An investigation of the effects of different shift schedules on the fatigue and sleepiness of officers on oil tankers during cargo handling operations.

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Abstract

Cargo handling is an operation, which requires a high level of performance from the officer of the watch (OOW). This study aimed to investigate the effect of different shift schedules on sleep quality, cognitive performance, and sleepiness of 139 OOWs on oil tankers with 4on-8off shifts, during the first shift of cargo handling. Sleep quality (Pittsburgh Sleep Quality Index (PSQI)), level of sleepiness (the Karolinska Sleepiness Scale (KSS)), Psychomotor Vigilance Task (PVT), and Arrow Flanker task performance were examined. The results showed that OOWs with (00:00-04:00,12:00-16:00) and (04:00-08:00,16:00-20:00) shifts had impaired cognitive performance and higher sleepiness during the cargo handling operation, and they also experienced impaired sleep quality. The results demonstrated that the circadian rhythm and homeostatic sleep drive have a greater impact on cognitive performance and sleepiness than time on shifts. These results suggest that allocating rest hours immediately before the cargo handling operation may reduce the risk of fatigue.

Keywords:

Shift Schedule, Officer of Watch (OOW), Cargo Handling Operation, Cognitive Performance, Sleepiness, Sleep

Practitioner Summary

To the best of our knowledge, this maritime field study shows for the first time the prevalence of seafarers' sleepiness and cognitive performance while on duty during cargo handling, using a pre-post shift comparison between three different shifts. The results show the negative effects of keeping watch at night on sleep quality, sleepiness, and the impaired cognitive performance both in the day and the night shifts.

1- Introduction

Maritime transportation experts have always tried to ensure the safe navigation and operations of all vessels, including oil tankers. However, many incidents and accidents still occur, especially in the coastal and port areas. This issue has become one of the fundamental challenges of this vital industry in world trade [1-3]. The officers of the watch (OOWs) are responsible for most of the ship's navigation duties, and the safety of operations such as cargo handling depends substantially on the vigilance and efficient performance that this group of officers have to maintain throughout the day and night [4-6]. In most ocean-going oil tankers, the OOWs work three 4on-8off fixed cycle shifts. The first shift schedule is from 04:00 to 08:00 /then 16:00 to 20:00, the second shift schedule from 00:00 to 04:00 / then 12:00 to 16:00, and the third shift schedule from 08:00 to 12:00 / then 20:00 to 00:00. These shifts are fixed during the long duration of the tour of duty so that the OOWs can cover navigation and other critical operations such as cargo handling 24 hours a day, seven days a week.

Shift work at sea can affect the performance of OOWs in a variety of ways. Laboratory and field studies show that night shift work causes misalignment in circadian rhythm and sleep homeostasis and hindrance of performance even in OOWs who have done night shifts for a long time. Evidence also suggests that only in a small percentage (less than %3) of people, who continuously work night shifts, is there "complete" adjustment of their endogenous rhythms to the night-work [7-9]. In addition to the usual problems caused by shift work, OOWs have to cope with other challenges that arise from the nature of seafaring. Many sectors of shipping involve a 24/7 industry, and seafarers live in an isolated and confined environment (ICE) for a long time. They sleep while exposed to the effect of stressors, such as noise, vibrations, and ship movements [5, 10, 11]. These factors hinder restorative sleep, impair the sleep quality chronically [11-13], and cause fatigue and sleepiness in OOWs [5, 10, 14, 15].

Fatigue is the inability to function at the desired level due to incomplete recovery from the prior work demands and other waking activities [16]. Acute fatigue can occur when there is inadequate time to rest and recover from a work period. Cumulative (chronic) fatigue occurs when there is insufficient recovery from acute fatigue over time. Recovery from fatigue, i.e., restoration of function (cognitive function in particular), requires sufficient good quality sleep [16]. Fatigue could undermine the performance of OOWs in their tasks through the reduction of alertness, failures of situational awareness, increasing reaction time, lapses of attention, easy distraction, and weakening of executive functions [7, 14, 17-21]. Also, chronic fatigue can impair seafarers' health, and it is associated with an increased risk of cardiovascular disease, gastrointestinal disease, mental health problems, and stress [22].

Studies show that fatigue and sleepiness may lead to human error, which can endanger the safety of operations and is one of the main risk factors in maritime accidents [6, 14, 23, 24]. Åkerstedt et al. (2000) describe fatigue as 'the largest identifiable and preventable cause of accidents in transport operations, causing an estimated 15 to 20% of all accidents [25]. Also, the history of the tanker transportation is full of high-profile and costly accidents attributed to seafarers' fatigue that result in oil spills and environmental pollution. In the case of the Exxon Valdez tanker disaster in 1989, the US National Transportation Safety Board found that in the 24 hours before grounding, the OOW had only 5 or 6 hours of sleep [26]. In addition, the Australian Transport Safety Bureau investigation found that in the grounding of the bulk carrier Shen Neng 1 in the Great Barrier Reef in April 2010, the OOW's actions were affected by fatigue. Investigations showed that he/she had only two and a half hours of sleep in the 38.5 hours prior to the incident [27].

Cargo handling operations are critical in tanker vessels and performed after two intensive operations of port approaching and berthing at the jetty which often lead to long working hours and excessive workloads for the OOWs [28, 29]. Long working hours have been shown to increase fatigue and sleepiness and to endanger the safety of the cargo handling operation [5, 21, 26, 29-32]. The OOWs' tasks during this operation are mainly calculation-driven and require accurate and immediate responses [33-35]. During these operations the OOWs have to perform multiple tasks simultaneously so that in parallel with the cargo handling operation, they have to supervise other port activities like ballast water adjustment as well [29]. Proper execution of such tasks requires their constant presence in the cargo control room, and the OOWs must maintain alertness throughout the shift [29] because even temporary lapses of attention can lead to irreversible events such as endangering the safety of life, damage to the ship, port facilities, and the marine environment [36]. Therefore, it is crucial to know which shift schedule is associated with impaired cognitive performance and more sleepiness. When this has been identified, the shipping companies can define appropriate strategies in their fatigue risk management systems to mitigate the likelihood of adverse consequences.

Firstly, whether the cargo handling is in the day or at night will affect performance because of the circadian rhythm of the body and the homeostatic sleep drive [37-39]. Studies [17, 21, 40] show that individuals have impaired cognitive performance during night shifts, but it has also been observed [4] that half of the marine accidents have occurred during the day shifts. Research [17, 21] has shown that sleepiness increases with the length of time on duty, which suggests that problems will occur at the end of the shift. Therefore, the present field research aimed to compare the cognitive performance and sleepiness of the OOWs at the beginning and the end of the first shift of cargo handling operations as well as comparing these variables between a group of them that performed their shift during the day, and another group that performed their shift during the night.

It should also be noted that sleep deprivation leads to a performance decrement [32]; therefore, the sleep quality of individuals during the tour of duty could affect their performance in cargo handling operation. Kazemi et al. [17] have shown a significant difference between the sleep quality of the day and night shift workers. They found that the sleep quality of the night worker was reduced; however, in general, the sleep quality of both groups was impaired due to their shift work. Since OOWs have had different shift schedules during their tour of duty, between-subjects' comparisons were also performed for the cognitive performance, sleepiness, and sleep quality of OOWs with different shifts. Overall, the aim was to determine which shift schedules had the greatest influence on the performance and sleep of the officers.

Finally, many studies show that taking a rest after long working hours can be considered as fatigue mitigation in the risk management system [41-44]. Therefore, the current study provided a comparison between the cognitive performance and sleepiness of the officers who started their shift in the cargo handling operation immediately after completing the berthing operation, and those who had approximately 6 to 8 hours of rest after finishing the berthing and then resumed their shift in the cargo handling operation.

Research Questions

1. How does the cognitive performance and sleepiness level of the OOWs change between the commencement and completion of cargo handling operation shifts?
2. How does cognitive performance, sleepiness, and sleep quality change in the three fixed 4on-8off shift schedules?

2- Materials and Method

Participants provided written informed consent prior to participation in the study. The protocol was approved by the Ethics Committee of the Shiraz University of Medical Science. The study protocol was carried out in accordance with the standards set by the latest version of the Declaration of Helsinki.

2.1- Participants

This research involved two parts including a total of 139 officers with 15 to 90 days duration at sea. The first part had a sample of 98 OOWs who started their first shifts of cargo handling operation immediately after completing the approaching and berthing operation. In the second part, there were two separate groups with a total of 92 participants. One group consisted of 51 officers from the first part who started the cargo handling operation immediately after the berthing operation without any rest, and the other group consisted of 41 OOWs whose cargo handling shift started after 6 to 8 hours of rest. The exclusion criteria included alcohol consumption, psychiatric disorders, and traumatic brain injury, using psychotropic medications, and suffering from epilepsy.

All participants were male and healthy and had no history of any special disease. Caffeine use was not restricted for the purpose of the study. All participants were OOWs and had the same educational status. Moreover, their work/rest timesheets were investigated, and the results showed that all participants had at least 10 hours of rest during a day and had at least 77 hours of rest in the week before data collection. In addition, the officers travel by plane from their city of residence to the port and then board the ship. Therefore, to eliminate the effects of some variables such as jet-lag and officers' sleep patterns while on leave on the sleep quality, individuals who had at least fifteen days duration at sea, were selected for this study.

2.2 Study Design

This cross-sectional study was a part of a larger project investigating the navigation officers' performance with a fixed 4on/8off work shift during three operations of approaching, berthing, and cargo handling [29, 45]. Ocean-going oil tankers with gross tonnage greater than 56,000 navigating in fixed routes were selected. Moreover, considering the time of sunrise and sunset and the data collection season, the terms "day" and "night" were defined from 08:00 to 20:00 for the day-shift schedules and from 20:00 to 08:00 for the night-shifts. Therefore, the participants were divided into two groups, the day and night watch-keepers, based on their first shift at the beginning of the cargo handling operation. Table 1 shows the number and details of the day and night workers.

Figure 1 shows three different shift schedules during the approaching, berthing, and cargo handling operations day and night. As shown in this figure, the selected officers were initially engaged in the approaching operation for six hours. The berthing operation was conducted for four hours following two hours of rest. Immediately after the berthing operation, the first shift of officers in the cargo handling operation began, and this shift was the focus of this research. In the first part of the research, the selected officers conducted the first shift of the cargo handling operation following ten hours of work in the approaching and berthing operations, and they had only two hours of rest, although they were on standby during that rest. The design of this study was similar to the design of a study [21] in which the staff were doing overtime at work, but in real-world conditions.

At the beginning of the cargo handling operations, the officers filled out the background questionnaire asking for demographic information (see table 1). The data collection procedure was organized, as illustrated in Figure 1. The Psychomotor Vigilance Task (PVT) and Arrow Flanker Task were administered at the beginning and end of the cargo handling operations shift to assess cognitive performance (see the dark grey sections in figure 1). While the experimenter was conducting these tests, participants sat in a closed and quiet room without any auditory or visual disturbance, away from the navigation bridge and ship's cargo control room. The Karolinska Sleepiness Scale (KSS) questionnaire was filled out at the beginning, the middle, and the end of the cargo handling operation shifts to evaluate the sleepiness level (see the light grey sections in figure 1). Sleep quality was measured using the Pittsburgh Sleep Quality Index (PSQI) questionnaire.

The second part of the study examined the effect of allocating rest time on the performance of officers during the cargo handling operation. This involved a comparison between the cognitive performance and sleepiness of officers who started their shift in the cargo handling operation immediately after completing the berthing operation, and those who had approximately 6 to 8 hours of rest before starting the cargo handling operation. The officers from the first day-shift (4 pm to 8 pm), the second night-shift (midnight to 4 am), and the third night-shift (8 pm to midnight) were involved in this part.

2.3- Data Collection Tools

2.3.1- Psychomotor Vigilance Task (PVT)

The Psychomotor Vigilance Task is a neurobehavioral assessment test administered to assess vigilance. The test has high validity and reliability and has also become one of the most popular measures of behavioral alertness which takes its repute from its high sensitivity to circadian misalignment, fatigue, and sleep deprivation [46, 47]. It can reflect real-world risks because deficits in attention affect many applied tasks, especially those which require quick reaction or timely responses [48, 49].

A 1-minute PVT training session was done before each test to remove the warm-up effect. If performance improves over trials regardless of the experimental conditions, you may have a warm-up effect. This can be eliminated by having participants perform preliminary trials until their performance on the task matches their asymptotic learning [50]. The participants were asked to look at the laptop and use either the index finger or thumb of their dominant hand to respond to the PVT signals. The participants were instructed to respond as quickly as possible to a simple visual stimulus (a red light display). Each PVT administration lasted 10 minutes with a random inter-stimulus interval of 2–10 seconds. In this test, reaction time (RT) was measured as the time between the red circle onset and the first keypress. Based on previous research on the PVT, the following outcome measures of PVT performance were included: 1) mean reaction time (RT), 2) the number of lapses, defined as RT > 500 milliseconds (errors of omission).

2.3.2- Arrow Flanker Task

The Flanker task is one of the psychological measures of inhibitory control and assesses the individual's selective attention capacity by focusing on the relevant stimulus and ignoring the irrelevant stimuli [51, 52]. The flanker task requires participants to respond quickly (Inter-trial interval (ITI) = 1200 milliseconds) using a forced-choice keypress to central target arrows (< or >) flanked by either congruent (<<<<<. >>>>>) or incongruent (<<><<. >><>>) arrows. Each trial started with the presentation of the central fixation cross "+", which lasted for 1000 milliseconds. Then the arrows appeared 200 milliseconds later after the fixation cross disappeared.

The participants were instructed that the arrows would appear rapidly, so they had to react quickly to perform the task; however, it was emphasized that speed and accuracy were equally important. The complete test was 10 minutes, with 300 congruent and incongruent trials which were presented randomly with equal probabilities. In this test, the reaction time (RT) was measured as the time between the onset of the arrow and the first keypress. The difference between RTs in the congruent and incongruent trials (Dif-RT) was of major interest. The difference in the correct percentages in the congruent and incongruent trials (Dif-error) was also analyzed.

2.3.3- Karolinska Sleepiness Scale (KSS)

The Karolinska Sleepiness Scale (KSS) was used to measure the subjective level of sleepiness at a particular time during the day [53, 54]. Previous studies have investigated the validity and reliability of the KSS with other subjective indicators of sleepiness, and objective measures such as electroencephalographic, and behavioral variables [53, 54]. The instrument is scored on a nine-point scale as follows: 1 (very alert), 3 (alert), 5 (neither alert and nor sleepy), 7 (sleepy), and 9 (very sleepy and trying to stay awake).

2.3.4- Sleep Quality (Pittsburgh Sleep Quality Index (PSQI) Questionnaire)

Subjective sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI) [55]. This 19-item questionnaire was developed to analyze the sleep quality of the respondents over the last month. The PSQI consists of self-rated questions and differentiates "poor" from "good" sleep by measuring seven domains, including subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, sleep medication use, and daytime dysfunction over the last month. Each component was scored from 0 to 3 based on the instruction and then summed into a global PSQI-score. Scores of more than 5 indicate low sleep quality. The PSQI has previously been validated with satisfactory validity and reliability [56, 57].

2.3- Statistical Analysis

The IBM® SPSS® statistics package was used to perform statistical analyses (p-value = 0.05). To compare the sleepiness level at the beginning of the shift (KSS1), at the middle of shift (KSS2), and at the end of the shift (KSS3), repeated measures tests were conducted. In addition, t-tests were used to compare the sleepiness level of the day and night watch keeping officers. Also, the MANOVA was used to compare the level of sleepiness among the officers with different shifts, and the significance of the univariate effects was then examined. The Bonferroni t-tests were then used to compare the different schedules, while age and seafaring experience were entered as covariates due to their significant effects in different work shifts (see Table 1). In summary, the following analyses involved:

- A Comparison of KSS1, KSS2, KSS3 between different day shift schedules
- A Comparison of KSS1, KSS2, KSS3 between different night shift schedules

The MANOVA analysis was performed to compare the PSQI scores of the officers in the three different shift schedules. In this analysis, age and seafaring experience were the covariates. Bonferroni t-tests were then used to compare the different schedules. T-tests were used to compare the pre-post shift cognitive performance for the day shifts and pre-post shift for the night shifts, with a Holm-Bonferroni correction applied to the p-values. MANOVA analysis was used to compare the cognitive performance of the officers with different shift schedules in the day shift, as well as the officers with different shift schedules in the night shift, and the significance of the univariate effects was then examined by Bonferroni t-tests. In this case, the age and seafaring experience of the officers were considered as covariates. Also, to compare the change percentage from pre- to post-shift ($\frac{post\_shift\ score - pre\_shift\ scores}{pre_{shift} score}$) $\times 100$, the MANOVA analysis was used, and Bonferroni t-tests were then applied to compare the different shift schedules. In summary, the analyses involved:

- Comparison of the pre-shift cognitive performance between day watch-keepers
- Comparison of the post-shift cognitive performance between day watch-keepers
- Comparison of the percentage of change from pre to post-shift measurements between day watch-keepers
- Comparison of the pre-shift cognitive performance between night watch-keepers
- Comparison of the post-shift cognitive performance between night watch-keepers
- Comparison of the percentage of change from pre to post-shift measurements between night watch-keepers

For the analysis of the second part of the study, the MANOVA test was used to compare the PVT test variables and the KSS questionnaire scores of the officers whose shifts started immediately without any rest with the officers whose same watches started after 6 to 8 hours of rest. The significance of the univariate effects then examined. Bonferroni t-tests were then used to compare the different watches.

3- Results

3.1- First Part

Number, average age, mean seafaring experience, and the range of these variables are presented in Table 1. Comparison of age and seafaring experience between the officers with similar shift schedules who performed their first shift in the day, and those who performed their first shift at night, did not show any significant differences. This meant that the age and seafaring experience did not need to be controlled when a comparison between officers with similar shift schedules was conducted. The results of the ANOVA obtained from a comparison between age and seafaring experience of the officers with different shift work schedules showed significant differences ($p<0.001$ for day shift schedules, $p<0.001$ for night shift schedules). Those on the first shift were the oldest, with the most experience, and those on the third shift the youngest, with the least experience. This shows that these variables should be considered as covariates when comparing officers doing different shifts.

3.1.1- The KSS Scores of the Day Watch-keepers vs. Night Watch-keepers

Table 2, shows the results of the comparison of the KSS scores of the day watch-keepers with the night watch-keepers. This table also shows the sleepiness trend during each shift. The results showed that $\mathrm{KSS1}_{first}$, $KSS2_{first}$, and $KSS3_{2nd}$, as well as $KSS1_{3rd}$, $KSS2_{3rd}$, and $KSS3_{3rd}$ in night shifts were significantly higher than their corresponding values in the day shifts (the subscript of each variable symbolizes the corresponding shift). Also, the results show that sleepiness significantly increased over the course of both the day and night shifts, except for second shift schedules in the day (12:00 to 16:00) (p=0.237). In contrast, the sleepiness trend for the officers in the first night-shift schedule (04:00-08:00) is significantly decreasing, and the lowest point is at the end of the shift, i.e., 08:00 (p=0.003). A Holms-correction showed that the only p values of less than 0.004 were significant after adjusting for the number of analyses.

3.1.2- The Effects of Different Shift Schedules on the KSS Scores

Figure 2 illustrates the overall effect of different shift schedules on the KSS scores using the MANOVA test results. The age and seafaring experience of the officers were considered as covariates. The results suggest that the KSS scores of the day watch-keepers varied significantly with the shift schedule ($F_{(6.82)} = 3.085, p = 0.009, Wilk's\ \Lambda = 0.666, partial\eta^2 = 0.184$). In particular, the schedule significantly affected the KSS scores at the beginning of the shifts (KSS1: F= $4.149, p = 0.006, partial\eta^2 = 0.278$). Bonferroni t-tests revealed a significant difference between the KSS1 of the first and third shift schedule (p==0.027) as well as the KSS1 of the second and third shift schedule (p=0.003).

The results also showed that the KSS scores of the night watch-keepers ($F_{(6.86)} = 4.806, p < 0.001, Wilk's\ \Lambda = 0.561, partial\eta^2 = 0.251$) significantly varied with their shift schedules. The night-shift schedule significantly affected the KSS scores at all time points in the shift; at the beginning of the shifts (KSS1) ($F_{(4.49)} = 11.109, p < 0.001, partial\eta^2 = 0.497$), the KSS scores in the middle of the shifts (KSS2) ($F_{(4.49)} = 4.531, p = 0.004, partial\eta^2 = 0.287$), and the KSS scores at the end of the shifts (KSS3) ($F_{(4.49)} = 3.106, p = 0.024, partial\eta^2 = 0.216$). Bonferroni t-tests revealed a significant difference between the KSS1 of the first and second shift schedule (p=0.004) as well as the KSS1 of the first and third shift schedule (p = 0.004). Figure 2 depicts the sleepiness trends of the different day-shift and night-shift schedules.

3.1.3- The Effects of Different Shift Schedules on the Sleep Quality

Sleep quality was assessed over the past month in which each officer worked in both night and day-shifts. Therefore, it was examined as a function of the different shift schedules, but no distinction was made between the night and day-shifts. Table 3 displays the effects of different shift schedules on the sleep quality of officers. The results of the MANOVA analysis showed that sleep quality was significantly different in the three shift schedules (p=0.001). The age and seafaring experience of the officers were considered as covariates. Although the quality of sleep of all watch keeping officers was low in general (PSQI-score > 5), Bonferroni t-tests revealed that there was a large significant difference between the second and third shift (p=0.001).

3.1.4- The Effects of Shift Schedule on the Cognitive Performance of Officers

MANOVA test was used to investigate the effect of shift schedules on the pre-shift cognitive performance of the day watch-keepers, with age and seafaring experience of the officers entered as covariates (see table 4). The results indicate that the cognitive performance scores varied significantly as a function of their shift schedules ($F_{(8.80)} = 2.244, p = 0.032, Wilk's\ \Lambda = 0.667, partial \eta^2 = 0.183$). In particular, the shift schedule significantly affected RT-pre ($F_{(4.47)} = 3.475, p = 0.015, partial \eta^2 = 0.244$) and lapse-pre ($F_{(4.47)} = 3.224, P = 0.021, partial \eta^2 = 0.231$). Bonferroni t-tests revealed a significant difference between the lapse-pre scores (p=0.008) of officers in the second and third shift schedule. The MANOVA test did not show any significant effect on post-shift cognitive performance ($F_{(8.80)} = 1.044, p = 0.411, Wilk's\ \Lambda = 0.820, partial \eta^2 = 0.095$). A MANOVA test was used to investigate the effects of shift schedules on the percentage change from pre to post-shift. The results did not show any significant change from pre to post-shift for the officers who performed their shift in the day ($F_{(8.80)} = 0.852, p = 0.561, Wilk's\ \Lambda = 0.849, partial \eta^2 = 0.078$).

For the officers who performed their shift at night, the results suggest that the respondents' overall pre-shift performance did not significantly vary as a function of their shift schedule ($F_{(8.84)} = 1.550, p = 0.152, Wilk's\ \Lambda = 0.759, partial \eta^2 = 0.129$). However, night-shifts significantly affected RT-pre ($F_{(4.49)} = 3.659, p = 0.012, partial \eta^2 = 0.245$) and the number of lapses-pre ($F_{(4,49)} = 8.550, p = 0.000, partial \eta^2 = 0.432$). Bonferroni t-test revealed a significant difference between lapse-pre in the first and third shift schedules (p=0.045) as well as the second and third shift schedule (p=0.039). There was also a significant difference between the officers in the second and third shift schedule (p=0.034) for Dif.error-pre. The results also showed that overall post-shift performance did not significantly vary by shift schedule ($F_{(8,82)} = 1.680, p = 0.116, Wilk's\ \Lambda = 0.746, partial \eta^2 = 0.136$). However, it significantly affected RT-post ($F_{(4.49)} = 3.441, p = 0.015, partial \eta^2 = 0.234$), the number of lapses-post ($F_{(4,49)} = 4.069, p = 0.007, partial \eta^2 = 0.266$), and the number of Dif.error-post ($F_{(4,49)} = 2.622, p = 0.047, partial \eta^2 = 0.189$). Bonferroni t-tests revealed a significant difference between the officers in the second and third shift schedule (p=0.034) concerning lapse-post and a significant difference between the officers in the second and third shift schedule (p=0.016) with respect to Dif.error-post. The results did not show any significant change from pre to post-shift for the officers who performed their shift at night ($F_{(8.84)} = 1.745, p = 0.100, Wilk's\ \Lambda = 0.735, partial \eta^2 = 0.142$). However, it significantly affected lapse-percent ($F_{(4.49)} = 12.237, p < 0.001, partial \eta^2 = 0.521$). There was a highly significant effect of shift for the lapse-percent. This was due to the difference between the first and second shift (p=0.027) with the first shift having a smaller number of lapses.

3.1.5. Cognitive Performance of the Officers before and after shift

Figure 3 shows the different components of cognitive performance, and the pre and post-shifts results for both day and night. The Holms-correction for day watch-keepers showed that the only p values of less than 0.006 were significant after adjusting for the number of analyses. Hence, the significant effects were Lapse_{first}, $\text{Dif}-\text{RT}_{first}$, RT_{first}, $\text{Dif}-\text{error}_{\text{3rd}}$ (the subscripts of each variable symbolize the corresponding shift).

On the other hand, for night watch-keepers, the Holms-correction showed that only those p's < 0.030 were significant after adjusting for the number of analyses. Hence, the significant effects were $\text{lapse}_{\text{2nd}}$, $\text{Dif}-\text{RT}_{\text{2nd}}$, $\text{Dif}-\text{error}_{\text{2nd}}$, RT_{2nd}, $\text{lapse}_{\text{3rd}}$, indicating that the performance declined at the end of the night shifts. However, there was a different situation for the officers on the first night-shift schedule (04:00-08:00), where $\text{Dif}-\text{RT}_{\text{first}}$, $\text{Dif}-\text{error}_{\text{first}}$, and RT_{first} did not show a significant increase at the end of the shifts. Interestingly, there was a significant reduction in the number of $\text{Lapse}_{\text{first}}$ at the end of the shift. Figure 3 demonstrates the different components of the cognitive performance of the officers before and after shifts during both day and night.

3.1.6. Cognitive Performance of day watch-keepers vs. night watch-keepers

In the MANOVA analysis, the performance of the officers at the end of the shifts was compared, and their performance at the beginning of the shifts was entered as a covariate. Table 4 shows the results of the MANOVA analysis comparing the cognitive variables of day watch-keepers with night watch-keepers. The Holms-correction shows that only those p's < 0.005 were significant after adjusting for the number of analyses.

3.2- Second Part: Effects of Rest

3.2.1- The Effects of Allocating Rest Time on Performance

The results derived from the PVT test as well as the KSS questionnaire based on the two different groups engaged in the cargo handling operation are presented in tables 5 and 6. The first group consisted of the officers who started their first shift in the cargo handling operation immediately after the berthing operation. The second group consisted of the officers who had between 6 to 8 hours of rest after the end of the berthing operation and then started their shifts in the cargo handling operation. It is worth mentioning that the differences in age and seafaring experience between the groups with similar shift schedules were not significant; therefore, there was no need to include them as covariates. The MANOVA test was used to investigate the overall effect of groups, shifts, and the interaction on the PVT performance and KSS scores of the officers. The results showed that the cognitive performance and KSS scores significantly varied by groups ($F_{(7,80)} = 12.815, P < 0.001, Wilk's\ \Lambda = 0.471, partial \eta^2 = 0.529$), and they also varied significantly with shift schedules ($F_{(14,160)} = 2.728, P < 0.001, Wilk's\ \Lambda = 0.652, partial \eta^2 =$

0.193), but the effect of the interaction of shift and group was not significant ($F_{(14,160)} = 0.704, P = 0.768, Wilk's\ \Lambda = 0.887, partial\eta^2 = 0.058$). The univariate analysis of groups and shifts is shown in table 5, and the significance of the univariate effects of groups was then examined using Bonferroni t-tests, and the results are shown in Table 6. The Holms-correction showed that only those p's < 0.05 were significant after adjusting for the number of analyses. The results of the MANOVA test showed that the majority of the PVT variables, as well as the level of sleepiness, were significantly different between the first and second groups and this indicated the positive effect of rest on the cognitive performance and sleepiness of navigation officers during the cargo handling operation.

4- Discussion

Cargo handling is one of the most sensitive and stressful ship operations requiring high vigilance of the watch-keepers. This study aimed to determine the effect of different shift schedules on sleep quality, cognitive performance, and sleepiness of OOWs, focusing on the first shift of the cargo handling operation. It also compared officers' cognitive performance and sleepiness at the beginning and the end of each shift schedules in the day and night. The results showed that the cognitive performance of the officers in the 16:00 to 20:00 shift deteriorated, and the level of their sleepiness also increased significantly at the end of their shift. However, the cognitive performance of these officers at night shifts, (i.e. 04:00 to 08:00), not only did not demonstrate any significant impairment in any of the variables at the end of their work shift, but the number of lapses even improved significantly. Examining their level of sleepiness during this shift confirmed that their sleepiness was at its highest level at the beginning of the shift, (i.e. 4 a.m.), while in the middle (6 a.m.) and at the end of the shift (8 a.m.), it reached its lowest level. Research shows [37, 38, 58, 59], that the worst performance occurs in the early hours of the morning, and this is known as the circadian nadir [39], and most accidents and human errors in the industry have occurred during this period. However, this is against the findings of other research [17, 21] which suggests that the level of sleepiness increases with time on shift, and shows that sleepiness and cognitive performance follow the time of day to a great extent.

In the second day-shift schedule (12:00-16:00), officers' performance on the PVT test was also impaired significantly at the end of the shift. Furthermore, their sleepiness also increased over time during the shifts, but this increase was not statistically significant. The cognitive performance of these officers at the end of the night shifts (00:00-04:00) was significantly impaired in both the PVT and Arrow Flanker tests, and their sleepiness also increased significantly. This is in accordance with the findings of other studies [21, 37, 59], suggesting that homeostatic sleep drive increases at night and reaches its maximum value early in the morning.

In the third shift schedule, the officers' cognitive performance was significantly impaired in both the day-shift (08:00-12:00) and night-shift (20:00-24:00), and it was the worst at the end of these shifts. Also, the sleepiness level increased significantly at the end of the day and night-shifts, which is in line with other studies [21, 40].

The performance of the officers on the second and third shifts at night was significantly worse for all PVT variables and in one of the variables of the Flanker test. These results are consistent with findings from a study [8], which indicated a greater vulnerability of attention and inhibitory control of attention on the night shifts. In contrast, the cognitive performance of officers on the first shift did not show any significant difference between day and night. This could be for two reasons: first, these officers have more seafaring experience than the other two groups, so they have a better ability to manage their duties and mitigate fatigue more skillfully on night-shifts. Secondly, the shift of these officers at night ends at 08:00, when their bodies have a low tendency to sleep. Comparing the level of sleepiness among the officers in the day and night shifts confirms upward trends during both shifts, although this increase was higher and the sleepiness dip was steeper during the night shift. However, in the first night-shift schedule, officers experienced much greater sleepiness at the beginning of the shift, and then it gradually decreases towards the end.

In general, comparing the officers' cognitive performance in the three different shift schedules showed that whether on the day or night shifts, the officers in the first and second shifts performed significantly worse in the PVT test than the officers in the third shift. This may be due to having to stay awake during the night (24:00 to 06:00) which is the lowest dip of the circadian rhythm in alertness and cognitive performance [60, 61]. Interestingly, most of the catastrophic maritime accidents and incidents caused by fatigue have occurred between 24:00 (midnight) and 08:00. [6, 60, 61]. The sleepiness scores also show that the officers in the first and second shift schedules have started and finished their shifts with higher sleepiness compared to the officers from the third shift schedule. These issues can dramatically affect their performance in the sensitive work shifts of cargo handling operations.

The PSQI scores showed that officers in the first and second shift schedules had reduced sleep quality compared to the third shift schedule. It should be noted that they have been on night shifts for a long time. Long-term irregularities in the circadian rhythm and cycle of sleep can result in chronic sleep deprivation. Furthermore, their sleep and rest time also occurs during the day. The officers in the first shift take rest and sleep from 08:00 to 16:00, and the officers of the second shift, from 16:00 to midnight, which means that their sleep is not restorative and does not have the required quality. For instance, the authors of one study [5] stated that most of the officers in the second shift start their sleep at 17:00, which is early evening and is known as the "forbidden sleep zone" [62, 63]. A review of their PSQI questionnaire also shows that the sleep quality of most OOWs in the past month was low, which is in line with the results of other research [64]. This issue combined with long working hours of approaching and berthing operations could substantially increase fatigue and sleepiness, and eventually weaken their cognitive performance [65].

It is clear that the officers of the watch during these three operations (A.B.C) struggle with all three main characteristics of fatigue, namely: (1) inadequate sleep, (2) circadian disruption and, (3) extended time on task [66]. Due to the high sensitivity of the cargo handling operation, special attention should be paid to the fatigue risk management at all three levels of (1) regulatory, (2) industry/company, and (3) individual. It is necessary to mitigate the risk of fatigue, and adopt strategies to maintain operational safety when OOWs are fatigued. The fatigue risk management strategy should reduce the acute effects of fatigue such as operator error [16], and also prevent the chronic effects on health, such as cardiovascular and gastrointestinal diseases, reproductive problems, mental and endocrine disorders [22].

Fatigue risk management is defined as the planning and control of the working environment to minimize the adverse effects of fatigue on workforce alertness and performance as far as practicable, in a manner appropriate to the level of risk exposure and nature of the operation [16]. For instance, in a study [44] of an appropriate fatigue risk management system (FRMS), the participants received adequate sleeping and rest time at the appropriate time, which reduced their fatigue and improved their performance. It seems that it would be necessary to make some better arrangements for the officer who starts the first shift in the cargo handling operation immediately after approaching and berthing to take enough rest. It causes that the chain of consecutive workloads to be broken, especially for officers in the first and second shift schedules, who experience more severe fatigue and sleepiness. For this purpose, it is recommended to use other officers on board who are less fatigued or to recruit a separate officer as a cargo officer to carry out the cargo handling operation. The latter suggestion is supported by the results of a study [28] which showed that additional cargo officers have a significant effect on reducing fatigue.

The international maritime organization (IMO), in line with the international labor organization (ILO), has introduced the hours of work and rest regulations to provide watch-keepers on-board ships with increased rest periods. The International Convention on Standards of Training, Certification, and Watch-keeping for Seafarers (STCW) and the Maritime Labor Convention (MLC) has set the work and rest hours regulations to enhance the fatigue risk management system for on-board watch-keepers. When an officer performs A.B.C operations consecutively and intermittently, it is practically and traditionally impossible to follow these rules, and eventually, he will suffer from fatigue and reduced cognitive performance. In this regard, the present study indicates the positive effect of allocating rest at the end of the berthing operation and before the cargo handling operation on officers' cognitive performance and sleepiness.

Since a comprehensive FRMS includes procedures to address the return to work of employees, especially those who have chronic sleep problems that increase the risk of fatigue-related accidents for themselves and others [16], strategies can be adopted so that the officers are periodically diagnosed and treated for sleep disorders. A focus on sleep disorders is important and results from a recent study [45] show that officers' sleep quality in the tour of duty directly affects their performances at the cargo handling operation. Further research, investigating other shiftwork patterns for other critical ship operations and finding the other weaknesses present under the current work and rest regulations is now required.

5- Limitations

The present study has some limitations that need to be addressed.

First, despite the sensitivity of the PVT test and KSS to the time of data collection during the day, there was no control over the precise time when the officers with different shift schedules were compared.

Secondly officers' workload varies in the three different shift schedules. It may affect their cognitive performance, sleepiness, and sleep quality, but no control or measurement of workload was carried out in the present study.

Thirdly, due to continuous crew change, different working hours, and arrival times of ships to the approach zone, it was challenging to control some of the factors affecting fatigue and sleepiness.

Fourthly, due to the different ships' tonnage, there was no control over the noise, vibration, motion, and ambient temperature. It is worth noting that these factors may affect fatigue and sleepiness. As the present research involved a field study with a long data collection time, there was no control for unstable weather conditions and ship's motion due to adverse weather conditions.

Fifthly, the subjective measurement of sleepiness provides lower precision than objective measures of sleep. Also, as for the officers who were at sea for less than one month, sleep quality may be affected by some factors such as sleep patterns on vacation and jet-lag, which is another limitation of this study.

In the second part of the research, the time interval between the awakening of the officers who had rest before the cargo handling operation and the first test of cognitive performance and sleepiness varied from 15 minutes to 2 hours, and thus there was a possibility that sleep inertia may have affected the results.

Although the number of participants in this study is satisfactory compared to other similar field researches or even similar studies performed in a simulator environment, the generalizability of this study to all navigation officers in the maritime industry can be considered as a limitation.

Conclusion

Approaching, berthing and cargo handling are among the most accident-prone operations of a tanker, yet they have been rarely studied. The present maritime field study had 139 participants and showed for the first time the prevalence of seafarers' sleepiness and cognitive performance on duty during cargo handling operation, and a comparison between three different shift schedules among Officers of Watch (OOWs). The study had a pre-post design with two cognitive tasks and also three times of measurement of sleepiness during the cargo handling shift. The results showed that the OOWs with (00:00-04:00, 12:00-16:00) and (04:00-08:00, 16:00-20:00) shifts during the cargo handling operation had impaired cognitive performance, higher sleepiness and experienced poorer sleep quality. The present study indicates the positive effect of allocating rest at the end of the berthing operation and before the cargo handling operation on officers' cognitive performance and sleepiness. This rest significantly reduced the fatigue and sleepiness of OOWs.

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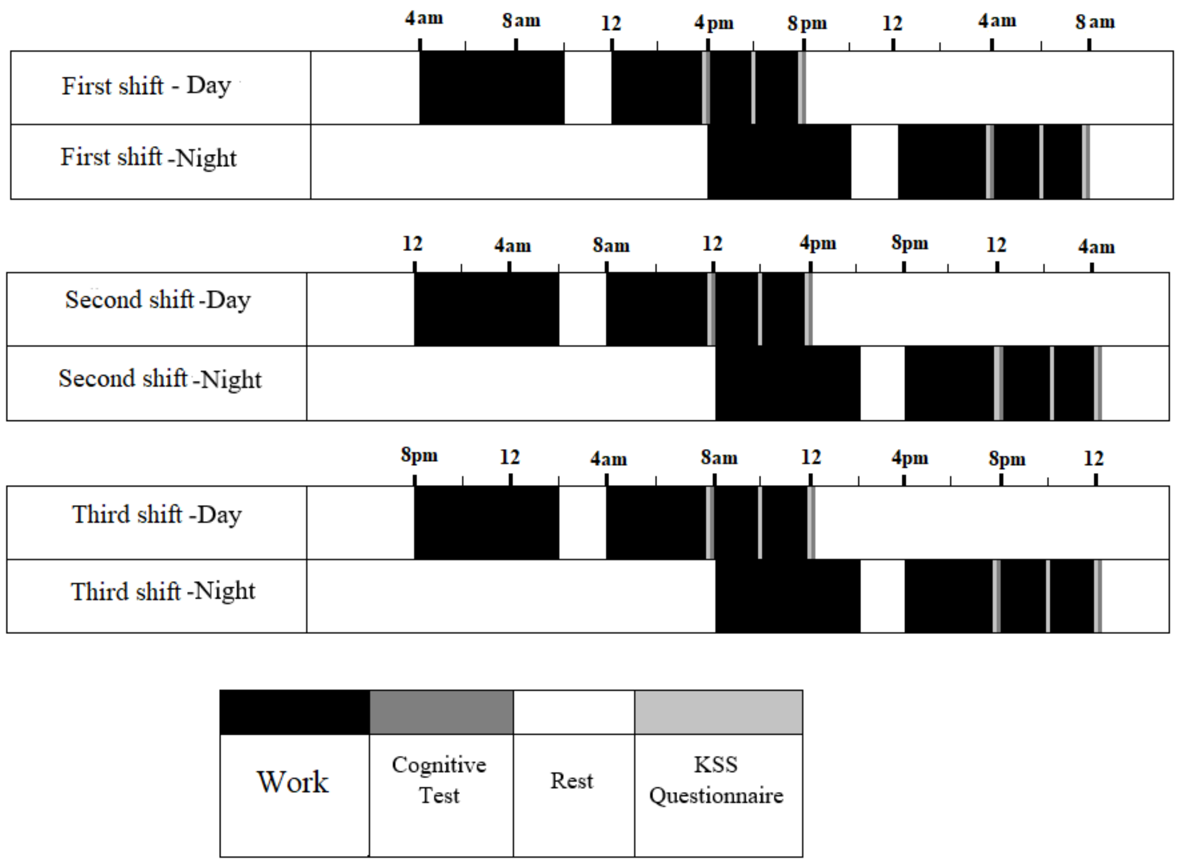

Figure 1 caption: shows three different shift schedules during the approaching, berthing, and cargo handling operations day and night. The data collection process was organized as highlighted in the figure. The participants were initially engaged in the approaching for six hours. The berthing operation was conducted for four hours following two hours of rest. Immediately after the berthing operation, the first shift of the cargo handling operation began, and this shift was the focus of this research. The only difference between the participants with the same shift schedules was the day and night working hours. The distinction between participants in various shift schedules was the different time of their shifts during a circadian cycle.

Figure 1 Alt text: The timetable for the three operations of approaching, berthing, and cargo handling for day and night shift officers and the data collection times. Working time is shown in black, cognitive test time in dark gray, rest time in white, and KSS questionnaire filling time in light gray.

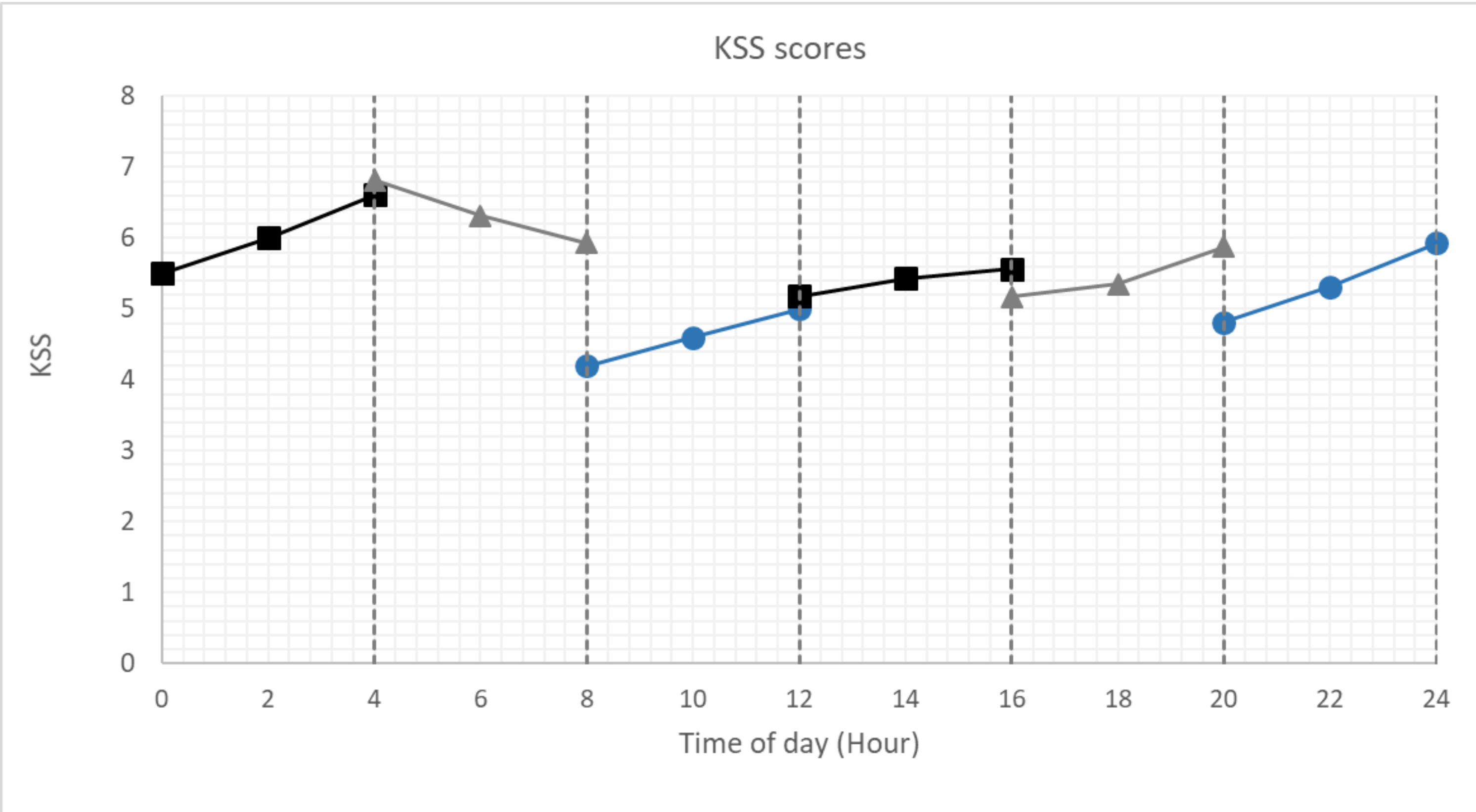

Figure 2 Caption: Figure 2. The effect of different shift schedules on the KSS scores

The first shift schedule: (04:00 to 08:00) and (16:00 to 20:00)

The second shift schedule: (24:00 to 04:00) and (12:00 to 16:00)

The third shift schedule: (08:00 to 12:00) and (20:00 to 24:00)

Figure 2 Alt text: The six-section line graph depicts the KSS scores of participants on different shift schedules over the course of a 24-hour period. Except for the 04:00 to 08:00 shift, the end-of-shift scores were significantly higher.

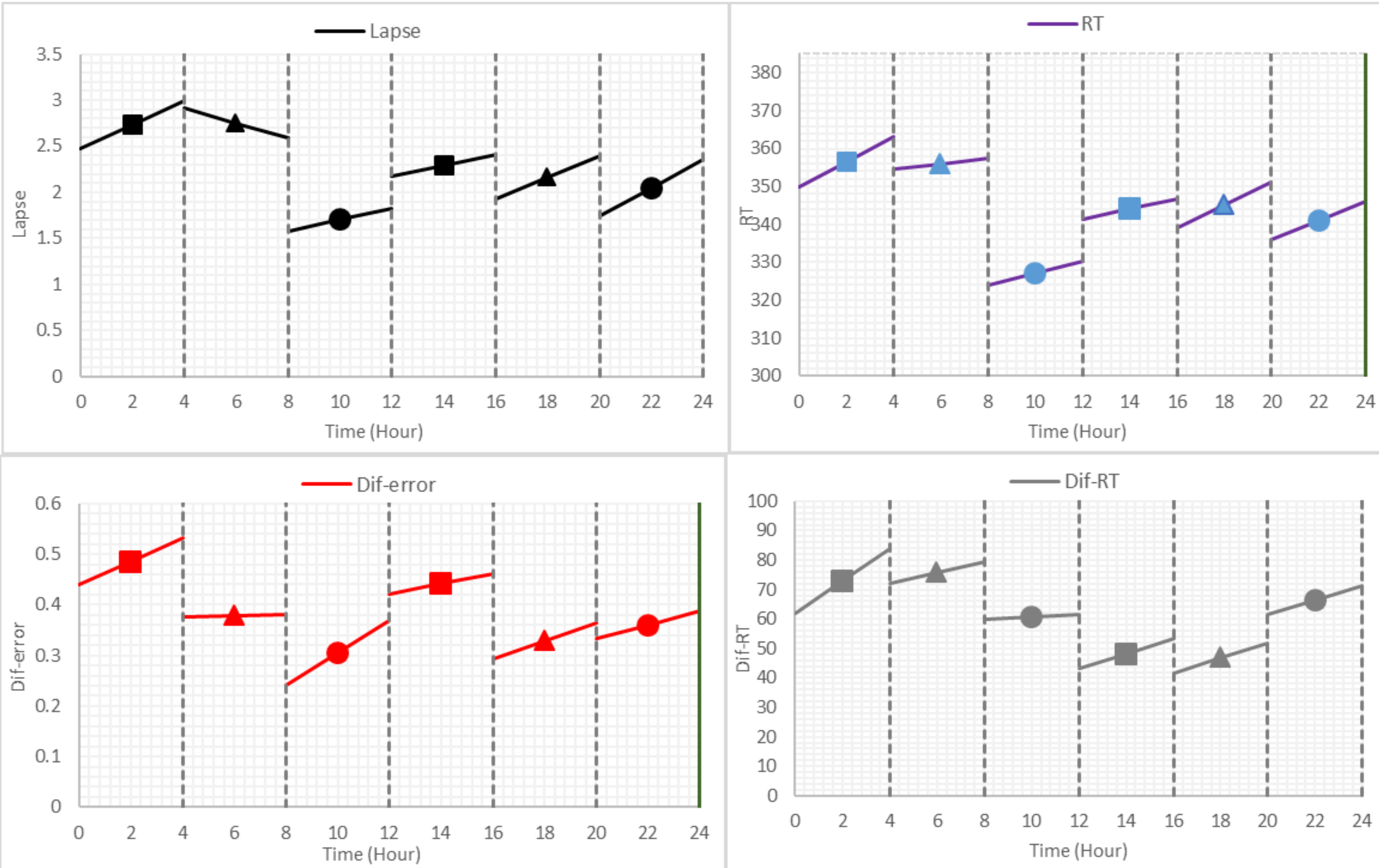

Figure 3 Caption: The different components of cognitive performance of the day and night watch-keepers. The results show the performance weakening at the end of both day and night-shifts except for the first night-shift schedule (04:00 to 08:00). Their results did not show a significant increase at the end of the shift. Also, the number of lapses have decreased significantly at the end of the shift.

The first shift schedule: (04:00 to 08:00) and (16:00 to 20:00)

The second shift schedule: (24:00 to 04:00) and (12:00 to 16:00)

The third shift schedule: (08:00 to 12:00) and (20:00 to 24:00)

Figure 3 Alt text: The image contains four separate line graphs plotting participants' cognitive performance. Each graph represents a different aspect of cognitive performance over the course of a 24-hour period, such as RT, Lapse, Dif-RT, and Dif-error.

officers	1st shift-day	1st shift-night	P-Value¥	2nd Shift-day	2nd shift-night	P-Value¥	3rd shift-day	3rd shift-night	P-Value¥	P-Value¥¥	P-Value¥¥¥
Number	17	16	_	16	18	_	15	16	_	_	_
Age (year)	40.41±3.31	38.88±2.24	0.132	33.56±2.22	33.22±1.95	0.638	29.93±1.7	29±1.82	0.153	0.000*	0.000*
Age range (year)	35-45	36-44	_	29-37	30-36	_	27-33	26-32	_	_	_
Seafaring experience (year)	8.41±1.27	7.81±1.42	0.212	5.31±0.94	4.94±0.99	0.280	3.33±0.81	3.12±0.8	0.481	0.000*	0.000*
SE range (year)	7-11	6-11	_	4-7	4-7	–	2-5	2-4	–	–	–

Table 1: The demographic characteristics of participants

¥ The difference between day and night watch-keepers (paired t-test)
¥¥ The difference between day watch-keepers (repeated measure ANOVA)
¥¥¥ The difference between night watch-keepers (repeated measure ANOVA)

Variables	First shift		P(value)¥	Second shift		P(value)¥	Third shift		P(value)¥
	Night shift (4am-8am)	Day shift (4pm-8pm)		Night shift (24-4am)	Day shift (12-4 pm)		Night shift (8 pm-24)	Day shift (8 am-12)	
KSS1	6.81±0.83	5.17±0.88	0.000*	5.50±1.15	5.18±0.91	0.391	4.81±0.75	4.20±0.86	0.043
KSS2	6.31±0.60	5.35±0.70	0.000*	6±1.08	5.43±1.03	0.132	5.31±0.87	4.60±0.73	0.021
KSS3	5.93±0.57	5.88±0.85	0.831	6.61±1.37	5.56±1.20	0.025	5.93±1.18	5±1.25	0.041
P(Value)¥¥	0.003*	0.009		0.000*	0.237		0.000*	0.016	

Table 2.
KSS scores of the day vs. night watch-keepers (paired t-test) and KSS scores of (beginning, middle, end) the shift (ANOVA test)
¥ Paired t-test
¥¥ Repeated measure test
***significant**

PSQI	Officers of the first shift	Officers of the second shift	Officers of third shift	p-value
	7.18±1.07	7.39±1.40	6.06±1.38	0.001

Table 3 – The effects of different shift schedules on the sleep quality of officers (MANOVA test).

Variables	First shift		P(value)	Second shift		P(value)	Third shift		P(value)
	Night shift (4am-8am)	Day shift (4pm-8pm)		Night shift (24-4am)	Day shift (12-4 pm)		Night shift (8 pm-24)	Day shift (8 am-12)	
RT(ms)	357.42±16.50	351.06±13.49	0.233	363.23±20.73	346.04±25.03	0.036	346.20±23.66	330.22±18.12	0.044
Lapse	2.59±0.511	2.39±0.711	0.364	3±0.637	2.41±0.38	0.003*	2.36±0.64	1.83±0.64	0.030
Dif-error	0.3813±0.210	0.367±0.202	0.820	0.533±0.19	0.462±0.22	0.333	0.387±0.234	0.406±0.264	0.832
Dif-RT(ms)	79.62±38.66	51.94±15.78	0.011	83.81±21.07	53.30±18.29	0.000*	71.18±28.35	61.64±27.99	0.354

Table 4. A comparison of the cognitive performance of officers working in day shifts vs. the night shifts. The performance of the officers before beginning of their shifts was entered as covariate.

*** Significant**

		RT-pre	RT-post	Lapse-pre	Lapse-post	KSS1	KSS2	KSS3
Groups	F	8.698	32.273	5.345	54.600	12.421	31.343	38.698
	P-value	0.004*	0.000*	0.023*	0.000*	0.001*	0.000*	0.000*
	$partial \eta^2$	0.092	0.273	0.059	0.388	0.126	0.267	0.310
Shifts	F	7.901	4.811	11.095	6.185	4.910	3.108	4.399
	P-value	0.001*	0.010*	0.000*	0.003*	0.010*	0.050	0.015*
	$partial \eta^2$	0.155	0.101	0.205	0.126	0.102	0.015	0.093

Table 5 Demonstrates univariate analyses of groups and shifts.

***Significant**

	Groups		P-value
	First (mean(SE))	Second (mean(SE))	
RT-pre	341.61±2.069	332.458±2.315	0.004*
RT-post	353.50±2.485	332.31±2.780	0.000*
Lapse-pre	2.05±0.084	1.76±0.094	0.023*
Lapse-post	2.58±0.092	1.57±0.102	0.000*
KSS1	5.16±0.110	4.58±0.123	0.001*
KSS2	5.57±0.119	4.57±0.134	0.000*
KSS3	6.14±0.137	4.86±0.153	0.000*

Table 6 The results of Bonferroni t-test to compare dependent variables between first and second groups.

***The first group: consists of officers who started the cargo handling operation immediately after the berthing operation without any rest.**

****The second group: consists of officers whose cargo handling shift started after 6 to 8 hours of rest.**