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Original Article

Antecedents of self-reported safety behaviors among commissioning workers in nuclear power plants: The roles of demographics, personality traits and safety attitudes

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ABSTRACT

Demographics, personality traits and attitudes are related to safety behaviors in varied workplaces, but their roles in nuclear power plants (NPPs) have not been fully understood. This study was conducted to explore the roles of a set of demographic, personality and attitudinal factors on self-reported safety behaviors (including safety participation and human errors) among NPP commissioning workers. Survey data were collected from 157 Chinese commissioning workers. Results showed that age and work experience were significantly associated with human errors, but not with safety participation. Neuroticism and conscientiousness were significantly related to human errors, while neuroticism, conscientiousness and agreeableness were significantly related to safety participation. Attitude towards questioning was observed as an antecedent of safety participation, and functioned as a mediating variable in the relation between conscientiousness and safety behaviors. The findings provide evidence-based implications on the design of diverse interventions and strategies for the promotion of safety behaviors in NPPs.

1. Introduction

Nuclear accidents can cause huge economic loss and even heavy casualties. Human errors have long been recognized as one of leading causes of nuclear events and accidents [1,2]. Statistics showed that 551 of 940 (59%) nuclear events recorded by World Association of Nuclear Operators (WANO) during 1993–2002 were related to human errors [3]. In China, it was reported that a large proportion of nuclear accidents occurred during 2003–2010 could be accounted for by human errors [4].

Much effort has been made on the investigation of causes of human errors in nuclear power plants (NPPs). The basic causes for human errors and accidents in safety-critical systems like NPPs include unsafe conditions and unsafe behaviors [5]. While unsafe conditions can be attributed to technical-related factors, such as insufficient technology design and poorly maintained equipment, unsafe behaviors may be individual and organizational dependent [6]. Past decades have seen great progress on the reduction of unsafe conditions by developing advanced technologies and on the promotion of safety behaviors by initiating a number of safety interventions within organizations (e.g., creation of safety culture and safety climate) [6,7]. However, human errors, especially those caused by unsafe behaviors, still represent a serious management problem in NPPs. The failure of some safety interventions can be explained by Peltzman's risk-compensation theory [8], which suggests that people will behave less cautiously (i.e., risk-compensation behaviors) if they consider the situation as sufficiently safe or protected. NPPs could be such a situation, as many years of effort may have reinforced workers' perceptions that NPPs are safe enough.

Although risk-compensation behaviors have been well recognized by many other industries (e.g., construction) [9], the underlying factors that may contribute to such unsafe behaviors remain unclear. The extent to which NPP workers may engage in unsafe behaviors, or adhere to safety behaviors, varies with individuals. In practice, records show that certain NPP workers may be more likely to adhere to safety behaviors and thus are less likely to commit human errors. This fact appears to suggest that there are individual factors that predispose some individuals, rather than others, to take

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safety behaviors. There is a critical need to examine the individual factors that are most likely to be linked to these behaviors, so that one can develop effective safety promotion interventions that are able to target high-risk individuals.

Previous studies in many safety-critical industries have suggested that demographics, personality traits and safety attitudes are three types of fundamental individual factors that can lead to human errors and influence safety behaviors [10,11]. Demographics and personality traits may also exert their roles indirectly through safety attitudes [11]. However, their roles in nuclear industry are still not known. Several points should be addressed before the research evidence could be applied to NPP contexts. First, although there are a number of studies potentially relevant to safety behaviors in NPPs, the evidence appears inconclusive and needs further scrutiny. In particular, previous studies have found substantial variability in the effects of demographics and personality traits on safety behaviors and workplace accidents in terms of significance and magnitude [12–19]. This seems to suggest that the effects could be context-dependent and should be examined with full consideration of the contexts where behaviors and accidents occur. Second, previous studies were mostly conducted in non-occupational settings (e.g., driving) or occupational settings such as construction, petrochemical and manufacturing sectors [12,17], with few in NPPs [20]. The findings obtained in these domains might not remain the same in NPPs, as nuclear industry has its unique characteristics featured by highly safety-critical system, extremely complex work procedures and tremendous damage to economy and society upon nuclear accidents [21]. NPP workers may behave differently from workers in other working scenarios. Finally, previous studies have barely endeavored to explore a comprehensive set of individual factors that might serve as antecedents of safety behaviors.

While nuclear industry is particularly understudied in terms of individual factors-safety behaviors associations, the undergoing construction and commissioning of NPPs in China enabled a cross-sectional survey on this issue with a relatively large sample of commissioning workers. Commissioning workers were surveyed because: 1) commissioning is the key phase in NPP construction, aiming at debugging and fixing deficiencies and errors before commercial operation [22], and 2) commissioning workers face great challenges in their work, such as high time pressure, severe work environment, and possible unexpected emergencies. Violation of safety behaviors can be a significant concern, as it can lead to a range of consequences, from minor ones like device malfunction, to severe ones like excessive radiation leakage [23]. Therefore, this study aimed to investigate the roles of a set of individual factors (i.e., demographics, personality traits and safety attitudes) in safety behaviors among Chinese commissioning workers. Identification of the individual factors can help managers and safety educators in NPPs to determine the important personal tendency that may influence behavioral change of the workers. It will also help managers to identify workers most at risk for showing unsafe behaviors, and to develop diverse safety interventions for worker management and new staff recruitment.

2. Literature review

2.1. Demographics and safety behaviors

A number of demographics have been documented to be associated with safety behaviors, such as age, experience, gender, income, education level, marriage status and job position [24,25]. For example, previous studies in coal mining [26], construction [27] and driving [11] have consistently showed that more experienced workers performed better in adhering to safety behaviors and committed fewer errors in their work. It is also reported that age was positively correlated with safety attitudes and safety behaviors among construction workers [27] and gas treatment workers [25]. Female drivers would pose a greater unsafety behavioral risk of road rage perpetration than male drivers [28]. Low income drivers exhibited more unsafety behaviors [29]. Some studies also found that job position could affect safety attitudes and safety behaviors for workers in petrochemical plants [30]. However, how demographics are related to safety behaviors in nuclear industry seems unknown. In light of this, this study contributes to the existing literature by examining the roles of multiple demographic factors in safety behaviors, including age, working experience, education level, and marriage status. Gender was not included, as NPP workers are mostly males.

2.2. Personality traits and safety behaviors

Personality traits refer to consistent and stable behavioral patterns that an individual holds at different times and situations [31,32]. In 1960s, researchers already noted the role of personality in safety driving behaviors [33]. Later studies have made much effort to examine the association between personality and safety behaviors. For example, studies suggest that personality traits of conscientiousness and agreeableness were positively associated with safety behaviors for high-speed railway drivers and construction workers [14,18]. Pilots with high levels of risk perception could be an effective predictor of safety operation behaviors [10]. Paul and Maiti [19] found that personality traits such as impulsivity, risk-taking and negative affectivity had negative associations with unsafety behaviors by mine workers. Previous studies also showed that personality traits can affect safety attitudes and subsequently influence safety behaviors [10,14–16,18,34–36]. For example, traffic offenders with high-risk personality were positively associated with unsafety attitudes (e.g., risky attitude towards drunk driving) [37]. Rau et al. [13] found that conscientiousness could positively predict elevator workers' safety attitudes. Drivers high in anxiety and low in hostility and normlessness exerted more positive attitude towards traffic safety, which in turn lead to fewer unsafety behaviors such as violations, lapses, and errors [38]. Ulleberg and Rundmo [16] suggested that the relationship between personality traits and unsafe driving behaviors was mediated by attitude towards traffic safety.

Big Five Personality Model is a well-recognized classification method for personality structure [31,32], whose validity and reliability have been consistently confirmed by a wide range of studies [12,14,15]. Our study also adopted Big Five Personality Model to assess personality traits. This model describes personality with five dimensions, including conscientiousness, neuroticism, agreeableness, openness to experience and extraversion [31].

Conscientiousness reflects a competent, dutiful and deliberate personality [31,32]. A positive correlation between conscientiousness and safety behaviors has been well documented in previous studies [14,39,40]. Conscientiousness could significantly predict safety compliance among high speed railway drivers [40]. Conscientious individuals are more likely to exhibit safety attitudes and safety behaviors, as characterized by adequate reflection on task processes, goal-setting and following rules and regulations [41]. Conscientiousness is negatively related to the occurrence of accidents among workers in chemical factories [39].

Neuroticism reflects an individual's emotional regulation and tendency to experience negative attitudes and emotional instability [31,32]. Neurotic people are more likely to show anxiety, hostility, impatience, depression, moodiness and impulsiveness [31,32]. They focus more on their own anxieties and worries and are hard for emotional regulation, so that they are more likely to get

distracted from tasks at hand [12]. A number of studies have indicated negative relationships among neuroticism, safety behaviors [42], human errors [43] and accident involvement [44].

Agreeableness is characterized by a tendency to be pleasant, tolerant, tactful and generally easy to get along with [31]. Agreeableness can be related to accidents in occupational settings involving interpersonal relations [12,14]. Agreeable individuals are more likely to develop positive attitudes to cooperate with others and to behave safely, thus reducing the likelihood of human errors [12,18]. Previous studies reported that agreeableness was associated with safety attitudes and safety behaviors in a wide range of industries, such as high-speed railway industries [14] and constructions [18].

Extraversion is a personality trait that reflects a tendency to be enthusiastic, social, decisive, active, adventurous and optimistic [31]. The literature provides inconsistent evidence on the relationship between extroversion and safety behaviors [12]. While some studies reported a negative relationship [40,45], others found a positive relationship [14]. For example, Guo et al. [14] found that people high in extroversion were more likely to take risky attitudes while driving and were more likely to engage in dangerous behaviors that led to accidents. In contrast, Chu et al. [40] found that extraversion was positively correlated with safety participation among high-speed railway drivers.

Openness to experience (or openness in short) refers to an individual's tendency to be imaginative, curious and broadminded [31,32]. Openness had less been examined compared with other personality dimensions [12]. While some reviews [31] showed that people high in openness were more likely to take positive attitudes towards their work and were more desirable to develop well-trained workforce, others found that individuals with openness were more likely to violate rules [12]. Therefore, the role of openness in safety behaviors seems unclear, and deserves further exploration, especially in NPP context.

2.3. Safety attitudes and safety behaviors

Attitudes can be described as "tendencies to evaluate an entity with some degree of favor or disfavor, ordinarily expressed in cognitive, affective and behavioral responses" [46]. Several social cognitive theories (e.g., The theory of reasoned action (TRA) [47] and the theory of planned behavior (TPB) [48] have explained the relationship between attitude and behavior, and argue that attitude is a direct antecedent of behavior. Similarly, safety attitudes are found to influence safety behaviors. For example, attitudes towards traffic safety were found to be related to risky driving behavior [16]. Iversen [49] examined three types of safety attitudes (i.e., attitude towards rule violations and speeding, attitude towards the careless driving of others, and attitude towards drinking and driving), and found that all the safety attitudes were associated with safety driving behaviors. Rau found that safety attitudes had a direct impact on compliant safety behaviors among elevator workers [13]. In addition, attitudes were also found to be able to mediate the relationships between demographics, personality traits and safety behaviors [13,15,16,38]. Therefore, this study was also aimed to examine the extent to which safety attitudes exerted influence on safety behaviors over and above demographics and personality traits.

3. Methods

3.1. Participants

Participants were recruited from commissioning departments of three NNPs managed by China General Nuclear Power Corporation (CGN), the largest nuclear power operator in China and also the largest nuclear power constructor worldwide [50]. It has been making every possible endeavor to ensure nuclear safety and promote safe behaviors in all of its affiliating NPPs. One hundred and fifty-seven male nuclear commissioning workers participated in this study. It should be noted that there were almost no female commissioning workers in these NPPs, as females usually could not afford the commissioning work, which was characterized by high physical workload and severe environment. Thus, no female workers were included in this study. After eliminating 3 incomplete samples, we obtained 154 valid samples for data analysis. The research was approved by the Institutional Review Board of Shenzhen University and CGN. The characteristics of the sample are presented in Table 1.

3.2. Procedures

Four trained research assistants visited all commissioning workers' offices in unrestricted areas of the NNPs during July and August 2019 and invited them to complete a paper-based questionnaire. In order to reduce possible biased responses, participants were explicitly informed that the questionnaire was answered anonymously and their responses would not be known by their supervisors; that their personal information would be kept secret and used for research purpose only; and that they should respond carefully and honestly to questionnaire items. It took approximately 15 min to complete the questionnaire. All participants gave informed consent. Then, they were asked to complete the questionnaire independently. It took approximately 15 min to complete the questionnaire.

3.3. Instruments

The questionnaire was designed after an extensive review of the literature and revised through multiple rounds of pilot tests with nuclear power plant commissioning staffs, which was conducted to improve the clarity and validity of questionnaire. We also consulted four human factors experts and three nuclear safety experts to guarantee the quality of the questionnaire. Necessary revisions

Table 1
The characteristics of the sample (N = 154).

Characteristics	N	%
Age		
25–35 years	124	80.5%
36–45 years	26	16.9%
46–55 years	4	2.6%
Education level		
College or below	10	6.5%
Bachelor	129	83.8%
Postgraduate	15	9.7%
Marriage status		
Unmarried	40	25.9%
Married	113	73.4%
Divorced	1	0.7%
Type of expertise		
Technical management	22	14.3%
Electrical commissioning	25	16.2%
Conventional Island and BOP Commissioning	31	20.1%
Instrument control commissioning	33	21.4%
Nuclear island commissioning	36	23.4%
Others	7	4.6%
Work experience		
Less than 5 years	25	16.2%
6–10 years	107	69.5%
More than 10 years	22	14.3%

Note: BOP = balance of plant.

were made on some items to improve fit of questionnaire to the specific situation of this study. The questionnaire consisted of items asking participants' demographic information and scales measuring personality traits, safety attitudes and safety behaviors. Scale items were rated with a 5-point Likert scale, ranging from 1-strongly disagree to 5-strongly agree for personality traits and safety attitudes, and from 1-never to 5-always for safety behaviors. Consistency reliability of all the scales was acceptable based on a minimal threshold of 0.6, as suggested by Taber [51]. Table 2 shows the examples, sources and reliability coefficients of scale items (Appendix A shows the detailed list of scale items).

3.3.1. Demographic information

Demographic information collected included age, gender, education level, marriage status, occupational division and work experience.

3.3.2. Personality traits

Personality traits were measured by a Chinese version of Big Five Personality Inventory (CBF-PI), whose validity and reliability have been confirmed among Chinese population [52]. The CBF-PI consisted of five 6-item subscales assessing five personality dimensions: extraversion, neuroticism, conscientiousness, agreeableness and openness to experience. A higher score indicated that the person was high in the personality trait.

3.3.3. Safety attitudes

Safety attitudes were assessed with two dimensions, i.e., violation attitude (a negative indicator) and questioning attitude (a positive indicator), which were considered as critical attitudinal factors related to safety behaviors and accident occurrence after discussion with managers in commissioning departments. Attitude towards violation was measured by a 4-item scale that was derived from a previous study on safety behaviors [49]. Attitude towards questioning was measured by a 3-item scale that was currently used in NPP practice, whose validity was practically verified, and was confirmed by commissioning managers. Higher scores indicated higher levels of attitudinal agreement towards violation and questioning.

3.3.4. Safety behaviors

Safety behaviors were assessed by self-reported frequency of human errors (a negative indicator) and safety participation behavior (a positive indicator). Human errors included memory errors, disturbance-related errors, misinterpretations and/or loss of important information that occurred in daily work. A 4-item scale derived from a previous study on work performance in nuclear power plants [1] was adopted to measure human errors. Safety participation reflects workers' actual behaviors that they voluntarily or proactively execute to improve safety within the workplace setting [53]. Safety participation was measured by a 3-item scale that was adopted from Neal et al.'s safety participation scale [54]. Higher scores for the scales indicated more errors and higher levels of safety participation, respectively.

3.4. Data analysis

Pearson's bivariate correlation analyses were conducted to determine intercorrelations among demographics, personality traits, safety attitudes and safety behaviors. Initially, we examined five demographics, including age, education level, work experience, type of expertise and marriage status (Gender was not examined, as all the participants were males). However, education level, type of expertise and marriage status were not significantly related to any of safety attitudes and safety behaviors. Therefore, they were excluded in our final analysis. Two separate hierarchical regression analyses were performed to examine whether demographics (i.e., age and work experience) and personality traits predicted the two safety attitudes dimensions, respectively. Another two hierarchical regression analyses were performed to examine whether the two safety attitudes dimensions predicted two types of safety behaviors, respectively, over and above demographics and personality traits. The hierarchical regression analyses were conducted by entering demographics in the first step, personality traits in the second step, and safety attitudes in the third step. The goodness of fit of the tested regression models was evaluated by the coefficient of determination (i.e., R-squared), which represents the percentage of dependent variables that could be explained by independent variables, and was visually examined by residual plots. The change of R-square was used to weigh the relative impacts of predictor variables. Before conducting the regression analyses, the variance inflation factor (VIF) and tolerance value were calculated to quantify the severity of multicollinearity. Multicollinearity was considered absent if VIF values were less than 5.0 and tolerance values were greater than 0.10 for the variables in regression models [55].

4. Results

4.1. Associations among major variables

Table 3 shows descriptive characteristics of and correlations among predictive variables and dependent variables. The major predictive variables were slightly or moderately correlated, indicating an acceptable degree of multicollinearity among the

Table 2
Examples, sources and reliability coefficients of the scale items.

Constructs	Number of scale items	Examples of scale items	Reliability coefficients	Sources
Extraversion	6	I enjoy attending social and recreational parties.	0.80	Wang et al., 2011 [52]
Neuroticism	6	I often feel afraid.	0.79	Wang et al., 2011 [52]
Conscientiousness	6	I like to plan things out right from the beginning.	0.78	Wang et al., 2011 [52]
Agreeableness	6	I often feel sorry for those who suffer misfortune.	0.64	Wang et al., 2011 [52]
Openness	6	I like adventure.	0.82	Wang et al., 2011 [52]
Attitude towards violation	4	It is acceptable to ignore regulations or rules to proceed faster.	0.74	Iversen, 2004 [49]
Attitude towards questioning	3	I should question coworkers' behaviors if such behaviors are considered to present threat to safety.	0.71	Adapted from scale items currently used in NPP practice
Human errors	4	Forgot to perform an operation in a sequence of operations that I planned to carry through.	0.78	Kecklund and Svenson, 1997 [1]
Safety participation	3	I voluntarily carried out activities and proposed suggestions that helped to improve workplace safety.	0.68	Neal et al., 2000 [54]

Table 3
Descriptive characteristics of and correlations among major variables.

	1	2	3	4	5	6	7	8	9	10	11
1. Age (year)	1										
2. Work experience (year)	0.59**	1									
3. Neuroticism	−0.14	−0.11	1								
4. Conscientiousness	0.08	0.11	−0.22**	1							
5. Agreeableness	0.09	0.21**	−0.31**	0.41**	1						
6. Openness	−0.07	−0.08	−0.14	0.45**	0.21**	1					
7. Extraversion	−0.09	−0.14	−0.32**	0.26**	0.20*	0.46**	1				
8. Attitude towards violation	−0.17*	−0.12	0.24**	−0.39**	−0.29**	−0.27**	−0.22**	1			
9. Attitude towards questioning	0.09	0.10	−0.26**	0.43**	0.34**	0.24**	0.28**	−0.44**	1		
10. Safety participation	0.09	0.03	−0.30**	0.48**	0.44**	0.35**	0.38**	−0.43**	0.58**	1	
11. Human errors	−0.11	0.05	0.37**	−0.34**	−0.31**	−0.23**	−0.21*	0.33**	−0.30**	−0.39**	1
Mean	32.55	7.71	2.46	4.05	3.74	3.49	3.25	3.95	3.96	3.93	3.93
SD	4.77	5.79	0.34	0.19	0.18	0.24	0.26	0.34	0.25	0.21	0.24

*p < 0.05; **p < 0.01.

Table 4
Multicollinearity analysis of independent variables.

Variables	Tolerance	Variance inflation factors
Age	0.634	1.578
Work experience	0.612	1.635
Neuroticism	0.797	1.255
Conscientiousness	0.620	1.614
Agreeableness	0.734	1.362
Openness to experience	0.655	1.527
Extraversion	0.678	1.474
Attitude towards violation	0.724	1.382
Attitude towards questioning	0.692	1.445

predictors. Table 4 shows the VIF and tolerance values of the examined variables. VIF values ranged from 1.255 to 1.635, and tolerance values ranged from 0.612 to 0.797. Therefore, multicollinearity would not be a concern for variables examined in this study.

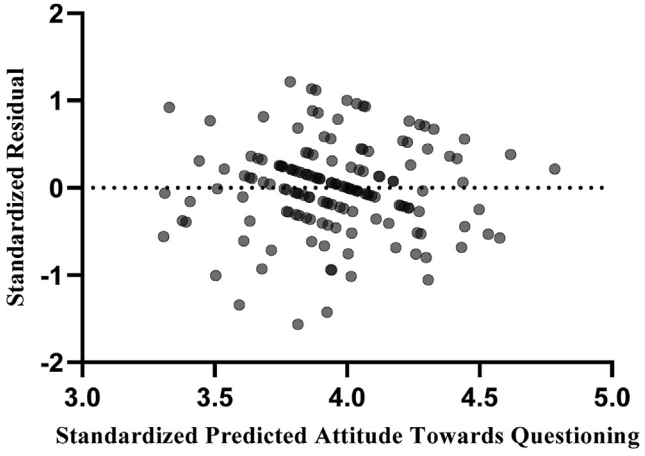

Fig. 1. Residual plot for hierarchical regression on attitude towards questioning.

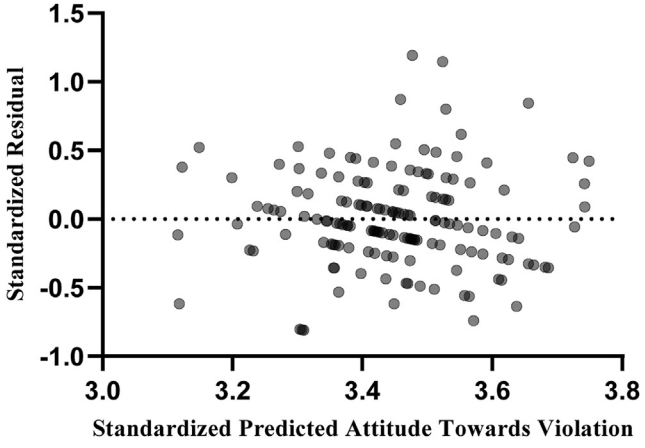

Fig. 2. Residual plot for hierarchical regression on attitude towards violation.

4.2. Hierarchical regression analysis results

Figs. 1–4 illustrate the residual plots for the last step of hierarchical regression models for attitude towards violation, attitude towards questioning, human errors and safety participation, respectively. It showed that the residuals were randomly distributed around the zero line, indicating the appropriateness of the hierarchical regression models.

Table 5 presents hierarchical regression analysis results estimating the effects of predicted variables on attitude towards violation and attitude towards questioning. In the first step, age and work experience could explain 1.1% of the variance in attitude towards questioning, and 2.8% of the variance in attitude towards violation. Both age and work experience were not significantly related to attitude towards questioning and attitude towards violation. In the second step, the Big Five personality traits were entered into the regression model. Inclusion of Big Five personality traits made a significant additional contribution to the variance of attitude towards violation ($\Delta R^2 = 0.19$) and attitude towards questioning ($\Delta R^2 = 0.24$). Specifically, conscientiousness negatively affected attitude towards violation ($\beta = -0.25$, $p < 0.05$), while it ($\beta = 0.30$, $p = 0.05$) was a positive predictor of attitude towards questioning. Table 2 also shows that Big Five personality traits, together with age and work experience, explained 25.2% of the variance in attitude towards questioning, and 21.8% of the variance in attitude towards violation.

Table 6 presents hierarchical regression analysis results estimating the effects of predictor variables on human errors and safety participation. In the first step, age was negatively related to human errors ($\beta = -0.21$, $p < 0.05$). In the second step, inclusion of Big Five personality traits made a significant additional contribution to the variance in human errors ($\Delta R^2 = 0.23$) and safety participation ($\Delta R^2 = 0.37$). Specifically, human errors were positively predicted by neuroticism ($\beta = 0.28$, $p < 0.05$) and negatively

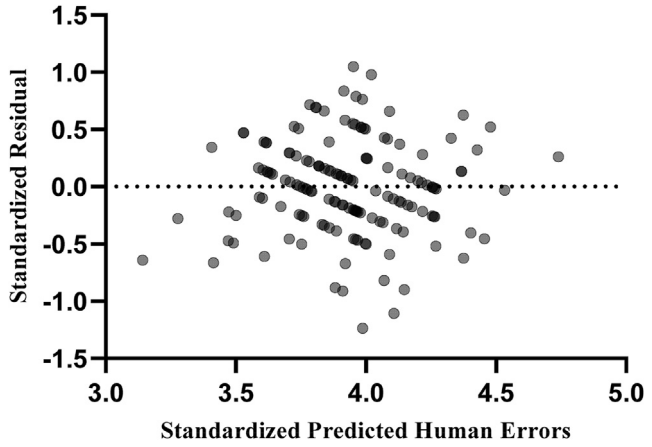

Fig. 3. Residual plot for hierarchical regression on human errors.

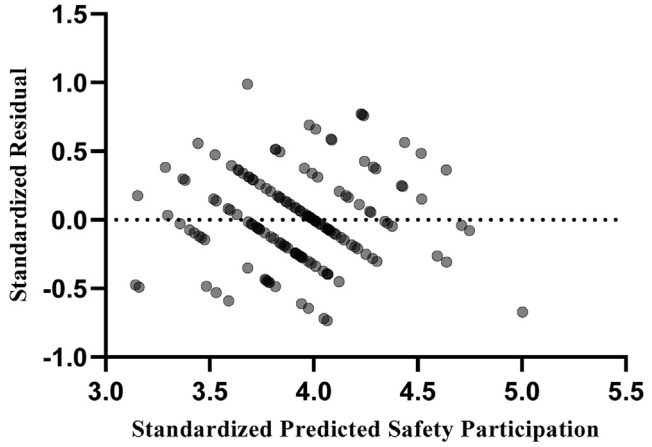

Fig. 4. Residual plot for hierarchical regression on safety participation.

Table 5
Hierarchical regression results on attitude towards questioning and attitude towards violation.

	Attitude towards questioning		Attitude towards violation	
	Step 1	Step 2	Step 1	Step 2
Age	0.047	0.037	−0.141	−0.133
Work experience	0.071	0.024	−0.041	−0.003
Neuroticism		−0.093		0.100
Conscientiousness		0.304*		−0.249*
Agreeableness		0.152		−0.112
Openness		−0.008		−0.096
Extraversion		0.152		−0.073
R^2	0.011	0.252	0.028	0.218
ΔR^2	0.011	0.241	0.028	0.190
ΔF	0.851	9.394***	2.190	7.086***

*p < 0.05; **p < 0.01; ***p < 0.001.

predicted by conscientiousness (β = - 0.20, p < 0.05). Conscientiousness (β = 0.28, p < 0.01), agreeableness (β = 0.26, p < 0.01) and extraversion (β = 0.19, p < 0.01) positively affected safety participation. Inclusion of attitude towards violation and attitude towards questioning made a further significant contribution to the variance in safety participation (ΔR^2 = 0.12). Attitude towards questioning significantly predicted safety participation (β = 0.35, p < 0.001). However, the predictive role of age on human errors turned non-significant, while the predictive role of work experience on human errors turned significant (β = 0.24, p < 0.01). In summary, the integration of age, work experience, Big Five personality traits and attitudinal dimensions accounted for 28.7% of the variance in human errors and for 49.3% of the variance in safety participation.

5. Discussion

While safety behaviors have always been one of the top concerns in nuclear safety management, its determinants, especially those individual-related, have not been well investigated. The purpose of this study was to examine the roles of individual factors in self-reported safety behaviors among Chinese commissioning workers in NPPs. The results clarified the roles of a set of demographic, personality and attitudinal factors in self-reported safety behaviors in NPP settings.

5.1. Demographics and safety behaviors

The results showed that, among the examined demographics, both age and work experience exerted effects on safety behaviors, but in opposite directions. This finding, though appearing counterintuitive, seems to suggest that age and work experience act independently in influencing safety behaviors and cannot be considered as the same, as did in many practical scenarios. In fact, older workers do not necessarily have longer work experience in NPPs. Specifically, age had a negative effect on human errors. It means that younger workers are more likely to commit human errors. This is consistent with previous studies, which showed that age was inversely proportional to human errors and microaccidents [25,56]. Similarly, previous studies also found that younger workers reported less safety compliance and more safety neglect in workplace [24,56]. These findings, together with ours, may present a significant concern for safety management of younger workers, as they usually work in the front line and are more likely exposed to unsafe working conditions.

Interestingly, work experience was positively correlated with human errors. The finding is congruent with previous studies in other occupational settings (e.g., construction workers [9]). One possible explanation may be that more experienced workers are overconfident on their safety skills and ability, and tend to have lower risk perceptions on safety issues. Thus, they are more likely to develop so called risk-compensation behaviors and make mistakes in workplace [9]. In fact, overconfidence and risk-compensation behaviors have been recognized as one of important causes for human errors [2,9]. Therefore, necessary precautions should be carried out to reduce human errors caused by overconfidence and risk-compensation behaviors.

5.2. Personality traits and safety behaviors

While most of previous studies examined the role of personality traits in driving behaviors [11,12,14,57], our study contributed to the literature by clarifying and emphasizing the role of Big Five personality traits in safety behaviors in a typical safety-critical occupational setting (i.e., NPPs), which suggests a mechanism for safety management from personality perspective in NPPs. Compared with previous empirical and meta-analysis studies [6,12,57–59], our findings show that there are both similarities and differences in the roles of personality traits and safety attitudes on safety behaviors (Table 7).

Our study found that neuroticism was shown to be positively related to human errors. This finding is consistent with previous meta-analysis studies [6,57,59]. For example, both Christian et al.

Table 6
Hierarchical regression results on human errors and safety participation.

	Human errors			Safety participation		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Age	−0.209*	−0.182*	−0.160	0.104	0.104	0.076
Work experience	0.168	0.234*	0.237**	−0.027	−0.087	−0.095
Neuroticism		0.276*	0.254**		−0.083	−0.040
Conscientiousness		−0.202*	−0.144		0.278**	0.145
Agreeableness		−0.161	−0.133		0.260**	0.194**
Openness		−0.065	−0.052		0.073	0.065
Extraversion		0.016	0.038		0.188*	0.128
Attitude towards violation			0.141			−0.114
Attitude towards questioning			−0.076			0.346***
R^2	0.031	0.263	0.287	0.008	0.377	0.493
ΔR^2	0.031	0.232	0.024	0.008	0.369	0.116
ΔF	2.379	9.200***	2.462	0.630	17.271***	16.532***

*p < 0.05; **p < 0.01; ***p < 0.001.

[6] and Clarke and Robertson [59] found a positive relation between neuroticism and accident involvement across varied workplace contexts, while Akbari et al. [57] reported a positive relation between neuroticism and risky driving behaviors. It is well-known that neurotic people are often impatient, anxious and irritated [12,31]. Thus, they might be easily occupied by worry and anxiety, and are more likely to be distracted from their tasks, which results in a high chance of committing errors and involving in accidents.

Conscientiousness was shown to be a significant antecedent of both safety attitudes and safety behaviors among commissioning workers. In particular, conscientiousness was negatively correlated with human errors and positively correlated with safety participation. The finding is in line with previous studies in both occupational (e.g., process control and construction) and non-occupational settings (e.g., driving) [13,14,39,40]. Several meta-analysis studies also suggest that conscientiousness strongly correlated with safety-related behaviors in workplace contexts [6,58], and led to less accident involvement [6,12,59] in both workplace and driving contexts. On the one hand, conscientious workers are characterized by a high degree of self-discipline and are more willing to take their responsibilities, such as compliantly adhere to rules for workplace safety [60]. On the other hand, conscientious workers would take proactively measures to improve workplace safety, as they tend to well plan and organize their own work in advance [13]. Such behavioral tendency is in line with the so-called “requirement communication and confirmation meeting before work” that are widely employed in many NPPs. Therefore, they are more likely to behave safely.

The role of conscientiousness on safety behaviors appeared to be partially mediated by safety attitudes, as showed by the results that the effects of conscientiousness on safety behaviors turned non-significant when safety attitudes were added in the regression model. Conscientiousness was positively related to attitude towards questioning and negatively related to attitude towards violation. It means that conscientious workers tended to be more serious about safety and less tolerant to violation, and thus are more likely to be engaged in safety behaviors.

Agreeableness was positively related to safety participation, consistent with previous empirical studies [10,15,40]. In contrast, agreeableness was also shown to be negatively related to accident involvement in workplace settings [59]. It is likely that agreeable people who are considerate and care about others are more willing to communication with their colleagues in workplace, which is likely to reduce safety risk due to misunderstanding and misinterpretation of regulations and operational procedures. Particularly, in NPP work scenarios, it is highly recommended that workers should confirm their operations repeatedly with relevant colleagues. In this case, agreeable people would act better in safety participation.

Our study found no effects of openness either on safety attitudes or on safety behaviors. While openness has less been examined in previous studies, the literature shows that the effects of openness on safety attitudes and safety behaviors have been mixed: it could be positive [31], non-existent [34,61], or negative [12]. Likely, previous meta-analysis studies also failed to demonstrate validity generalization for the relationship between openness and safety behaviors [12,57,59]. It might indicate that the effects of openness could be limited, but this speculation awaits confirmation by future studies.

The result showed that extraversion had a significant relationship with safety participation, but the relationship turned non-significant when safety attitudes were considered. It may indicate that the roles of extraversion could be partially explained by safety attitudes. Extrovert workers are more likely to initiate dialogue and open communication in workplace, and therefore play an active role in safety attitudes and safety participation, similar with the way performed by agreeable workers. However, this is not always the case. Previous studies found that extroverts performed worse in safety behaviors and accident avoidance among drivers [12,40], as extroverts are unstable in their behavioral pattern, and tend to be risk takers, which is more likely to behave unsafely. Therefore, more research efforts should be required before conclusion could be made on whether or not extraversion acts as a risky personality in NPP context.

5.3. Safety attitudes and safety behaviors

Attitude is perhaps one of the most widely examined factors in relation to safety behaviors. A convincing amount of research has confirmed that attitude is a direct antecedent of safety behaviors across varied occupational and non-occupational settings [13,16,27,49,62]. For example, a previous meta-analysis indicated that job attitude could predict safety compliance and safety participation behaviors [6]. In the present study, however, we only observed a significant relationship between attitude towards questioning and safety participation. One plausible reason may be that our study examined different types of safety attitudes from previous ones. While most of previous studies examined an overall safety attitudes [13,16,62], our study examined two of its subtypes, attitude towards questioning and attitude towards violation, both of which were pertinent to safety management in commissioning work in NPPs. Iversen [49] examined three types of safety attitudes (i.e., attitude towards rule violations and speeding, attitude towards the careless driving of others, and attitude towards drinking

Table 7
Comparison of results from our study with that from previous meta-analysis studies on relationships between personality, attitudes, safety behaviors and involvement of accidents/human errors.

Studies	Contexts	Outcome measures	Extraversion			Neuroticism			Openness			Conscientiousness			Agreeableness			Safety attitudes		
			N	n	r	N	n	r	N	n	r	N	n	r	N	n	r	N	n	r
Akbari et al., 2019	Driving	Risky driving behaviors	10	2509	−0.01	16	5820	0.16*	8	2209	−0.06	17	10,105	−0.05	14	5044	−0.27*			
Beus et al., 2015	Overall	Unsafe behaviors	14	3851	0.08	17	3498	0.15*				10	2898	−0.23*						
Beus et al., 2015	Overall	Safety behaviors	4	2488	0.13	5	864	−0.11				8	1636	0.32*						
Christian et al., 2009	Workplace	Safety behaviors										5	1317	0.18*				4	924	0.25*
The present study	Nuclear workplace	Safety behaviors	1	154	0.13	1	154	−0.04	1	154	0.07	1	154	0.15	1	154	0.19*	1	154	0.35*
Christian et al., 2009	Workplace	Accident involvement	5	2083	−0.06	12	5129	0.15*				4	852	−0.22*						
Clarke and Robertson, 2008	Workplace	Accident involvement	16	2137	0.02	13	1934	0.30*	7	570	0.50*	10	1290	−0.31*	8	715	−0.44*			
Clarke and Robertson, 2005	Driving	Accident involvement	16	4424	0.24*	8	1460	0.10	3	577	0.13	9	3425	−0.26*	7	3108	−0.22*			
The present study	Nuclear workplace	Human errors	1	154	0.04	1	154	0.25*	1	154	−0.05	1	154	−0.14	1	154	−0.13	1	154	−0.08

* This symbol indicates a statistically significant relationship. N, The number of studies. n, The number of participants.

and driving) in their driving behavior study, and found that the three types of safety attitude exerted varied effects on safety driving behaviors. Similarly, Siu et al. [27] examined 12 subtypes of safety attitudes in relation to safety performance in construction workers, and found that only 4 types of safety attitudes were associated with safety performance. These findings seem to suggest that there are indeed different aspects of attitudes, which are likely to have different relations with safety behaviors. As personality traits are usually stable and difficult to change, strategies to promote safety behaviors could be targeted at changing workers' safety attitudes. Therefore, the examination of specific types of safety attitudes is helpful, or even necessary, as it is able to provide specific evidence, based on which, effective measures can be designed to target the most relevant attitude aspects for safety improvement.

5.4. Theoretical and practical implications

Our study has both theoretical and practical implications. Theoretically, our study provides a comprehensive understanding of the roles of demographics, personality traits and safety attitudes in safety behaviors among NPP commissioning workers. The inclusion of the three types of factors helps establish a complete framework to examine antecedents of safety behaviors from individual side. Remarkably, these factors included not only variables that are independent of work scenarios (e.g., demographics and personality), but also variables that might be highly influenced by safety culture and safety climate within the organization. Future studies are advised to incorporate both individual and organizational factors to achieve more integrative explanation of safety behaviors in NPP context.

From a practical point of view, our findings suggest that we should consider the influence of demographics, personality and attitudes in safety management in NPP context. Safety managers should also be aware of specific demographic, personality and attitudinal factors that are related to safety behaviors, so that they can design specific measures and educational programs, and prioritize resources for effective safety improvement. Although causal relationships between examined factors were difficult to determine from the cross-sectional survey in our study, there are widely recognized theoretical consensus on considering personality traits as exogenous variables in behavior research, as personality traits are considered relatively stable across time [16]. It is believed that personality traits are basic and fundamental in nature compared with attitudes that may change over time. Likely, age and work experience could inevitably increase over time. Therefore, safety managers are advised to diversify their strategies in response to the nature and roles of the factors.

Specifically, psychological selection can be carried out in the recruitment of new workers in nuclear industry to ensure that suitable workers are selected so as to minimize possible unsafety behaviors and errors from human side. Conscientious and agreeable workers should be preferred as they will hold more serious attitudes towards safety, tend to be more active in safety participation and are less likely to be involved in human errors. In addition, interventions should not be aimed at changing unfavorable personality traits into favorable ones, which surely would have little effectiveness and be a waste of resources. Instead, interventions to change and reinforce workers' positive attitude towards questioning would be more effective. Moreover, managers should not feel frustrated for personality traits that are not related to any safety attitudes and safety behaviors. While our study has identified such personality traits, strategies can be designed to let workers with these personality traits find out effective ways for attitudinal and behavioral change themselves.

The strategy that letting people figure out their own ways for behavioral change has been previously successfully applied in safety interventions among professional drivers [63]. However, this strategy has not yet been employed in commissioning work in NPPs and its effectiveness deserves confirmation by future studies. Finally, managers are also recommended to pay close attention to experienced workers and monitor their behavioral pattern regularly. Longitudinal measures seem especially important for them to prevent them from developing unnecessary overconfidence and risk-compensation behaviors.

5.5. Limitations

This study has several limitations. First, although self-report measures of safety behaviors appear intuitively plausible, such measures might be subject to biases due to respondents' tendency to respond in a socially desired manner (e.g., report more conservatively). Thus, responses in the survey may be conservative compared with actual behaviors, especially for sensitive information such as human errors committed, even though we have guaranteed the anonymous and confidential nature of the survey in order to obtain reliable data. This may have led to the large portion of neutral response to questionnaire items, which may present as a limitation for the statistical analysis. Future research can benefit from objective data from work performance logs and event reports in NPPs, if the data can be extracted ethically and practically in relation to corresponding workers. Second, our participants came from commissioning departments only. Whether the evidence obtained in this study can be applied to other NPP departments (e.g., operation department) with different work content and procedures awaits confirmation. Future studies could examine a diverse range of participants in NPPs to address the limitation. Third, this study recruited Chinese commissioning workers only, and thus failed to make cross-cultural comparisons between commissioning workers from China and other countries, which deserves further exploration. Finally, while we limited our study scope to individual factors, safety behaviors can also be resulted from organizational and environmental factors [34], such as safety culture and safety climate. It is meaningful to integrate factors from multiple levels to develop comprehensive safety promotion strategies in NPP practice.

6. Conclusions

This study contributes to the understanding of antecedents of safety behaviors among commissioning workers in NPP context by examining the roles of a set of demographic, personality and attitudinal factors. The findings demonstrate that several demographics (age and work experience), personality traits (i.e., conscientiousness and agreeableness) and attitude towards questioning were associated with safety behaviors. In addition, attitudes seem to partly mediate the influence of conscientiousness on safety behaviors. While the findings clarified the roles of examined demographic, personality and attitudinal factors in safety behaviors among commissioning workers, we suggest safety managers to apply diverse strategies for safety behavior promotion in NPP context by tailoring measures to specific individual factors.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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