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ORIGINAL RESEARCH

# Mapping Connection and Direction Among Symptoms of Sleep Disturbance and Perceived Stress in Firefighters: Embracing the Network Analysis Perspective

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**Purpose:** There is an intricate relationship between sleep disturbances and perceived stress in firefighters. Network analysis offers novel perspectives for examining the interactions between diseases. Hence, this study aimed to elucidate the relationship between sleep disturbances and perceived stress in firefighters through network analysis approaches.

**Methods:** A total of 786 Chinese firefighters were included in this study. Two methodologies, the regularized partial correlation network (RPCN) and the directed acyclic graph (DAG), were employed to perform network analysis.

**Results:** Within the RPCN, P2 "Unable to control important things" and P7 "Unable to control irritations in life" were identified as central symptoms that simultaneously maintained sleep disturbances and perceived stress among firefighters. S7 "Daytime dysfunction" and P3 "Felt nervous and stressed" were classified as bridge symptoms, connecting sleep disturbances with perceived stress and perpetuating their comorbid nature. From a probabilistic priority perspective, the DAG demonstrated that the bidirectional spiral between sleep disturbances and perceived stress might be attributed to the fact that the upstream symptom S7 "Daytime dysfunction" influenced the perceived self-efficacy dimension of perceived stress, which in turn influenced other sleep disturbance symptoms.

**Conclusion:** Our findings not only provided innovative insights into further understanding the relationship between sleep disturbances and perceived stress among firefighters, but also identified potential targets for ameliorating these symptoms, such as the central, bridge, and upstream symptoms. Future intervention programs should prioritize these potential targets. Through the implementation of interventions like mindfulness-based stress reduction, cognitive behavioral therapy, and group psychotherapy, tailored to address these targeted symptoms, it is feasible to effectively mitigate both sleep disturbances and perceived stress in firefighters, and ultimately improve the mental health of this particular occupational group.

**Keywords:** sleep disturbances, perceived stress, network analysis, firefighters

## Introduction

Sleep is an essential physiological process that is necessary for the body and mind to recuperate and function properly.[1] Sleep disturbances can cause poor sleep quality, leading to various negative consequences.[2] Due to the shift schedule of work, the unpredictable nature of work, and the hazardous conditions on the job, firefighters are susceptible to sleep disturbances.[3] Numerous recent studies conducted in countries as diverse as the United States, France, Brazil, and Korea have demonstrated that sleep disturbances are highly prevalent among firefighters.[4–8] A meta-analysis revealed that the global prevalence of sleep disturbances among firefighters is 30.49%, far surpassing that of the general population.[9] Sleep



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disturbances among firefighters not only impair their physical and mental health, resulting in diseases like diabetes,[10] cardiovascular diseases,[11] anxiety, and depression,[12] but also disrupt their safety outcomes, causing occupational accidents and injuries.[3] More importantly, sleep disturbances are also an important risk factor for suicidal ideation and suicide attempts.[13]

Additionally, as emergency responders fighting on the front lines of rescue, firefighters are frequently exposed to stressors of various strength and intensity.[14] These stressors encompass not only severe traumatic stressors, such as witnessing bloodshed or death, suffering or being involved in life-threatening events, but also chronic daily stressors, like shift work activities, irregular life cycles, and financial pressures.[15,16] Consequently, the firefighting community typically suffers elevated levels of stress.[17,18] Notably, the transactional model of stress and coping[19,20] suggests that objective stressful events do not directly lead to negative impacts and that the extent to which stress generates negative effects is contingent upon the individual's perception, reaction, or evaluation of stress, which is known as Perceived Stress.[21] Optimal levels of perceived stress can enhance firefighter performance, whereas excessive levels of perceived stress can result in a range of adverse consequences, including various physical and mental illnesses,[22] social function impairments,[23] and even suicidal behaviors.[24]

The intricate relationship between sleep disturbances and perceived stress has long been an intriguing subject. On the one hand, numerous cross-sectional studies have demonstrated a high degree of co-occurrence between perceived stress and various sleep disturbance symptoms, such as daytime sleepiness and fatigue, restless sleep, difficulty falling asleep, early awakenings, shortened sleep duration, and self-reported poor sleep quality.[25–27] On the other hand, both longitudinal and experimental research indicate a bidirectional spiral between sleep disturbances and perceived stress.[28,29] Simply put, sleep disturbances are both antecedents and consequences of perceived stress.[30] From a psychological perspective, chronic stress activates maladaptive cognitive processes such as persistent worry and rumination, which impair sleep initiation through heightened cognitive arousal.[31] The cognitive model of insomnia posits that stress-induced negative thoughts about sleep consequences create a self-perpetuating cycle of sleep difficulties.[32] Biologically, stress activates the body's stress response system, specifically the hypothalamic-pituitary-adrenal (HPA) axis. When an individual experiences stress, the HPA axis releases cortisol, a stress hormone. Elevated cortisol levels can interfere with the normal sleep-wake cycle by suppressing the production of melatonin, a hormone that regulates sleep,[33] while sleep deprivation conversely elevates cortisol levels.[34] In the inflammatory pathways, Sleep fragmentation elevates pro-inflammatory cytokines (IL-6, TNF-α) that enhance stress sensitivity, creating a positive feedback loop.[35] Higher levels of perceived stress and more severe sleep disturbances are considered a potent combination leading to health issues, and the vicious cycle they form can lead to a downward spiral of physical and mental well-being.[28]

Firefighters have several unique characteristics that make them particularly vulnerable to sleep disorders and stress, distinguishing them from other high-risk occupations such as police, emergency medical personnel, or the military. One of the key factors is their irregular shift work patterns. Firefighters often work long, unpredictable shifts, including overnight and extended duty periods, with no fixed recovery time.[3] This erratic schedule can disrupt the body's internal clock, or circadian rhythm, making it difficult for firefighters to fall asleep and stay asleep.[9] Another significant factor is firefighters' exposure to toxic environments, including smoke, toxic gases, and other harmful substances. These exposures can have a direct impact on the nervous system, causing neurological damage and disrupting normal sleep patterns.[36] Furthermore, the nature of firefighting work is extremely dangerous, requiring quick reflexes and split-second decision-making. This high level of stress and pressure can lead to chronic stress and anxiety, which are major contributors to sleep disorders.[37] In comparison to other high-risk occupations, the unique combination of danger, physical exertion, and exposure to toxins in tasks makes firefighting a particularly stressful and sleep-disruptive profession. Given the distinctive characteristics of the occupation, the hazardous combination of sleep disturbances and perceived stress may potentially result in even graver adverse outcomes among firefighters.[15] Hence, it is crucial to explore the psychological mechanisms underlying the high comorbidity and the bidirectional spiral between sleep disturbances and perceived stress, which would offer theoretical enlightenment and prospective strategies for breaking this hazardous vicious cycle. Regrettably, the existing relevant studies are primarily correlation analyses based on the overall conceptual level of the disease,[21,38–40] whereas the deep psychological mechanisms underlying the intricate relationship between sleep disturbances and perceived stress are still poorly understood, restricting the suitable application of psychotherapy and the precise selection of intervention targets.

In recent years, network analysis approaches have been widely used to understand mental illness, offering an innovative method to quantitatively examine and depict interactions among complex variables.[41] Conventional approaches for studying psychological disorders, such as correlation analyses and regression analyses, typically rely on the traditional latent variable model, which assumes that symptoms (manifest variables) derive from underlying disease entities (latent variables).[42,43] Based on this assumption, previous studies predominantly utilized scale total scores to represent the level or severity of mental illness. Nevertheless, it is crucial to note that individuals with the same total score may exhibit completely distinct symptom combinations.[41] Thus, this traditional model ignores the heterogeneous nature of mental disorders, which limits insight into psychological disorders.[44,45] Unlike the latent variable model, the network model posits that mental illness arises from interactions among symptoms.[46] In other words, symptoms actively contribute to the activation and maintenance of mental disorders, rather than being merely their passive indicators or outward reflections.[46] Instead of relying on the priori hypothesis of causal relationships among variables, network analysis views mental disorders as interactive systems and explores the interactions among different symptoms through a data-driven approach, providing a new perspective for understanding mental illness.[47–49] The network structure consists of nodes and edges. The nodes represent the objects of study, whilst the edges represent the connections between them. In the context of psychopathology networks, nodes represent symptoms, and edges represent associations between symptoms.[50] Networks may comprise either weighted edges or unweighted edges. An unweighted edge merely signifies that two symptoms are connected, whereas a weighted edge indicates the magnitude of the connection (eg, correlation coefficients).[46] Based on whether the edges have direction or not, the networks can be categorized into undirected and directed networks. Of these, the regularized partial correlation network (RPCN) is an undirected network, and the directed acyclic graph (DAG) is a directed network. Within the RPCN, the centrality index can be calculated for each node to quantify its importance in the network.[51] For the network with multiple disease constructs (also known as "community"), the bridge centrality index can also be computed to assess the importance of a given node in connecting external communities.[52] The DAG is expected to offer theoretical references for exploring the potential causality and activation sources from a perspective of probabilistic priority.[41]

Previous studies focusing on the relationship between sleep and stress have primarily used traditional statistical methods, such as correlation analysis and regression models.[21,38–40] It is worth noting that these studies were predicated on the overall level of the disease, thereby precluding the researchers from examining the more fundamental and profound relationship between sleep disorders and perceived stress in firefighters. Additionally, the existing network analysis studies on firefighters predominantly concentrated on posttraumatic stress disorder (PTSD),[53–55] anxiety,[56] and depression.[53,56] To the best of our knowledge, relatively few studies have used network analysis methods to explore sleep problems or stress problems in firefighter populations. One study employed the network analysis method to examine the relationships between sleep and mental health among firefighters,[57] and another study used the method to explore the relationships between stress and musculoskeletal symptoms in firefighters.[58] In addition, a previous study we conducted explored the relationship between burnout and sleep disturbances among firefighters.[59] However, there is a dearth of network analysis studies examining the intricate relationship between sleep disturbances and perceived stress symptoms in firefighters, which hinders the identification of precise targets for intervention and the selection of effective intervention methods.

Hence, the present research attempted to elucidate the psychological mechanisms underlying the intricate relationship between sleep disturbances and perceived stress among firefighters from a network perspective. Two different model construction methods, the RPCN and DAG, were employed to perform network analysis. The specific purposes of this study were: (a) to clarify the most central symptoms in the co-occurrence network of sleep disturbances and perceived stress; (b) to identify the influential bridge symptoms connecting sleep disturbances and perceived stress; and (c) to explicate the bidirectional spiral between sleep disturbances and perceived stress from a perspective of probabilistic priority. It is anticipated that our findings will provide theoretical insights into a more comprehensive understanding of the intricate relationship between sleep disturbances and perceived stress among firefighters, as well as offer potential intervention targets for alleviating symptoms and breaking this vicious cycle.

# Materials and Methods

## Participants

In this study, the snowball sampling was employed to collect data from September 12 to September 27, 2023 in Shaanxi Province, China. Considering the efficiency of questionnaire collection and the decentralized work units of firefighters, the questionnaire data was collected through an online platform named Wenjuanxing (www.wjx.cn). With reference to previous studies, online collection methods have been widely employed in network analysis studies.[60,61] Several measures were taken to broaden the source of subjects in this study. On the one hand, we informed in detail in the introduction of the questionnaire about the content of the survey, the anonymity of the study, and the strict confidentiality of the information submitted to reduce non-participation due to misunderstanding. On the other hand, we broadened the range of sources for the firefighter sample through multiple channels, such as posting posters, Wechat Moments, and QQ Space. The first section of the questionnaire was anonymous informed consent. After reading the informed consent, participants could click "I agree" to continue filling out subsequent survey questions. The inclusion criteria included (a) certificated firefighters in fire stations; (b) understanding the purpose and content of this research; and (c) consent to volunteer for this study. The research team received responses from 812 firefighters. Of these, 12 questionnaires were excluded due to incorrect polygraph questions, and 14 questionnaires were excluded due to incomplete basic information or incomplete questionnaire content. Ultimately, 786 (96.80%) valid questionnaires were included for subsequent analysis. This study has been reviewed and approved by the Ethics Committee of the First Affiliated Hospital of the Fourth Military Medical University (No. KY20202063-F-2).

## Measures

### Sleep Disturbances

The sleep disturbances of firefighters were assessed by the Pittsburgh Sleep Quality Index (PSQI). The PSQI is a self-rated questionnaire to assess individuals' sleep quality and sleep disturbances over the past month.[62] The scale consists of 18 items belonging to seven components: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction.[63] The individual scores for each of the seven components range from 0 (*good*) to 3 (*very poor*), and the total scores of these seven components range from 0 to 21. The higher the total scores, the more severe the sleep disturbance symptoms are.[63] The Cronbach's α coefficient for this scale was 0.787 in this study.

### Perceived Stress

The Perceived Stress Scale (PSS), developed by Cohen et al,[64] was employed to measure the individual's perception of uncontrollable, unpredictable, or overloaded stress in life. The PSS consists of 10 items, with each item being assigned a score ranging from 1 (*never*) to 5 (*always*).[65] The total score is calculated by adding up the scores of all items and ranges from 10 to 50, with higher scores indicating more severe stress perceptions. The PSS can be divided into two dimensions: perceived helplessness (items 4, 5, 7, 8) and perceived self-efficacy (items 1, 2, 3, 6, 9, 10).[66] The Cronbach's α coefficient for this scale was 0.761 in this study.

## RPCN

### Network Estimation and Visualization

R software (version 4.3.1) was employed for conducting network analysis. The Gaussian graphical model (GGM) was employed to estimate the network.[67] GGM is categorized as an undirected network, in which edges represent the partial correlations between two nodes after controlling for all other nodes in the network.[68] To account for the ordinal nature of the PSQI and PSS, RPCN was estimated via the Extended Bayesian Information Criterion (EBIC) Graphical LASSO.[68] This regularization procedure primarily entails narrowing all edges and punishing edges with exceedingly small partial correlation coefficients to zero, facilitating the elimination of false connections and ultimately leading to the construction of a more robust, sparse, and comprehensible network.[69] The EBIC hyperparameter $\gamma$ was set to 0.5 to balance sensitivity and specificity.[70] Theoretically, the EBIC hyperparameter $\gamma$ plays a crucial role in balancing the trade-off between model fit and model complexity.[71] A smaller hyperparameter value implies a weaker penalty for adding edges to the model, which may lead to a more complex model that could potentially overfit the data. Conversely, a larger hyperparameter value imposes a stronger penalty, resulting in a simpler model that might underfit. Previous studies have typically set the EBIC hyperparameter γ to 0.5, and the results have confirmed that the metric strikes an optimal balance between sensitivity and specificity in identifying genuine edges.[72–75] The network was visualized employing the Fruchterman-Reingold algorithm.[76] The presented network employed blue and red edges to represent positive and negative correlations, respectively. The thickness of the edges indicated the strength of the correlations. The R-package "qgraph"[77] was used to estimate and visualize the network.

### Centrality Index and Bridge Centrality Index

To ascertain the importance of nodes in the co-occurrence network of sleep disturbances and perceived stress, we calculated the centrality index for each node. Expected influence (EI) was employed as the centrality index in this study. EI is defined as the sum of the weights of all edges connected to a node, which is more suitable for networks with both positive and negative edges.[78] The larger the EI value, the more essential the node is in maintaining network stability.[79] The nodes with the highest EI values are regarded as central symptom nodes. The R-package "qgraph"[77] was used to calculate the EI for each node in the network.

Additionally, in order to identify influential bridge symptoms linking the sleep disturbance symptoms and perceived stress symptoms, we calculated the bridge expected influence (BEI) by employing the R-package "networktools".[80] BEI refers to the sum of all edge weights linking a given node with nodes in the other community, which reflects the significance of the node in connecting external communities.[81] A higher BEI value indicates a greater risk of transmission to other communities.[82] The nodes with the highest BEI values are considered as bridge symptom nodes.

### Network Accuracy and Stability

The R-package "bootnet"[67] was employed to evaluate the accuracy and stability of the network. First, the accuracy of the edge weights was estimated by calculating the 95% confidence interval (CI) through a nonparametric bootstrap approach with 2000 samples. A narrower CI indicates greater reliability of the network.[71,83] Second, the correlation stability (CS) coefficient was calculated to evaluate the stability of EI and BEI by using a case-dropping bootstrap method with 2000 samples. The CS coefficient is a statistical metric and refers to the maximum percentage of sample cases that can be eliminated from the original cases to still maintain a correlation of 0.7 in at least 95% of the samples.[84] Previous research indicates that the CS coefficient should not be lower than 0.25, with a preference for values above 0.5.[68]

## DAG

The DAG can be employed to encode the conditional independence relationships between symptoms in cross-sectional data and facilitate the identification of potential (or acceptable) causality among them.[85] This approach is constructed based on Bayesian inference, a statistical methodology that utilizes causal reasoning to evaluate and refine the structural network.[86,87] Within a DAG, nodes are connected by directed edges (illustrated by arrows), which signify the relationships between nodes and indicate the direction of these relationships. While the technique cannot determine the temporal precedence of symptoms, it does enable researchers to evaluate directional dependence from a probabilistic priority perspective,[88] and thus to theorize about potential (or acceptable) causal relationships between symptoms.[54,85]

We employed the Bayesian hill-climbing algorithm of the "bnlearn" package to evaluate the DAG of sleep disturbance and perceived stress symptoms.[89] Through employing the bootstrap function, the approach allows for the addition, elimination, or reversal of edges to optimize the Bayesian information criterion (BIC), thus estimating the structural features of the model.[41] According to the latest operational approach of the bootstrap function, 50 different random restarts were conducted to avoid local maxima (that is, using possible edges that connect different nodes), and 100 perturbations were performed to each restart (that is, adding, deleting, and reversing the edges' direction).[90]

To ensure the stability of the final DAG model, we performed the following operations. Firstly, we employed the bootstrap method (10,000 bootstrap samples with replacement) and evaluated a DAG for each sample. A larger number of bootstrap samples helps to better capture the variability and uncertainty in the data, especially when dealing with potential non-linear and complex structures within the DAG.[87] Previous research in related fields has indicated that

10,000 bootstrap samples can lead to more stable and reliable results.[86,91–94] Secondly, we determined how frequently a given edge appeared in the 10,000 samples. For the threshold criteria for edge retention in the DAG analysis, we aimed to strike a balance between retaining meaningful relationships and avoiding overfitting the data. A very lenient threshold would result in an overly complex DAG with numerous spurious edges, which could mislead the interpretation of causal effects. Whereas an overly strict threshold might discard important potential causality. Hence, after referring to relevant literature in the field of potential causal inference using DAGs, we employed the optimal cut-off method of Scutari and Nagarajan[95] to preserve edges, which has been demonstrated to generate DAGs with both high sensitivity and specificity.[86,91–94] The edge will be retained in the final DAG only when its frequency of occurrence in the 10,000 DAGs exceeds the threshold determined through the optimal cutoff method. Finally, we identified the directions of the edges retained in the final DAG. If there were edges with the same direction in 51% or more of bootstrapped DAGs, the directional edges would be represented in the final DAG.[96]

To facilitate the interpretation of DAG, we generated two visualizations of outputs recommended by current studies.[92] In the first visualization, the arrow thickness indicates the BIC change when this arrow is dropped from the DAG. The thicker the arrow, the more the edge contributes to the structure of the model. In the second one, the arrow thickness represents the probability of direction. The thicker the arrow, the greater the proportion of the direction pointed to by that arrow in the DAG.

# Results

## Descriptive Statistics

A total of 786 firefighters were included in the final analysis, of which 703 (89.44%) were male and 83 (10.56%) were female. The mean age of the 786 firefighters was 30.16 years (SD = 4.74), and the average length of service was 7.53 years (SD = 6.77). The demographic characteristics are presented in Table 1. The descriptive statistics for each variable (sleep disturbances and perceived stress symptoms), including the abbreviation, mean, standard deviation, EI value, and BEI value, are shown in Table 2. For the results of the Spearman correlation analysis of the symptoms, please see Figure 1.

**Table 1** Descriptive Information of Demographic

| Variables | n | % |
|---|---|---|
| **Gender** | | |
| Male | 703 | 89.44 |
| Female | 83 | 10.56 |
| **Education** | | |
| Primary school and below | 3 | 0.38 |
| Junior school | 60 | 7.63 |
| Senior school | 375 | 47.71 |
| University and above | 348 | 44.28 |
| **Marital Status** | | |
| Unmarried | 303 | 38.55 |
| Married | 478 | 60.81 |
| Other (Divorced, Widowed, etc.) | 5 | 0.64 |
| **Only child** | | |
| Yes | 129 | 16.41 |
| No | 657 | 83.59 |
| **Years of service** | | |
| ≤ 3 years | 186 | 23.66 |
| 4–9 years | 383 | 48.73 |
| ≥10 years | 217 | 27.61 |

**Table 2** Descriptive Data of Node Psychometrics

| Symptoms | Abb | M | SD | EI | BEI |
|---|---|---|---|---|---|
| Subjective sleep quality | S1 | 0.61 | 0.75 | 0.69 | 0.15 |
| Sleep latency | S2 | 1.18 | 0.95 | −0.30 | 0.19 |
| Sleep duration | S3 | 0.84 | 0.80 | 0.02 | 0.05 |
| Habitual sleep efficiency | S4 | 0.40 | 0.72 | −1.43 | 0.03 |
| Sleep disturbances | S5 | 0.70 | 0.61 | −0.42 | 0.22 |
| Use of sleeping medication | S6 | 0.04 | 0.28 | −2.78 | 0.03 |
| Daytime dysfunction | S7 | 0.65 | 0.87 | 0.74 | 0.36 |
| Upset by something unexpected | P1 | 1.91 | 0.90 | 0.56 | 0.19 |
| Unable to control important things | P2 | 1.81 | 0.89 | 1.24 | 0.14 |
| Felt nervous and stressed | P3 | 1.60 | 0.79 | 0.86 | 0.29 |
| Not confident to handle personal problems | P4 | 2.33 | 1.43 | −0.06 | 0.03 |
| Things were not going your way | P5 | 2.95 | 1.32 | 0.16 | 0.06 |
| Could not cope with all things to do | P6 | 2.04 | 1.00 | −0.75 | 0.02 |
| Unable to control irritations in life | P7 | 2.64 | 1.38 | 1.22 | 0.07 |
| Did not feel on top of things | P8 | 3.07 | 1.36 | −0.30 | 0.00 |
| Angered by things outside control | P9 | 1.86 | 0.91 | 0.16 | 0.09 |
| Difficulties piling up cannot overcome | P10 | 1.75 | 0.88 | 0.37 | 0.16 |

**Abbreviations**: Abb, abbreviations; M, mean; SD, standard deviation; EI, expected influence; BEI, bridge expected influence.

# RPCN

## Network Structure

The RPCN of sleep disturbances and perceived stress symptoms is shown in Figure 2. Out of 136 possible edges, 70 (51.47%) were non-zero, of which 65 (92.86%) were positive and 5 (7.14%) were negative. The strongest edges emerged between P4 "Not confident to handle personal problems" and P7 "Unable to control irritations in life" (weight = 0.43), P1 "Upset by something unexpected" and P2 "Unable to control important things" (weight = 0.40), P7 "Unable to control irritations in life" and P8 "Did not feel on top of things" (weight = 0.35).

## Centrality and Bridge Centrality

The nodes P2 "Unable to control important things" (EI = 1.24) and P7 "Unable to control irritations in life" (EI = 1.22) were identified as central symptoms, which had the largest EI values. Followed by P3 "Felt nervous and stressed" (EI = 0.86), S7 "Daytime dysfunction" (EI = 0.74), and S1 "Subjective sleep quality" (EI = 0.69). Additionally, S7 "Daytime dysfunction" (BEI = 0.36) from the sleep disturbance symptoms and P3 "Felt nervous and stressed" (BEI = 0.29) from the perceived stress symptoms were identified as bridge symptoms, which had the highest BEI values. Followed by S5 "Sleep disturbances" (BEI = 0.22), S2 "Sleep latency" (BEI = 0.19), and P1 "Upset by something unexpected" (BEI = 0.19). The EI and BEI of sleep disturbances and perceived stress symptoms are shown in Figure 3 and Table 2.

## Network Accuracy and Stability

The results of network accuracy and stability showed that the network was reliable. The bootstrapped 95% CI was narrow, demonstrating that the estimations of edges were reliable. The CS coefficients of EI and BEI were both 0.75, indicating that the network kept stable after dropping 75% of the sample. The results of bootstrapped 95% CI and CS coefficients are shown in Figure 4.

# DAG

The DAG of sleep disturbances and perceived stress is shown in Figure 5.

In Figure 5A, the thickness of the arrow represents that the BIC changes when this arrow is removed from the DAG. A thicker arrow indicates a larger contribution to the model. In the current study, the most influential arrows of DAG were from P7 "Unable to control irritations in life" to P4 "Not confident to handle personal problems" (BIC change =

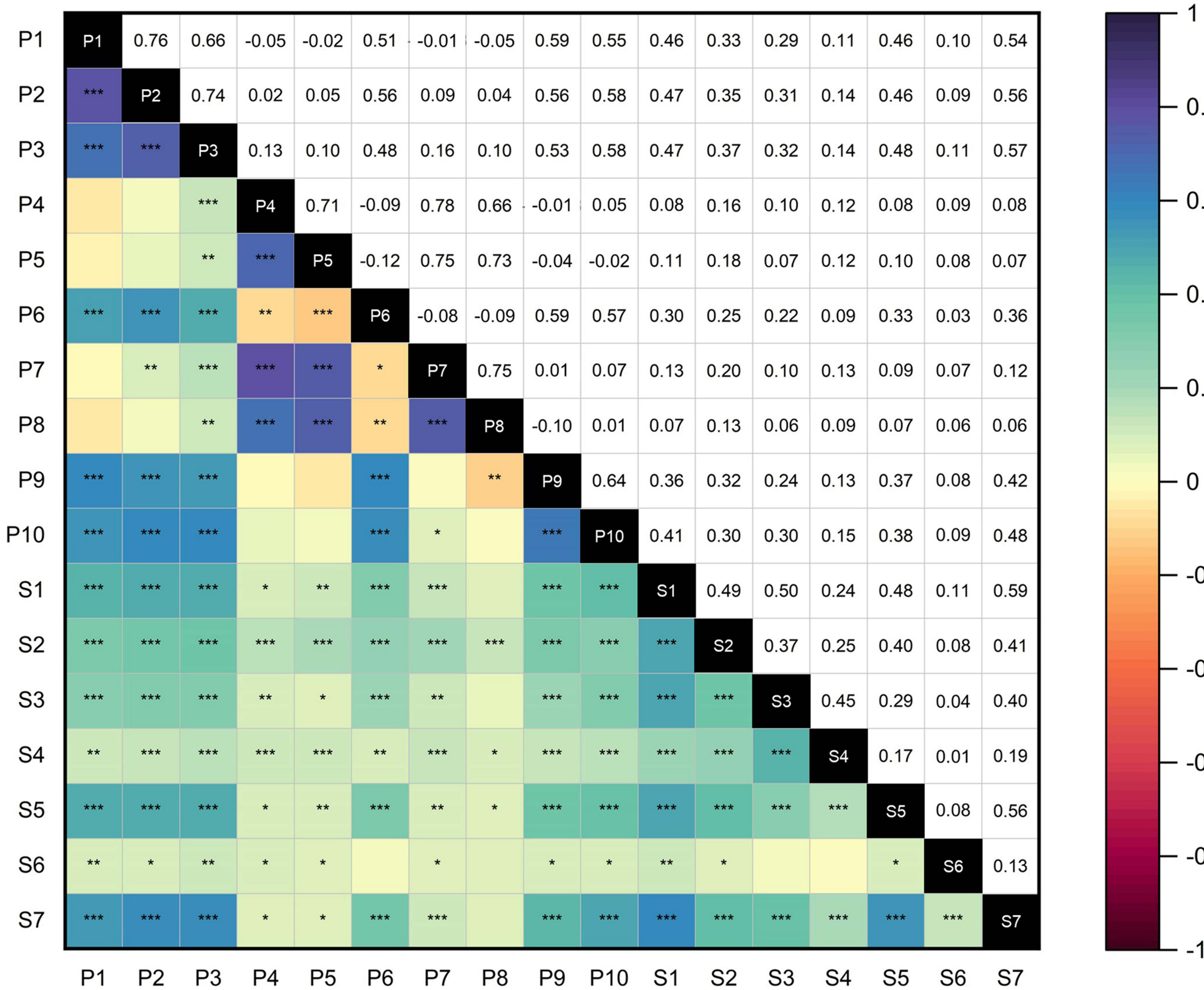

**Figure 1** The Spearman correlation heat map of symptoms. The specific meaning of each abbreviation is shown in Table 2. **p* < 0.05, ***p* < 0.01, ****p* < 0.001.

−411.55), from P2 "Unable to control important things" to P3 "Felt nervous and stressed" (BIC change = −154.31), and from S7 "Daytime dysfunction" to P2 "Unable to control important things" (BIC change = −146.46).

In Figure 5B, the thickness of the arrow indicates the directional probability of each arrow in the bootstrapped DAG. A thicker arrow represents a greater proportion of the direction in the bootstrapped DAG. The thickest arrows were from P2 "Unable to control important things" to P6 "Could not cope with all things to do" (Probability = 0.85; that is, 8500 DAGs were in this direction of the 10,000 bootstrapped DAGs), from S1 "Subjective sleep quality" to S2 "Sleep latency" (Probability = 0.85), and from S3 "Sleep duration" to S4 "Habitual sleep efficiency" (Probability = 0.80).

## Discussion

In the current study, we conducted network analysis employing two different network model construction methods, the RPCN and DAG, in an attempt to elucidate the psychological mechanisms underlying the intricate relationship between sleep disturbances and perceived stress among firefighters. From the results pertaining to the network structure of the RPCN and DAG, centrality and bridge centrality, accuracy and stability, and probabilistic priority, we could clarify the most central symptoms of the co-morbidity of sleep disturbances and perceived stress, identify the influential bridge symptoms connecting the two, and explicate the bidirectional spiral between the two from a perspective of probabilistic priority. Our findings may contribute to a deeper understanding of the intricate relationship between sleep disturbances and perceived stress in firefighters and provide potential intervention targets for alleviating symptoms.

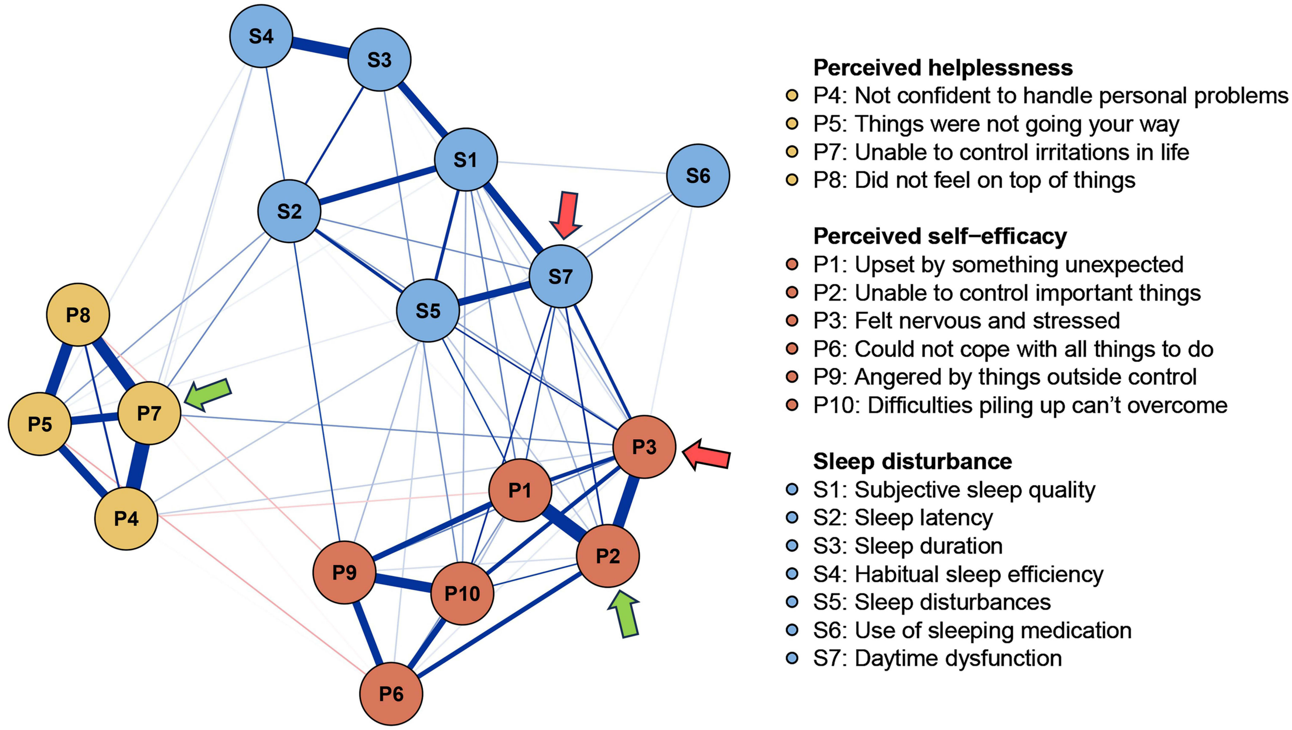


**Figure 2** The RPCN of sleep disturbances and perceived stress symptoms. Blue and red edges represent positive and negative correlations, respectively. The thickness of the edges indicates the strength of the correlation. The thicker the edge, the stronger the correlation. The green arrows point to the central symptoms, that is, P2 "Unable to control important things" and P7 "Unable to control irritations in life", which simultaneously maintain sleep disturbances and perceived stress among firefighters. The red arrows point to the bridge symptoms, that is, S7 "Daytime dysfunction" and P3 "Felt nervous and stressed", which connect sleep disturbances with perceived stress and perpetuate their comorbid nature.

The Stress-Vulnerability Model proposes that individuals develop psychological or physiological problems as a result of a combination of intrinsic vulnerabilities (eg genetic, physiological factors) and extrinsic stressors.[97] In terms of vulnerability, shift systems for firefighters (eg, 24-hour on-call) predispose to circadian rhythm disruption, which in turn affects melatonin secretion and HPA axis rhythmicity, leading to physiologic vulnerability. Furthermore, firefighters are often exposed to traumatic events (eg, witnessing deaths and unsuccessful rescues), which can result in psychological vulnerability. In terms of stressors, due to the unique nature of the profession, firefighters not only have to cope with dangerous and stressful situations but also have to deal with various chronic daily stressors including shift work activities, irregular sleep cycles, and financial pressures.[14] This vulnerability, which is both physiological and psychological in nature, interacts with the acute and chronic stressors that firefighters are routinely exposed to, resulting in a heightened propensity for sleep disturbances and perceived stress problems. A substantial body of research has demonstrated a robust correlation between psychological distress and sleep disturbances among firefighters. On the one hand, stress has been demonstrated to have a detrimental effect on the sleep quality among firefighters and can result in the development of sleep disturbances. A cross-sectional survey study of 154 career firefighters working in Northern California found that job stress significantly affected firefighters' sleep health.[3] A systematic review also indicated that work-related psychosocial stressors can affect the health and well-being of those in the fire service, including depression-suicidality, non-depressive mental health problems, burnout, alcohol use disorders, sleep quality, and somatic disorders.[98] On the other hand, sleep disturbances are a risk factor for the development of stress-related health conditions. A study assessed firefighters from 66 US fire departments for common sleep disorders as well as health and safety. Results indicated that sleep disturbances are prevalent in firefighters and are associated with an increased risk of adverse health and safety outcomes.[99] A narrative review indicated that sleep disturbances are related to stress-related disorders in firefighters.[100] There is also a study that demonstrated that firefighters who exhibited poor sleep quality exhibited elevated levels of depression, anxiety, and stress.[101] However, it is worth noting that these studies were predicated on

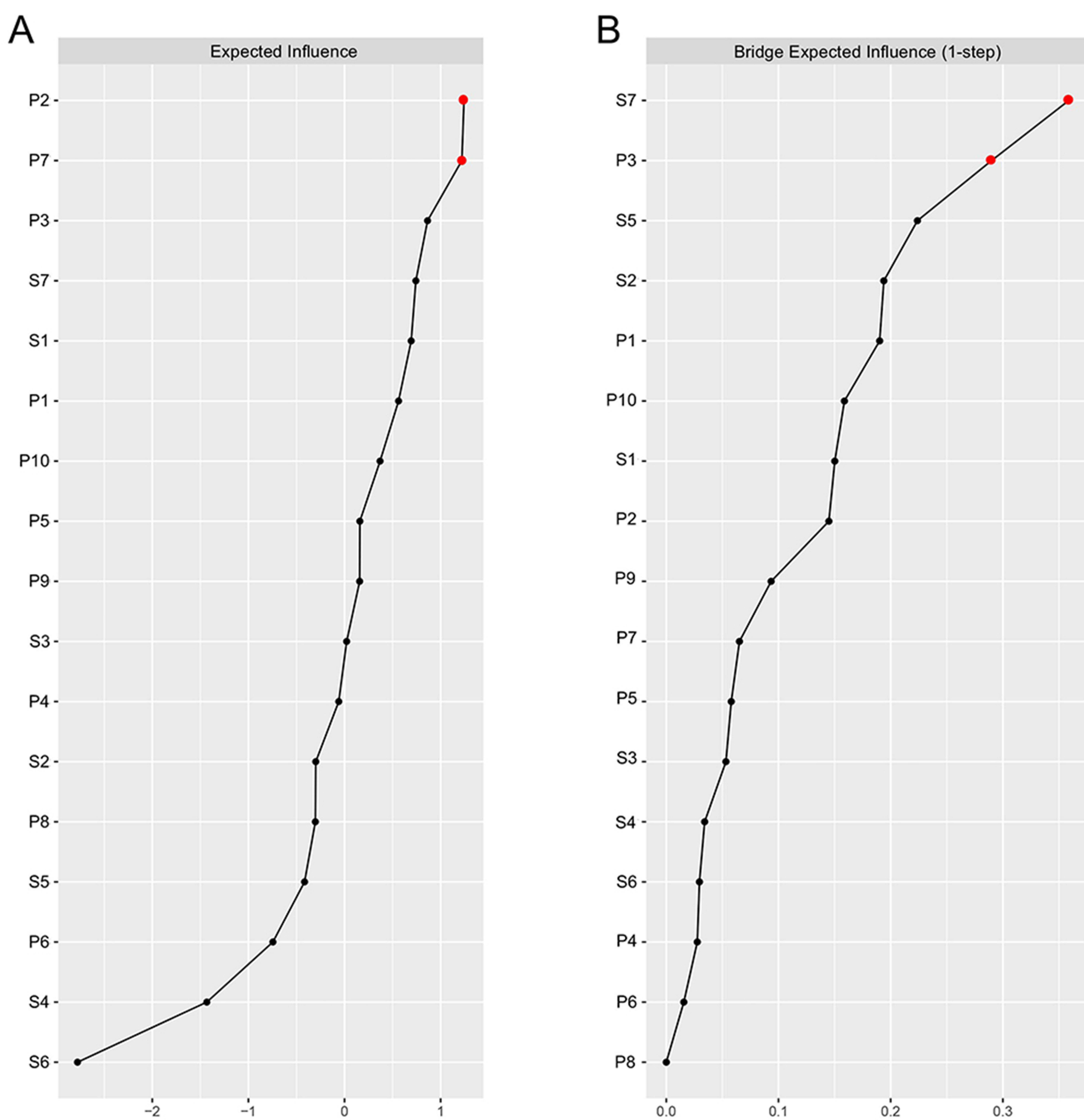


**Figure 3** The EI and BEI of sleep disturbances and perceived stress symptoms. (**A**) The EI of each node. (**B**) The BEI of each node. The specific meanings, EI values, BEI values of each node are shown in Table 2.

the overall level of the disease, thereby precluding the researchers from examining the more fundamental and profound relationship between sleep disorders and perceived stress in firefighters. This limitation hinders the identification of precise targets for intervention and the selection of effective intervention methods. In contrast, our study used network analysis to explore the intricate relationships between specific symptoms, offering an innovative perspective for understanding the relationship between sleep disturbance and perceived stress in firefighters and identifying potential targets for subsequent prevention and intervention.

Within the RPCN, the strongest edges emerged between P4 "Not confident to handle personal problems" and P7 "Unable to control irritations in life", P1 "Upset by something unexpected" and P2 "Unable to control important things", P7 "Unable to control irritations in life" and P8 "Did not feel on top of things". It can be seen that the stronger links

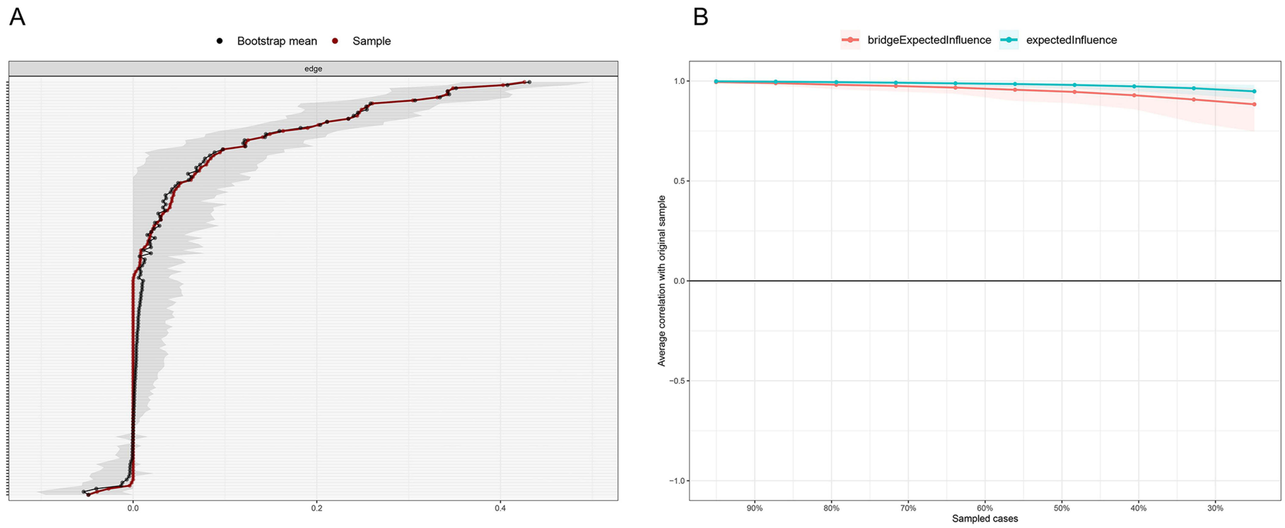


**Figure 4** The results of bootstrapped 95% CI and CS coefficients in the RPCN. (**A**) The bootstrapped 95% CI in the RPCN. The red nodes indicate edge weights in the sample, and the black nodes represent edge weights in the bootstrapped test. The grey horizontal bars indicate 95% confidence intervals for edge weights. (**B**) The CS coefficients of EI and BEI in the RPCN. Green and red nodes represent the average correlation of node EI and BEI between the full sample and the case-dropped sample, respectively. The green or red areas around nodes represent the 2.5th to the 97.5th quantiles of correlation.

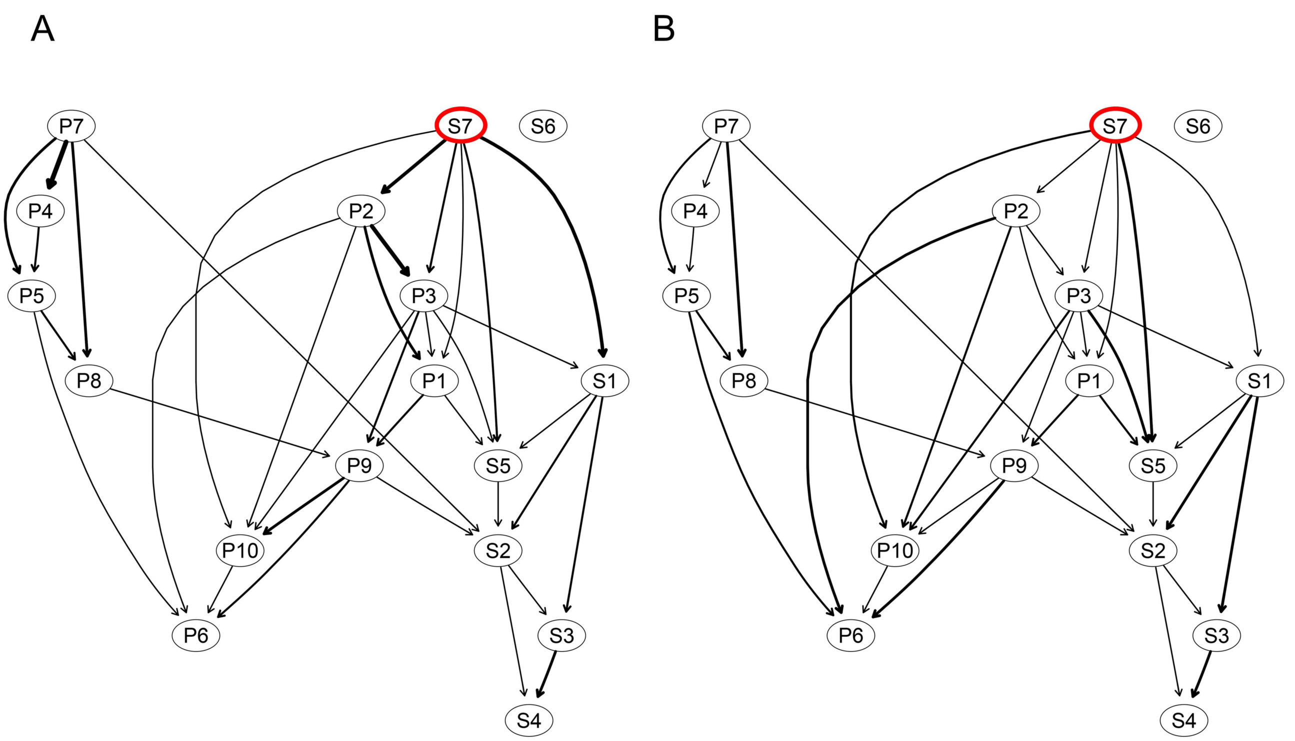


**Figure 5** The DAG of sleep disturbances and perceived stress symptoms. (**A**) The thickness of the arrow represents that the BIC changes when this arrow is removed from the DAG. (**B**) The thickness of the arrow indicates the directional probability of each arrow in the bootstrapped DAG. The specific meaning of each abbreviation is shown in Table 2. The S7 "Daytime dysfunction" marked by the red circle appears at the upstream position of the DAG network, indicating that it potentially affects the downstream symptoms.

primarily existed among the symptom nodes belonging to the same disease concept, which aligns with previous research findings.[53] Additionally, according to prior studies, the higher the centrality index, the greater the contribution of the node in maintaining the network stability.[102] By calculating EI values, we found that the nodes P2 "Unable to control important things" and P7 "Unable to control irritations in life" had the highest EI values, and were therefore identified as the central symptom nodes in the co-occurrence network of sleep disturbances and perceived stress among firefighters. This result may be related to the inherent nature of the firefighter's occupation. The suddenness of the rescue task and the unpredictability of the rescue outcome may diminish the tolerance for uncertainty, personal mastery, and self-efficacy of firefighters, which may trigger a series of adverse effects.[103,104] A study of Korean firefighters suggests that the inability to manage work schedules was an important risk factor for sleep disturbances in firefighters, which is consistent with our findings and emphasizes the important role that a sense of uncontrollability (eg, work schedule instability) plays in the firefighter population.[105] Given the high degree of comorbidity of sleep disturbances and perceived stress in firefighters, it makes sense to identify the most central symptoms in the comorbidity network and target them for precise intervention. According to previous studies, targeting the central symptom of a comorbidity may simultaneously relieve all individual structures of the comorbidity.[84] Therefore, the aforementioned central symptoms might be potential targets for simultaneously alleviating sleep disturbances and perceived stress symptoms among firefighters.

Furthermore, the sleep disturbance symptom S7 "Daytime dysfunction" and the perceived stress symptom P3 "Felt nervous and stressed" had the highest BEI values and were identified as the bridge symptoms. On the one hand, S7 "Daytime dysfunction" from the sleep disturbance symptoms was most strongly associated with symptoms of perceived stress. According to the original scale interpretation, the daytime dysfunction indicated that the individual had low energy and frequently felt sleepy.[106] The Conservation of Resources theory (COR) suggests that individuals have a tendency to acquire and preserve diverse resources, both physical and mental, that are beneficial to their survival, while the scarcity and depletion of resources cause stress.[107] Moreover, according to the Person-Environment fit theory, stress arises when there is a discrepancy between the competencies of individuals and the requirements of the surrounding environment.[108] As emergency responders, firefighters operate in an environment that requires high levels of physical fitness and mental performance.[3] However, daytime dysfunction due to sleep problems may impair these abilities, leading to a mismatch between their competencies and the job requirements, ultimately causing stress. Furthermore, when firefighters experience poor sleep quality or insufficient sleep, it can lead to difficulties in concentration, fatigue, and reduced cognitive function during the day. These symptoms can then affect their work performance and daily life, causing them to feel stressed and anxious. For example, if a firefighter is unable to concentrate during a training session or a work task due to daytime fatigue, they may worry about making mistakes or not being able to perform their duties effectively, which in turn leads to increased perceived stress. On the other hand, P3 "Felt nervous and stressed" from the perceived stress symptoms had the strongest links to symptoms of sleep disturbance. From a psychological perspective, the pathway by which feeling nervous and stressed leads to sleep disturbances can be conceptualized through the Perseverative Cognition Hypothesis.[109] Chronic perception of tension and stress may cause cognitive changes, and perseverative cognition might act directly on sleep disturbance via enhanced activation of the cardiovascular, immune, endocrine, and neurovisceral systems.[110] In addition, according to the Embodied Cognition Theory, body sensation plays a special and important role in the cognitive process.[111] When experiencing stress and poor sleep, individuals may develop negative perceptions and expectations about their next sleep behavior, which may further exacerbate sleep disturbances. From a biological perspective, feeling high levels of stress can trigger the activation of the HPA axis and lead to an increase in cortisol secretion, which in turn interferes with the production of melatonin, a hormone that regulates sleep. Elevated cortisol levels can interfere with the normal sleep-wake cycle by suppressing the production of melatonin,[33] while sleep disturbance conversely elevates cortisol levels,[34] creating a vicious cycle.[112] Besides the neuroendocrine system, the tension can also activate the autonomic nervous system, resulting in poorer sleep quality.[113] In the inflammatory pathways, Sleep fragmentation elevates pro-inflammatory cytokines (IL-6, TNF-a) that enhance stress sensitivity, creating a positive feedback loop.[35]

The Transactional Model posits that stress arises from individuals' appraisals of environmental demands and their perceived ability to cope with those demands. In firefighters, this dynamic interplay is acutely relevant due to their high-stakes, unpredictable work environment. For the appraisals of environmental demands, firefighters' irregular shift work and exposure to traumatic events (eg, smoke inhalation, life-threatening situations) may lead to persistent activation of the stress response system. Symptoms like "Daytime Dysfunction" (eg, fatigue, reduced concentration) directly compromise their ability to appraise tasks as manageable. For the perceived ability to cope with those demands, the model emphasizes that perceived coping resources (eg, self-efficacy) buffer stress, whereas the central symptom we identified,

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"Unable to control important things", reflects a malfunctioning of the assessment, where firefighters perceive themselves as incapable of coping with the demands. Such anomalies in the assessment of environmental demands and in the perceived ability to cope may contribute to firefighters' increased vulnerability to stress-related symptoms. Stress-related symptoms like "Felt nervous and stressed" may trigger hyperarousal, disrupting sleep quality via elevated cortisol levels.[114] Conversely, sleep disturbance further impairs cognitive flexibility and emotional regulation, perpetuating maladaptive coping strategies and reinforcing stress.[115] This cycle underscores the critical role of bridge symptoms like "Daytime Dysfunction" and "Felt Nervous and Stressed" in sustaining the sleep-stress relationship. Prior studies have proposed that targeting the bridge symptoms can effectively interrupt links between different diseases and alleviate their comorbidities.[84] Thus, targeting S7 "Daytime dysfunction" and P3 "Felt nervous and stressed" may be advantageous in disrupting the connection between sleep disturbances and perceived stress, and consequently alleviating their co-morbidity.

Previous studies have demonstrated that DAG was helpful in elucidating acceptable (or potential) causality between different variables from a perspective of probabilistic priority.[41,96] While the technique cannot determine the temporal precedence of symptoms, it does enable researchers to evaluate directional dependence from a probabilistic priority perspective.[88] Hence, this technique enables researchers to theorize about potential (or acceptable) causal relationships between symptoms using cross-sectional data.[54,85] Researchers can determine which symptoms strongly predict the presence of other symptoms. Symptoms with higher probabilistic priorities are more likely to influence and activate downstream symptoms, and the symptom with the highest probabilistic priority is considered the activation symptom in the DAG.[41] Currently, in the field of psychological and psychiatric research, DAGs have been widely employed to explore potential (or acceptable) causal associations among multiple symptoms using cross-sectional data.[116–118] Moreover, DAGs have also been extensively utilized in disease networks to identify the upstream symptom with the highest probabilistic priority, thereby providing potential targets for future clinical interventions.[75,119–121] In this study, the DAG was employed to elucidate the bidirectional spiral relationships between sleep disturbances and perceived stress symptoms. Structurally, the DAG can be divided into two sections, with the left side dominated by the perceived helplessness community and the right side dominated by the perceived self-efficacy with sleep disturbance communities. Notably, S6 "Use of sleeping medication" did not establish connections with other nodes in the DAG and functioned as a separate node. P7 "Unable to control irritations in life" was upstream of the perceived helplessness community and directly influenced P4 "Not confident to handle personal problems", P5 "Things were not going your way", and P8 "Did not feel on top of things" of the perceived helplessness community. That is, P7 "Unable to control irritations in life" was the source of activation for perceived helplessness symptoms and has the highest probabilistic priority. However, as depicted in the figure, the associations between the perceived helplessness community and the other two communities were not robust, with only three direct influence pathways, including from P7 "Unable to control irritations in life" to S2 "Sleep latency", from P5 "Things were not going your way" to P6 "Could not cope with all things to do", and from P8 "Did not feel on top of things" to P9 "Angered by things outside control".

S7 "Daytime dysfunction" appeared at the most upstream position of the perceived self-efficacy and sleep disturbance symptoms; in other words, from a probabilistic and statistical point of view, S7 "Daytime dysfunction" has the highest probabilistic priority and was the source of activation for perceived self-efficacy and sleep disturbance symptoms. The causes of this phenomenon have not been fully elucidated, and the potential explanations are manifold. First, daytime dysfunction is the direct manifestation and core symptom of circadian rhythm dysregulation. The core function of the circadian rhythm is to coordinate the rhythmic synchronization of physiology and behavior with the external environment. When the biological clock, governed by the suprachiasmatic nucleus of the hypothalamus,[122] is dysfunctional or disturbed by external social rhythms (eg, irregular work and rest), it will lead to decreased daytime alertness, distraction, and increased fatigue, that is, daytime dysfunction.[123] The social rhythm theory states that irregularities in daily activities (eg, work schedule instability) can weaken the stability of the biological clock, which directly leads to impaired daytime functioning, manifested as reduced work efficiency and difficulties in emotional regulation.[124] Secondly, daytime dysfunction exacerbates stress perception through emotional and cognitive mechanisms. On the one hand, daytime dysfunction resulting from circadian rhythm dysregulation can interfere with the functional balance of the prefrontal cortex and limbic system, reducing emotion regulation and impairing stress-buffering mechanisms, thereby exacerbating stress perception. On the other hand, daytime dysfunction and reduced attention can weaken an individual's cognitive reserves for coping with stress, resulting in the exhaustion of cognitive resources. The COR suggests that individuals have a tendency to acquire and preserve diverse resources that are beneficial to their survival, while the scarcity and depletion of resources cause stress.[107] Lastly, daytime dysfunction exacerbates circadian rhythm dysregulation by interfering with hormone production and secretion. Daytime dysfunction has been demonstrated to affect the normal functioning of stress response systems, such as the HPA axis, resulting in abnormal cortisol secretion.[114] Elevated cortisol levels inhibit the secretion of melatonin, thereby interfering with the normal sleep-wake cycle.[33] In turn, sleep disturbances could elevate cortisol levels, thus creating a vicious cycle.[34]

The DAG-based findings aligned with the results of the bridge centrality analysis in the RPCN, further demonstrating that S7 "Daytime dysfunction" was an influential bridge symptom in the sleep disturbances and perceived stress co-occurrence network. On the one hand, it directly influenced S1 "Subjective sleep quality" and S5 "Sleep disturbances" of the sleep disturbances community and indirectly influenced other downstream nodes of sleep disturbances through these two nodes. On the other hand, it directly influenced P1 "Upset by something unexpected", P2 "Unable to control important things", P3 "Felt nervous and stressed", and P10 "Difficulties piling up can't overcome" of the perceived self-efficacy community and indirectly influenced other downstream perceived self-efficacy nodes through these nodes. Notably, P3 "Felt nervous and stressed", P1 "Upset by something unexpected", and P9 "Angered by things outside control" in the perceived self-efficacy community also directly influenced S1 "Subjective sleep quality", S5 "Sleep disturbances", and S2 "Sleep latency" in the sleep disturbances community. Simply put, the bidirectional spiral relationships between sleep disturbances and perceived stress may stem from the fact that S7 "Daytime dysfunction" influences the symptoms of perceived self-efficacy, which in turn influences other sleep disturbance symptoms, whereas the symptoms of perceived helplessness do not seem to play important roles in this relationship. Based on insights from previous studies, the upstream symptoms had a higher probabilistic priority and broadly affected the downstream symptoms, and thus should be considered as important targets for intervention.[116] The results of DAG once again highlighted the importance of S7 "Daytime dysfunction", which may be a key target for improving sleep disturbance and perceived stress symptoms among firefighters. However, it is imperative to recognize that these DAG-based findings do not suggest temporal prioritization. Consequently, these results should be interpreted as potential (or acceptable) causal effects rather than real causal effects, which aligns with the consensus of previous research.[54,85]

Based on our network analysis findings, several potential applications can significantly contribute to firefighter health management. Firstly, our identification of central symptoms related to sleep disturbances and perceived stress among firefighters, namely "Unable to control important things" and "Unable to control irritations in life", provides potential targets for intervention. Since central symptoms act as key nodes within the network, exerting a significant influence on the overall manifestation of these problems,[82] cognitive behavioral therapy (CBT) can be used to directly address these symptoms.[125] Furthermore, regular mental health check-ups are also needed to monitor and manage these central symptoms. By doing so, potential problems can be detected at an early stage. In addition, other measures, such as mindfulness training and group psychotherapy, can also be taken to target these specific symptoms, thereby preventing the escalation of sleep disturbances and perceived stress. Secondly, the bridge symptoms we have elucidated, namely "Daytime dysfunction" and "Felt nervous and stressed", offer a more comprehensive approach to firefighter health management. These bridge symptoms, which link sleep disturbances and perceived stress, can be targeted through integrated intervention strategies. For instance, in addition to sleep therapy methods, interventions can incorporate stress management techniques such as mindfulness-based stress reduction (MBSR),[126] which help reduce the underlying connections between sleep disturbances and perceived stress, thereby enhancing firefighter health management in a more integrated manner. Furthermore, our understanding of the probabilistic priority and the bidirectional spiral relationship between sleep disturbances and perceived stress allows for the development of preventive strategies. Firefighter health management can focus on breaking this potential cycle by promoting healthy lifestyle habits. For instance, fitness programs can be set up to promote healthful exercise, optimize shift schedules to ensure firefighters have adequate time to rest, and facilitate regular educational activities on healthful sleep and stress management, and so on.

Several limitations need to be considered when interpreting our results. First, the use of the snowball sampling method, a non-probability sampling technique, represents an important limitation of this study. This method relies on referrals from initial participants, which may result in a sample that is homogeneous in certain characteristics. Consequently, the findings derived from such a sample might not be representative of the broader population, thereby limiting the generalizability of our results. Additionally, the use of a single web-based platform is another important limitation, which may lead to potential sampling biases due to individuals' varying familiarity with the online platform and its accessibility across units, thereby undermining the generalizability of the findings. Future studies should employ probability sampling methods and adopt multiple survey techniques to enhance the scientific rigor and reliability of the results. Second, the utilization of cross-sectional data is an important limitation of this study. Although we employed DAGs to examine the directions of relationships between different symptoms, it is important to recognize that the results cannot indicate temporal prioritization and should not be interpreted as real causal effects. Further research could utilize ecological momentary assessment[127] and longitudinal time series analysis (eg, cross-lagged panel networks)[128] to elucidate the temporal causality among symptoms. Third, the present study only explored two variables, namely sleep disturbance and perceived stress, in the firefighter population. It is important to recognize that the incorporation of other relevant variables, such as PTSD, burnout, depression, anxiety, and obsessive-compulsive disorder, would significantly improve the quality of research in future studies. The inclusion of these variables would enable a more nuanced and comprehensive analysis of the intricate interplay among various psychological factors in firefighters. This, in turn, would have provided more scientific and comprehensive theoretical evidence, which could inform the development and implementation of more effective strategies in the management of firefighters' mental health. Finally, the network structures constructed in this study were based on the Chinese firefighter population, limiting their generalizability across culturally distinct firefighter populations. This constraint underscores the critical need for cross-cultural validation, as the construction and symptom manifestations of mental problems may differ significantly due to variations in cultural background, social support systems, and healthcare access. Future research should systematically examine potential disparities in the network architecture of psychological problems among firefighters from different cultural backgrounds (eg, Eastern and Western, Collectivist and Individualist). Such research would enhance the generalizability and validity of network analytic findings and inform mental health management interventions for global firefighter populations.

## Conclusions

In the present study, we employed two methodologies (the RPCN and DAG) for network analysis to elucidate the psychological mechanisms underlying the intricate relationship between sleep disturbances and perceived stress in firefighters. Within the RPCN, P2 "Unable to control important things" and P7 "Unable to control irritations in life" were identified as central symptoms that played an important role in simultaneously sustaining sleep disturbances and perceived stress in firefighters. S7 "Daytime dysfunction" and P3 "Felt nervous and stressed" were identified as bridge symptoms, primarily connecting sleep disturbance symptoms with perceived stress symptoms. From a probabilistic priority perspective, the DAG results demonstrated that the bidirectional spiral between sleep disturbances and perceived stress may be due to the fact that the upstream symptom S7 "Daytime dysfunction" influenced the perceived self-efficacy dimension of perceived stress, which in turn influenced other sleep disturbance symptoms. However, the perceived helplessness dimension of perceived stress contributed less to this relationship. It is important to emphasize that these DAG-based findings do not suggest temporal prioritization, and thus these results should be interpreted as potential (or acceptable) causal effects rather than real causal effects.

Our study provides important insights for practice application. Firstly, through network analysis, we have identified the most central symptoms that simultaneously maintained sleep disturbances and perceived stress symptoms in firefighters. These central symptoms act as key nodes within the network, exerting a significant influence on the overall manifestation of these conditions. Secondly, we have elucidated the bridge symptoms that serve as crucial connectors, linking the firefighters' sleep disturbances and perceived stress symptoms and perpetuating their comorbid nature. By identifying these bridge symptoms, we have gained a more nuanced understanding of the complex interplay between these two problems, which is essential for developing targeted intervention strategies. Furthermore, from a probabilistic priority standpoint, our results provide an acceptable explanation for the bidirectional spiral relationship between sleep disturbances and perceived stress. This understanding of the potentially reciprocal nature of these problems is an important advancement, as it allows for a more comprehensive approach to addressing the mental health challenges faced by firefighters.

In summary, our findings offer some theoretical insights into further understanding the intricate relationship between sleep disturbances and perceived stress among firefighters. More importantly, the central, bridge, and upstream symptoms identified in this study may be potential targets for ameliorating symptoms. Future intervention programs could focus on these potential targets. By implementing interventions such as MBSR, CBT, and group psychotherapy, tailored to target these specific symptoms, it is possible to mitigate both sleep disturbances and perceived stress in firefighters, thereby improving the mental health and overall life satisfaction of this respectable professional group.

## Data Sharing Statement

The datasets generated and/or analyzed in this study are available from the corresponding author on reasonable request.

## Ethics Approval

The survey was conducted according to the Declaration of Helsinki. Informed consents were obtained from all participants for this study. This study has been reviewed and approved by the Ethics Committee of the First Affiliated Hospital of the Fourth Military Medical University (No. KY20202063-F-2).

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## Author Contributions

Bin Liu: Conceptualization, Formal analysis, Investigation, Methodology, Writing - original draft, and Writing - review and editing. Mingxuan Zou: Data curation, Formal analysis, Methodology, Writing - original draft, and Writing - review and editing. Lin Liu: Conceptualization, Formal analysis, Methodology, Writing - original draft, and Writing - review and editing. Zhongying Wu: Investigation, Methodology, Writing - original draft, and Writing - review and editing. Yinchuan Jin: Conceptualization, Investigation, Writing - original draft, and Writing - review and editing. Yuting Feng: Methodology, Visualization, Writing - original draft, and Writing - review and editing. Qiannan Jia: Investigation, Writing - original draft, and Writing - review and editing. Mengze Li: Formal analysis, Writing - original draft, and Writing - review and editing. Lei Ren: Conceptualization, Formal analysis, Writing - original draft, and Writing - review and editing. Qun Yang: Conceptualization, Methodology, Writing - original draft, and Writing - review and editing. All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas. All authors took part in drafting, revising or critically reviewing the article. They have agreed on the journal to which the article will be submitted. They have reviewed the manuscript and approved its final version for submission. All authors agree to take responsibility and be accountable for the contents of the article.

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## Disclosure

The authors report no conflicts of interest in this work.

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