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The association between resilience and fatigue among mariners during ocean voyages: a chain mediating effect of coping style and psychological stress

Zhanying Sun[1,2], Nan Tang[1], Xueyang Gan[1], Jingru Chen[2], Qingqing Su[2], Jie Song[2*†] and Yuan Gao[2*†]

Abstract

Background Fatigue seriously reduces the sensory sensitivity and operational efficiency ofmariners, which is a major safety threat to ship navigation. This study aimed to investigate the relationship between resilience and fatigue and to explore the chain-mediated role of coping style and psychological stress among mariners during ocean voyages.

Methods Using Connor-Davidson resilience scale, simplified coping style questionnaire, psychological stress self-evaluation test and multidimensional fatigue inventory, a questionnaire survey was conducted on 510 mariners from a Shandong fleet who finished a 32-day ocean voyage on September 12, 2023. SPSS 26.0 was employed to perform correlation analysis, while Amos 21.0 was applied to establish structural equation model and demonstrate the mediator effects.

Results Daily working hours, negative coping style and psychological stress were positively correlated with fatigue, while resilience was negatively related to fatigue (all $P < 0.01$). The structural equation indicated that the 4 paths of "resilience → fatigue", "resilience → psychological stress → fatigue", "resilience → positive coping → psychological stress → fatigue" and "resilience → negative coping → psychological stress → fatigue" occupied 68.72%, 11.45%, 9.99% and 9.84% of the total effect, respectively (all $P < 0.05$), suggesting the validity of hypothesis.

Conclusion Resilience exerts significant direct and indirect effects on fatigue of mariners during ocean voyages. In addition, coping style and psychological stress partially and serially mediate the relation between resilience and fatigue. The results have significant implications for the intervention and prevention of fatigue, providing additional evidence for the relationship between resilience and fatigue among mariners during ocean voyages.

Keywords Fatigue, Resilience, Coping style, Psychological stress, Mediator effect, Ocean voyage

Introduction

The International Maritime Organization defines fatigue as "a state of physical and/or mental impairment resulting from various factors including inadequate sleep, extended wakefulness, work/rest requirements out of sync with circadian rhythms and other physical, mental or emotional exertion" [1]. In China, it is customary to refer to voyages west of Aden Port and crossing the ocean

†Jie Song and Yuan Gao contributed equally to this work.

*Correspondence:
Jie Song
285619923@qq.com
Yuan Gao
gaoyuanzd@163.com
[1] Graduate School of Chinese PLA Medical School, Beijing 100853, China
[2] Department of Nursing, The First Medical Center, Chinese PLA General Hospital, Beijing 100853, China

as ocean voyages. Mariners during ocean voyages are more likely to experience fatigue than the general population due to exposure to multiple challenges, including harsh sailing conditions (high temperature, high humidity, high salinity, high noise, high magnetic field, high concentrations of harmful gases, etc.), closed ship environments, unpredictable risks and day/night shifts, which is manifested as sluggish response, lax attention, deteriorated memory, work errors, listlessness, depression, etc [2–4]. It is reported that 28% of the crew of a U.S. aircraft carrier is in a high fatigue state [5]. Fatigue seriously lowers the sensory sensitivity and operational efficiency of mariners, which is a major safety threat to ship navigation [1]. An analysis of 274 marine accidents in recent years by the U.S. Coast Guard indicated that approximately 16% of serious incidents and 33% of casualties were related to crew fatigue [6]. Therefore, it is of great significance to focus on and explore the fatigue state of mariners as well as its influencing factors for alleviating the fatigue state during the voyage, which can improve operation efficiency and reduce the incidence of navigation accidents.

Resilience frequently refers to an individual's capacity to maintain adequate function and structure, which encompasses the ability to resist, adapt, recover and grow from challenges (e.g., environmental or biological stressors) [7]. Resilience is a dynamic process by which individuals utilize protective factors and resources to their benefit [8]. Research has found that resilience is a protective factor against fatigue and exerts a vital role in regulating individuals' emotions [9]. Individuals with higher resilience have stronger adaptability to special environments, better stress resistance, and exhibit lower levels of fatigue [10].

Resilience process theories have posited that personal attributes interact with the way one appraises and responds to the internal and external environmental stressors to influence the outcome [11]. These cognitive and behavioral efforts to manage different demands are referred to as coping [12]. According to the transactional theory of stress [13], the same stressors influence different individuals to varying degrees, depending on how the individuals evaluate and cope with stressors. It has been suggested that resilience can affect an individual's evaluation of events [14], while coping style is the strategy an individual adopts after evaluating stress [15]. Positive coping strategies refer to those aimed at problem-solving, including planning, instrumental coping, and seeking support. They can reduce excessive self-awareness during stressful events, alleviate stress reactions and maladjustment. In addition, negative coping strategies are focused on emotional regulation, encompassing cognitive behavioral avoidance, persistent and repetitive thinking, and emotional catharsis. These strategies are prone to causing painful experiences and adverse stress reactions in individuals [16]. Some scholars consider that coping style can regulate the impact of stressors on individuals. If individuals can adopt effective coping strategies in response to different stressors, the level of psychological stress can be reduced, thus weakening the adverse effects of excessive stress on them [17].

Psychological stress refers to the abnormal state caused by an organism's inability to adapt to the current environment after exposure to psychological, social, cultural and other irritant events [18]. Multiple studies [19–21] have revealed that when experiencing stressful events, soldiers with higher resilience have lower stress and fatigue levels, who can better cope with challenges, complete tasks and more quickly recover to the state before experiencing stressful events, while individuals with low resilience are just the opposite.

In summary, resilience can directly predict psychological stress, which may also influence psychological stress through coping style; besides, resilience can not only predict the fatigue level of individuals directly, but also indirectly through coping style and psychological stress pathway in sequence.

Several studies have currently explored the factors influencing mariners' stress and fatigue [6, 22]. However, no relevant studies were found on the chain-mediating role of coping style and psychological stress in resilience and fatigue among mariners during ocean voyages in China. Therefore, this study aimed to investigate the relationship between fatigue, resilience, coping style, and psychological stress. This study proposes the following hypotheses: 1. Psychological stress of mariners during ocean voyages has a mediating effect between resilience and fatigue; 2. Coping style and psychological stress of mariners during ocean voyages exert multi-chain mediating effects between resilience and fatigue. Relevant hypothetical model diagram is shown in Fig. 1. The objectives of this study are to verify the chain mediator role of coping style and psychological stress between the resilience and fatigue, and to further explore their internal relationships, aiming to provide a theoretical basis for ameliorating fatigue, maintain mental health and improve mission effectiveness of mariners during ocean voyages.

Subjects and methods

Subjects

Totally 510 mariners from a Shandong fleet who finished a 32-day ocean voyage on September 12, 2023 were selected as the objects of investigation using the whole convenient sampling method. Prior to conducting the survey, we communicated with the leader of surveyed fleet, and obtained the consent and support

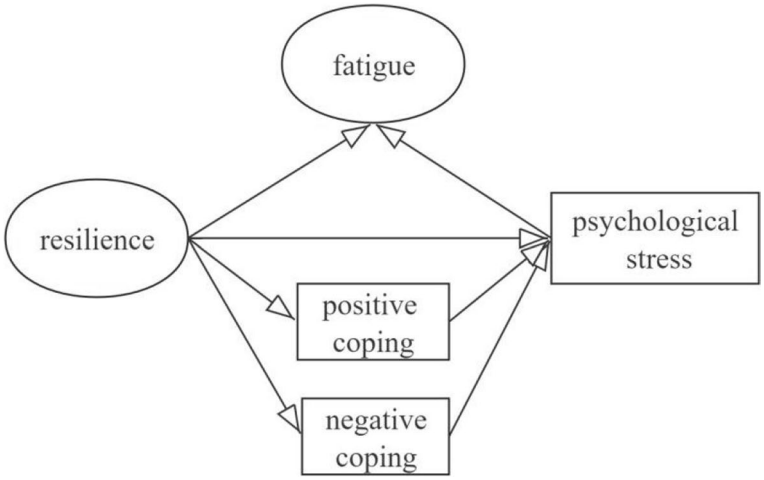

Fig. 1 Hypothetical model diagram

from the administrative leader and the subjects. All subjects signed an informed consent and agreed to participate in this study voluntarily. This study has been approved by the Ethics Committee of Chinese PLA General Hospital Decisions Letter for Scientific Research Projects (No. S2023-564–01).

Measures

Covariates

This study was conducted through a literature review, involving reviewing and referring to relevant literature, and developing a general information questionnaire including gender, age, position, seniority, education level, marital status, family structure, cumulative voyages, accumulated sailing time, job responsibilities, and daily working hours. Age was classified as "< 25 years", "25 ~ ≤ 30 years", and "> 30 years". Position was divided into officer, NCO, and conscript. Seniority was categorized as "< 5 years", "5 ~ ≤ 9 years", and "≥ 10 years". Educational level was divided into three levels: "senior high school or below", "junior college", and "bachelor's degree or above". Marital status was categorized as married or nonmarried. Family structure was categorized as complete families and incomplete families. Cumulative voyages were categorized as follows: "≤ 5 times", "6 ~ ≤ 10 times", "11 ~ ≤ 20 times", and "> 20 times". Accumulated sailing time classifications included "≤ 3 months", "> 3 ~ ≤ 12 months", and "> 12 months". Job responsibilities was divided into command and administration, system operation and logistics support. Finally, daily working hours were classified into three groups: "< 8 h", "≥ 8 ~ < 10 h", and "≥ 10 h".

Resilience

Resilience was measured by the Connor-Davidson resilience scale (CD-RISC) [23], which was compiled by Connor and Davidson and revised by Yu and Zhang [24], consists of 25 items under 3 dimensions: tenacity (items 11 to 23), optimism (items 2, 3, 4, 6), and strength (items 1, 5, 7, 8, 9, 10, 24, 25). Each item is scored from 0 to 4, and the sum of scores in each dimension is regarded as the total score. It indicates the higher the total score, the higher the level of resilience. Cronbach's α coefficient of CD-RISC was 0.97, and Cronbach's α of the three dimensions of tenacity, optimism and strength were 0.95, 0.95 and 0.81, respectively.

Coping style

Coping style was measured by the Simplified coping style questionnaire (SCSQ) [25]. SCSQ was adapted from Lazarus and Folkman's ways of coping questionnaire (WCQ) by Xie [26], which includes 20 items under 2 dimensions: positive coping and negative coping. The positive coping dimension represents the constructive strategies used by the individual in response to stress, whereas the negative coping dimension signifies the maladaptive strategies. Using the 4-level scoring method, each item is scored between 0 and 3. The positive coping subscale comprises items 1–12, while the negative coping subscale comprises items 13–20. The scores for both dimensions are average. The dimension with a higher score indicates the coping style more usually adopted by an individual. The Cronbach's α of SCSQ was 0.86, and the respective Cronbach's α values of positive and negative coping dimensions were 0.96 and 0.90.

Psychological stress

Psychological stress was measured by the Psychological stress self-evaluation test (PSET) [27], which was compiled by Chinese scholars Li et al.. PSET is consisted of 10 items, each of which is scored between 1 and 3. The sum of scores for each item is the original score, which is then converted to the standard score $T = 50 + 10(\chi - \bar{\chi})/s$, with χ being original score, $\bar{\chi}$ being average score and s being standard deviation. It indicates the higher the score, the higher the stress level. $T \geq 70$ represents a high level of psychological stress. Cronbach's α coefficient of PSET was 0.9.

Fatigue

Fatigue was measured by the Chinese version of the Multidimensional Fatigue Inventory (MFI-20) [28]. Jepsen et al. assert that the MFI-20 is a suitable scale for measuring fatigue among mariners [6]. Chinese version of MFI-20 was compiled by Smets and adapted by Miao for the Chinese military personnel [29], which measures fatigue in the last two weeks and consists of 20 items covering 4 dimensions: physical fatigue (items 1, 2, 3, 5, 8, 12, 14, 16, 18, 20), mental fatigue (items 7, 11, 13, 19), reduced activity (items 6, 10, 17) and reduced motivation (items 4, 9, 15). Forward scoring is used for items 2, 5, 9, 10, 13, 14, 16, 17, 18, and 19, whereas reverse scoring is adopted for items 1, 3, 4, 6, 7, 8, 11, 12, 15, and 20. Using the Likert 5-level scoring method, each item is scored between 1 and 5. It indicates the higher the score, the severer the fatigue. Cronbach's α coefficient of MFI-20 was 0.0.98, and Cronbach's α coefficients of the four dimensions of physical fatigue, mental fatigue, reduced activity and reduced motivation were 0.97, 0.96, 0.88, and 0.86.

Survey methods and quality control

On September 12, 2023, researchers of this questionnaire survey explained the purpose, significance and questionnaire filling method to the subjects with unified guidance language, and then delivered the questionnaires to the subjects to fill in on a ship docked in port for approximately 20 min. After filling out the questionnaires, they were collected on the spot strictly following the confidentiality principle and checked one by one. If the answer options were the same or the number of missing answers exceeded 2/3 of the total question number, the questionnaires would be deemed invalid and excluded. In addition, each questionnaire was documented by two professionals, and 10% of the questionnaires were reviewed and corrected by a third researcher to ensure the accuracy of data entry.

The Chinese version of the CD-RISC, SCSQ, PSET, MFI-20 are all scales with good reliability and validity and are widely used in Chinese navy soldiers during ocean voyages [30, 31]. Since all data were derived from self-reports of study subjects, Harman single factor test was used for common method bias test. To mitigate the potential influence of common method variance (CMV), we utilized the randomization function in Microsoft Excel to randomize the sequence of items on the scale before data collection. Specifically, items 1, 3, 4, 6, 7, 8, 11, 12, 15, and 20 of the Multidimensional Fatigue Inventory (MFI-20) were reverse-scored. Furthermore, respondent anonymity was preserved throughout the survey process to enhance the reliability and validity of the data. The results showed that there were 7 factors with eigenvalues greater than 1, and the variance explained by the first factor was 45.5% (< 50%), indicating no serious common method bias [32].

Statistical methods

Data were statistically analyzed using SPSS 26.0, and normality test was performed on the measurement data. Those conforming to normal distribution were presented as means ± SDs and their inter-group comparisons were made by the t test and one-way ANOVA. Non-normally distributed data were described as medians (M) and 25th and 75th percentiles (P_{25}, P_{75}). Kruskal–Wallis test was used for inter-group comparisons, and post hoc pairwise comparisons were undertaken. Count data were indicated as number of cases and percentages. Pearson correlation and Hierarchical regression were used to analyze the correlations among resilience, positive coping, negative coping, psychological stress and fatigue of mariners during ocean voyages. Structural equation model was created via Amos 21.0, and effect size was estimated by 5000 Bootstrapping. Furthermore, using the User-defined estimands function in Amos 21.0, the mediating effects of specific paths were tested for significance at the $\alpha = 0.05$ level.

Results

Demographic characteristics and scale scores of subjects

In this study, 510 questionnaires were delivered, and 502 were effectively collected, with a valid response rate of 98.4%. All subjects were males aged 19–57 (27.26 ± 5.13) years, whose seniority was 1–38 years, with M (P_{25}, P_{75}) of 7.00 (3.00, 11.00) years. Among them, 92 (18.3%) were officers, 354 (70.5%) were NCOs, and 56 (11.2%) were conscripts; 197 (39.2%) had senior high school or below education, 167 (33.3%) had junior college education, and 138 (27.5%) had bachelor's degree or above; besides, 288 (57.4%) were unmarried and 217 (42.6%) were married; 457 (91.0%) had complete families and 45 (9.0%) had incomplete families. Table 1 lists the scores of resilience, coping style, psychological stress and fatigue scales for 502 mariners during ocean voyages.

Table 1 Resilience, coping style, psychological stress and fatigue scores of mariners during ocean voyages

Scale	Item	Score $n=502$ ($\overline{\chi} \pm s$)
CD-RISC	Tenacity	37.86 ± 11.01
	Optimism	10.38 ± 3.54
	Strength	24.55 ± 6.55
	Resilience	72.79 ± 20.54
SCSQ	Positive coping	2.02 ± 0.78
	Negative coping	1.10 ± 0.72
PSET	Psychological stress	50.06 ± 9.67
MFI-20	Physical fatigue	26.41 ± 13.22
	Mental fatigue	10.17 ± 5.62
	Reduced activity	8.04 ± 3.99
	Reduced motivation	8.05 ± 3.91
	Total fatigue score	52.68 ± 26.06

Effects of different demographic characteristics on the psychological stress and fatigue of mariners during ocean voyages

The fatigue scores of mariners with different positions (conscripts, NCOs, officers), educational levels (senior high school or below, junior college, bachelor's degree or above) and daily working hours ($<8, \geq 8 \sim <10, \geq 10$) were compared, finding that the differences were statistically significant (all $P<0.01$). Pairwise comparison revealed that the fatigue scores of conscripts were higher than those of NCOs and officers (all $P<0.05$), although insignificant score differences were observed between NCOs and officers ($P>0.05$). Mariners with bachelor's degree or above exhibited higher fatigue scores than those with junior college or senior high school or below education (all $P<0.05$), although insignificant score differences were found between with junior college education and those with senior high school or below education ($P>0.05$). The fatigue score of mariners during ocean voyages with daily working hours greater than or equal to 10 h is the highest, the fatigue score of mariners during ocean voyages with daily working hours ($\geq 8 \sim <10$) is the second, and the fatigue score of mariners during ocean voyages with daily working hours less than 8 h remains the lowest (all $P<0.01$). No statistical significance was found in fatigue scores of mariners with different seniorities, ages, marital statuses, family structures, cumulative voyages, accumulated sailing time or job responsibilities (all $P>0.05$) (See Table 2).

Correlation analysis of resilience, coping style, psychological stress and fatigue of mariners during ocean voyages

For the surveyed 502 subjects, resilience was positively correlated with positive coping, but negatively correlated with negative coping, psychological stress and fatigue (all $P<0.01$). Positive coping was negatively correlated with psychological stress, fatigue and four dimensions, while negative coping was positively related to psychological stress, fatigue and four dimensions (all $P<0.01$). A positive correlation was observed between psychological stress, fatigue and four dimensions ($P<0.01$) (See Table 3).

Hierarchical regression scores of resilience, coping style, psychological stress and fatigue of mariners during ocean voyages

Positions, educational levels, daily working hours, resilience, coping styles (positive and negative coping) and psychological stress were included in hierarchical regression analysis as independent variables and fatigue as dependent variables, respectively. In Model 2, Positions, educational levels, daily working hours, and resilience as independent variables explained 65.2% of the variance variation of psychological stress [$F=235.803$, $P<0.01$]. Model 3, with Positions, educational levels, daily working hours, resilience, coping styles (positive and negative coping) and psychological stress as independent variables, accounted for 70.7% of the variance variation of psychological stress [$F=173.858$, $P<0.01$], and the newly included independent variables of positive coping, negative coping and psychological stress explained 5.5% more of the variance variation. The results are presented in Table 4.

Analysis of the mediating effects of coping style and psychological stress between resilience and fatigue of mariners during ocean voyages

According to the theoretical hypotheses and above results, path analysis was performed via Amos 21.0, as described in Fig. 2. Model fit was estimated by maximum likelihood method using the following fit indices: $\chi 2=71.941$, $df=31$, $\chi 2/df=2.321$, goodness-of-fit index (GFI) = 0.972, adjusted GFI (AGFI) = 0.950, normalized fit index (NFI) = 0.987, Tucker–Lewis index (TLI) = 0.989, comparative fit index (CFI) = 0.993, incremental fit index (IFI) = 0.993 and root mean square error of approximation (RMSEA) = 0.051. All of these indices met the measurement standards, suggesting a good data fit.

Bootstrapping was employed to examine the main effect of resilience on fatigue, as well as the mediating effects of coping style and psychological stress between

Table 2 Comparison of MFI-20 scores of mariners during ocean voyages with different demographic characteristics ($n = 502$)

Item	Number of subjects (%)	Score ($\overline{\chi} \pm s$)	*F/t*	*P*
Age (years)				
< 25	173 (34.5)	53.38 ± 25.66	0.126	0.882
25 ~ ≤ 30	217 (43.2)	52.06 ± 26.56		
> 30	112 (22.3)	52.81 ± 25.90		
Position				
Officer	92 (18.3)	64.15 ± 25.13	11.367	< 0.001
NCO	354 (70.5)	50.13 ± 25.75		
Conscript	56 (11.2)	49.98 ± 24.77		
Seniority (years)				
< 5	151 (30.1)	53.92 ± 26.37	0.808	0.446
5 ~ ≤ 9	170 (33.9)	50.62 ± 25.41		
≥ 10	181 (36.0)	53.58 ± 26.43		
Educational level				
Senior high school or below	197 (39.2)	51.59 ± 25.83	4.905	0.008
Junior college	167 (33.3)	49.29 ± 25.91		
Bachelor's degree or above	138 (27.5)	58.33 ± 25.82		
Marital status				
Unmarried	288 (57.4)	53.07 ± 26.22	0.383	0.072
Married	214 (42.6)	52.16 ± 25.88		
Family structure				
Complete family	457 (91.0)	52.00 ± 26.13	-1.361	0.174
Incomplete family	45 (9.0)	57.90 ± 24.26		
Cumulative voyages (times)				
≤ 5	178 (35.5)	54.64 ± 26.62	2.282	0.078
6 ~ ≤ 10	81 (16.1)	51.14 ± 25.69		
11 ~ ≤ 20	73 (14.5)	45.95 ± 24.10		
> 20	170 (33.9)	54.26 ± 26.15		
Accumulated sailing time (months)				
≤ 3	227 (45.2)	52.66 ± 26.08	2.263	0.105
> 3 ~ ≤ 12	160 (31.9)	49.88 ± 25.11		
> 12	115 (22.9)	56.63 ± 27.00		
Job responsibilities				
Command and administration	86 (17.1)	49.02 ± 26.51	1.309	0.271
System operation	259 (51.6)	52.69 ± 25.35		
Logistics support	157 (31.3)	54.68 ± 26.90		
Daily working hours				
< 8	223 (44.4)	33.51 ± 13.07	370.339	< 0.001
≥ 8 ~ < 10	133 (26.5)	53.19 ± 21.20		
≥ 10	146 (29.1)	81.50 ± 16.55		

resilience and fatigue of mariners during ocean voyages. The direct effect of resilience on fatigue was significant [95% *CI* (−0.861 ~ −0.588) excluding 0]. The overall mediating effects of coping style and psychological stress between resilience and fatigue were also significant (95% *CI* (−0.433 ~ −0.253) excluding 0). Obviously, coping style and psychological stress exert a partial mediating role in the relationship between resilience and fatigue, and this mediating effect accounts for 37.3% of the total effect of resilience on fatigue, and thus hypothesis 1 is valid.

Furthermore, the significance of path-specific mediating effects was tested by the User-defined estimands function in Amos 21.0. The 95% *CI*s of "resilience → psychological stress → fatigue", "resilience → positive coping → psychological stress → fatigue" and "resilience → negative coping → psychological stress → fatigue" all did not contain 0,

Table 3 Correlation analysis of resilience, coping style and psychological stress for mariners during ocean voyages

Item	resilience	Positive coping	Negative coping	Psychological stress
resilience	1			
Positive coping	0.538**	1		
Negative coping	−0.550**	−0.263**	1	
Psychological stress	−0.514**	−0.486**	0.482**	1
Total fatigue score	−0.661**	−0.468**	−0.510**	0.648**
Physical fatigue	−0.654**	−0.470**	−0.510**	0.654**
Mental fatigue	−0.636**	−0.444**	−0.497**	0.636**
Reduced activity	−0.633**	−0.434**	−0.471**	0.633**
Reduced motivation	−0.636**	−0.444**	−0.479**	0.636**

**$P < 0.01$

Table 4 Hierarchical regression scores of resilience, coping style, psychological stress and fatigue of mariners during ocean voyages

model	Item	β	t	adjusted R^2	$\triangle R^2$	F
Model 1				0.534	0.537	192.612**
	Position	−0.069	−2.069*			
	Educational level	−0.018	−0.530			
	Daily working hours	0.722	23.352**			
Model 2				0.652	0.118	235.803**
	Position	−0.040	−1.384**			
	Educational level	−0.014	−0.476*			
	Daily working hours	0.531	13.437**			
	resilience	−0.396	−13.026**			
Model 3				0.707	0.056	173.858**
	Position	−0.025	−0.913			
	Educational level	−0.052	−1.948			
	Daily working hours	0.446	15.210**			
	Positive coping	−0.058	−1.898			
	Negative coping	0.077	2.526*			
	Psychological stress	0.247	7.735**			

β: standardized regression coefficient

* $P < 0.05$

** $P < 0.01$

Argument assignment method: Position(Officer = 1; NCO = 2; Conscript = 3), Educational level(Senior high school or below = 1; Junior college = 2;Bachelor's degree or above = 3), Daily working hours (< 8 = 1; ≥ 8 ~ < 10 = 2; ≥ 10 = 3)

indicating that the 3 paths all reached the level of significance. Mediating effects exerted by the 3 paths accounted for 36.62% [(−0.078)/(−0.213)], 31.92% [(−0.068)/(−0.213)] and 31.46% [(−0.067)/(−0.213)] of the total mediating effect, respectively, and therefore the hypothesis 2 is valid. Table 5 details the results.

Discussion

During the ocean voyage, mariners are in a relatively narrow and closed ship environment with persistent noise and irregular shaking. Additionally, they should be adapted to frequent day/night shifts and highly alert, who often have many problems including sleep rhythm disturbance, sleep deprivation and poor sleep quality, and are prone to fatigue. Among them, mariners during ocean voyages with obvious fatigue symptoms accounted for 39.4% of the total crew number, suggesting that the fatigue of mariners during ocean voyages is unignorable.

Stratified regression shows that daily working hours are the influencing factors of the fatigue of mariners, longer the working day, the more fatigued the mariner. This is consistent with previous studies that the long working

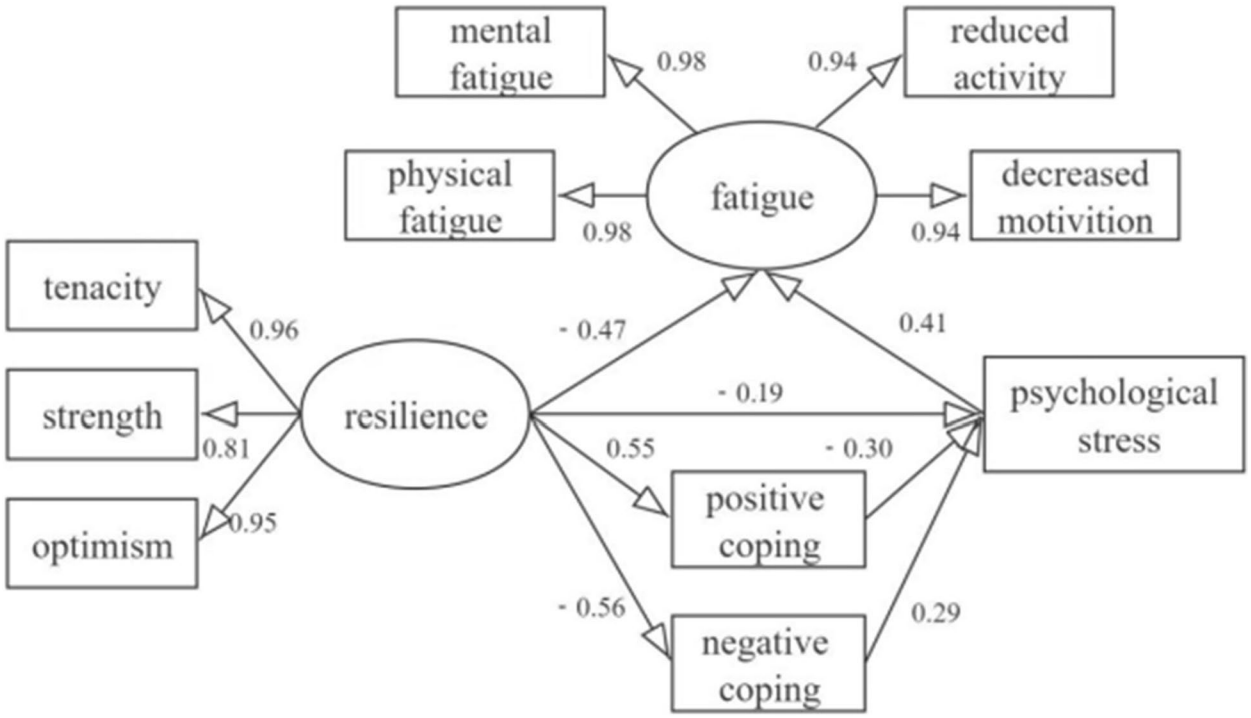

Fig. 2 Mediating effects of coping style and psychological stress between resilience and fatigue of mariners during ocean voyages. Note: All the path coefficients are standardized

Table 5 Effect analysis of coping style as a mediating variable between resilience and fatigue of mariners during ocean voyages

Effect	Path	Standardized coefficient	Effect size (%)	Standard error	95% *CI*
Direct effect	Resilience → fatigue	−0.468	68.72	0.069	(−0.861 ~ −0.588)
Mediating effect	Resilience → psychological stress → fatigue	−0.078	11.45	0.029	(−0.128 ~ −0.034)
	Resilience → positive coping → psychological stress → fatigue	−0.068	9.99	0.016	(−0.098 ~ −0.044)
	Resilience → negative coping → psychological stress → fatigue	−0.067	9.84	0.014	(−0.092 ~ −0.047)
Total mediating effect		−0.213	31.28	0.045	(−0.433 ~ −0.253)
Total effect		−0.681	100	0.059	(−1.182 ~ −0.950)

Bootstrapping times 5000; *CI* confidence interval

hours (> 8 h per day or > 40 h per week) are usually associated with insufficient recovery, increasing the risk of poor sleep and fatigue [33]. In this study, the fatigue level varied among mariners with different positions and educational levels, with officers and those having bachelor's degree or above education being the most fatigued. Officers and highly educated mariners with bachelor's degree or above often exert vital roles such as organizers, commanders and technical backbone, who assume more tasks and bear higher pressure, causing their higher level of fatigue [34]. Research indicates that ageing decreases the speed of circadian adaptation to night work and has a major impact on sleep quality and feelings of being well rested after sleep [35], and a study reveals that participants of older ages in naval service are associated with a greater amount of fatigue on board [36]. However, there is no statistical significance in fatigue scores of mariners with different age groups in this study. We speculate that this may be caused by the relatively young age distribution (27.26 ± 5.13) of the survey objects.

The findings of this study indicate that resilience serves as a negative predictor of fatigue levels experienced by

mariners during ocean voyages. Resilience is viewed as a combination of individual resources including economic, cognitive, behavioral and emotional regulation [37]. According to the conservation of resources (CORs) theory [38], individual resources help individuals effectively cope with stressors from work and environment, and highly resilient individuals can relieve their pressure and enhance their work enthusiasm through individual resources, therefore reducing their fatigue level [39].

Additionally, psychological stress plays a partial mediating role between resilience and fatigue, supporting H1. That is, resilience not only can predict the fatigue level of mariners during ocean voyages directly, but also can indirectly influence the fatigue through the mediating effect of psychological stress. Mariners during ocean voyages encounter unpredictable dangers and high-intensity training and duty tasks, who are often in a state of high psychological stress [40, 41]. Overstress easily leads to the disorder of hypothalamic–pituitary–adrenal (HPA) axis [42] and the imbalance of gamma-aminobutyric acid (GABA) pathway [43], which is a vital factor affecting fatigue. However, resilience helps individuals successfully adapt to external pressures and challenges, predicting their psychological stress responses [20]. For example, under stress conditions, individuals with high resilience produce higher levels of neuropeptide Y (NPY) [44], which has crucial functions including relieving stress, anxiety and pain [45].

The coping style and psychological stress of mariners during ocean voyages have multi-chain mediating effects between resilience and fatigue, supporting H2. Resilience reflects an individual's ability to adapt to the environment [46]. When facing stressors, individuals with high resilience are more likely to make challenging comments and adopt positive coping style [47]. As a problem-solving style comprising planning, instrument coping and support seeking, positive coping can reduce excessive self-awakening upon exposure to stress, consequently lowering stress response and maladjustment. Additionally, negative coping focuses mostly on emotional regulation, including psychological withdrawal, behavioral avoidance, emotional catharsis, talking about emotions and repeated thinking, which easily leads to painful experiences and adverse stress reactions [16]. Hence, resilience can not only predict the fatigue level of mariners during ocean voyages directly, but also indirectly through the coping style and psychological stress pathway in sequence.

The influence of fatigue is multifaceted and reducing mariners' fatigue requires collective and individual management. As for collective fatigue management, the above results suggest that training of resilience and strengthening of positive coping style may become an effective way to lower the psychological stress level and fatigue state of mariners during ocean voyages. The management of mariners and their hours of work and rest should ensure that the various tasks can be performed safely and that fatigue is prevented; we can apply physiological monitoring devices to track fatigue objectively and apply biomathematical models to predict fatigue risk effectively [48, 49]. For individual fatigue management, a daytime nap between 30 and < 60 min can reduced the perception of fatigue [50]; Caffeine is freely and widely available and is an effective and safe interventions to reduce mental fatigue, and individuals should avoid caffeine within 4 h of bedtime [51].

Strengths and limitations

This study demonstrated the predictive role of resilience on fatigue and the chain mediation of coping style and psychological stress among mariners during ocean voyages. In terms of theoretical implications, the chain mediating role of coping style and psychological stress between resilience and fatigue was argued, providing additional theoretical foundations for subsequent research. Regarding practical implications, this study provides a vital reference for the development of preventions and interventions for fatigue among mariners during ocean voyages. However, this study still has some limitations. At first, cross-sectional studies cannot draw definitive causal conclusions, and longitudinal studies are needed to further infer causal relationships. Secondly, even if the data collection time is set at the end of the ocean voyage, there may still be memory bias. Thirdly, the objects of investigation were performed by the whole convenient sampling method in this study. We selected mariners from the same fleet in Shandong province. Moreover, we hope to include different fleets and provinces to encompass a broader range of mariners during ocean voyages by the method of stratified sampling in future studies. Furthermore, some potential confounders such as smoking, drinking, coffee, and noise exposure were not available in this study, which may have caused residual confounding. Finally, despite our efforts to ensure respondent anonymity, randomize the sequence of items, and employ reverse coding techniques to mitigate the potential influence of common method variance (CMV), it is essential that we diversify measurement sources. Furthermore, extending the data collection process across various time periods by incorporating additional data collection methods will help alleviate the potential impact of CMV in future studies.

Conclusion

To conclude, this study confirms that resilience is negatively correlated with fatigue of mariners during ocean voyages. Not only can it directly predict fatigue, but also indirectly through the mediating role of coping style and psychological stress, respectively, as well as indirectly through the chain mediating effect of coping style and psychological stress on the fatigue of mariners. This study enables us to understand the mechanisms between resilience and fatigue, providing some theoretical reference for preventing and intervening the fatigue of mariners during ocean voyages.

Abbreviations

CD-RISC	Connor-Davidson resilience scale
CMV	Common method variance
GABA	Gamma-aminobutyric acid
HPA	Hypothalamic–pituitary–adrenal
MFI	Multidimensional Fatigue Inventory
NPY	Neuropeptide Y
PSET	Psychological stress self-evaluation test
SCSQ	Simplified coping style questionnaire

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Authors' contributions

Y.G. and Z.S. collaborated on the conception and design of this study; Z.S., N.T. and X.G. wrote the main manuscript text; J.C., N.T. and Q.S. collected and analyzed data; J.S., N.T. and Y.G. reviewed and edited the manuscript. All authors have read and approved the manuscript.

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Data availability

Data and materials are available upon reasonable request. Requests to access the datasets should be directed to Z.S., 1206224470@qq.com.

Declarations

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki, and it has been approved by the Chinese People's Liberation Army General Hospital Ethics Committee (S2023–564–01) and informed consent was obtained from all the participants.

Consent for publication

Not applicable.

Competing interests

All authors declare that there are no conflicts of interests.

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