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Comparison of Sleep-related Cardiac Autonomic Function between Rotating-shift and Permanent Night-shift Workers

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Abstract: The purpose of this study was to explore whether sleep-related cardiac sympathetic activity is significantly lower in rotating shift workers than in permanent night shift workers, in order to evaluate whether shift work is preferable to permanent night work. Our sample comprised of twelve permanent night shift nurses and twelve rotating three-shift nurses. All female nurses slept in their dormitories, where they were allowed to sleep and wake spontaneously. All sleep parameters were recorded and analyzed using an ambulatory polysomnographic recorder. No significant differences were identified between permanent night shift (PNS) nurses and rotating three-shift (RTS) nurses in terms of basic demographics and sleep patterns. The low frequency (LF) of PNS nurses was significantly higher than that of RTS nurses during both daytime sleep and wakefulness, as was the low-to-high frequency ratio (LF/HF) during both nighttime sleep and wakefulness. PNS nurses also exhibited significantly higher LF and LF/HF during the first to third episode of non-rapid eye movement (NREM1-3) sleep, and the first episode of rapid-eye movement (REM1) sleep. PNS nurses had higher sympathetic activity during nighttime and daytime sleep than did RTS nurses. These results suggest that a rotating three-shift schedule may be preferable to permanent night work in terms of cardiac autonomic regulation.

Key words: Night shift, Nurse, Shift work, Heart rate variability

Introduction

Permanent night shift nurses experienced reversed sleep patterns and desynchronized the internal biological clocks. Nurses who work in the three-shift rotating

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schedule experience seriously disruptions in daily patterns consequential to shift changes. There is evidence that shift work leads to higher risk of cardiovascular disease[1]. It has been proposed that disturbed circadian rhythms are the main contributing factors to such problems among shift workers[2]. The exact mechanisms by which shift work contributes to cardiovascular disease; however, remains to elucidated[3].

There is evidence that frequency domain heart rate variability (HRV) analysis serves as a useful indicator of cardiac dysfunction[4]. HRV indicates time-to-time changes in the activities of the sympathetic and parasympathetic nerves innervating to the sinus node[5]. The high-frequency (HF) power of HRV is used as an index of parasympathetic activity level. The low-frequency (LF) power of HRV reflects both sympathetic and parasympathetic activity, and the LF to HF ratio (LF/HF) is believed to reflect cardiac sympathetic modulations or sympathovagal balance[6]. Therefore, the frequency domain HRV analysis can provide interpretable data reflecting cardiac autonomic function. Previous studies have found no significant differences in HF and LF components and LF/HF ratios between day and night shift workers[7, 8]. People working both kinds of shift schedule showed decreased LF/HF ratios and increased HF components during sleep compared to working periods[7, 8]. However, these studies did not compare indicators of cardiac autonomic function during particular sleep stages between people working different shifts. Earlier studies have indicated that it is important to analyze cardiac changes during sleeping periods, not only during wakefulness[9]. Small alternations in cardiac autonomic functions such as sympathetic activation —which has been associated with hypertension— are detectable only during sleep[9]. One reason for this is that differential levels of physical activity between sleep and wakefulness confound analyses of cardiac autonomic functions between these two conditions[8]. Given the foregoing, we reasoned that our present endeavorusing polysomonography to examine differences in sleep-related cardiac autonomic regulation between rotating three-shift (RTS) and permanent night-shift (PNS) workers—could prove useful in illuminating issues surrounding the longstanding debate over whether RTS or PNS schedules are preferable in terms of worker health outcomes, and particularly in terms of cardiovascular-related health outcomes.

Many studies have compared autonomic functioning of shift workers with that of daytime workers, and have sought to illuminate the effects of day- versus evening- versus night-shift schedules on cardiac autonomic function[8, 10, 11]. In our own previous work, we found that working permanent night shifts affects sympathetic activity in nighttime sleep significantly more than does working regular daytime shifts[12]. However, differences in sleep-related cardiac function between RTS and PNS have yet to be fully examined. Our aim in this study was to explore whether cardiac sympathetic activity among RTS nurses is significantly lower than that among PNS nurses to help evaluate whether RTS schedules may be preferable to PNS schedules in terms of cardiovascular health effects.

Subject and Methods

Participants and procedures

The study design and criteria for identifying permanent night shift nurses were the same as used in our previous study, and part of our dataset derives from that study[12]. Potential participants were excluded if they were identified as exhibiting certain characteristics known to affect cardiovascular functioning (psychopathology, neuropathology, cardiovascular pathology, use of hypnotics, and self-reported caffeine or nicotine consumption). Three participants were excluded before the analysis due to missing data on these variables. All nurses lived in the same dormitory where they were allowed to sleep and wake according to their usual patterns. The female nurses chose to work at night mainly because of financial reasons or the options that such work offered. Circadian types were categorized as follows: (i) morning-type, (ii) evening-type, and (iii) intermediate type[13]. We used the Pittsburgh Sleep Quality Index (PSQI) questionnaire[14] to measure self-reported sleep quality over the one-month period prior to the study period; higher scores indicate poorer sleep quality. Heart rate and blood pressure were measured before polysomnographic recording. No significant differences were found between PNS nurses and RTS nurses in terms of age, body mass index, years employed in nursing, blood pressure, tea or coffee consumption, or circadian type (Table 1). All nurses worked on the medical-surgical ward at the same hospital.

Nurses in the PNS group worked three consecutive night shifts (from 23:30 to 07:30 h) followed by 2 or 3 days off, and then another 3 or 4 consecutive night shifts. RTS nurses worked on a fast forward-rotating shift schedule: a sequence of 3 consecutive morning shifts (07:30 to 15:30 h), 3 afternoon shifts (15:30 to 23:30 h), and 3 night shifts (23:30 to 07:30 h) with two or three days off between each rotation. Both groups were first habituated to polysomnographic equipment for a single sleep session, and then recordings were taken during the second nighttime sleep period after two consecutive days off, and during the second daytime sleep period after working two consecutive night shifts. Over

Table 1. Selected participant characteristics by study group

Variable	Rotating three-shift nurses (N=12)	Permanent night shift nurses (N=12)	*p*-value^
Age (yr)	27.25 ± 1.86	26.82 ± 2.09	0.21
Years employed in nursing	2.83 ± 1.90	2.18 ± 0.87	0.33
Body mass index	20.05 ± 1.81	20.04 ± 1.88	0.10
Heart rate (bpm)	80.92 ± 10.18	80.55 ± 7.22	0.39
Diastolic blood pressure (mmHg)	66.50 ± 5.40	63.55 ± 3.62	0.60
Systolic blood pressure (mmHg)	113.17 ± 4.63	111.36 ± 5.68	0.80
Global PSQI	9.17 ± 4.84	9.73 ± 4.65	0.43
Tea consumption (number of nurses)			0.26
Never	1	1	
< once per week	5	6	
1–2 times per week	5	4	
3–4 times per week	1	1	
5–7 times per week	0	0	
Coffee consumption (number of nurses)			0.92
Never	4	4	
< once per week	2	4	
1–2 times per week	3	2	
3–4 times per week	1	1	
5–7 times per week	2	1	
Diurnal type (number of nurses)			0.63
Morningness	1	1	
Neither	9	9	
Eveningness	2	2	

^Mann-Whitney U tests for continuous variables and χ^2 tests for categorical variables; the data are expressed as mean ± SD.
Pittsburgh Sleep Quality Index (PSQI); beats per minute (bpm).

all studied sleep periods, and across all participants, time of sleep onset ranged from 01:00 h to 03:00 h and time of awakening ranged from 07:00 to 09:00 h for nocturnal sleep. For daytime sleep, time of sleep onset ranged from 10:00 h to 12:00 h, and time of awakening ranged from 15:00 to 17:00 h. The mean number of sleep hours per week was approximately 40 h across all participants, and no napping occurred during work periods.

Data recording

The recordings were carried out using electroencephalography (EEG, C3/Cz), electro-oculography (EOG), submental electromyography (EMG), and electrocardiography (ECG). Recorded data were synchronously digitized and stored on a memory card using a portable recorder (SS2, Enjoy Research Inc., Taiwan). The filter bandwidths of the signals used different multipliers as follows: EEG (5,000), EMG (2,000), ECG (5,000), and EOG (1,000). Both EEG and EMG were filtered with 0.32–40 Hz, EOG with 0.032–40 Hz, and ECG with 0.64–40 Hz. These bioelectric signals were relayed through an eight-bit analog-to-digital converter to an IBM-compatible PC. The EEG, EOG, EMG, and ECG signals were synchronously digitized at sampling rates of 128, 128, 128, and 256 Hz, respectively. All acquired data were analyzed online and simultaneously stored on a hard disk for subsequent offline verification.

Digital signal processing

For sleep stage analyses, the data files were converted into European Data Format and then imported into the sleep analysis application Somnologica 3.1.2 (Embla, Denver, CO, USA). For our analyses, we defined "wakefulness" as the wakeful state after retiring for sleep and prior to sleep onset. Nurses' body movements were not restricted during wakefulness. Rapid eye movement (REM) sleep stages were differentiated from non-rapid eye movement (NREM) sleep stages by EEG, EMG, and EOG. The sleep analyses were carried out according to protocols defined in Rechtschaffen and Kales[15]. An epoch of 30 s was used to score and code all sleep stage data, and all results were verified by a qualified sleep technician. An event was coded as an arousal when (i) there occurred an abrupt shift in EEG frequency to alpha or theta patterns, or to frequencies greater than 16 Hz (but not spindles); and (ii) such a change persisted for at least 3 s; and, (iii) when such a change was immediately preceded by at least 10 s of stable. In addition, the coding of an arousal during rapid-eye movement (REM) sleep required a concurrent increase in submental EMG persisting for least 1 s[15]. An event was coded as a stage awakening when there occurred either a reactive alpha or age-appropriate dominant posterior rhythm over the occipital region occupying greater than 50% of the associated epoch. Furthermore, the arousal and awakening indexes indicated that both times of arousal and awakening were divided into total sleep time[15].

Sleep macrostructure is based on cyclic patterns of NREM and REM states, whereas sleep microstructure mainly consists of arousal and awakening indexes. The emergence of abnormal motor activity may be related to disturbed macrostructure or microstructure of sleep. The detailed procedures performed by the computer application are described as follows. The scheme for preprocessing ECG signals was designed according to well-established procedures[6], which we have described fully in previous reports[16]. In brief, the computer algorithm identified each normal ventricular discharge waveform, and rejected each ventricular premature complex or noise according to its likelihood of occurrence as measured against a standard template. In order to assess the ventricular rate, stationary R-R intervals (RR) were re-sampled and interpolated at a rate of 8 Hz to provide continuity in the time domain. The sampling rate of EEG signals was also reduced to 64 Hz.

Power spectral analysis

All subjects slept for more than three sleep cycles in every period of sleep recorded; therefore, we analyzed sleep periods categorized into (i) the first through the third stages of NREM sleep (NREM 1-3); and (ii) the first through the third stages of REM sleep (REM 1-3). The EEG and RR signals analyzed were truncated into successive 64-s time segments (windows) with 50% (32 s) overlapping. A Hamming window was applied to each time segment in order to attenuate leakage effects[17]. Our algorithm then estimated the power density of the spectral components based on the fast Fourier transformation.

The resulting power spectrum was corrected for attenuation from sampling error and through application of the Hamming window[16] and consequently underwent fast Fourier transformation. For each 64-second time segment, we quantified the high-frequency power (HF; 0.15–0.4 Hz) and low-frequency power (LF, 0.04–0.15 Hz) of the RR spectrogram, and the delta power (0.5–4 Hz) of the EEG spectrogram[18]. EEG delta-power is a characteristic of NREM and used to define deep (stage 3 and 4) sleep[15].

Statistical analysis

The first step in our analyses involved a comparison of basic characteristics in order to increase confidence in the comparability between the PNS RTS study groups. Years employed in nursing, heart rate, blood pressure, tea and coffee consumption, circadian type, and scores of sleep quality were examined for between-group differences using *t*-tests for continuous variables and χ^2 tests for categorical variables.

The specific design included two comparison scenarios: (i) comparisons of nighttime sleep between PNS nurses and RTS nurses, and of daytime sleep between the two groups; and, (ii) comparisons of nighttime sleep with daytime sleep within each group. Sleep pattern indices of two groups during REM or NREM periods were compared by using the Mann-Whitney U test. The Wilcoxon Signed-Rank test was carried out to examine differences within their daytime and nighttime sleep data. A similar analytic strategy was employed for logarithmically transformed EEG delta-powers, HF, LF, and LF/HF of the RR spectrogram, in order to correct for the skewness of their distributions. All statistical analyses were undertaken using the SPSS 16.0 for Windows software package, with *p*-values of less than 0.05 considered to be statistically significant.

Results

As shown in Table 2, there was no significant difference in sleep patterns between RTS nurses and PNS nurses. In their daytime compared to nighttime sleep, PNS nurses exhibited significantly lower sleep onset latency, longer durations of stages 3 and 4 sleep, and higher delta powers.

Table 3 presents the results of comparisons of cardiac autonomic functioning between the two study groups by daytime and nighttime sleep periods and by sleep status or stage (wakefulness, NREM sleep, and REM sleep). The LF/HF power values in PNS nurses were found to be significantly higher than those of RTS nurses in both NREM and REM nighttime sleep. LF values in PRN nurses were also significantly elevated compared with those of RTS nurses in wakefulness as well as both NREM and REM daytime sleep. However, no significant difference in terms of autonomic cardiac activity was found within their daytime and nighttime sleep in either of the different shift groups.

Figure 1 plots HRV between study groups by episodes of sleep stages (episodes 1, 2, and 3 of both NREM and REM sleep) and by daytime versus nighttime sleep periods. LF in PNS nurses significantly exceeded that in RTS nurses during NREM1, NREM2, and NREM3. PNS nurses also demonstrated signifi-

Table 2. Differences in sleep patterns between shifts

Variables	Rotating three-shift nurses (N=12)			Permanent night shift nurses (N=12)		
	Days off sleeping at night	Night shift sleeping in the day	*p* value	Days off sleeping at night	Night shift sleeping in the day	*p* value
Time in bed (min)	395.39 ± 117.83	301.24 ± 71.49	0.060	409.19 ± 92.77	340.37 ± 130.20	0.099
Total sleep time (min)	359.79 ± 105.34	280.79 ± 68.06	0.10	364.96 ± 91.14	306.75 ± 137.16	0.18
Wake after sleep onset (min)	23.36 ± 16.70	14.11 ± 6.83	0.20	30.31 ± 19.55	28.88 ± 32.79	0.33
Sleep onset latency (min)	12.29 ± 13.23	6.29 ± 4.31	0.29	13.92 ± 18.32	4.71 ± 1.90	0.04*
Sleep efficiency	0.91 ± 0.05	0.93 ± 0.03	0.64	0.89 ± 0.07	0.89 ± 0.13	0.64
NREM %	73.33 ± 3.91	71.13 ± 4.84	0.18	71.25 ± 7.24	73.02 ± 7.45	0.33
Stage l %	12.54 ± 4.86	9.29 ± 5.14	0.12	9.16 ± 4.54	8.00 ± 4.91	0.23
Stage 2 %	58.95 ± 8.13	59.30 ± 8.81	0.94	61.37 ± 7.42	61.75 ± 10.76	0.88
Stage 3+4 %	3.67 ± 6.56	5.07 ± 9.31	0.75	1.45 ± 2.06	7.59 ± 5.90	0.01*
REM %	24.84 ± 3.57	26.33 ± 5.35	0.43	28.02 ± 7.04	21.85 ± 6.53	0.02*
REM latency from sleep onset (min)	81.50 ± 47.80	46.92 ± 25.71	0.020*	69.96 ± 33.98	63.04 ± 24.19	0.99
Number of sleep stage transitions/h	15.81 ± 4.80	13.98 ± 2.76	0.15	14.08 ± 3.93	15.98 ± 4.98	0.18
Awakening index (events/h)	3.99 ± 1.22	3.35 ± 1.24	0.27	4.50 ± 1.44	3.32 ± 1.19	0.08
Arousal index (events/h)	3.11 ± 1.28	2.69 ± 1.23	0.10	2.97 ± 1.16	3.65 ± 1.51	0.14
Delta power [lnV^2)]	3.71 ± 0.61	3.78 ± 0.65	0.58	3.38 ± 0.71	3.79 ± 0.58	0.03*

There were no significant differences between permanent night shift nurses and rotating three-shift nurses on any of the listed variables;
*p<0.05 nighttime vs daytime sleep by Wilcoxon Sign-Rank test;
The data are expressed as mean ± SD.

Table 3. Comparison of cardioautonomic function data between PNS and RTS groups (between-group nighttime vs nighttime and daytime vs daytime comparisons)

	Rotating three-shift nurses (N=12)	Permanent night shift nurses (N=12)	*p* value	Rotating three-shift nurses (N=12)	Permanent night shift nurses (N=12)	*p* value
	Days off nighttime sleep	Days off nighttime sleep		Night shift daytime sleep	Night shift daytime sleep	
Wakefulness						
RR, ms	892.98 ± 122.08	895.07 ± 148.93	0.77	815.43 ± 85.54	822.68 ± 57.77	0.42
HF, ln (ms^2)	6.31 ± 0.83	6.38 ± 0.94	0.95	5.69 ± 1.00	6.38 ± 0.73	0.22
LF, ln (ms^2)	6.54 ± 0.76	7.04 ± 0.70	0.07	5.86 ± 1.41	7.14 ± 0.57	0.00*
LF/HF	0.24 ± 0.62	0.67 ± 0.49	0.05*	0.26 ± 0.36	0.77 ± 0.67	0.01*
NREM sleep						
RR, ms	971.49 ± 124.44	988.52 ± 83.68	0.64	920.20 ± 94.30	955.65 ± 90.91	0.27
HF, ln (ms^2)	6.44 ± 0.83	6.30 ± 0.86	0.42	6.09 ± 0.74	6.39 ± 0.72	0.30
LF, ln (ms^2)	6.47 ± 0.57	6.93 ± 0.59	0.06	6.18 ± 0.61	6.79 ± 0.44	0.02*
LF/HF	0.01 ± 0.53	0.59 ± 0.56	0.02*	0.14 ± 0.46	0.39 ± 0.54	0.18
REM sleep						
RR, ms	941.07 ± 100.41	952.54 ± 76.90	0.91	896.28 ± 77.55	913.06 ± 91.80	0.39
HF, ln (ms^2)	6.17 ± 0.65	6.16 ± 0.97	0.82	5.86 ± 0.79	6.20 ± 0.76	0.26
LF, ln (ms^2)	6.75 ± 0.82	7.28 ± 0.70	0.13	6.57 ± 0.71	7.21 ± 0.59	0.01*
LF/HF	0.66 ± 0.50	1.12 ± 0.53	0.04*	0.79 ± 0.52	1.01 ± 0.49	0.39

*p<0.05 PRN vs RTS nurses by Mann-Whitney U test;
The data are expressed as mean ± SD.

cantly higher LF/HF than RTS nurses during NREM1, NREM2, NREM3, and REM1 nighttime sleep periods.

Discussion

We found that nurses working permanent night shifts had higher levels of sympathetic activity during sleep compared to nurses working three rotating shifts. No significant differences in sleep quality were observed between the two groups. This paper provides important information suggesting that in addition to physiological sleep parameters, cardiac autonomic activity should also be taken into consideration when attempting to evaluate effects of shift patterns on workers' health.

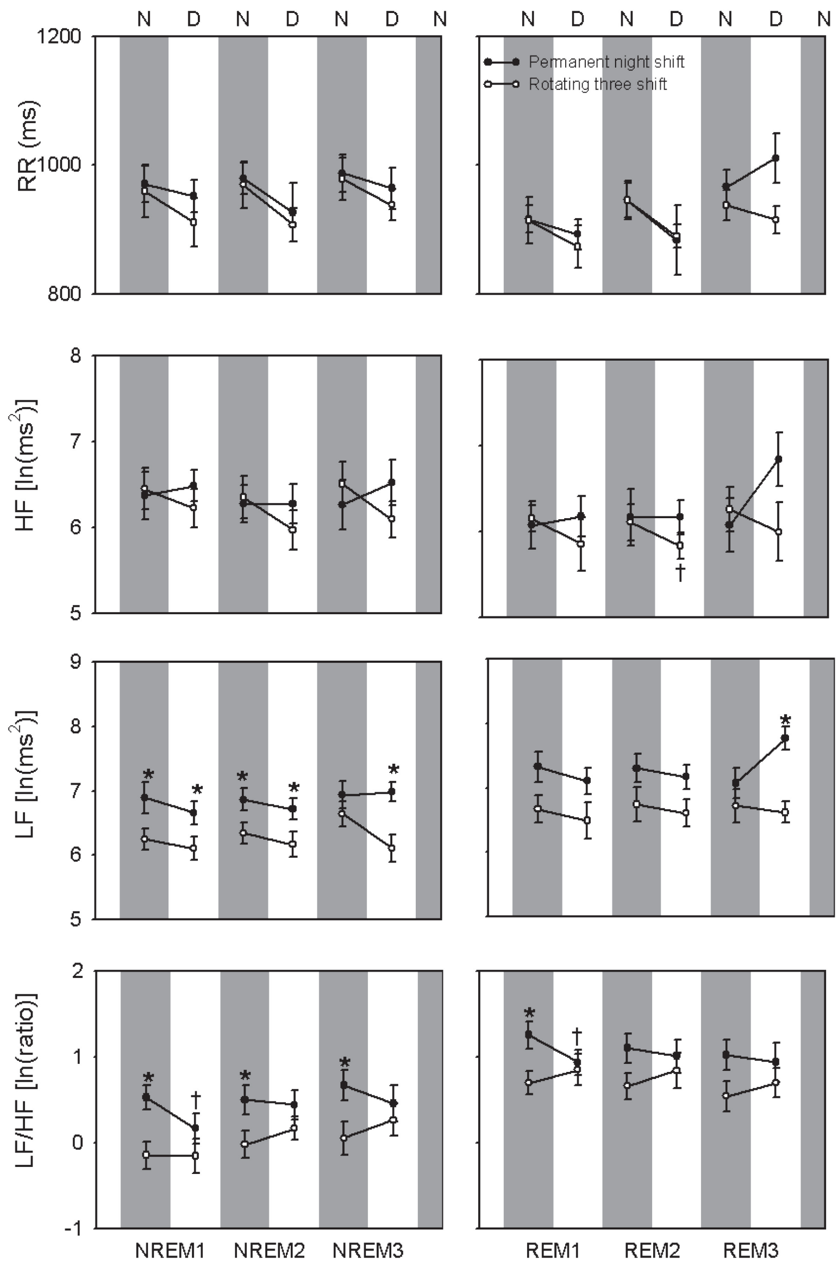

Fig. 1. Cardioautonomic functioning data among RTS (N=12) and PRN (N=12) nurses during episodes 1–3 of NREM and REM sleep; (N=nighttime sleep; D=daytime sleep).
*p<0.05 PRN vs RTS nurses nighttime sleep by Mann-Whitney U test;
†p<0.05 vs their daytime sleep by Wilcoxon Sign-Rank test;
All data are expressed as mean ± SD.

Two major hypotheses have been propounded on mechanisms that may explain the elevated cardiovascular risk that has been associated with shift work[4]. One is that the circadian rhythm associated with cardiac neural regulation is disturbed. The other is that shift workers experience higher psychosocial stressors compared with day workers, resulting in poorer sleep quality that in turn adversely impacts cardiovascular health. Previous studies have indicated that permanent night work confers greater risks for cardiovascular disease than do other shift schedules[19]. Our study lends additional support to such findings and suggests that disturbances in neurocardiovascular control could be an important mediator of cardiovascular disease among permanent night shift workers.

In both nighttime and daytime sleep, we found that, in comparison with RTS nurses, PNS nurses demonstrated higher LF and LF/HF power values. The LF/HF ratio is a marker of the sympathovagal balance—with higher levels indicating increased sympathetic activity or reduced vagal activity—whereas LF is influenced by both the parasympathetic and sympathetic nervous systems[6]. We conclude that the PNS nurses had elevated sympathetic activity during both daytime and nighttime sleep compared with the RTS nurses. Also, our results indicate that in PNS nurses, sympathetic nocturnal dominance was enhanced and nighttime parasympathetic activity was not elevated compared to their daytime sleep. This phenomenon contrasts with the natural circadian rhythm of the cardiac autonomic nervous system, which normally causes a nocturnal decrease in the power of HRV and the LF component, and a nocturnal increase in the HF component[20]. These changes in neural cardiovascular control associated with permanent night shift work could represent a vital element in a causal pathway leading to increased cardiovascular disease risk. Because the data for nighttime sleep and daytime sleep were collected on different days, however, further investigation is warranted into whether the circadian rhythm of the cardiac autonomic nervous system is violated in permanent night shift workers.

There was no significant difference in global PSQI and total sleep time between PNS and RTS nurses (Tables 1 and 2). The analyses of PNS nurses' daytime versus nighttime sleep showed no significant difference in terms of sleep duration, though occasionally nighttime sleep was characterized by a lower proportion of deep sleep and a higher proportion of REM sleep. PNS nurses experience similar sleep duration and sleep quality to that of RTS nurses. At the time of this study, all female nurses were unmarried and lived in a dormitory; therefore, social stress related to family life presumably interfered less with their sleep than may occur in differently-situated shift workers. Shift work affects not only social aspects of life, but also behaviors such as smoking and sleep habits[2]. None of the nurses in this study smoked; all nurses were accustomed to sleeping immediately following night shifts and then sleeping again for a shorter period prior to the next night shift. These circumstances might explain why no remarkable differences in sleep quality or quantity were observed. However, the amount of slow wave sleep (SWS) was extremely high during daytime sleep, which is consistent with earlier studies, indicating that sleep deficits may accumulate with increased waking time, possibly accounting for a higher amount of SWS in daytime recovery sleep compared to nighttime sleep[21]. This finding might reflect long-term accumulation of exhaustion among night shift nurses before eventually falling asleep during the day compared to at night.

This study provides a limited picture of sleep-related cardiac autonomic functioning in nurses who have been working permanent night shifts for more than two years. The small sample size may not be representative of shift workers as a whole; however, this is an important explorative pilot study comparing the effects of shift schedules on sleep-related frequency domain HRV. Some limitations include the possibility that the study groups may have systematically differed in subject characteristics before they started doing shift work. Also, the higher sympathetic activation could be an artifact of selection factors, because high arousal may help permanent night shift workers stay awake during their shifts. In this study, we cannot rule out the presence of disturbed circadian rhythms related to cardiac autonomic activity in the PNS group, in spite of no significant difference in sleep quality compared with rotating shift workers. Furthermore, while our results suggest that increased cardiac autonomic activity is associated with PNS schedules compared to RTS schedules, sample size and study design limitations suggest caution in interpreting our results. For example, pre-existing between-group differences may alternatively or partially explain our findings. Because there is an economic incentive for choosing the permanent night shift, the PNS nurses in our study may have experienced higher levels of economic stress prior to selecting or accepting a permanent night shift, with such stress manifesting in increased cardiac autonomic activity levels.

This paper demonstrates that permanent night shift nurses had higher sympathetic activity during wakefulness before going to sleep compared to rotating three-shift nurses. We cannot exclude the possibility that differential levels of between-group work-related stress may have affected the observed differences between the study groups. Factors related to the sleep environment, including noise levels, may have caused or contributed to sympathetic stimulation. PNS nurses who always sleep during the day may experience more environmental noise caused by cohabitating nurses who work different shift patterns. Similarly, RTS nurses may experience fewer sleep interruptions because they sleep for short periods in the daytime, then return to sleep at night. Our measurements samples included only three consecutive night shifts following two days off, with our rotational shift study group working a rapid clockwise schedule and with all participants working a total of approximately 40 h per week. Longer-term studies with larger samples, examining other kinds of shift work schedules, and examining different kinds of shift workers, appear indicated given the important implications that our findings hold for understanding the impact of shift work schedules on cardiovascular health.

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