The Effect of Ship Department on Crew Sleep Patterns and Psychomotor Vigilance Performance

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U.S. Navy ship crews are organizationally divided into departments, i.e., functional groups with specific tasks and an officer in charge. The objective of this study is to assess the effect of ship departments on crew sleep patterns and psychomotor vigilance performance. Crewmembers (N=93) from an Arleigh Burke-type destroyer participated in a 16-day quasi-experimental study while the ship was forward deployed. Each sailor wore an actigraph, completed a daily activity log, and performed a 3-minute psychomotor vigilance test (PVT) before and after standing watch. Actigraphy results show that crewmembers were chronically sleep deprived, receiving on average 6.6 hours of daily sleep. Rest and sleep opportunities were varied significantly depending on the department to which the crewmember belongs. Specifically, the Operations department, followed by Engineering, had the worst sleep patterns as indicated by reduced and fragmented sleep. Using actigraphic recordings, approximately 22% of the participants occasionally napped during their night watch. Although not statistically significant due to its large variability, the pattern of PVT results agrees with the sleep analysis. In conclusion, this study provides evidence that the department to which a crewmember belongs is a factor to be taken into account when assessing performance at sea. In our sample, results demonstrate that the two departments most affected are the Operations and the Engineering. Both of these departments have critical duties while underway, yet they experience the most sleep deprivation. Future efforts should strive to further quantify this phenomenon and to address methods to ameliorate the problem.

INTRODUCTION

It is well established that the naval environment is characterized by sleep problems, sleep deprivation, increased levels of fatigue, sub-optimal performance and worrisome levels of cognitive effectiveness. (See for example, Miller, Matsangas, & Kenney, 2012 and Shattuck, Matsangas, & Powley, 2015). The scientific literature has clearly identified the deleterious effect of sleep deprivation on a wide range of human cognitive functions such as attention, memory, mood, and decision making (Broughton & Ogilvie, 1992; Dinges & Kribbs, 1991). However, in the military, there is often a reluctance to accept such findings, coupled with the belief that motivation and determination will allow individuals to perform in real-world environments despite fatigue and lack of sleep (Shay, 1998).

To fulfill their mission, U.S. Navy ships have a command structure led by the commanding officer (CO), who has the absolute responsibility for the safety, well-being, and efficiency of the ship (Department of the Navy, 2012). The direct representative of the commanding officer is the executive officer (XO), who is primarily responsible to the commanding officer for the organization, performance of duty, training, maintenance, and good order and discipline of the entire ship. Organizationally, each ship is divided into departments, i.e. functional groups with specific tasks and an officer charge (Department of the Navy, 2012).

With the exemption of three studies conducted at the Naval Postgraduate School (NPS), our review failed to identify research addressing the departmental effect on the sleep hygiene on the ship's crew. In all three NPS studies, the ships were at sea in Condition III, i.e. wartime steaming. During a 14-day predeployment training at sea, Haynes (2007) evaluated sleep patterns (N=25) onboard the USS Chung Hoon (DDG-93), an Arleigh Burke–class Aegis destroyer. Based on sleep logs, personnel in the Operations department (n=4) received the least daily sleep (6.15 hours) compared to the Combat Systems and Engineering departments. In the second study, data (N=39 participants) were collected over an entire 24-day underway period during the Rim of the Pacific (RIMPAC) Exercise 2008. The study was conducted on the USS Lake Erie (CG-70) and the USS Port Royal (CG-73), two Ticonderoga-class guided-missile cruisers (Mason, 2009). Based on sleep logs, Mason showed that the Combat Systems department received the least sleep, 6.62 hours daily. Green (2009) examined rest patterns (N=24) during a 21-day predeployment underway training period on USS Rentz (FFG-46), an Oliver Hazard Perry–class guided missile frigate. Based on sleep logs and assisted by actigraphy, analysis showed that the Engineering department reported the least daily sleep amount, 5.82 hours, followed by Combat Systems (6.62 hours) and Operations (6.64 hours).

With this evidence in mind, this analysis focuses on how ship department affects crewmember opportunities for rest and sleep and psychomotor vigilance performance. This work is part of multi-year effort at the Naval Postgraduate School to assess the macroergonomic impact of a wide range of environmental and organizational factors on crew performance

(Shattuck & Matsangas, 2014; Shattuck et al., 2015; Shattuck, Matsangas, & Waggoner, 2014).

METHOD

Participants

Participants were crewmembers of a Flight IIA (9300 tons) Arleigh Burke class destroyer. From the initial 122 volunteers, 93 individuals with valid actigraphic sleep recordings and psychomotor vigilance task data were included in this study (74 males; 18 officers and 75 enlisted; 78 watch standers and 15 non-watch standers). Participants were on average 27.5±5.58 years old and had 6.43±4.98 years of military service. Table 1 shows the number of participants by ship department.

Table 1: Participants by department

Department	No.	Officers
Air Department (AIR)	14	5
Combat Systems (CS)	19	2
Engineering (ENG)	25	6
Operations (OPS)	21	4
Weapons (WEPS)	14	3

Equipment and instruments

Sleep was objectively assessed using two actigraphs, the Motionlogger Watch (Ambulatory Monitoring, Inc.- AMI; Ardsley, NY), and the Philips Respironics Spectrum actiwatch (PR) actiwatch. Data for both devices were collected in 1-minute epochs. AMI data (collected in the Zero-Crossing Mode) were scored using Action W version 2.7.2155 software. The Cole-Kripke algorithm with rescoring rules was used. Sleep statistics criteria for long sleep and long wake episodes was 5 minutes. The sleep latency criterion was no more than 1 minute wake in 20 minutes period (all values are default for this software). PR data were scored using Actiware software version 6.0.0 (Phillips Respironics, Bend, OR). The medium sensitivity threshold (40 counts per epoch) was used with 10 immobile minutes the criterion for sleep onset and sleep end (all values are default for this software). As expected from previous research (Meltzer, Walsh, Traylor, & Westin, 2012), a comparison between AMI and PR actiwatches in terms of daily There were no significant differences in rest and daily total sleep time (TST) for the two types of actigraphs (Wilcoxon Rank Sum test, for all differences p>0.20). Hence, the work presented herein will use the combined dataset with data from both devices.

All participants completed a daily activity log throughout the study, documenting their daily routine. The logs covered a 24-hour period in 30-minute intervals. The Epworth Sleepiness Scale (ESS) was used to assess average daytime sleepiness (Johns, 1991). Responses are summed to the total score. A sum of 10 or more reflects above normal daytime sleepiness and need for further evaluation (Johns, 1992). The Morningness-Eveningness Scale (Horne & Östberg, 1976) was used to assess participants' chronotype, an attribute of human beings related to whether they have a preference for waking earlier or later in the day. The scale includes 19 multiple-choice questions. Scores range from 16 to 86, with scores less than 42 corresponding to evening chronotypes and scores higher than 58 indicating morning chronotypes.

Psychomotor vigilance task (PVT) performance data were collected using a version of the PVT, which was conveniently integrated into the AMI Motionloggers. The PVT involves a simple reaction time test where participants are required to press a response button when the stimulus appears on the screen. Operational demands prevented the use of the original 10-minute PVT version in this study. Therefore, we used a 3-minute version of PVT with 2 – 10 seconds interstimulus interval. On the screen of the actiwatch, a red backlight appeared for one second and the letters "PUSH" were used as visual stimuli; the response time was then displayed to the participant in milliseconds.

Procedures

This quasi-experimental study was conducted at sea from December 3 to December 18, 2012. The study protocol was approved by the NPS Institutional Review Board and informed consent was obtained from all participants at the beginning of the study. Crewmembers had been working the same schedule for several weeks before the data collection commenced. Each sailor wore an actigraph, completed a daily sleep and activity log, and performed a 3-minute psychomotor vigilance test before and after standing watch. They also completed the pre- and post-test questionnaires.

Analysis

This analysis is based on the data obtained during the underway data collection period from December 4th to 14th, 2012. The primary source of sleep data was from the actigraphic recordings from the individual participants. However, since there were occasional gaps and discrepancies in the actigraphic recordings, we also evaluated the self-reported activity logs, comparing the actigraphy data with these logs. The sleep logs also assisted in the determination of start and end time of the sleep intervals. Using the log data, we adjusted the start and end times of sleep episodes in the actigraphy data.

PVT data were analyzed based on the metrics of Basner and Dinges (2011) for individuals with chronic sleep deprivation. Specifically, a PVT response was regarded as valid if RT was ≥ 100 ms. Responses without a stimulus or RTs < 100 ms were identified as false starts. Lapses were defined as RTs ≥ 500 ms. All PVT responses were aggregated per participant. Detailed information about the cleaning and data reduction procedures are included elsewhere (Shattuck & Matsangas, 2014).

Statistical analysis was conducted with a statistical software package (JMP Pro 10; SAS Institute; Cary, NC). Data normality was assessed with the Shapiro-Wilk test. Given that our data violated the assumption of normality, statistical analysis was based on non-parametric methods. Results are presented as mean (M) ± standard deviation (SD) or median (MD) as appropriately needed. Significance level was set at $p < 0.05$. Non-parametric methods were used;

Wilcoxon Rank Sum test, and for multiple comparisons the Dunn method for joint ranks accounting for family-wise error. Correlation analysis was performed using Spearman's rho.

Initially, a descriptive analysis of the data was performed focusing on sleep intervals and daily rest/sleep amounts, followed by an analysis by participant. Then, the effect of department was investigated, focusing on the AIR, CS, OPS, ENG, and WEPS departments. To assess the effect of ship department on crew rest, sleep and psychomotor vigilance performance, the independent variable was ship department. Dependent variables were the daily rest and sleep amount, the number of sleep episodes per day, and PVT performance. The latter was assessed in terms of mean reaction time (RT), mean response speed (1/RT), fastest 10% RT (i.e., 10th percentile of RT), slowest 10% of 1/RT (i.e., 10th percentile of 1/RT), percentage of 500ms and 355ms lapses, percentage of lapses and false starts, and percentage of false starts (FS).

RESULTS

The average ESS score was 10.6±3.82 ranging from 2 to 22. ESS scores suggested that 45 participants (43%) demonstrate considerable daytime sleepiness (ESS score > 10). The average ME score was 48.4±7.32. Eight participants (8.60%) were moderately morning types, 14 (15.1%) were moderately evening types, and 71 (76.3%) were in "Neither type."

The average rest episode was 4.03±2.77 hours, whereas the average sleep episode was 3.63±2.57 hours. Eighty-two episodes (4%) occurred within watch periods, with an average rest duration of 0.80±0.45 hours, and an average sleep duration of 0.40±0.50 hours. During the 11-day data collection period, each participant experienced on average 19.9±6.59 sleep episodes (MD=20), ranging from 9 to 44. Therefore, the average number of sleep episodes per day was 1.70±0.548 (MD=1.67) ranging from 0.909 to 3.67. Next, we assessed the average daily rest and sleep amount by participant. Table 2 shows these results. It is notable that 25% of the participants received on average less than 6 hours of sleep per night. On average, participants were sleep deprived by approximately 1.5 hours daily. In the 11-day period of this study, the crewmembers accumulated approximately 16 hours of sleep deficit.

Table 2: Daily rest and sleep duration by participant, in hours

	M	SD	MD	Min	Max
Rest	7.33	0.857	7.27	5.51	9.65
Sleep	6.64	0.852	6.69	4.81	8.78

Next, we focused on the effect of department on daily rest, sleep and fragmentation index. Results show that the AIR department has the largest daily rest and sleep duration, followed by the CS and WEPS departments. The least rest and sleep are received by crewmembers in the ENG and OPS departments. A multiple comparison among departments showed that the ENG department had less rest (Z=2.94, p=0.032) and sleep (Z=3.0, p=0.027) than the AIR department. Furthermore, the OPS department had less rest (Z=3.56, p=0.004) and sleep (Z=2.91, p=0.037) than the AIR department. The same pattern is identified in the number of sleep episodes per day; crewmembers in the OPS department received their sleep in more episodes (split sleep) than their peers in the AIR (Z=4.13, p<0.001), and WEPS (Z=2.55, p=0.10) departments. The number of sleep episodes of the ENG department was also larger than the AIR (Z=4.0, p<0.001). Table 3 shows the durations of daily rest, daily sleep, and number of sleep episodes per day by department. These findings are further depicted in Figures 1 and 2.

Table 3: Daily rest/sleep duration (hours) and sleep episodes per day

Department	Daily Rest M ± SD	Daily Sleep M ± SD	Sleep episodes per day
AIR	8.08±0.89	7.30±0.87	1.28±0.44
CS	7.50±0.81	6.79±0.82	1.63±0.52
WEPS	7.26±0.58	6.64±0.71	1.52±0.34
ENG	7.15±0.73 [1]	6.40±0.73 [1]	1.90±0.49 [1]
OPS	6.94±0.89 [1]	6.35±0.89 [1]	2.05±0.61 [1]

Multiple comparisons with Dunn's method for joint ranks
[1] Different from AIR department

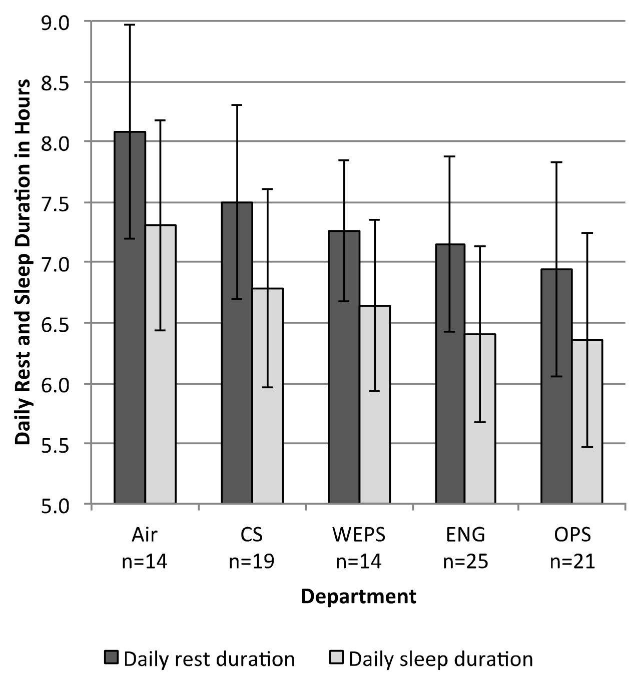

Figure 1. Daily rest and sleep by department

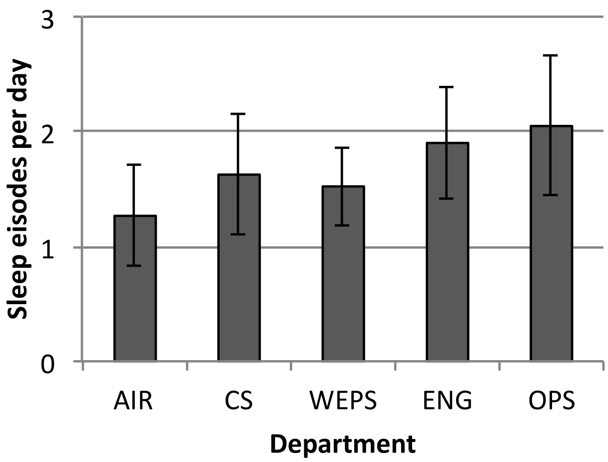

Figure 2. Sleep episodes per day by department

To assess the extent to which napping while on watch contributes to daily rest and sleep amount, we focused on the 22 (21.6%) participants who napped during watch periods. Four participants were in the CS department (21.1%), 10 in ENG (40%), 6 in OPS (28.6%), and 2 in WEPS (14.3%). For these participants, napping increased their daily rest amount on average by 16.8 minutes (4.4%), and the sleep amount by 13.8 minutes (4%). The corresponding naps occurred predominantly (n=48, 59%) from midnight to 0800, whereas 22 (27%) occurred from 0800 till 1600, and 12 (15%) from 1600 to midnight. Correlation analysis showed that participants who experienced less daily sleep during non-watch periods had longer naps during watch periods (rho= -0.412, p=0.057). Although the number of participants does not allow for an analytical comparison, the increase in daily sleep because of napping during watches was more pronounced in the participants in the OPS department, amounting to approximately 9%.

Due to large variability in PVT performance, analysis of PVT metrics failed to identify significant differences between departments ($p > 0.20$). However, the pattern of results agrees with our findings from the sleep analysis. The worst PVT performance is found in the ENG and OPS department. In contrast, the AIR department has the best PVT performance followed by the CS and WEPS. These results are shown in Table 3.

Table 3. PVT metrics by department

PVT Metric	AIR	CS	WEPS	ENG	OPS
Mean RT, [ms]	269+67	314+73	310+47	342+60	327+104
Mean 1/RT	4.52+0.75	4.03+0.61	4.0+0.33	3.89+0.43	3.87+0.71
Fastest 10% RT, [ms]	179+29	193+30	192+16	196+23	205+39
Slowest 10% 1/RT	2.99+0.6	2.48+0.62	2.55+0.41	2.27+0.21	2.45+0.62
False Starts (FS), %	2.29+2.0	1.87+1.34	1.46+0.94	2.33+2.0	1.82+1.54
Lapses 500ms	3.75+3.11	7.47+5.26	6.02+3.19	8.59+3.15	8.19+7.52
Lapses 355ms	9.78+7.60	16.3+11.6	14.0+5.39	17.8+5.98	19.5+14.7
Lapses 500ms+FS, %	6.03+4.37	9.34+5.68	7.48+3.85	10.9+7.30	10.0+7.31
Lapses 355ms+FS, %	12.1+7.73	18.2+11.7	15.4+5.76	20.1+6.03	21.4+14.3

Assessment of departments

Based on the previous results, we compared departments based on their ranks in the following factors: daily rest duration, daily sleep duration, napping during watch, sleep fragmentation, and PVT performance. The best rank is considered the first (i.e., more sleep, more rest, fewer sleep episodes per day). Napping during watch is regarded negatively; thus rank 1 refers to the department with the least napping, whereas the lowest rank denotes the department with the largest percentage of napping individuals. Although the PVT performance data provide interesting trends, no conclusive results can be drawn regarding the effect of department on psychomotor vigilance performance. This comparison is based on AIR, WEPS, CS, ENG, OPS departments. The ranks given for each factor denote the general pattern of differences between departments including the inferential statistics already presented (Table 4). The overall ranking suggests that, compared to the other departments, crewmembers in the Engineering and the Operation departments have the worst challenges in terms of sleep amount and quality.

Table 4: Rank comparison between departments

Watch Schedule	AIR	CS	ENG	OPS	WEPS
Daily Rest duration	1	2	4	5	3
Daily Sleep duration	1	2	4	5	3
Napping in watches	1	3	5	4	2
Sleep episodes per day	1	3	4	5	2
PVT performance	Inconclusive				
Overall	1	2	4	5	3

DISCUSSION

Overall, our results show that rest and sleep opportunities are significantly affected by the department to which the crewmember belongs. In our sample, the Operations Department has the worst combination of sleep hygiene conditions, i.e. reduced and fragmented sleep. This combination of poor sleep patterns is closely followed by the Engineering Department.

Except for the Air Department, results show that 22% of the participants occasionally napped during their night watch. However, the increase in daily sleep due to napping was more pronounced in the OPS department, approximately 9% for both rest and sleep compared to approximately 4% for the rest of the departments. These findings suggest that participants in the Operations Department experienced the most pronounced need for napping, probably because they received less sleep compared to other departments. These findings agree with earlier research showing that involuntary sleep occurs on night shifts, with 7% to 20% of the personnel reporting falling asleep during night work (Åkerstedt et al., 2002; Åkerstedt & Wright, 2009). Yet, whether a specific watch location affords napping depends on the duties assigned. Therefore, the need for napping may be evident also in other departments but it is not feasible to nap because of the duties assigned to the corresponding personnel. We postulate that the issue of napping during watch is interesting because it may show an actual need to sleep. That is, the sleepy individuals use every possible opportunity to compensate for some of the sleep debt accumulated. Future efforts should investigate whether napping during watch is a viable operational measure to ameliorate sleep deprivation, in conjunction with the specific duties of each watch location. That being said, we should note that the identification of naps was based solely on actigraphy activity patterns. None of the activity logs reported a nap within a watch period, probably due to the controversial nature of such a statement for a military member. Yet our approach for identifying periods of low activity as naps was conservative; we identified naps only when the activity change was clearly distinct.

In conclusion, this study shows not only the extent of sleep deprivation at sea, but it also provides evidence that the department to which a crewmember belongs is a factor to be taken into account when assessing performance at sea. In our sample, results demonstrate that the two departments mostly affected are the Operations and the Engineering. Both of these groups have critical duties while underway, yet they suffer the most. Future efforts should further quantify this phenomenon, and address methods to ameliorate the problem.

Study limitations

This study has a number of limitations. First, the study was a naturalistic observation rather than an experiment. In addition, all participants were volunteers performing their normal daily duties; there was no randomization in the assignment to watchstanding schedule. Hence, the study is quasi-experimental in nature. Furthermore, watch schedule and department in our sample are confounded. For example, all participants in the operations department were on the 6/6 watchstanding schedule. This fact could have biased some of the results observed. Finally, some groups in this analysis had fewer participants than had been originally planned, resulting in unequal cell sizes and making statistical analysis challenging. It should also be noted that workload on a ship, and hence afforded sleep, depends on the mission the ship has. For this reason, analysis of afforded sleep must incorporate mission type as a confounding factor. Future studies should assess the department effect in multiple mission types.

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