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Original Article

Field Study of Effects of Night Shifts on Cognitive Performance, Salivary Melatonin, and Sleep

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ABSTRACT

Background: Night shift work is associated with many problems such as sleep deprivation, sleepiness, decreased cognitive performance, increased human errors, and fatigue. This study set out to measure cognitive performance, melatonin rhythms, and sleep after different consecutive night shifts (7 vs. 4) among control room operators (CORs).

Methods: The participants included 60 CORs with a mean age of 30.2 years (standard deviation, 2.0) from a petrochemical complex located in Southern Iran. Cognitive performance was assessed using the n-back task and continuous performance test. To evaluate melatonin, saliva was collected and tested by enzyme-linked immunosorbent assay. To assess sleep and sleepiness, the Pittsburgh Sleep Quality Index and Karolinska Sleepiness Scale were used, respectively.

Results: Individuals who worked 7 consecutive night shifts had a significantly better cognitive performance and sleep quality than those who worked 4 consecutive night shifts. However, salivary melatonin profile and sleepiness trend were not affected by shift type.

Conclusion: The main duty of CORs working night shifts at the studied industry included managing safety-critical processes through complex displays; a responsibility that demands good cognitive performance and alertness. It is suggested that an appropriate number of consecutive night shifts in a rotating shift system should be planned with the ultimate aim of improving CROs performance/alertness and enhancing safety.

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1. Introduction

Technological, economic, and social pressures have led to an increase in the number of shift workers. In developed countries, about 20% of the workforce is engaged in shift work, with one-third of them working in night shifts [1,2].

Night shift work is associated with many problems such as sleep deprivation, sleepiness, decreased cognitive performance, increased human errors, and fatigue [3]. It is also one of the major factors increasing the risk of industrial accidents [4]. A previous study has suggested that the alertness decline and fatigue caused by night shifts are among the major factors contributing to industrial disasters such as the Chernobyl and Three Mile Island accidents [3]. The decline in night shift workers' performance can be

attributed to the circadian misalignment, caused by working and sleeping at the wrong circadian phase [5,6]. A worker's adaptability to night work can be enhanced via designing an appropriate work shift pattern [7]; however, one of the main challenges in this regard is identifying the optimum speed of shift rotation or the number of consecutive night shifts.

Most of the previous studies related to this issue have been conducted under laboratory settings, simulated night work design, or extreme environments (e.g., offshore oil rigs). They have concluded that because consecutive night shifts change circadian rhythms and reduce sleep debt, they are more likely to improve cognitive performance [8]. In a study by Barnes et al [9] that was conducted among offshore workers involved in 2-week night shifts and 2-week day shifts, it was reported that the delay in melatonin

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occurred during the first week of night work. The results of Waage et al [34] showed that in the first day of working fixed night work and rotating shifts, subjective and objective sleepiness was higher than on the next days and the indicators of sleepiness improved over time [6]. Also, studies have shown that impairment of cognitive performance at the end of a night shift is greater in nurses working fast rotating shifts. Such nurses are more likely to commit a human error than shift workers with slower rotating shifts [10]. In a simulated shift work study, Lamond [11,12] showed that there was a significant increase in performance mean score on a visual psychomotor vigilance task across the week and daytime when sleep quality and quantity were not negatively affected. However, some of the other research projects have indicated that consecutive night shifts may lead to sleep debt and impaired performance outcome. Åkerstedt has demonstrated that night shift is connected with the highest risk of accidents and incidents [13]. A review of safety and productivity measures showed that risk was significantly elevated on the 2nd, 3rd, and 4th consecutive night shifts compared to the first one [14]. The results of the study by Ferguson et al [15] revealed that reaction time at the end of night shifts slowed across consecutive night shifts, and Australian mining operators failed to adapt themselves to consecutive night shifts.

While many studies have investigated the influence of consecutive night shifts on cognitive performance and alertness in laboratory and extreme environments, few studies have focused on the effects of consecutive night shifts on cognitive performance, sleepiness, and melatonin rhythm in the field.

The present study was conducted among control room operators within the context of the Iranian petrochemical industry. Two popular shift schedules [i.e., 4 nights, 7 days, 3 nights, 7 off (4N7D3N7O) and 7 nights, 7 days, 7 off (7N7D7O)] were evaluated. This study investigated whether different consecutive night shift patterns (4 vs. 7) used in the field under study led to any differences in cognitive performance, sleepiness, and sleep/melatonin rhythm during night shifts. The results of this study could be useful in choosing better shift work patterns to decrease the risk of making errors that may lead to disastrous events.

2. Materials and methods

2.1. Participants and study design

We recruited 60 individuals who were working as control room operators in the largest petrochemical complex in Southern Iran. The individuals were equally divided into two common shift work systems. Exclusion criteria were the use of hypnotic drugs, mental illness, major systemic diseases, extreme late or extreme early chronotype (as determined by the use of Munich Chronotype Questionnaire) [16], and sleep disorders. In both groups, night shift was from 7:00 PM to 7:00 AM. The shift rotation from night shift to day shift was counterclockwise (backward). To determine the effects of consecutive night shifts, measurements were carried out on the last night shifts, that is, the 7th night in the 7N pattern and the 4th night in the 4N pattern. The collected demographic and baseline data included age, education, history of shift work, amount of caffeinated drinks consumed during each shift, and the quality and quantity of sleep during the previous night shift assessed via Pittsburgh sleep quality index (PSQI) questionnaire [17]. To observe ethical concerns, written informed consent was obtained from all the participants prior to conducting the study.

2.2. Working memory

To assess working memory, we used the n-back test, which has been frequently used to evaluate memory performance [18].

Although this test has rarely been used to assess shift workers in real work environments, it has been repeatedly used in the laboratory to measure the impact of sleep deprivation on working memory [19,20]. The n-back test is used to weigh the ability to process, select, and save information in a short time. In this study, the computer type and $n = 1$ were used because research has shown that the 1-back test is more sensitive for people who have to deal with sleep deprivation [19]. In this test, 120 numbers were shown in the center of the computer screen consecutively for 5 minutes, with an interval of 1,500 milliseconds between every two numbers. Participants compared the last number that appeared on the screen with the one shown before; if the last two consecutive numbers were the same, individuals instantly pressed the answer button on the keyboard. The number of correct answers (scores) and response time (milliseconds) were recorded as the dependent variables of the study. This test is highly reliable for evaluating working memory [21]. In the current study, participants' working memory was assessed three times (at the beginning, in the middle, and at the end) during the shift.

2.3. Continuous performance test

Continuous performance test is a standardized computer test with an appropriate level of reliability. This test is used for quantitative assessment of sustained attention over time [22]. In the test, 150 visual stimuli (of which 20% are target stimuli) were displayed on the computer screen; the participants pressed the space bar as soon as a target stimulus was shown. Every visual stimulus was presented for 150 milliseconds, with a 500-millisecond interval between every two stimuli. Commission error, omission error, and response time (in milliseconds) were recorded as the dependent variables of the study. Participants' sustained attention was assessed three times (at the beginning, in the middle, and at the end) during the shift.

2.4. Melatonin

Melatonin is a reliable indicator for circadian rhythm and has frequently been used for this purpose in past studies [23]. Saliva samples were taken at 4-hour intervals from 7:00 PM to 7:00 AM using a saliva sample collector (Sartser, Nümbrecht, Germany). To limit the effect of food on melatonin, the participants were asked to avoid eating 1 hour before sampling. After centrifugation, the samples were immediately frozen and stored at -20°C , and transferred to the laboratory. Melatonin levels were directly measured by enzyme-linked immunosorbent assay (Biotech Company, Shanghai, China). The sensitivity of the test was 1.6 ± 1.3 pg/mL.

2.5. Sleepiness Scale (Karolinska Sleepiness Scale)

We used the Karolinska Sleepiness Scale (KSS) to measure subjective sleepiness. This test has a good level of reliability and validity [24] and has a 9-point Likert scale, which includes: 1 = very alert; 3 = alert; 5 = neither alert and nor sleepy; 7 = sleepy; and 9 = very sleepy and trying to stay awake. In this study, each participant recorded their own sleepiness level seven times (in 2-hour intervals) during the shift.

2.6. Sleep duration and quality

Sleep duration and quality were measured for day shifts off before the night shift study using the PSQI questionnaire. The items on the instrument included: "How many hours do you usually sleep during the last day shift off?" and "How well do you assess your sleep quality during this period?" The validity and reliability of the

questionnaire for the studied sample were 0.86 and 0.89, respectively.

2.7. Statistical analysis

SPSS version 23 (IBM Corp., Armonk, NY, USA) was used to perform the statistical analyses. Data were analyzed using a repeated measures analysis of variance with shift type (4N or 7N) and time as the within-participant factors. The main factor (i.e., time) had three levels in cognitive variables, four levels in melatonin, and seven levels in sleepiness assessment. An analysis of covariance with repeated measures was also performed to control for the influence of intelligence (as a covariate) on cognitive performance as well as light and caffeine (as 2 other covariates) on melatonin and sleepiness for the two tested shift types. Finally, univariate analysis was carried out via independent samples *t* test for comparing sleep quality and quantity between the two shift types. Significance level was set at 0.05 for all statistical analyses.

3. Results

3.1. Working memory

Reaction times on the working memory task were not significantly affected by the shift type (Table 1 and Fig. 1B). In other words, there was no significant difference between the 7N and 4N consecutive shifts. Furthermore, the effect of time or shift \times time interaction on reaction times was not statistically significant. Considering the accuracy of the working memory task, the mean number of correct responses was significantly higher in the 7N than in the 4N shift ($F = 16.6, p = 0.001$; Table 1 and Fig. 2A). In addition, the main effect of shift was time-invariant and there was also no significant shift \times time interaction for the mean of correct responses.

3.2. Sustained attention

The mean commission error was not affected by the shift type (Table 1 and Fig. 2C). Furthermore, neither time nor shift \times time interaction significantly affected commission error. By contrast, the mean number of omission errors and response time were affected by shift type (Table 1). The mean number of omission errors ($F = 11.6, p = 0.003$) and response time ($F = 6.1, p = 0.02$) were significantly higher in the 4N than 7N shift (Fig. 3D). The response time of the sustained attention task was influenced by time ($F = 9.2, p = 0.001$; Table 1). On the contrary, the mean number of omission errors was not affected by time ($F = 0.02, p = 0.97$; Table 1).

Table 1
Results of repeated measure analysis of variance

Variables	Shift		Time		Shift \times time	
	F	p	F	p	F	p
n-back						
Correct responses	16.6	0.001	2.3	0.14	1.3	0.27
Responses time	2.3	0.14	0.2	0.7	0.006	0.9
CPT						
Commission error	1.6	0.2	1.4	0.3	0.02	0.9
Omission error	11.6	0.003	0.02	0.97	0.9	0.4
Responses time	6.1	0.02	9.2	0.001	0.17	0.8
Melatonin	0.3	0.6	49.00	0.001	15.00	0.001
Sleepiness	3.1	0.08	63	0.001	9.9	0.001

CPT, continues performance test.

3.3. Salivary melatonin

Salivary melatonin was not significantly affected by the shift type (Table 1 and Fig. 2). In other words, there was no significant difference between the 4N and 7N shifts ($F = 0.3, p = 0.6$). However, the effects of time ($F = 49, p = 0.001$) and shift \times time interaction ($F = 15, p = 0.001$) on melatonin levels were statistically measurable.

3.4. Sleepiness

With respect to the indices of subjective sleepiness, there was no significant difference between 4N and 7N shift participants in terms of sleepiness mean scores ($F = 14.29, p = 0.01$) (Table 1 and Fig. 3). Considering the mean scores of subjective sleepiness, the time effect and the shift \times time interaction were statistically significant.

3.5. Sleep quality and quantity

Sleep quality and quantity as well as PSQI score were compared between the two shift types through an independent samples *t* test. There was no difference between participants in the two shifts in terms of sleep quality and sleep quantity ($p > 0.05$; Fig. 4). Nevertheless, the PSQI score in the 4N shift participants was higher than that in their 7N shift counterparts ($t = -2.2, p = 0.03$).

4. Discussion

The findings of this study revealed that the reaction time in the working memory task was not influenced by the shift type. More precisely, there was no significant difference in the mean scores of the reaction time to the n-back task (which is a reliable test of assessing working memory) between the participants in the two shift types. The mean of correct responses to the cognitive performance task, however, was significantly higher among 7N shift workers compared to their 4N shift colleagues. Furthermore, with respect to the sustained attention task, the mean scores of omission errors and response time were significantly higher among 4N shift workers. These results support the idea that cognitive performance is significantly better among workers in the 7 consecutive night shift than their counterparts in the 4 consecutive night shift.

The results also indicated no significant effect of shift type on participants' level of salivary melatonin or sleepiness; however, the effects of time and time \times shift interaction were statistically significant. This can be attributed to changes in melatonin rhythm and sleepiness among 4N shift workers. Seven night shift workers had an inconsiderable change in their melatonin rhythm and sleepiness compared to their 4N shift counterparts. Furthermore, an increasing trend was observed in terms of salivary melatonin and sleepiness among 7N shift workers.

Finally, while no significant discrepancy was observed between 4N and 7N shift workers in terms of their sleep quantity, their sleep quality indices were significantly different in favor of the 7N shift workers.

The findings of the current study are in line with those of Chang et al [10]. They compared cognitive performance among three groups of 2, 3, and 4 consecutive night shift workers and concluded that 2N shift workers' cognitive performance was lower than that of 4N shift workers [10]. This difference can be explained in the light of the participants' circadian rhythm adaptability. In fact, workers who do more consecutive night shifts are more likely to adapt their circadian rhythm to the new situation than those who spend a smaller number of night shifts at work. Previous studies conducted in laboratory settings or extreme environments (e.g., offshore oil

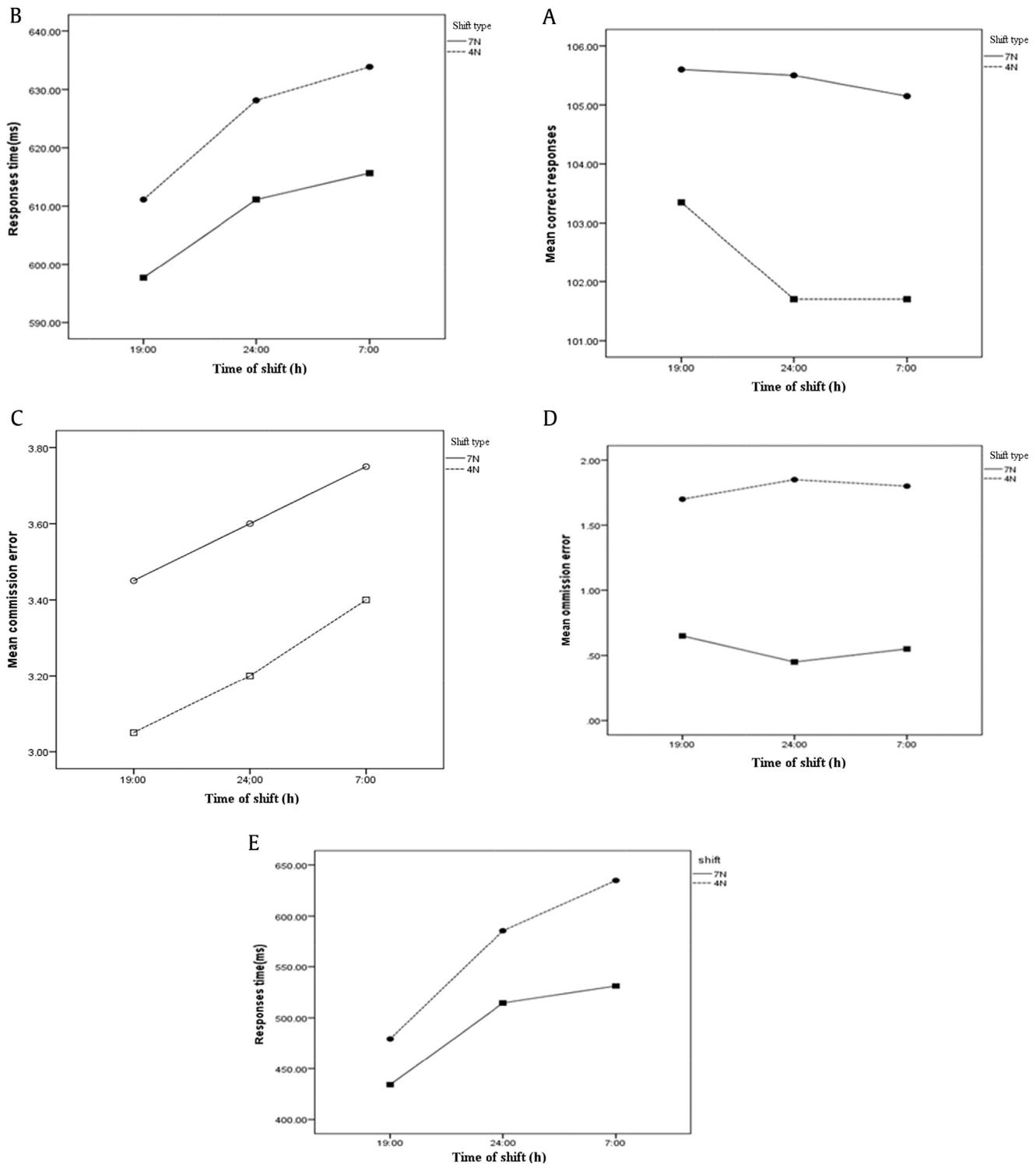


Fig. 1. The effect of shift type on cognitive performance. (A, B) Mean number of correct responses and response times for the working memory task. (C) Mean number of commission errors for the sustained attention task. (D) Mean number of omission errors for the sustained attention task. (E) Mean number of response time for the sustained attention task. 4N, 4 consecutive night shifts; 7N, 7 consecutive night shifts.

rigs) have indicated that people tend to adapt themselves to the new sleep–wake cycle in the course of consecutive night shifts, leading to an increasing trend in their cognitive performance [8,25]. For example, in a laboratory experiment, Lamond et al [11,12] showed that participants' nightly performance improved significantly during 1 week of consecutive night shifts under optimal

conditions (i.e., in the absence of intervening environmental variables such as noise, light, and social/family-related factors). In another study, Bjorvatnet al [8] studied offshore oil rig workers who had to work in 14-day 12-hour night shifts. They discovered that, upon adapting themselves to the night shift after 4–6 nights, participants' cognitive performance measurably improved.

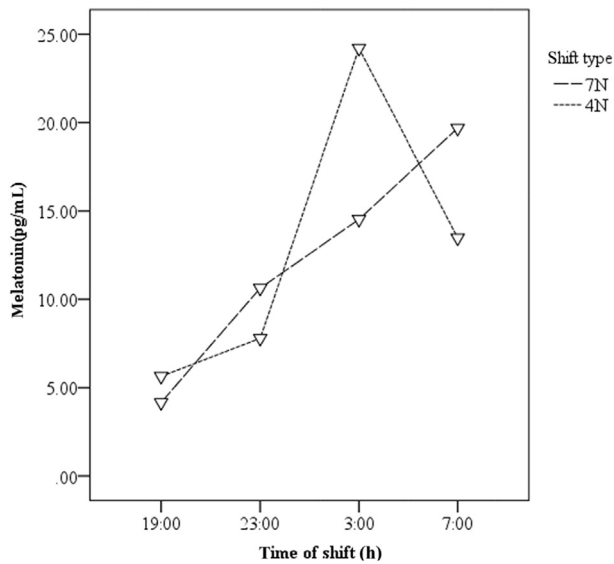


Fig. 2. The trend of melatonin changes for each shift among four measurements. 4N, 4 consecutive night shifts; 7N, 7 consecutive night shifts.

More studies are required to exactly determine the optimal number of night shifts for achieving adaptability and pinpoint the adaptability rate; nevertheless, the obtained values for the melatonin rhythm, sleepiness, and daily sleep quality among the two groups of participants in our study support the idea that adaptability increases over the course of night shifts. Although no significant difference was observed between the two groups in terms of their salivary melatonin and sleepiness indices, the significant effect of time \times shift interaction indicates that circadian rhythm follows a comparatively more disorderly pattern among 4N shift workers. There was a steady increase in the melatonin rhythm and sleepiness of participants working 7 consecutive night shifts. These two indices reached their peak at the end of the shift. By contrast, considering 4N shift workers, the melatonin rhythm experienced ups and downs during the shift; a clear indicator of circadian rhythm disorder. In fact, melatonin rhythm naturally increases in

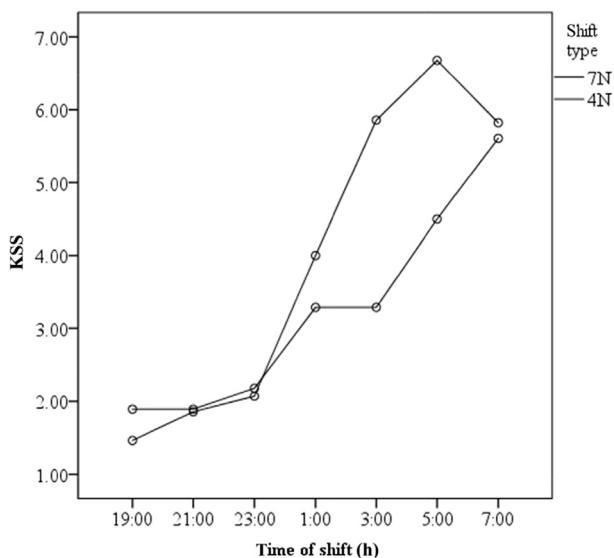


Fig. 3. The trend of sleepiness changes for each shift among seven measurements. 4N, 4 consecutive night shifts; 7N, 7 consecutive night shifts.

humans during the night and declines during the day, reaching its maximum and minimum levels at 4:00 AM and 4:00 PM, respectively [26].

Melatonin peak phase change from night to day is recognized as an indicator of night shift adaptability, which in turn improves night shift workers' performance and alertness [26]. In the present study, we did not concentrate on the 24-hour rhythm of melatonin to be able to determine the maximum level of melatonin more reliably. However, the difference between the two groups in terms of the time to the formation of the melatonin peak during the night shift can be a proper indicator for recognizing adaptability. For 7N pattern workers, maximum level of melatonin was recorded at the end of the shift. When it came to 4N pattern workers, however, the highest melatonin level was registered around 3:00 AM. This further supports the idea that the adaptability of 7N shift workers was higher than that of 4N shift employees. In a study conducted among offshore workers [27], adaptability rate (as measured through changes of melatonin acrophase) was found to be around 1.5 hours per shift, with complete adaptability being observed after 14 consecutive nights when melatonin peak completely moved from night to day. Another study showed that night shift adaptability takes place after 4–7 consecutive nights, which means that, after this time, melatonin acrophase moves from night to day [8].

In addition, sleepiness trend in the two studied groups was approximately similar to the melatonin pattern. More specifically, this trend had more fluctuations among 4N night shift workers, with its maximum and minimum registered at 3:00–5:00 AM and the end of the shift, respectively. When it came to 7N pattern workers, however, the melatonin level had a steady increase, indicating their better adaptability to night shift working.

Another possible factor resulting in better cognitive performance of 7N night shift workers (compared to those who worked 4 consecutive night shifts) is sleep. Several studies have indicated that night shift work interferes with sleep–wake cycle and reduces the quantity and quality of daily sleep [15,28]. Night shift results in an approximately 2-hour reduction of individuals' average daily sleep. The accumulation of lack of enough sleep, in turn, leads to performance decline [8]. By contrast, it has been observed that as individuals adapted themselves to night shifts, their sleep quantity and quality improve. In a laboratory study, Lamond et al [12] investigated participants' daily sleep following night shifts and concluded that their sleep quantity and quality significantly improved during the week. They attributed this improvement to individuals' adaptability to night shifts. In accordance with previous research projects, the current study demonstrated that, despite similarities between the two groups' amount of sleep during the day before the last night shift, sleep quality of 7N pattern workers was significantly higher than that of 4N shift workers. By contrast, sleep quality of 4N night shift workers was weak, with a PSQI score > 5 [17].

The results of the present study are in sharp contrast with those obtained by Ferguson et al [15]. They focused on Australian miners' daily sleep quantity and quality as well as cognitive performance during 7 consecutive night shifts. They found no significant difference in participants' sleep quantity and quality during 1 week of consecutive night shifts. Their cognitive performance, nonetheless, declined steadily during the same period. The researchers argued that adaptability to night shifts depends on various factors (e.g., exposure to morning light and environmental conditions like noise and light) and individuals' characteristics (e.g., chronotype) and cannot necessarily be achieved through consecutive night shifts. Thus, in real work settings, adaptability to night shifts is achieved late. In some cases, it does not happen at all.

In the present study, the influence of environmental factors, such as exposure to morning light and environmental conditions,

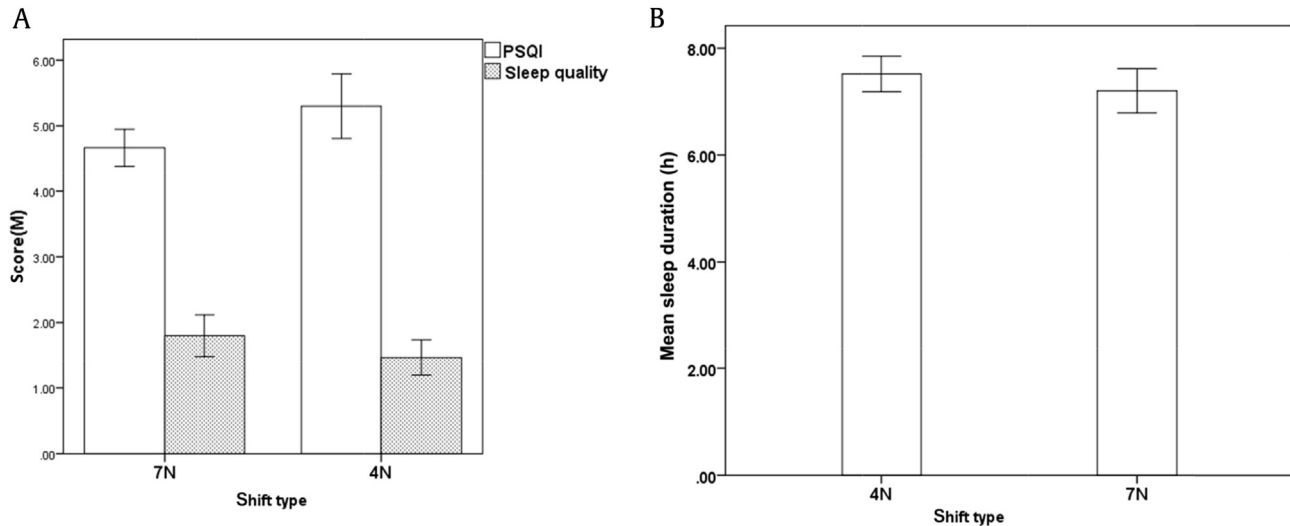


Fig. 4. Comparison of mean and standard error of sleep quality, PSQI score (A) and sleep duration (B) before night shift for the two shift types. 4N, 4 consecutive night shifts; 7N, 7 consecutive night shifts; PSQI, Pittsburgh Sleep Quality Index.

was not investigated; nonetheless, the role of these intervening variables may have been minimized because of our exclusion criteria (i.e., not choosing extremely early or late individuals), the young age of all the participants, their high level of education, and their knowledge of shift-work-related issues (which they had gained as a result of their training) [29,30]. It should also be noted that this study was conducted during winter. Previous studies have shown that because the sun rises later in winter, morning light exposure plays a less serious role during this season (compared to summer) and, therefore, adaptability to night shift work is facilitated [26].

This study had several limitations. First, we did not measure the baseline data related to the first night of the shift, nor those related to the time off at home. Instead, with regard to both 4N and 7N shift patterns, we only concentrated on our assessment of individuals in the last night of the shift. In order to make more dependable generalizations, future studies should take these baseline data into consideration. Second, research has indicated that family-related issues (e.g., number of children) and second job engagement are influential on night shift adaptability [31–33]. Nevertheless, these variables were not taken into account in the present study. Additionally, sleep and sleepiness were assessed through subjective methods. In order to have more reliable results, future studies should utilize objective methods for assessing these two variables. Finally, the present study made a comparison between the two night shift types in terms of cognitive performance and circadian rhythm. Given the effect of shift type on individuals' health, especially the suppression of melatonin and its relationship with health-related factors, future studies should separately focus on the two abovementioned variables (without considering its interaction with the other variable).

5. Conclusion

Despite the aforementioned limitations, the results of this study show that the cognitive performance of workers who did 7 consecutive night shifts was superior to that of participants with the 4N shift pattern. Furthermore, since sleep quality was higher among participants in the 7N pattern and their melatonin rhythm and sleepiness were more organized, they were more likely to adapt themselves to the night shift as a result of longer periods of night shift.

Based on the obtained results, it is recommended that policy makers avoid scheduling night shifts with fast rotations, especially in sensitive positions (e.g., petrochemical industry control rooms) where individuals' proper performance is of crucial importance for supervising and controlling high risk processes. When it comes to selecting between weekly and faster shift patterns, it is the former that should be given the priority.

Conflicts of interest

All authors declare that they have no financial or personal relationships that could have inappropriately influenced the research described.

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