637-671.

Kines, P. (2003). Case studies of occupational falls from heights: Cognition and behavior in context. *Journal of Safety Research, 34*(3), 263-271.

Liang, N.J. (2014). *Contemporary cognitive psychology.* Shanghai: Shanghai Educational Publishing House.

Li, L. (2016). Research on the importance of influencing factors of employees' unsafe behaviors in coal enterprises. *Technology and Innovation Management*, *37*(4), 397-400.

Li, Y., & Yang, S. (2018). Simulation analysis on unsafe behavior of miners in perspective of behavioral economics. *Journal of Safety Science and Technology*. *14*(1), 18-23.

Liu, S.Y., Chen, L.N., Zhou, P.L., Peng, L., & Fang, Z.X. (2013). Cause analysis and control measures of miners' unsafe behaviors. *Journal of Safety Science and Technology, 9*(1), 158-163.

Lombardi, D.A., Verma, S.K., Brennan, M.J., & Perry, M.J. (2009). Factors influencing worker use of personal protective eyewear. *Accident Analysis & Prevention, 41*(4), 755-762.

Mullen, J. (2004). Investigating factors that influence individual safety behavior at work. *Journal of safety Research, 35*(3), 275-285.

Murray-Johnson, L., Witte, K., Patel, D., Orrego, V., Zuckerman, C., Maxfield, A.M., & Thimons, E.D. (2004). Using the extended parallel process model to prevent noise-induced hearing loss among coal miners in Appalachia. *Health Education & Behavior, 31*(6), 741-755.

Ni, F. (2013). Study on lighting condition and ergonomics in underground coal mine. *Coal Engineering*, *45*(9), 109-111.

Oppenheimer, D.M., & Kelso, E. (2015). Information processing as a paradigm for decision making. *Annual review of psychology,* (66), 277-294.

Paul, P.S. (2013). Investigation of the role of personal factors on work injury in underground mines using structural equation modeling. *International Journal of Mining Science and Technology, 23*(6), 815-819.

Polit, D.F., Beck, C.T., & Owen, S.V. (2007). Is the CVI an acceptable indicator of content validity? Appraisal and recommendations. *Research in nursing & health, 30*(4), 459-467.

Reason, J. (1990). *Human error.* New York: Cambridge University Press.

Seegmiller, J.K., Watson, J.M., & Strayer, D.L. (2011). Individual differences in susceptibility to inattentional blindness. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(3), 785-791.

Shi, J.C., Mo, X.K., & Sun, Z.Q. (2012). Content validity index in scale development. *Journal of Central South University. Medical sciences, 37*(2), 152-155.

Surry, J. (1969). *Industrial accident research: a human engineering appraisal.* Canada: University of Toronto.

Swets, J. A. (1998). Separating discrimination and decision in detection, recognition, and matters of life and death. D. Scarborough, & S. Sternberg*, An invitation to cognitive science, 4*, 635-702.

Tang, X.W., Shui, R.D., Sun, D., & Dai, J.H. (2012). *Introduction to Cognitive Science.* Hangzhou: Zhejiang University press.

Tong, R.P., Li, C.X., & Li, Y. (2015). Research on method for assessing safety management behavior in coal mine. *China Safety Science Journal, 25*(11), 129-133.

Wang, J.F., & Li, W.J. (2002). *Coal accidents and expert review.* Beijing: China Coal Industry Publishing House.

Wang, S.G., Xu, Z., Zhang, T.F., & Liang, Y.T. (2010). Human thermal comfort for mine environment. *Journal of China Coal Society*, *35*(1), 97-100.

Wigfield, A., & Eccles, J.S. (2000). Expectancy–value theory of achievement motivation. *Contemporary educational psychology, 25*(1), 68-81.

Wu, L., & Xing, L.K. (2014). Study on quantitative measurement method of deleterious gases in underground mine using non-dispersive infrared technology. *Journal of Safety Science and Technology, 10*(3), 155-159.

Zhang, B.B. (2014). How coal miners consciously develop the habits of safety production. *China Science and Technology Information,* (2), 147-148.

Zhang, J., & Deng, Q.S. (2015). Research on fuzzy comprehensive evaluation method for safety psychological characteristics of coalmine workers. *Industrial Safety and Environmental Protection, 41*(6), 69-72.

Zhao, J.P. (2014). *Safety man-machine engineering.* Xi'an: Xidian University Press.