Journal of Integrative Neuroscience

J. Integr. Neurosci. **2024**; 23(1): 9
https://doi.org/10.31083/j.jin2301009

Original Research

Differences in Functional Activity and Connectivity in the Right Frontoparietal Network between Nurses Working Long-Term Shifts and Fixed Day Shifts

Yuqin Dong[1,†], Xiaohong Wu[2,†], Yang Zhou[3], Ke Qiu[1,*]

[1]Department of Nursing, Leshan Vocational and Technical College, 614000 Leshan, Sichuan, China
[2]Department of Radiology, Leshan Hospital of Traditional Chinese Medicine, 614001 Leshan, Sichuan, China
[3]Tumor Center, West China Hospital of Sichuan University, 610044 Chengdu, Sichuan, China
*Correspondence: qiuke90930@126.com (Ke Qiu)
[†]These authors contributed equally.

Academic Editor: Gernot Riedel
Submitted: 16 May 2023 Revised: 9 July 2023 Accepted: 21 July 2023 Published: 15 January 2024

Abstract

Objectives: To investigate the differences in functional brain activity and connectivity between nurses working long-term shifts and fixed day shift and explore their correlations with work-related psychological conditions. **Methods**: Thirty-five nurses working long-term shifts and 35 nurses working fixed day shifts were recruited. After assessing work-related psychological conditions, such as burnout and perceived stress of these two groups of nurses, amplitude of low-frequency fluctuations (ALFF) and functional connectivity (FC) analyses were performed to investigate the between-group differences in brain functional activity and connectivity. Furthermore, correlation analysis between the ALFF/FC metrics and psychological conditions was conducted. **Results**: Compared with nurses working fixed day shifts, nurses working long-term shifts showed higher levels of burnout, perceived stress, and depression scores; lower z-transformed ALFF (zALFF) values in the right dorsolateral prefrontal cortex (dlPFC), right superior parietal lobule (SPL), and right anterior cingulate cortex (ACC); and higher zALFF values in the right middle temporal gyrus (voxel-level $p < 0.001$, cluster-level $p < 0.05$, gaussian random field (GRF) correction), as well as lower FC values in the right dlPFC-right SPL and right dlPFC-right ACC ($p < 0.05$, false discovery rate (FDR) corrected). Moreover, the FC values in the right dlPFC-right SPL were negatively correlated with the perceived stress score in nurses working long-term shifts ($p < 0.05$, FDR corrected). **Conclusions**: This study demonstrated that nurses working long-term shifts had lower functional activity and weaker functional connectivity in the right frontoparietal network, which mainly includes the right dlPFC and right SPL, than those working on regular day shift. The current findings provide new insights into the impacts of long-term shift work on nurses' mental health from a functional neuroimaging perspective.

Keywords: shift work; nurses; amplitude of low-frequency fluctuations; functional connectivity; frontoparietal network

1. Introduction

Nursing is an essential component of clinical healthcare. High-quality and sustainable nursing is an important guarantee of clinical outcomes. Given the continuity and uncertainty of clinical work, hospitals generally adopt shift-based nursing. Namely, three groups of nurses take turns to provide nursing services for patients at specific periods through shifts [1], which is an effective approach for providing uninterrupted nursing services, alleviating manpower shortages, and improving nursing quality [2]. However, long-term irregular shifts tend to disrupt the biological rhythm of nurses, and are associated with symptoms of burnout, emotional disorders, and various physical and mental illnesses [3] such as anxiety and depression [4], dementia [5], and cardiovascular [6] and endocrine disorders [7]. A recent cross-sectional study from China showed that 58.1% of nurses working long-term shifts exhibited work-related disorders, manifesting as a higher incidence of mental health problems, sleep disorders, and burnout [8].

Neuroimaging techniques provide visual evidence that can help elucidate the impacts of shift work on the physical and mental health of workers. A recent neuroimaging study [9] enrolling 39 nurses demonstrated that long-term shift work might contribute to a change in gray matter morphology in the bilateral postcentral gyrus, right paracentral lobule, and left superior temporal gyrus. Moreover, gray matter alterations in the left postcentral gyrus are correlated with the degree of impact of sleep disturbance on depression in nurses. Another study [10] compared differences in the white matter structure of 61 shift workers and 31 non-shift workers, finding that the shift workers exhibited higher fractional anisotropy in the bilateral anterior cingulum, and that the increased fractional anisotropy in the right anterior cingulum was correlated with poor sleep quality in shift workers. These studies provided preliminary evidence that shift work influences the brain structural plasticity of workers. However, it remains unclear whether and how long-term shift work affects the functional brain activity patterns of nurses and what the relationship is between these patterns and work-related psychological conditions in nurses.

After assessing the burnout, perceived stress, anxiety, and depression conditions using self-reported questionnaires, we collected the brain functional magnetic resonance imaging (fMRI) data of 35 nurses working long-term shifts and 35 nurses working fixed day shifts, and then compared the regional spontaneous neuronal activity and interregional functional coupling patterns between these two groups using the amplitude of low-frequency fluctuations (ALFF) [11] and functional connectivity (FC) [12] methods. Correlation analysis between the ALFF/FC metrics and psychological conditions was then performed among these participants. The results were expected to provide visual evidence that would help to elucidate the impacts of long-term shift work on the psychological conditions and neuroplasticity of nurses.

2. Materials and Methods

2.1 Participants

Thirty-five nurses working long-term shifts and 35 nurses working fixed day shifts were recruited from three hospitals in Leshan City, Sichuan, China. Participants were identified for inclusion based on their self-reported information in the history taking. The inclusion criteria were as follows: (1) female, aged between 20 and 35 years old; (2) right-handed; (3) unmarried or married but not pregnant; (4) absence of endocrine, neurological, or psychiatric diseases, or any other primary illnesses; and (5) no contraindications for magnetic resonance imaging (MRI) scans. Furthermore, nurses working long-term shifts had to fulfill the following criteria: the work time alternated between days (8:00–16:00), evenings (16:00–23:00), and nights (23:00–8:00) for more than 1 year. Nurses working fixed day shifts needed to have been working on day (8:00–18:00) shifts only, for almost 1 year, with no experience of working shifts.

2.2 Psychological Conditions

The Chinese version of the Maslach Burnout Inventory Human Service Survey (MBI-HSS) [13] developed by Maslach *et al*. [14] was applied to evaluate the occupational burnout of the participants. The MBI-HSS consists of 17 items, which belong to three dimensions: emotional exhaustion, depersonalization, and reduced personal accomplishment. MBI-HSS adopts a Likert scale of 0–6. The higher the score, the more severe the burnout of subjects. The Chinese version of the Perceived Stress Scale (PSS) [15] was used to evaluate the subjective perception of stress in the participants. PSS has 14 items and is scored on a Likert scale of 0–4. The higher the score, the greater the perceived stress of subjects. Furthermore, the Zung Self-Rating Anxiety Scale (SAS) [16] and the Zung Self-Rating Depression Scale (SDS) [17] were utilized to evaluate the anxiety and depression states of the subjects.

Statistical analysis of the demographic characteristics and psychological conditions was performed using SPSS 24.0 (IBM Corp., Armonk, NY, USA). Continuous variables were reported as mean ± standard deviation. Two-sample t-tests were used for intergroup comparisons of age; work experience; and MBI-HSS, PSS, SAS, and SDS scores; with a statistical significance threshold of $p < 0.05$.

2.3 MRI Data Acquisition

High-resolution T1-weighted structural images and blood-oxygen-level-dependent images were acquired using a 3.0 T Philips MRI scanner (Philips Corp., Amsterdam, Netherlands). The scanning parameters of the structural images were as follows: repetition time/echo time = 9.1 ms/3.0 ms, slice thickness = 1 mm, field of view = 240 × 240, matrix size = 256 × 256, flip angle = 12°. The scanning parameters of the functional images were as follows: repetition time/echo time = 2000 ms/30 ms, slice thickness = 3.5 mm, number of slices = 37, field of view = 240 × 240, flip angle = 90°, matrix size = 64 × 64.

2.4 fMRI Data Preprocessing

fMRI data preprocessing, as well as ALFF and FC analyses, were performed using DPABI 4.1 (http://rfmri.org/DPARSF) [18]. The preprocessing steps of the fMRI data were as follows: (1) removal of the first ten time points of the scanning sequence; (2) slice timing correction; (3) motion correction, excluding participants with mean frame-wise displacement >0.2 [19]; (4) co-registration and spatial segmentation using diffeomorphic anatomical registration through exponentiated lie algebra (DARTEL); (5) normalization of the functional images to the Montreal Neurological Institute coordinate space and registration of individual images to a standard space template, and the resampling of these images from 3.5 × 3.5 × 3.5 mm^3 to 3 × 3 × 3 mm^3 voxels; (6) spatial smoothing with a 6 mm kernel; and (7) removal of linear trends and band-pass filtering (0.01–0.08 Hz).

2.5 ALFF and FC Analyses

Based on the preprocessed data, the ALFF values were calculated and then transformed into z-scores to obtain the final z-transformed ALFF (zALFF) maps for statistical analysis using DPABI. As the differences in age and work years between nurses working long-term shifts and fixed day shifts were insignificant, the two-sample t-test was used for intergroup comparisons of zALFF values, with statistical significance thresholds set at voxel-level $p < 0.001$ and cluster-level $p < 0.05$ with Gaussian random field (GRF) correction.

The regions identified through ALFF analysis that showed significant differences between nurses working long-term shifts and fixed day shifts were selected as regions of interest (ROIs). The mean time series of the ROIs were extracted using DPABI, and the ROI-ROI FC analysis was conducted using *Pearson* correlation analysis. The two-sample t-test was used for intergroup comparisons of FC, with a statistical significance threshold of $p < 0.05$ with false discovery rate (FDR) correction.

IMR Press

Table 1. Demographic characteristics and psychological conditions of the two groups of nurses.

Group	Age (Years)	Working years	MBI-HSS	PSS	SAS	SDS
Group A	27 ± 3.66	4.3 ± 1.89	63.55 ± 6.24	31.18 ± 6.68	52.75 ± 13.97	51.32 ± 10.39
Group B	26.6 ± 3.96	3.97 ± 2.01	47.34 ± 10.99	24.69 ± 6.07	46.64 ± 11.34	44.45 ± 11.79
T-value	0.371	0.699	7.415	4.199	1.986	2.542
p-value	0.712	0.487	<0.001***	<0.001***	0.051	0.013*

Group A: Nurses working long-term shifts, Group B: Nurses working fixed day shifts, *** $p < 0.001$, * $p < 0.05$. Abbreviations: MBI-HSS, Maslach Burnout Inventory Human Service Survey; PSS, Perceived Stress Scale; SAS, Zung Self-Rating Anxiety Scale; SDS, Zung Self-Rating Depression Scale.

Table 2. Brain regions with different zALFF values between nurses working long-term shifts and fixed day shifts.

Brain regions	Cluster size	MNI coordinates (x, y, z)			T-value	Direction
R_dlPFC	133	54	24	18	–5.61	↓
R_SPL	91	21	–60	63	–5.13	↓
R_ACC	66	3	36	15	–4.32	↓
R_MTG	125	54	–36	–3	4.86	↑

Abbreviations: dlPFC, dorsolateral prefrontal cortex; SPL, superior parietal lobule; ACC, anterior cingulate cortex; MTG, middle temporal gyrus; R, right hemisphere; MNI, Montreal Neurological Institute; ALFF, amplitude of low-frequency fluctuations; zALFF, z-transformed ALFF; ↓ , nurses working long-term shifts < nurses working fixed day shifts; ↑ , nurses working long-term shifts > nurses working fixed day shifts.

In addition, partial correlation analysis was performed between the ALFF/FC metrics showing significant between-group differences and the psychological conditions, including MBI-HSS, PSS, SAS, and SDS scores, for nurses working long-term shifts, nurses working fixed day shifts, as well as all of them, respectively. Age, working years, and mean frame-wise displacement were used as covariates in the correlation analyses.

3. Results

3.1 Demographic Characteristics and Psychological Conditions

Two nurses working long-term shifts were excluded due to excessive head movements; therefore, 68 participants were included in the data analysis. There was no statistically significant difference between the two groups regarding age and years of work ($p > 0.05$). Compared with nurses working fixed day shifts, the nurses working long-term shifts had significantly higher MBI-HSS, PSS, and SDS scores ($p < 0.05$), indicating that nurses working long-term shifts had higher levels of occupational burnout, perceived stress, and depression (Table 1).

3.2 ALFF Analysis

The results of ALFF analysis showed that compared with nurses working fixed day shifts, nurses working long-term shifts had significantly decreased spontaneous functional activity (lower zALFF values) in the right dorsolateral prefrontal cortex (dlPFC), right superior parietal lobule (SPL), and right anterior cingulate cortex (ACC), and significantly increased functional activity in the right middle temporal gyrus (MTG) (voxel-level $p < 0.001$, cluster-level $p < 0.05$, GRF correction) (Table 2, Fig. 1A).

3.3 FC Analysis

The results of the ROI-ROI FC analysis showed that compared with nurses working fixed day shifts, nurses working long-term shifts had significantly decreased FC between the right dlPFC and right SPL, as well as between the right dlPFC and right ACC ($p < 0.05$, FDR correction) (Fig. 1B).

3.4 Correlation Analysis

The results of the correlation analysis are shown in Table 3 and Fig. 1C. As shown in Fig. 1C, the FC value between the right dlPFC and right SPL was negatively correlated with the PSS score in nurses working long-term shifts under the threshold of FDR-corrected $p < 0.05$, i.e., the lower the connectivity between the right dlPFC and right SPL, the higher the PSS score was, meaning that the participants felt higher levels of work-related stress. Moreover, the zALFF value of the right dlPFC, as well as the right ACC, was negatively correlated with the MBI-HSS score. The FC value between the right dlPFC and right SPL was negatively correlated with the MBI-HSS and PSS scores in these 68 nurses (threshold: FDR-corrected $p < 0.05$). These findings meant that nurses having lower spontaneous activity in the right dlPFC and right ACC and lower connectivity between the right dlPFC and right SPL manifested higher levels of occupational burnout and perceived stress.

4. Discussion

This study investigated the differences in functional brain activity and connectivity between nurses working long-term shifts and fixed day shifts. The results demonstrated that compared with nurses working fixed day shifts,

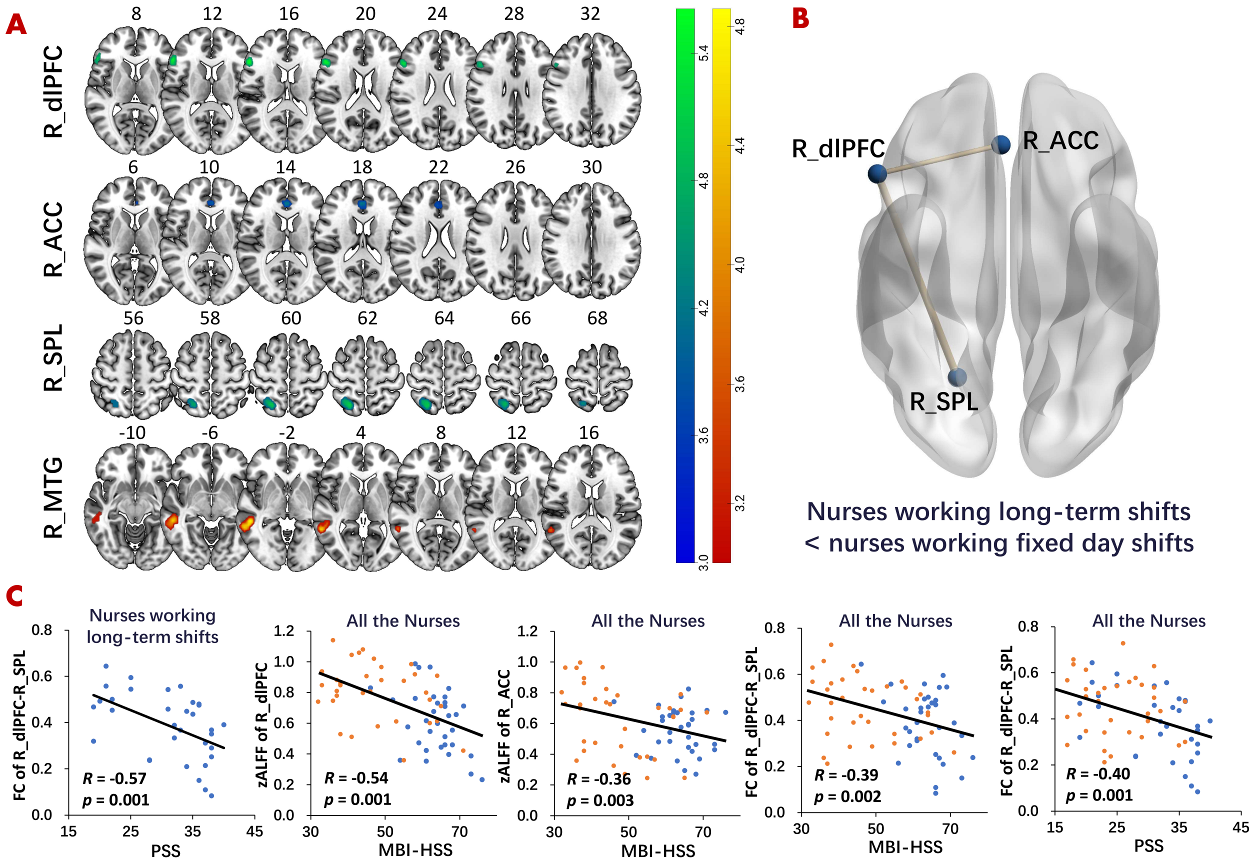

Fig. 1. Differences in brain activity and functional connectivity between nurses working long-term shifts and fixed day shifts and the correlations between ALFF/FC metrics and psychological conditions in nurses. (A) Results of between-group comparison in ALFF analysis, the color bar indicates the T-value of the clusters, warm colors indicate nurses working long-term shifts > nurses working fixed day shifts, while cool colors indicate the opposite. (B) Results of between-group comparison in ROI-ROI FC analysis. (C) Correlations of ALFF/FC metrics and psychological conditions in nurses. The blue dots indicate nurses working long-term shifts and the orange dots indicate nurses working fixed day shifts. Abbreviations: FC, Functional Connectivity.

those who worked long-term shifts had reduced spontaneous activity and functional connectivity in the critical nodes of the right frontoparietal network, including the right dlPFC and SPL. Moreover, the FC of the right dlPFC-right SPL was significantly correlated with the perceived stress of nurses working long-term shifts.

Our results demonstrated that nurses working long-term shifts had higher MBI-HSS, PSS, and SDS scores than those nurses who work regular day shifts, which is consistent with the findings of previous studies [4,20,21]. For example, Booker *et al*. [4] found that shift work might lead to sleep disorders and symptoms of depression and anxiety. Another perspective study [21] demonstrated that after 1 year of shift work, workers experienced an impairment in their mental health, which manifested as burnout, depression, and anxiety, as well as sleep disturbances. Moreover, sleep disorders mediated the impacts of shift work on the mental health of participants. These highly consistent findings could be plausibly explained by a concept in chronobiology, that is, rhythm disruption. The irregular or reduced sleep duration in shift work leads to reduced sensitivity to peripheral cortisol receptors [22], decreased production of melatonin [23], and decreased secretion of monoamine neurotransmitters [24], which further contributes to the development of psychological disorders.

Our results support the altered activity patterns in the right frontoparietal network in nurses working long-term shifts, which manifested as lower spontaneous activity and weaker connectivity than nurses who worked fixed day shifts. The frontoparietal network is composed of the dlPFC and the parietal cortex, which includes the SPL, superior parietal sulcus, and lateral parietal cortex. According to the lateralization of their functions, the frontoparietal network is divided into left and right networks. The right frontoparietal network is mainly responsible for working memory, endogenous perception, emotion perception, and inhibitory control. In contrast, the left frontoparietal network mainly involves speech, semantic recognition, and cognition [25,26]. Numerous neuroimaging studies have shown that the altered activity of the right frontoparietal network might be closely related to impaired working memory, attention deficits, and abnormal psychological states

Table 3. Correlation between ALFF/FC metrics and psychological conditions in nurses.

	MBI-HSS	PSS	SAS	SDS
Nurses working long-term shifts (N = 33)				
zALFF of R_dlPFC	$R = -0.41$ $p = 0.02$*	$R = -0.14$ $p = 0.46$	$R = -0.12$ $p = 0.53$	$R = -0.09$ $p = 0.64$
zALFF of R_ACC	$R = -0.11$ $p = 0.55$	$R = -0.12$ $p = 0.54$	$R = -0.15$ $p = 0.43$	$R = -0.14$ $p = 0.46$
zALFF of R_SPL	$R = -0.01$ $p = 0.95$	$R = -0.05$ $p = 0.79$	$R = 0.06$ $p = 0.74$	$R = -0.07$ $p = 0.71$
zALFF of R_MTG	$R = -0.12$ $p = 0.52$	$R = 0.17$ $p = 0.37$	$R = -0.13$ $p = 0.50$	$R = 0.05$ $p = 0.80$
FC of R_dlPFC-R_SPL	$R = -0.37$ $p = 0.03$*	**$R = -0.57$** **$p = 0.001$****	$R = -0.21$ $p = 0.26$	$R = -0.03$ $p = 0.86$
FC of R_dlPFC-R_ACC	$R = 0.19$ $p = 0.32$	$R = 0.22$ $p = 0.23$	$R = -0.03$ $p = 0.87$	$R = 0.09$ $p = 0.63$
Nurses working fixed day shifts (N = 35)				
zALFF of R_dlPFC	$R = -0.36$ $p = 0.04$*	$R = -0.07$ $p = 0.71$	$R = 0.27$ $p = 0.14$	$R = -0.04$ $p = 0.81$
zALFF of R_ACC	$R = -0.28$ $p = 0.11$	$R = 0.30$ $p = 0.09$	$R = 0.33$ $p = 0.07$	$R = -0.28$ $p = 0.13$
zALFF of R_SPL	$R = 0.06$ $p = 0.74$	$R = 0.03$ $p = 0.89$	$R = 0.08$ $p = 0.66$	$R = -0.11$ $p = 0.54$
zALFF of R_MTG	$R = -0.07$ $p = 0.72$	$R = 0.38$ $p = 0.03$*	$R = 0.08$ $p = 0.65$	$R = -0.10$ $p = 0.60$
FC of R_dlPFC-R_SPL	$R = -0.29$ $p = 0.11$	$R = -0.11$ $p = 0.53$	$R = -0.36$ $p = 0.04$*	$R = -0.05$ $p = 0.80$
FC of R_dlPFC-R_ACC	$R = -0.10$ $p = 0.59$	$R = 0.03$ $p = 0.88$	$R = 0.06$ $p = 0.75$	$R = 0.02$ $p = 0.92$
All the nurses (N = 68)				
zALFF of R_dlPFC	**$R = -0.54$** **$p < 0.001$*****	$R = -0.30$ $p = 0.02$*	$R = -0.06$ $p = 0.62$	$R = -0.18$ $p = 0.16$
zALFF of R_ACC	**$R = -0.36$** **$p = 0.003$****	$R = -0.05$ $p = 0.70$	$R = 0.01$ $p = 0.91$	$R = -0.23$ $p = 0.07$
zALFF of R_SPL	$R = -0.20$ $p = 0.11$	$R = -0.17$ $p = 0.17$	$R = -0.03$ $p = 0.81$	$R = -0.13$ $p = 0.29$
zALFF of R_MTG	$R = 0.05$ $p = 0.70$	$R = 0.25$ $p = 0.04$*	$R = -0.02$ $p = 0.85$	$R = 0.05$ $p = 0.71$
FC of R_dlPFC-R_SPL	**$R = -0.39$** **$p = 0.002$****	**$R = -0.40$** **$p = 0.001$****	$R = -0.30$ $p = 0.01$*	$R = -0.12$ $p = 0.34$
FC of R_dlPFC-R_ACC	$R = -0.20$ $p = 0.10$	$R = -0.03$ $p = 0.81$	$R = -0.04$ $p = 0.75$	$R = -0.07$ $p = 0.60$

* $p < 0.05$, ** $p < 0.05$, *** $p < 0.001$. Bold text in the table indicates correlations that remain significant after FDR correction. Abbreviations: FDR, false discovery rate.

[27–30]. A recent neuroimaging meta-analysis also showed that clinical subjects with emotion regulation disorders exhibited reduced activity in the right frontoparietal network and compensatory activation of the emotion-related brain regions, such as the ACC [31]. The results of the current study suggest that nurses working long-term shifts exhibited not only higher levels of burnout, heavier psychological stress, and more pronounced depression symptoms, but also lower spontaneous activity and weaker connectivity in the right dlPFC and right SPL. Our correlation analysis showed significant correlations between the FC of the right dlPFC-right SPL and both the MBI-HSS and PSS scores of nurses. The negative correlation coefficient indicates that nurses having lower frequency activity/synchrony of the right dlPFC have higher levels of burnout and perceived stress. It is worth noting that correlation between ALFF/FC metrics and MBI-HSS/PSS scores is not specific for shift-working nurses. It is, however, the case that shift-working nurses show generally higher values in scores, but lower ALFF/FC. Hence, the association between ALFF/FC and symptoms is possibly not specific for shift work, but in shift-working nurses the level of both is more severe. These findings suggest that the inhibition of functional activity of the right, rather than left, frontoparietal network in nurses working long-term shifts may imply a work-related impairment in their emotional perception and regulation.

Furthermore, sleeping disorder studies have provided further evidence for understanding the right frontoparietal network and psychological disorders of shift-working nurses. For instance, one study detected that long-term sleep deprivation could seriously affect emotion regulation, cognitive attention, and working memory [32,33]. In another study, subjects in a state of sleep deprivation exhibited reduced activity in the right frontoparietal network and unstable mutual inhibition between the frontoparietal network and the default mode network when performing attention control tasks [34]. Long-term and high-density shift working is highly likely to cause chronic sleep deprivation, which could impair the working memory and emotion regulation of nurses [35]. The plasticity of the right frontoparietal network and increased burnout and perceived stress of nurses working long-term shifts may therefore attribute to their long-term chronic sleep deprivation.

In addition to the right frontoparietal network, our study also detected decreased spontaneous activity in the right ACC in nurses who work long-term shifts. The ACC is an essential component of the limbic system and a key node for emotion perception and stress control [36,37]. Previous studies have shown that patients with emotional disorders, such as anxiety and depression, generally exhibit functional and structural abnormalities in the ACC [38–40]. Results from animal experiments have also demonstrated that the content of ACC-derived neurotrophic factors is closely related to the negative emotions and behaviours of rats [41,42]. In our study, we observed a significant increase in psychological stress and depression scores and decreased spontaneous activity in the ACC in nurses who work long-term shifts, which validated the correlations between the ACC and stress and depression from a clinical perspective. Except for emotion regulation, as part of the old cortex, the ACC is closely related with vigilance in humans [43]. Piantoni *et al.* [44] found that acute sleep deprivation caused a decrease in vigilance and task performance in healthy subjects, which could be explained by the altered functional connectivity patterns of the ACC. Nurses who work long-term shifts always suffer from chronic sleep deprivation and decreased vigilance and reaction [45,46]. The decreased functional activity of the ACC in nurses working long-term shifts may therefore also be associated with their vigilance impairment. However, since this study did not directly assess the vigilance and reactions of participants, further task-based neuroimaging studies are needed to explore the relationship between the decreased functional activity in the ACC and vigilance.

Our study had some limitations. First, this was a cross-sectional study that investigated the differences in functional brain activity and connectivity patterns of nurses working long-term shifts versus nurses working fixed day shifts. The progressive impacts of long-term shift work on the brain of nurses need to be further investigated in a longitudinal study. Second, this was a resting-state fMRI study, and the findings were unable to identify the causal relationship between functional brain activity and alterations in work-related psychological conditions. Follow-up studies could apply a task design to further explore the relationships between brain activity associated with long-term shift work and impairments in cognition and working memory. Third, the inclusion criteria for nurses working fixed day shifts were no experience of shift work for almost 1 year. However, a recent study suggested that former night shift workers may also manifest structural and functional neural plasticity [47]. Therefore, further validation of the current findings in nurses who have not experienced shift work is needed.

5. Conclusions

In conclusion, this current study using ALFF and FC methods indicated that nurses working long-term shifts had lower functional activity and weaker functional connectivity in the right frontoparietal network than nurses working fixed day shifts. The altered functional activity and connectivity patterns in the right frontoparietal network were correlated with occupational burnout and perceived stress in nurses. The results provide new insights into the impacts of long-term shift work on the mental health of nurses from a functional neuroimaging perspective and provide a potential and quantifiable indicator for future research regarding the mitigation of the hazards of shift work.

Availability of Data and Materials

The main data supporting our findings can be found within the manuscript. The raw data can be requested from the corresponding author.

Author Contributions

KQ and YZ contributed to the conception and design of the study. YD and XW performed data collection and analysis. YD wrote the first draft of the manuscript. KQ revised the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Leshan Hospital of Traditional Chinese Medicine (Approval number: 2019-10-003).

Acknowledgment

The authors would like to express their sincere gratitude to all those who provided valuable guidance and support throughout the research. Additionally, we would like to thank our colleagues for their invaluable assistance with data collection and analysis.

Funding

This work was supported by Sichuan Science and Technology Project (NO. 19RKX0261) and the Key Science and Technology Innovation Project of Leshan Vocational and Technical College (NO. 2019020).

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Min A, Hong HC, Son S, Lee TH. Alertness during working hours among eight-hour rotating-shift nurses: An observational study. Journal of Nursing Scholarship. 2022; 54: 403–410.
[2] Cheng P, Drake C. Shift Work Disorder. Neurologic Clinics. 2019; 37: 563–577.
[3] Matheson A, O'Brien L, Reid JA. The impact of shiftwork on health: a literature review. Journal of Clinical Nursing. 2014; 23: 3309–3320.
[4] Booker LA, Sletten TL, Alvaro PK, Barnes M, Collins A, Chai-Coetzer CL, *et al*. Exploring the associations between shift work disorder, depression, anxiety and sick leave taken amongst nurses. Journal of Sleep Research. 2020; 29: e12872.
[5] Ling Y, Yuan S, Huang X, Tan S, Huang T, Xu A, *et al*. The association of night shift work with the risk of all-cause dementia and Alzheimer's disease: a longitudinal study of 245,570 UK Biobank participants. Journal of Neurology. 2023; 270: 3499–3510.
[6] Vetter C, Devore EE, Wegrzyn LR, Massa J, Speizer FE, Kawachi I, *et al*. Association Between Rotating Night Shift Work and Risk of Coronary Heart Disease Among Women. Journal of the American Medical Association. 2016; 315: 1726–1734.
[7] Hansen AB, Stayner L, Hansen J, Andersen ZJ. Night shift work and incidence of diabetes in the Danish Nurse Cohort. Occupational and Environmental Medicine. 2016; 73: 262–268.
[8] Cheng H, Liu G, Yang J, Wang Q, Yang H. Shift work disorder, mental health and burnout among nurses: A cross-sectional study. Nursing Open. 2023; 10: 2611–2620.
[9] Park CH, Bang M, Ahn KJ, Kim WJ, Shin NY. Sleep disturbance-related depressive symptom and brain volume reduction in shift-working nurses. Scientific Reports. 2020; 10: 9100.
[10] Lee J, Kim M, Kim N, Hwang Y, Lee KH, Lee J, *et al*. Evidence of White Matter Integrity Changes in the Anterior Cingulum Among Shift Workers: A Cross-Sectional Study. Nature and Science of Sleep. 2022; 14: 1417–1425.
[11] Zang YF, He Y, Zhu CZ, Cao QJ, Sui MQ, Liang M, *et al*. Altered baseline brain activity in children with ADHD revealed by resting-state functional MRI. Brain & Development. 2007; 29: 83–91.
[12] Briley PM, Webster L, Boutry C, Cottam WJ, Auer DP, Liddle PF, *et al*. Resting-state functional connectivity correlates of anxiety co-morbidity in major depressive disorder. Neuroscience and Biobehavioral Reviews. 2022; 138: 104701.
[13] Mao H, Sang Z, Liang J, Zhang J, Fu Q, Jin B. Reliability and Validity of MBI-HSS Scale in the Assessment of Job Burnout Among the Basic Public Health Service Staff. Journal of Preventive Medicine Information. 2021; 37: 1711–1715, 1721. (In Chinese)
[14] Maslach C, Jackson SE, Leiter MP. Maslach Burnout Inventory: Third edition. In Zalaquett CP, Wood RJ (eds.) Evaluating stress: A book of resources (pp. 191–218). Scarecrow Education: Lanham. 1997.
[15] Zang MR, Huang HG, Deng YF, Chen HX. Reliability and validity test of perceived stress scale in nurses. Occupation and Health. 2022; 38: 1788–1791, 1796.
[16] Zung WW. A rating instrument for anxiety disorders. Psychosomatics. 1971; 12: 371–379.
[17] ZUNG WW. A SELF-RATING DEPRESSION SCALE. Archives of General Psychiatry. 1965; 12: 63–70.
[18] Yan CG, Wang XD, Zuo XN, Zang YF. DPABI: Data Processing & Analysis for (Resting-State) Brain Imaging. Neuroinformatics. 2016; 14: 339–351.
[19] Power JD, Barnes KA, Snyder AZ, Schlaggar BL, Petersen SE. Spurious but systematic correlations in functional connectivity MRI networks arise from subject motion. NeuroImage. 2012; 59: 2142–2154.
[20] Karatsoreos IN. Effects of circadian disruption on mental and physical health. Current Neurology and Neuroscience Reports. 2012; 12: 218–225.
[21] Kalmbach DA, Pillai V, Cheng P, Arnedt JT, Drake CL. Shift work disorder, depression, and anxiety in the transition to rotating shifts: the role of sleep reactivity. Sleep Medicine. 2015; 16: 1532–1538.
[22] Kino T, Chrousos GP. Acetylation-mediated epigenetic regulation of glucocorticoid receptor activity: circadian rhythm-associated alterations of glucocorticoid actions in target tissues. Molecular and Cellular Endocrinology. 2011; 336: 23–30.
[23] Rahman SA, Marcu S, Kayumov L, Shapiro CM. Altered sleep architecture and higher incidence of subsyndromal depression in low endogenous melatonin secretors. European Archives of Psychiatry and Clinical Neuroscience. 2010; 260: 327–335.
[24] Ye H, Ji M, Wang C, Wang C, Li Y, Chen Y, *et al*. Integrated Functional Neuroimaging, Monoamine Neurotransmitters, and Behavioral Score on Depressive Tendency in Intensive Care Unit Medical Staffs Induced by Sleep Deprivation After Night Shift Work. Frontiers in Psychiatry. 2022; 13: 848709.
[25] Marek S, Dosenbach NUF. The frontoparietal network: function, electrophysiology, and importance of individual precision mapping. Dialogues in Clinical Neuroscience. 2018; 20: 133–140.
[26] Vendetti MS, Bunge SA. Evolutionary and developmental changes in the lateral frontoparietal network: a little goes a long way for higher-level cognition. Neuron. 2014; 84: 906–917.
[27] Letkiewicz AM, Cochran AL, Cisler JM. Frontoparietal network activity during model-based reinforcement learning updates is reduced among adolescents with severe sexual abuse. Journal of Psychiatric Research. 2022; 145: 256–262.
[28] May KE, Kana RK. Frontoparietal Network in Executive Functioning in Autism Spectrum Disorder. Autism Research. 2020; 13: 1762–1777.
[29] Tan W, Liu Z, Xi C, Deng M, Long Y, Palaniyappan L, *et al*. Decreased integration of the frontoparietal network during a working memory task in major depressive disorder. The Australian and New Zealand Journal of Psychiatry. 2021; 55: 577–587.
[30] Yuk V, Urbain C, Anagnostou E, Taylor MJ. Frontoparietal Network Connectivity During an *N*-Back Task in Adults With Autism Spectrum Disorder. Frontiers in Psychiatry. 2020; 11: 551808.
[31] Picó-Pérez M, Radua J, Steward T, Menchón JM, Soriano-Mas C. Emotion regulation in mood and anxiety disorders: A meta-analysis of fMRI cognitive reappraisal studies. Progress in

Neuro-psychopharmacology & Biological Psychiatry. 2017; 79: 96–104.
[32] Gerhardsson A, Åkerstedt T, Axelsson J, Fischer H, Lekander M, Schwarz J. Effect of sleep deprivation on emotional working memory. Journal of Sleep Research. 2019; 28: e12744.
[33] Gerhardsson A, Fischer H, Lekander M, Kecklund G, Axelsson J, Åkerstedt T, *et al*. Positivity Effect and Working Memory Performance Remains Intact in Older Adults After Sleep Deprivation. Frontiers in Psychology. 2019; 10: 605.
[34] Krause AJ, Simon EB, Mander BA, Greer SM, Saletin JM, Goldstein-Piekarski AN, *et al*. The sleep-deprived human brain. Nature Reviews. Neuroscience. 2017; 18: 404–418.
[35] Esmaily A, Jambarsang S, Mohammadian F, Mehrparvar AH. Effect of shift work on working memory, attention and response time in nurses. International Journal of Occupational Safety and Ergonomics. 2022; 28: 1085–1090.
[36] Seamans JK, Floresco SB. Event-based control of autonomic and emotional states by the anterior cingulate cortex. Neuroscience and Biobehavioral Reviews. 2022; 133: 104503.
[37] Qiu Y, Fan Z, Zhong M, Yang J, Wu K, Huiqing H, *et al*. Brain activation elicited by acute stress: An ALE meta-analysis. Neuroscience and Biobehavioral Reviews. 2022; 132: 706–724.
[38] Cheng B, Meng Y, Zuo Y, Guo Y, Wang X, Wang S, *et al*. Functional connectivity patterns of the subgenual anterior cingulate cortex in first-episode refractory major depressive disorder. Brain Imaging and Behavior. 2021; 15: 2397–2405.
[39] Gasquoine PG. Localization of function in anterior cingulate cortex: from psychosurgery to functional neuroimaging. Neuroscience and Biobehavioral Reviews. 2013; 37: 340–348.
[40] Wlad M, Frick A, Engman J, Hjorth O, Hoppe JM, Faria V, *et al*. Dorsal anterior cingulate cortex activity during cognitive challenge in social anxiety disorder. Behavioural Brain Research. 2023; 442: 114304.
[41] Yang CR, Bai YY, Ruan CS, Zhou FH, Li F, Li CQ, *et al*. Injection of Anti-proBDNF in Anterior Cingulate Cortex (ACC) Reverses Chronic Stress-Induced Adverse Mood Behaviors in Mice. Neurotoxicity Research. 2017; 31: 298–308.
[42] Wen J, Xu Y, Yu Z, Zhou Y, Wang W, Yang J, *et al*. The cAMP Response Element- Binding Protein/Brain-Derived Neurotrophic Factor Pathway in Anterior Cingulate Cortex Regulates Neuropathic Pain and Anxiodepression Like Behaviors in Rats. Frontiers in Molecular Neuroscience. 2022; 15: 831151.
[43] Leehr EJ, Redlich R, Zaremba D, Dohm K, Böhnlein J, Grotegerd D, *et al*. Structural and functional neural correlates of vigilant and avoidant regulation style. Journal of Affective Disorders. 2019; 258: 96–101.
[44] Piantoni G, Cheung BLP, Van Veen BD, Romeijn N, Riedner BA, Tononi G, *et al*. Disrupted directed connectivity along the cingulate cortex determines vigilance after sleep deprivation. NeuroImage. 2013; 79: 213–222.
[45] Durán-Gómez N, Guerrero-Martín J, Pérez-Civantos D, López-Jurado CF, Montanero-Fernández J, Cáceres MC. Night Shift and Decreased Brain Activity of ICU Nurses: A Near-Infrared Spectroscopy Study. International Journal of Environmental Research and Public Health. 2021; 18: 11930.
[46] Min A, Hong HC, Son S, Lee T. Sleep, fatigue and alertness during working hours among rotating-shift nurses in Korea: An observational study. Journal of Nursing Management. 2021; 29: 2647–2657.
[47] Bittner N, Korf HW, Stumme J, Jockwitz C, Moebus S, Schmidt B, *et al*. Multimodal investigation of the association between shift work and the brain in a population-based sample of older adults. Scientific Reports. 2022; 12: 2969.