Originals

Asian Pacific Journal of Disease Management 2013; 7(3·4), 35-43

Effects of a rotating-shift schedule on nurses' vigilance as measured by the Psychomotor Vigilance Task

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Abstract

The aim of this study was to investigate the effects of a rotating-shift schedule on nurses' vigilance by comparing vigilance before and after day-shift duties and night-shift duties. We conducted objective and subjective sleep and vigilance tests by means of actigraphy and the Psychomotor Vigilance Task, and we attempted to identify common factors in the sleep habits of participants with conspicuously low vigilance. A total of 13 rotating-shift female nurses, aged 25-62 years, participated in the one-week study. Means of reaction time (RT) were adjusted to 1/RT to account for the possibility of outliers. A significant decrease of vigilance was detected after night-shift duty (mean 1/RT of 0.0033 ± 0.0008 ms before duty vs. 0.0031 ± 0.0008 ms after duty, F [1,2] = 224.64, $p < 0.01$). A significant individual difference in vigilance was observed for day shifts (F [12,19] = 5.49, $p < 0.01$). We also found that a wider spread of day-by-day total sleep time (TST) was associated with a longer mean RT (r =0.64, $p = 0.02$), while no clear correlation between the mean TST and RT was found. Our findings suggest that rotating-shift work may have a negative impact on vigilance during night shifts, while an irregular duration of sleep during the week may reduce vigilance during day shifts. Our results further suggest that the negative effects of rotating shifts occur not only during night shifts but also during day shifts if sleep length varies day by day.

Key words: sleep, vigilance, shift work, nurse, Psychomotor Vigilance Task, actigraphy

❖1 Background

In Japan, 18.6% of the workforce is involved in shift work, and half of these more than 10 million individuals work overnight shifts[1)]. As modern society has changed to 24-hour operation, the number of workers with sleep disorders has increased. Of these shift workers, it has been estimated that around 80% of them have experienced a sleep disorder[2)].

According to The Diagnostic and Statistical Manual of Mental Disorders, 4th edition, and the International Classification of Sleep Disorders, the essential feature of circadian rhythm sleep disorders is a misalignment between the endogenous circadian rhythm and exogenous factors that impact sleep duration and timing[3,4)]. One of the more common circadian rhythm sleep disorders is shift work sleep disorder (SWSD), which is defined as difficulty falling asleep, difficulty staying asleep, or nonrestorative sleep for at least one month; the problems must be associated with work that occurs during the habitual sleep phase[3-5)]. Excessive daytime sleepiness is a major symptom of SWSD. Bright light, melatonin, and therapeutic napping are well-known therapeutic options for SWSD. Drake et al. estimated that 10% of the population suffers from SWSD[5)].

Night shifts and irregular shifts at work may cause an irregular lifestyle and sleep patterns, resulting in reduced and poorer quality sleep and lower vigilance and work performance when awake[6-9)]. From a social-risk-management point of view, it is important to pay attention to workers' reduced sleep and lack of vigilance in order to prevent accidents caused by human errors. Gold et al. reported that rotating-shift nurses nodded off more at work and had "twice the odds of a

Received: December 12, 2012
Accepted: June 5, 2013
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reported accident or error related to sleepiness" compared to nurses who worked only day or evening shifts[10]. In a survey by Rosekind, 19% of health care workers, primarily nurses, reported aggravating a patient's condition because of fatigue[11]. In Japan, Tanaka et al. investigated the effect of exposure to bright light to improve work performance and subjective symptoms of sleepiness in rotating-shift nurses. Nurses exposed to bright light showed significant improvement.[12].

Various reports have evaluated the negative effects of shift work on vigilance, but chronological changes in vigilance during shifts remain unclear. The aim of this study was to investigate the effects of a rotating-shift schedule on nurses' vigilance before and after day and night shifts. We hypothesized that post-shift vigilance would be poorer than pre-shift vigilance for both day and night shifts.

The participants were administered several sleep and vigilance tests to assess the effects of night- and day-shift work on sleepiness. We also examined if participants with conspicuously low vigilance shared any common sleep habits.

❖2 Method

2.1 Subjects

A total of 13 rotating-shift female nurses, aged 25-62 years, and five day-shift nurses, aged 35-53 years, volunteered for this study by responding to written recruitment advertisements. All participants were volunteers and were not randomly selected. The study was conducted from September to November 2008 at a 96-bed medical care center in Tokyo. The eligibility criteria for rotating-shift nurses were the ability to wear a wrist actigraph for one full week, including during sleep and off-work periods, and one or more night-shifts and day-shifts scheduled during the study. The exclusion criteria were pregnancy or a history of sleep disorder treated with medication. The majority of the rotating-shift nurses worked in the inpatient department.

This study was approved by the ethics committee of Keio University, and written informed consent was obtained from all participants.

2.2 Objective measurements

2.2.1 Sleep

The subjects were asked to wear an actigraph (AMI Inc., Ardsley, NY) on the non-dominant wrist during the entire study. The actigraph is equipped with a 3-D acceleration sensor and is widely used to measure sleep/wake rhythms. Correlation between polysomnographic recording, a gold standard of sleep measurement, versus actigraphic whole-night measures of sleep and Sleep Efficiency (SE) have been found to be sufficiently high (above 0.80)[13-15], while Sadeh et al. concluded that validation studies for normal subjects showed a correlation of greater than 0.90.[12] The device distinguishes between the subject being asleep or awake. The black vertical lines in Figure 1 show activities during waking hours. The light blue horizontal zone indicates sleep, and the red horizontal line below the light blue horizontal zone shows whether the subject is in the sleep mode or wake mode. In this study, we recorded total sleep time (TST), the duration from the start to the

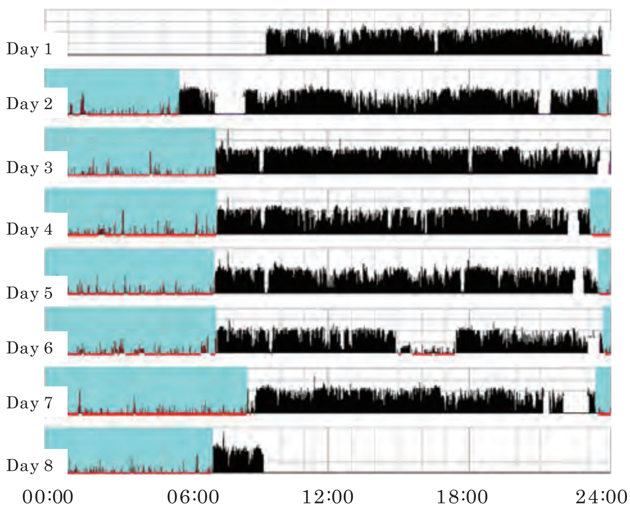

Figure 1 Example of actigraphy data

end of the main sleep period of the day, and SE, the percentage of actual sleep while lying in bed during the sleep period. Increases in arousal or waking during the sleep period correspond to decreases in SE. An average TST and SE value was calculated for each participant for the week, including all data from sleep and wake cycles and work and off-work days. These sleep values were calculated by the automatic sleep scoring algorithm provided by AMI Inc.'s AW2 software version 2.6.[16]. The main sleep period–the longest sleep period from 15:00 of one day to 14:59 of the next day–was used for TST. Naps were excluded from TST values as only the main sleep period was scored automatically by the AW2 software.

The objective-measurements data of one participant were excluded from analysis because she failed to wear the actigraph before and after her night-shift duty.

2.2.2 Vigilance

The subjects were also asked to use a Psychomotor Vigilance Task (PVT) monitor (AMI Inc., Ardsley, NY) for 10 min at the start and end of each shift. Using this device, the subject waits for the screen on the top surface to flash, and then clicks a button on the bottom surface (Figure 2). We expected performance measures on this monotonous task to fall post-shift, when subjects would be drowsy. Reaction Time (RT) was calculated as the average response time throughout the 10-min test. A lapse is defined as a response time longer than 500 ms[17-19]. This device and these measurements are often used to measure vigilance in studies conducted outside of sleep research institutes, where polysomnographic recording is difficult to conduct[20,21]. A quiet research room was dedicated to the PVT tests, and subjects were asked to wear a headset to block surrounding noises. All participants completed the full series of PVT tests.

2.2.3 Physical activity

Physical activity was assessed with a uniaxial accelerometer (Lifecorder EX, Suzuken Co. Ltd., Nagoya, Japan) worn around the waist during waking periods. Mean total step counts per day were recorded, and a day was defined as a 24-hour period starting at midnight.

Figure 2 Psychomotor Vigilance Task. When a light flashes on the upper screen (flashes were presented at randomly defined intervals), the subject presses the button at the bottom.

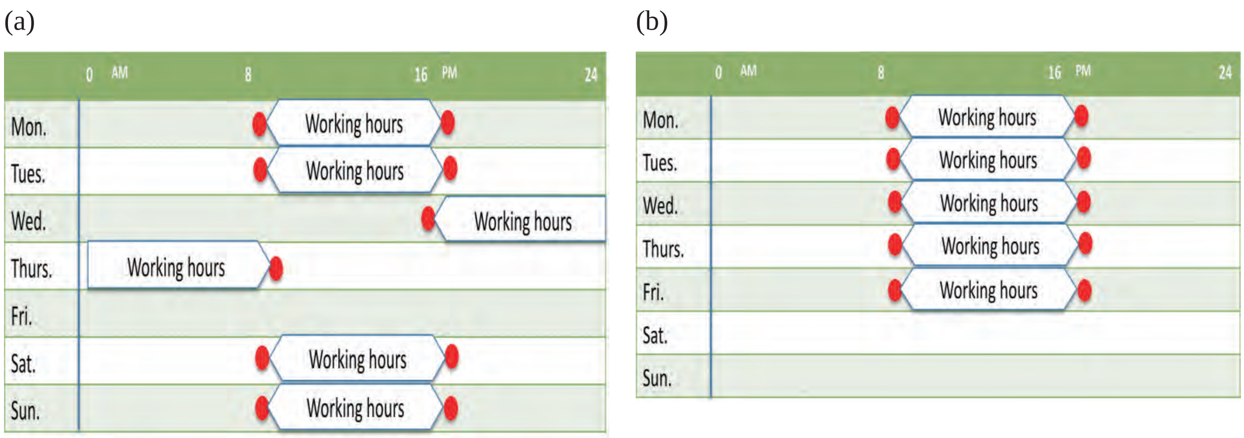

Figure 3 (a) Example of the PVT test timings with regard to the schedule of the rotating shift nurses. Each rotating shift nurse covered multiple day-shift duties and one or more night shift duties. (b) Example of the PVT tests time schedule of day shift nurses. Dots indicate when the PVT tests took place.

2.3 Subjective measurements

2.3.1 Sleep

The Pittsburgh Sleep Quality Index (PSQI), composed of 24 questions, is a widely used questionnaire in clinical practice[22,23]. It measures subjective sleep quality over the previous one-month time period and is found to be useful for screening sleep disorders. Most of the questions are related to the frequency of sleep disorder symptoms, which are rated on four scales. The validity and reliability of the Japanese version of this questionnaire (PSQI-J) have been confirmed in previous studies[23]. Scores range from 0-21 points, with higher scores indicating worse sleep quality. A global score of greater than 5.5 has been shown to distinguish healthy controls from sleep-disordered patients with high sensitivity and high specificity[23].

2.3.2 Vigilance

The Epworth Sleepiness Scale (ESS), originally developed as a screening tool for hypersomnia, measures daytime sleepiness by asking about the probability of dozing in eight different situations. Probability is rated on a 4-point scale, and the maximum score is 24 points. A cut-off score of 10-11 points provides the best match of sensitivity and specificity[24,25]. The ESS was administered at the beginning of the study.

2.4 Time schedule

At the medical care center, the rotating-shift nurses worked from 08:00 to 16:30 for day shifts and from 15:30 to 09:00 for night shifts (Figure 3a). Day-shift nurses worked from 08:00 to 16:30 (Figure 3b). Strategic naps during night-shift work had not been introduced at this workplace, and naps could be taken only if work conditions allowed. No work was scheduled on the day following a night shift. Each rotating-shift nurse had multiple day-shift duties and one or more night-shift duties.

2.5 Statistical analyses

To account for the possibility of outliers in the means of pre- and post-duty RT and number of lapses, the means of RT were transformed to 1/RT, and the numbers of lapses was transformed according to the formula $\sqrt{x}+\sqrt{x+1}$. Within-subject analysis to compare pre- and post-duty measurements was performed by two-way ANOVA (time × subject) with repeated measurements. A selective bivariate relationship between sleep (the variation in TST and the standard deviation of TST) and vigilance (RT and lapses) was investigated with Spearman's rank correlation coefficient. PASW software version 19.0 for Windows (SPSS Inc., Tokyo, Japan) was used for all statistical analyses. The level of significance was set at $p < 0.05$.

❖3 Results

3.1 Participants' demographic and sleep characteristics

Table 1 summarizes the study participants' characteristics. The median (range) age of 13 rotating-shift nurses was 32 (25-62) years, and their median number of years of experience was 8 (1-35). The median (range) ESS (subjective drowsiness) scores of rotating-shift nurses and day-shift nurses were 5 (0-12) and 2 (1-7), respectively. Only one rotating-shift subject exceeded the cut-off point and claimed excessive subjective drowsiness.

The median (range) TST and SE of the rotating-shift nurses were 430 (327-665) min and 96.6% (82.8%-99.2%). The TSTs of three rotating-shift nurses were greater than 600 min. When these outliers were excluded from the analyses, the median (range) TST was 412 (327-510) min. Eleven rotating-shift nurses showed an actigraph sleep mode of more than 15 min during the night shift around 03:00. The median (range) TST and SE of day-shift nurses were 417 (360-459) min and 94.1% (90.6%-99.1%). Most day-shift nurses kept a regular sleep/wake cycle, whereas rotating-shift nurses showed a wide range of sleep start and end times. In particular, an irregular sleep/wake cycle was observed for rotating-shift nurses right before and after night-shift duties.

The median (range) subjective sleep quality measured by the PSQI was 5.5 (0-14) in rotating-shift nurses and 7 (4-9) in day-shift nurses. The recorded uniaxial-accelerometer data indicated that most of the participants were physically active, when considering that Japanese females average 6,267 step counts/day[26].

3.2 Night-shift and day-shift vigilance of rotating-shift nurses

The differences in pre-duty and post-duty PVT scores for rotating-shift nurses were evaluated (Table 2). No significant main effect of individuals was observed for night shifts. However, the mean estimated value for the number of lapses was significantly higher after a night shift (7.13 ± 9.24 pre-duty vs. 9.33 ± 10.98

Table 1 Participant characteristics

	Rotating Shift Nurses	Day Shift Nurses
	(n = 13)	(n = 5)
Age, years	32 (25-62)	45 (35-53)
BMI, kg/m^2	20.3 (17.1-27.3)	19.4 (18.6-25.6)
Years of experience	8 (1-35)	22 (6-26)
Workplace		
Outpatient department, n (%)	3 (23)	0 (0)
Inpatient department, n (%)	10 (77)	2 (40)
Surgical department, n (%)	0 (0)	2 (40)
Management, n (%)	0 (0)	1 (20)
Sleep problems, n (%)	2 (15)	1 (20)
Smoking, n (%)	6 (46)	1 (20)
Drowsiness (Epworth Sleepiness Scale)	(n = 12)	(n = 5)
	5 (0-12)	2 (1-7)
	(n = 12)	(n = 5)
Total sleep time, min	430 (327-665)	417 (360-459)
Sleep effeciency, %	96.6 (82.8-99.2)	94.1 (90.6-99.1)
Sleep quality (Pittsuburg Sleep Quality Index)	(n = 12)	(n = 5)
	5.5 (0-14)	7 (4-9)
Physical activity	(n = 10)	(n = 5)
Steps/day	10,194 (4,723-13,324)	11,043 (6,765-13,643)

Table 2 Effects of time and subject on reaction time and number of lapses during the psychomotor vigilance task

	Night-shift days of rotating shift nurses							
	Mean ± SD		Time		Subject		Time × Subject	
	Pre	Post	F	p	F	p	F	p
Mean RT	324.23 ± 99.47	363.82 ± 120.34	F (1,2) = 8.02	0.11	F (12,2) = 0.91	0.64	F (12,2) = 1.30	0.52
Number of lapses[1)]	7.13 ± 9.24	9.33 ± 10.98	F (1,2) = 48.00	0.02	F (12,2) = 1.54	0.46	F (12,2) = 42.70	0.02
Transformed mean RT[2)]	0.0033 ± 0.0008	0.0031 ± 0.0008	F (1,2) = 224.64	<0.01	F (12,2) = 3.69	0.23	F (12,2) = 22.84	0.04
Transformed number of lapses[3)]	4.45 ± 3.34	5.10 ± 3.73	F (1,2) = 228.23	<0.01	F (12,2) = 4.46	0.20	F (12,2) = 131.25	<0.01

	Day-shift days of rotating shift nurses							
	Mean ± SD		Time		Subject		Time × Subject	
	Pre	Post	F	p	F	p	F	p
Mean RT	337.74 ± 133.22	387.81 ± 233.28	F (1,19) = 2.80	0.11	F (12,19) = 2.10	0.72	F (12,19) = 1.36	0.27
Number of lapses[1)]	7.13 ± 11.29	10.22 ± 15.50	F (1,19) = 4.03	0.06	F (12,19) = 3.24	0.01	F (12,19) = 2.15	0.07
Transformed mean RT[2)]	0.0033 ± 0.0008	0.0030 ± 0.0009	F (1,19) = 4.26	0.05	F (12,19) = 5.49	<0.01	F (12,19) = 0.76	0.68
Transformed number of lapses[3)]	4.08 ± 3.72	5.24 ± 3.95	F (1,19) = 6.89	0.02	F (12,19) = 5.69	<0.01	F (12,19) = 1.34	0.26

Time (pre duty and post duty), RT: reaction time in ms, [1)] Number of times that RT exceeded 500 ms in 10 min. [2)] Means of the RTs were transformed to reciprocal RTs (1/mean RT). [3)] Numbers of lapses were transformed as $\sqrt{(x)}+\sqrt{(x+1)}$. Data were analyzed using a two-way ANOVA.

post-duty, F [1,2] = 48.00, *p* = 0.02), and the post-conversion number of lapses was also significantly higher (4.45 ± 3.34 pre-duty vs. 5.10 ± 3.73 post-duty, F [1,2] = 228.23, $p < 0.01$). Significant differences in pre- and post-duty mean 1/RT were also found after a night shift (0.0033 ± 0.0008 ms pre-duty vs. 0.0031 ± 0.0008 ms post-duty, F [1,2] = 224.64, $p < 0.01$). A significant main effect of interaction between individual and time of the PVT tests was observed in pre-conversion lapses (F [12,2] = 42.70, *p* = 0.02), post-conversion lapses (F [12,2] = 131.25, $p < 0.01$), and mean 1/RT (F [12,2] = 22.84, *p* = 0.04).

The main effect of individuals was confirmed in the pre-conversion number of lapses (F [12,19] = 3.24, *p* = 0.01), the post-conversion number of lapses (F [12,19] = 5.69, $p < 0.01$), and the mean 1/RT (F [12,19] = 5.49, $p < 0.01$) for rotating-shift nurses working the day shift. No significant main effect of interaction between individuals and time of the PVT tests was observed. The mean estimated value for the number of transformed lapses was significantly higher for rotating-shift nurses after a day shift (4.08 ± 3.72 pre-duty vs. 5.24 ± 3.95 post-duty, F [1,19] = 6.89, *p* = 0.02). We expected performance measures on this monotonous task to fall post-shift, when subjects would be drowsy.

3.3 Sleep habits among participants with conspicuously low vigilance

A significant correlation was observed between the mean RT (for night shifts and day shifts) and the standard deviation of TST in rotating-shift nurses (r = 0.64, *p* = 0.02). However, no significant correlation was found between the mean RT and non-adjusted TST. A non-significant association was observed between lapses and the standard deviation of TST (r = 0.55, *p* = 0.06), while no association was observed between lapses and TST (Figure 4).

Three rotating-shift nurses whose mean RTs on day-shift days were outliers in the box-and-whisker

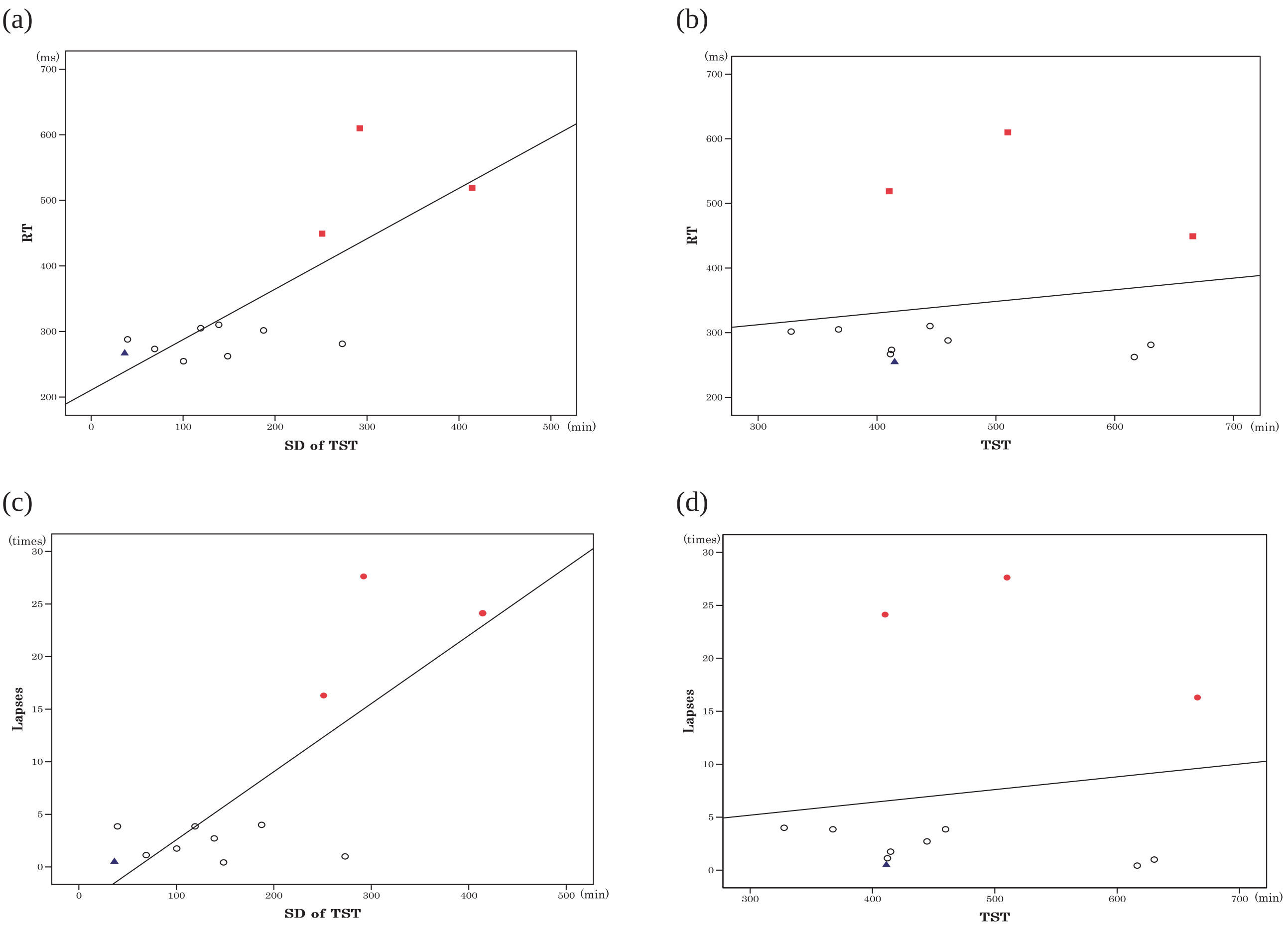

Figure 4 Correlations between sleep and vigilance of rotating shift nurses. (a) Reaction Time vs. Standard Deviation of Total Sleep Time. (b) Reaction Time vs. Total Sleep Time. (c) Lapses vs. Standard Deviation of Total Sleep Time. (d) Lapses vs. Total Sleep Time. (Spearman's rank correlation coefficient)

plots showed a high correlation between mean RT and the standard deviation of TST, as shown by the squares in Figures 5a and 5c. One subject, who showed the smallest standard deviation of TST (36 min), had a low RT and no lapses (shown by the triangle).

❖4 Discussion

We examined the effects of rotating shifts on day-shift and night-shift vigilance and investigated common sleep habits among participants with conspicuously low vigilance.

In this study, we recorded data on the basic characteristics of the participants and their sleep and vigilance states. The mean TST of rotating-shift nurses was 430 min, which is in line with the average TST among Japanese workers in 2010 (415 min on weekdays, 444 min on Saturdays, and 471 min on Sundays)[27]. Most rotating-shift participants slept longer before and took a nap after a night shift to limit acute fatigue. For many participants who took a short diurnal nap and experienced a normal nocturnal sleep period after a night shift, sleep and wake cycles remained unchanged. Some participants advanced the main sleep period to the daytime and had a shorter nocturnal sleep period. Diverse approaches for recovering from acute sleep loss were seen, but regaining the lost TST the day after a night shift seemed to be a key for recovery. The median SE of all participants was over 90%, nearly equal to that of healthy young Japanese adults[28]. Results of actigraphy, TST, and SE were in the normal range, while subjective assessments of sleep quality measured by the PSQI indicated that neither rotating-shift nor day-shift participants were satisfied with their sleep states. The results of the ESS were in the normal range, implying that the deterioration of vigilance was an acute reaction after a night-shift rather than a sign of a chronic sleeping problem.

We found that the participants were physically active, with most subjects being active during work and less active during off-work periods. Previous studies have reported that people who are active in daily life show increased slow-wave sleep and longer TST[29,30], but activities during work time and leisure time may have different effects on sleep quality.

In the present study, we found that rotating-shift nurses' transformed mean RT deteriorated and the number of lapses increased after a night shift, while only the number of lapses was significantly increased after a day shift. The main effect of time was significant for night shifts but not for day shifts. These results suggest that night-shift duty itself, rather than changes in circadian rhythms or sleep/wake schedules has a negative impact on vigilance. The participants whose sleep/wake schedules were irregular and whose sleep durations varied the most each day showed slower PVT response times even on day-shift days. These results imply that the acute sleep loss or gain associated with rotating shifts may lead to irregular sleep patterns and may have a certain level of association with lower vigilance. Gander et al. reported that poorer performance was associated with longer shift length, longer time since waking, and acute sleep loss[31]. Our results support a negative correlation between disrupted sleep/wake patterns and vigilance among rotating shift nurses.

Our study had several limitations. The first is that we were not able to measure all of the confounding factors, including differences in personal background and physical variations. The second is that the study was not designed as a randomized controlled trial nor the day-shift nurses used as a control group. The third is that the effects of naps on vigilance were not investigated. Despite these limitations, we believe our study proves that work styles and work shifts are important areas of focus in sleep and performance management.

❖5 Conclusion

In conclusion, we have demonstrated that the vigilance of rotating-shift nurses dropped significantly from pre- to post-night-shift-duty. On day-shift days, participants with the widest spread of day-by-day TST showed poorer vigilance. Van Dongen et al. investigated the efficacy of the current restart break rule in the U.S., which specifies off-duty time to recuperate after a duty cycle, and found that it helped workers recover from fatigue during day-time duty but not during night-time duty.[32] It seems that an appropriate restart break for night-time duty should be introduced. Mollicone et al. reported that split sleep schedules, with a nocturnal anchor sleep period and a diurnal nap to secure sufficient TST, can prevent deterioration of work performance[33]. Taking sleep patterns and sleep time into account by using sleep logs or actigraph recordings, proper sleep hygiene management could be performed at an individual level to prevent workplace errors and accidents. At the same time, there is a need to conduct further research in this field.

❖Acknowledgement

We thank the late Shohei Onishi for help in the design of this study.

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