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Contributory Factors to Fatigue Among High-Speed Train Drivers: A Questionnaire Study in China

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ABSTRACT

Based on global statistics from 1993 to 2017, most railway accidents were caused by human errors (Liu et al., 2019). One of the main contributing factors to driver errors is driver fatigue. Therefore, it's essential to evaluate the level of fatigue among high-speed train (HST) drivers and identify the main influencing factors of fatigue. We designed a questionnaire that used the subjective score of the SSS (Stanford Sleepiness Scale) to assess the fatigue of HST drivers. A follow-up questionnaire survey was conducted with 243 HST drivers, and then exploratory factor analysis and hierarchical regression were conducted to determine the significant influencing factors of fatigue and form a prediction model. The results showed that HST drivers' characteristics (health status, personal trait score, number of chronic diseases), sleep, and working tasks (communication task, lookout task) had a significant effect on fatigue. The outcome of this research provided the main influencing factors of HST drivers' fatigue and proposed an effective prediction model to promote a structural understanding of HST drivers' fatigue.

Keywords: Fatigue, High-speed railway drivers, Railway safety

INTRODUCTION

High-speed train (HST) has become a new mode of transportation that has emerged in recent years with its fast, comfortable, punctual, and environmentally friendly features. Previous studies have shown that high-speed rail injuries and accidents due to technical failures have decreased worldwide and that unsafe human behavior has become one of the main causes (Liu et al., 2019). Fatigue of drivers is one of the main contributing factors to drivers' unsafe operations. According to the U.S. Federal Railroad Administration (FRA), fatigue accounts for 30% to 40% of train driver accidents(Administration, 2008, pp. 2005–2008). Chang's research (Chang and Ju, 2008) revealed an average accident rate of 13.82 accidents per million driving hours, and accident risk for train driving doubled after 4 h of consecutive driving because of fatigue. Therefore, there is a strong need to develop HST drivers' fatigue impact factor models to take targeted measures to mitigate their fatigue.

Despite the prevalence of driving fatigue among HST drivers, which can lead to serious consequences, only a few researchers have focused on HST drivers' fatigue. Yan et al. analyzed the mechanisms of fatigue generation in different individual HST drivers, combined with subjective sleepiness assessment, to reveal individual differences in fatigue in HST driving (Yan et al., 2018). Multiple physiological signals collected by wireless wearable technology were also used to classify the fatigue status of HST drivers (Chen et al., 2022; Zhou et al., 2018). Most studies related to HST drivers' fatigue focus on real-time HST drivers' fatigue monitoring. How to evaluate their fatigue level and find out the main factors leading to fatigue is still unclear.

The special nature of conventional train driving often leads to train drivers being more prone to sleepiness and fatigue, and this fatigue has a unique characteristic (Fan et al., 2022). There are quite a few studies on conventional train drivers that explored the influencing factors of fatigue. These studies have suggested a series of such factors, including personal characteristics such as age, gender, and educational level (Di Milia et al., 2011), drivers' experience, and the ability to maintain alert and attentive (Cheng and Tian, 2020; Dunn and Williamson, 2012), personality (Fan and Smith, 2017), lifestyle (Paterson et al., 2012), sleep and rest factors such as sleep length, sleep quality, rest time during work, and frequency of rest (Körber et al., 2015; Tsao et al., 2017), Work-related factors such as work hours and workload (Prakash et al., 2011), occupational environments such as noise, and vibration (Fan and Smith, 2017). However, whether key factors of conventional train drivers' fatigue continue to have a critical impact on HST drivers requires further research.

We constructed a questionnaire using potential factors related to fatigue. A representative questionnaire survey was conducted in China to quantitatively investigate the fatigue status of HST drivers and the factors affecting fatigue. This study intends to reveal the important influencing factors affecting the fatigue of HST drivers and propose a prediction model to enhance the structural understanding of the impact relationship.

METHOD

Questionnaire Survey

A total of 243 HST drivers were recruited to participate in the questionnaire study in China Railway Beijing Bureau Group Co., Shanghai Bureau Group Co., and Lanzhou Bureau Group Co. Paper copies of the questionnaires were distributed to railroad employees and recorded manually in digital format by the researchers. This study complied with the academic code of ethics established by the Department of Industrial Engineering at Tsinghua University, as well as the academic code of ethics established by the American Psychological Association. Each HST driver who participated in the study gave informed consent.

The three-stage questionnaire was based on the results of previous research and a focus group. In the first part (6 items), participants were asked to provide some demographic information and driving experience, including their age, height, weight, education, and number of years as a railroad driver and highway driver. In the second part (6 items), participants' fatigue status and brain load were collected. Fatigue levels were studied using the Stanford Sleepiness Scale (SSS), a single-question, 7-point scale. The participants' workload was measured using the NASA-TLX scale developed by Hart and Staveland (Hart, 2006). This scale includes the following 6 dimensions: mental demand, physical demand, time demand, performance level, effort level, and frustration level. On each dimension, from 1 (low task load) to 21 (high task load), the participant is asked to fill in the level of the load he feels. The participant's score on each dimension was converted from 0 to 100 on a scale of 1 to 21 that he completed. The factors affecting HST fatigue (26 items) were investigated in the third part, which can be divided into the following five categories: environment, sleep and rest, work demand, effect of work on fatigue, and effect of non-work factors on fatigue.

Data Analysis

We investigated participants' fatigue levels and mental workload using descriptive statistics. we calculated correlations between each item and fatigue-related indicators. after screening out items that were not significantly correlated with the SSS and NASA-TLX, we assessed the appropriateness of factor analysis for the remaining items using the Kaiser-Meyer-Olkin test and Bartlett's test. An overall sample adequacy measure (MSA) of >0.70 and Bartlett's p-value of <0.01 indicated that these items could be used for subsequent factor analysis. we conducted an exploratory factor analysis (EFA) with orthogonal rotation to help understand the underlying structure of fatigue influences. Finally, a hierarchical multiple regression analysis was performed to analyze how fatigue-related characteristics (i.e., sleep, Environment, task-related factors) predict HST drivers' fatigue. In the first step, demographic variables were entered, including age, physical condition, Personality trait score, and railroad driving experience. In the second step, the sleep factor was entered, as this factor reflects the driving status of HST drivers. in the third step, the Environment factor was entered. in the fourth step, the task-related factors were entered. Data analysis was performed using R studio.

RESULT

Participant Characteristics and Fatigue Level

All participants were male, and basic information is presented in Table 1. Participants' overall health was scored on a Likert 5-point scale, with higher scores associated with better health status. The participants' ages ranged from 24 to 52 years ($M = 39.28$, $SD = 6.47$). Each participant had experience in conventional rail driving before working as an HST driver. The mean value of the participants' years of HST driving was 5.71 years ($SD = 3.53$). The mean value of years of railroad driving (both HST driving and conventional train driving) was 15.73 years ($SD = 7.05$). The mean value of BMI was 24.67 and the mean score of self-rated health status was 3.22, between "fair" and "good".

Table 1. Demographic information and working experience of participants.

Variable	Mean	SD	Min	Max
Age	39.28	6.47	24.00	52.00
Overall Health	3.22	0.76	1.00	5.00
Experience HST (years)	5.71	3.53	0.50	15.00
Experience Railway (years)	15.73	7.05	1.00	31.00
BMI	24.67	2.87	17.04	32.11
Chronic Disease Num	1.64	1.60	0.00	7.00
Average Trait Score	0.17	0.45	–1.10	1.80

Fatigue levels were measured by the SSS. Scores ranged from 1 (low fatigue) to 7 (high fatigue). The raw NASA-TLX scores investigated six dimensions of task load. A scale from 1 to 21 was used to collect the task load for each dimension. The scores for the six dimensions were then rescaled from 0 (low task load) to 100 (high task load). The mean score for Raw NASA-TLX is above 50.0 (medium task load level.) HST drivers have higher Mental demand, higher Temporal demand, and lower Physical demand. the mean score for Subscale Frustration is low, and they put effort into their work and are satisfied with their performance.

Correlation Between Fatigue-Related Items and Fatigue, Task Load

We calculated the Pearson correlation between fatigue-related items and fatigue and workload. We found that the correlations of the variables: Sleep Duration (SD), Cumulative Driving Time (Daily), Driving Range Monthly, Driving Hours Monthly, ATP Switch Frequency, Driving Lightness, Mobile Entertainment In Non-Working Hours to Fatigue, Pedal Task to Fatigue with SSS and NASA-TLX were not significant and the correlations were less than 0.2. The above variables will not be analyzed.

Exploratory Factor Analysis

The factorability of the 16 items was examined. Several well-recognized criteria for the factorability of a correlation were used. Firstly, the Kaiser-Meyer-Olkin measure of sampling adequacy value for the organizational ability measure was 0.73, above the recommended value of 0.6. Secondly, Bartlett's test of sphericity was significant ($\chi^2 = 663.32$, $p < .001$), indicating that the data were suitable for factor analysis. Given these overall indicators, factor analysis was conducted with all 16 items.

We used principal components analysis to recognize and calculate the comprehensive response score of the factors behind organizational ability. 48% of the total variance is explained by four factors. Due to its previous theoretical support, after four factors, the eigenvalues on the screen plot tend to flatten, which indicates that the model is very suitable.

A principle-components factor analysis of the 16 items, using varimax rotations was conducted, with the three factors explaining 48% of the variance. The varimax rotation provided the best-defined factor structure. Most items had primary loadings over 0.45. The factor loading matrix

Table 2. Factor loading matrix.

	RC3	RC2	RC4	RC1	Communality
1. Lookout Task					
Monotonous Driving Task to Fatigue	0.735				0.597
Monotonous External Environment to Fatigue	0.689				0.489
Video Recording to Fatigue	0.657				0.486
Lookout to Fatigue	0.476		0.418		0.405
Routing Planning to Fatigue	0.421				0.333
2. Sleep					
Sleepless Frequency		–0.809			0.663
Sleep Quality		0.773			0.627
Sleep Duration (Mean)		0.624			0.393
Temp And Humidity Comfort					0.159
3. Communicate Task					
Emergency to Fatigue			0.770		0.620
Communicate to Fatigue			0.707		0.521
Family Affairs to Fatigue			0.501	0.471	0.485
Sleep Loss to Fatigue					0.331
4. Environment and Rest					
Driving Noise				–0.678	0.586
Temp Task to Fatigue				0.495	0.474
Rest Break Quality		0.414		–0.469	0.453

for this final solution is presented in Table 2. Four factors were extracted from these items: Lookout task, Sleep, Communicate task, Environment, and Rest.

Regression on the Prediction of Fatigue

The questionnaire data satisfies all levels of multiple regression assumptions, and the results are shown in Table 3. In the first step, demographic variables were entered, including age, physical condition, Personality trait score, and railroad driving experience. In the second step, the sleep factor was entered, as this factor reflects the driving status of HST drivers. In the third step, the Environment factor was entered. In the fourth step, the work-related factors and non-work-related factors were entered.

The hierarchical multiple regression revealed that at step 1, Overall Health, Chronic Disease Num, and Average Trait Score contributed significantly to the regression model, $F(236) = 24.46$, $p < .001$) and accounted for 38.3% of the variation in SSS. Adding Sleep to the regression model explained an additional 5% of variations in SSS and this change in R^2 was significant, $F(238) = 26.74, p = < .001$. Adding Environment and Rest to the regression model explained an additional 0.01% of the variation in SSS and this change in R^2 was not significant. Finally, adding Lookout Task and Communicate Task to the regression model explained an additional 2.1% of the variation in SSS and this change in R^2 square was significant, $F(236) = 6.05$, $p < .001$. When all five independent variables were included in stage four of the regression model, the factor Environment and Rest was not significant predictors of SSS. Together the five independent variables accounted for 45.4% of the variance in SSS.

Table 3. Summary of hierarchical regression analysis for variables predicting SSS.

Model	Variable	B	SE	R2	Adj. R^2	ΔR^2
Step 1				0.383	0.383	0.383
	(Intercept)	5.364***	0.666			
	Age	–0.008	0.022			
	Overall Health	–0.475***	0.092			
	Experience (HST)	–0.034	0.023			
	Experience (Railway)	0.025	0.019			
	Chronic Disease Number	0.090*	0.046			
	Average Trait Score	–0.937***	0.137			
Step 2				0.433	0.426	0.050***
	(Intercept)	5.054***	0.279			
	Overall Health	–0.374***	0.085			
	Average Trait Score	–0.817***	0.133			
	Sleep	–0.367***	0.066			
Step 3				0.433	0.423	<0.001
	(Intercept)	5.053***	0.279			
	Overall Health	–0.374***	0.085			
	Average Trait Score	–0.817***	0.133			
	Sleep	–0.367***	0.066			
	Environment and Rest	–0.004	0.0566			
step 4				0.454	0.441	0.021***
	(Intercept)	4.889***	0.281			
	Overall Health	–0.331***	0.085			
	Average Trait Score	–0.656***	0.142			
	Sleep	–0.404***	0.066			
	Environment and Rest	–0.008	0.056			
	Communicate Task	0.115*	0.057			
	Lookout Task	0.147*	0.060			

CONCLUSION

This study focused on HST drivers' fatigue, which was considered to have a direct impact on driving safety. A questionnaire was used to propose a prediction model to enhance the structural understanding of the impact relationship. Based on EFA and hierarchical regression, four aspects of influence on HST drivers' fatigue levels were identified. Among them, sleep and HST driving tasks were shown to have a significant effect on fatigue. The results of this study provide insight into the factors that contribute to HST driver fatigue, and highlight the importance of addressing these factors to improve driving safety. Future research could focus on developing interventions to reduce driver fatigue, such as implementing rest breaks, providing training on fatigue management, and promoting healthy sleep habits.

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