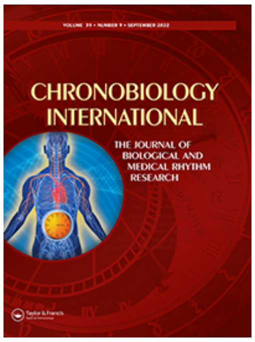

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Effects of operational assessment of the 4:4 and 4:4/6:6 watch systems on sleepiness, fatigue, and stress responses during patrolling on a navy missile patrol boat

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ABSTRACT

The operation of naval vessels involves watchkeeping 24 h per day, which is globally carried out by a variety of different watch systems. In this study, the rotating 4:4 and fixed 4:4/6:6 two-section watch systems were compared in terms of sleepiness, fatigue, and stress responses. The data collection took place on a Finnish Defence Forces' (FDF) Navy missile patrol boat with 15 crew members serving as study participants. The data collection periods lasted two separate weeks (7 days, 6 nights) with the different watch systems. The subjective sleepiness of the participants was assessed before and after every watch using the Karolinska Sleepiness Scale (KSS). Stress responses were assessed daily by the recorded levels of salivary alpha-amylase (sAA), cortisol (sCor), immunoglobulin A (sIgA), and dehydroepiandrosterone (sDHEA). The participants' sustained attention, inhibitory control, and working memory were assessed daily by cognitive tests (SART, N-Back). The heart rate variability (HRV) during an orthostatic test was used as an additional daily marker to assess the amount of psychological stress of the participants. In this study, the difference regarding sleepiness and fatigue between the study weeks was most visible in the subjective KSS, which clearly favored the 4:4/6:6 system. The results of sAA and sIgA also suggested that the subjects were psychologically less stressed during the study week with the 4:4/6:6 watch system. Cognitive test results (SART, N-Back) indicated that there were overall no significant differences in the subjects' sustained attention, inhibitory control, or working memory during the study weeks or between the study weeks. The results of the HRV data during the daily orthostatic tests were inconclusive but there was some indication that the subjects were less stressed during the study week with the 4:4/6:6 watch system. In conclusion, the present study indicates that in navy surface operations: working with the fixed 4:4/6:6 watch system causes less sleepiness, fatigue, and psychological stress than working with the rotating 4:4 watch system. The study result is well in line with previous research regarding watch systems.

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Shiftwork; watchkeeping; watch systems; sleep; sleepiness; fatigue; stress; navy

Introduction

In surface navy operations, continuous watchkeeping is needed to be able to operate 24 h per day. On the other hand, continuous watchkeeping together with sleepiness can lead to fatigue (Akerstedt 2007). Excessive fatigue has subsequently the potential to reduce vigilance and other aspects of cognitive performance (Goel et al. 2009). Fatigue is also a major factor in maritime safety because excessive fatigue is estimated to be associated with 25% of maritime accidents (Raby and McCallum 1997).

For watch keeping in the navy, numerous watch systems are available and these require different numbers of watch sections. The number of watch sections refers basically to the number of working groups needed to maintain the watch keeping system. In a naval environment, there are usually two or three watch sections. Watch systems that consist of three watch sections are usually considered preferable in terms of sleepiness and fatigue than systems which consist of only two watch sections (Harma et al. 2008; Lutzhoft et al. 2010; Paul and Love 2021). Generally, the more watch sections a watch system has the more manning power is needed to sustain it. In terms of watch systems that consist of two watch sections, the 4:4/8:8 watch system has been considered most preferable regarding sleepiness and fatigue (Paul and Love 2021; Størkersen et al. 2011). The two sections 4:4/8:8 watch system consists of 4

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h daytime watches and rest periods and one 8 h night-time watch and rest period. One 8 h rest period once in 24 hours seems to provide the opportunity for a sufficient daily continuous sleep period. Nevertheless, The two-section 4:4/8:8 watch system is not suitable for all conditions. Surface navy operations in the challenging, shallow, and rambling archipelago of Finland demand continuous high alertness. Therefore, 8 h work periods, especially, at night time and thus the two-section 4:4/8:8 watch system are generally considered unsuitable for naval operations along the Finnish coast. There is a lack of knowledge concerning other more suitable two-section watch systems for these conditions. Thus, the aim of this descriptive study was to compare the two-section 4:4 and 4:4/6:6 watch systems in terms of sleepiness, fatigue, and stress responses.

Methods

Participants

Fifteen healthy FDF Navy soldiers (n = 12) and conscripts (n = 3) took part in the study. The participants were recruited and served in the same FDF Navy missile patrol boat where the data collection took place. They participated voluntarily and gave their informed consent for the study, and they did not receive any financial reward for their participation in the study. The participants were instructed to maintain regular sleep-wake schedules and avoid sleep deprivation for 3 days preceding the study weeks. All the participants also reported the approximation of the mean duration of their sleep on the last 3 days preceding the study weeks and the actual duration of sleep on the last day preceding the study weeks. A more detailed description of the study participants is shown in Table 1. The study is a part of a research project approved by the Ethical Committee of Tampere University Hospital (R18166/2018). Research permission was granted from the Finnish Defence Forces' Defence Command (AO22851, 18.12.2018)

Table 1. Description of the study participants.

	n	Range	Mean
Age (y)	15	19–45	29.1
Height (m)	14	1.65–1.87	1.80
Body mass (kg)	14	62.8–102.1	83.6
BMI (kg/m2)	14	19.8–32.0	26.0
Before study week with 4:4 watch system			
Sleep/day, last 3 days (h)	14	5.5–8.0	7.0
Sleep/day, last 1 day (h)	14	7.9–9.0	7.6
Before study week with 4:4/6:6 watch system			
Sleep/day, last 3 days (h)	14	6.0–8.75	7.5
Sleep/day, last 1 day (h)	14	5.0–10.0	7.0

Study design

The data collection took place on a Finnish Defence Forces' (FDF) Navy missile patrol boat. The data collection periods lasted 2 weeks in total: the first week (7 days, 6 nights) with the 4:4 watch system and then another week (7 days, 6 nights) with the 4:4/6:6 watch system. During study weeks all data collection was conducted during the rest time of the crew. Same participants took part in both data collection periods, and there was a 16-day timespan between the study weeks to ensure that the participants had enough time to recover from the first data collection period.

The studied 4:4 watch system was a rotating system containing two daily 2 h half watches at 16:00–18:00 h and 18:00–20:00 h. The studied 4:4/6:6 watch system was a fixed system containing the same two daily half watches at 16:00–18:00 h and 18:00–20:00 h. The main difference between the studied 4:4 and 4:4/6:6 systems in addition to the rotation were two daily 6 h watches at 20:00–02:00 h and 02:00–08:00 h in the 4:4/6:6 system. More detailed structures of the studied watch systems are shown in Figure 1.

During the first study week (4:4 watch system), the vessel's duty was to monitor and secure Finland's territorial integrity. During the second study week (4:4/6:6 watch system), the vessel took part in a national naval exercise. In both weeks, standing watch duties contained a variety of tasks, which were essential to the operation of the vessel. However, each participant had the same tasks on both data collection periods. The standing watch duties did not require any significant physical effort. There were no major differences in wind conditions between the study weeks. During the first study week, the mean wind speed was 5.6 m/s (range 0–12 m/s) and during the second study week, it was 7.4 m/s (range 2–12 m/s). There were also no major differences in the sea state between the study weeks in the cover of dense archipelago.

The Karolinska Sleepiness Scale (KSS) value was collected to the personal sleep diary of the participants before and after every watch to assess the subjective sleepiness. Once a day at 16:00 h or 18:00 h depending on the watch schedule, daily saliva samples were collected in the canteen of the vessel to assess the objective level of mental stress from salivary alfa-amylase (sAA), cortisol (sCor), immunoglobulin A (sIgA) and dehydroepiandrosterone (sDHEA). After collection of the saliva samples, an orthostatic test (5 min supine, 5 min standing) was performed in the cabin of the participants following the execution of cognitive tests (SART, N-Back). As an additional marker to assess the amount of mental stress, the heart rate variability (HRV) was recorded for 24 h on days 1–3 a

4:4 watch system (rotating)					
		Work group 1		Work group 2	
Time	Duration	Day 1	Day 2	Day 1	Day 2
08:00 - 12:00	4 h	Duty	Rest	Rest	Duty
12:00 - 16:00	4 h	Rest	Duty	Duty	Rest
16:00 - 18:00	2 h	Duty	Rest	Rest	Duty
18:00 - 20:00	2 h	Rest	Duty	Duty	Rest
20:00 - 24:00	4 h	Duty	Rest	Rest	Duty
24:00 - 04:00	4 h	Rest	Duty	Duty	Rest
04:00 - 08:00	4 h	Duty	Rest	Rest	Duty

b

4:4/6:6 watch system (fixed)					
		Work group 1		Work group 2	
Time	Duration	Day 1	Day 2	Day 1	Day 2
08:00 - 12:00	4 h	Duty	Duty	Rest	Rest
12:00 - 16:00	4 h	Rest	Rest	Duty	Duty
16:00 - 18:00	2 h	Duty	Duty	Rest	Rest
18:00 - 20:00	2 h	Rest	Rest	Duty	Duty
20:00 - 02:00	6 h	Duty	Duty	Rest	Rest
02:00 - 08:00	6 h	Rest	Rest	Duty	Duty

Figure 1. (a) Structures of the studied 4:4 watch system. (b) Structures of the studied 4:4/6:6 watch system.

and 5–7. In addition, the HRV was recorded during the orthostatic test. The HRV measurement device had to be reloaded once during each study week and on both weeks, the reloading took place on the fourth day of the week.

Tools

The Karolinska sleepiness scale (KSS)

The KSS is a valid subjective scale to assess sleepiness and may also represent as a feasible marker concerning fatigue (Akerstedt and Gillberg 1990; Akerstedt et al. 2004; Kaida et al. 2006; Lutzhoft et al. 2010). During the study weeks, the participants marked up a numeric KSS-value in individual sleep diaries as instructed. The scale consists of numeric values from 1 (extremely alert) to 9 (extremely sleepy–fighting sleep).

Saliva samples

In the current literature sAA, sCor, sIgA, and sDHEA are considered to be reasonable tools for assessing the amount of psychological stress (Strahler et al. 2010; Hellhammer et al. 2009; Afrisham et al. 2016; Izawa et al. 2008). In this study, saliva samples were collected daily using the Salivette® sampling device. The participants placed a swab in the mouth, chewing it for 60 s to stimulate salivation and returned the swab with absorbed saliva back to the Salivette® device. During the study weeks, saliva samples were contained in a freezer before further analysis. To obtain reliable results, the participants were instructed to avoid physical exercise for 3 h or eating or brushing their teeth for 1 h before taking the saliva sample. They also did not use any cortisol medication during these data collection periods.

After thawing, the samples were centrifuged (Megafire 1.0 R Heraeus, DJB Lab Care, City of Germany, DJB Labcare Ltd, Buckinghamshire, UK) at 2000 × g for 10 min for the analysis. Saliva concentrations of cortisol (sCOR) and dehydroepiandrosterone (sDHEA) were analyzed with Siemens Immulite 2000 XPI (Siemens Healthcare, Malvern, PA, USA) using chemiluminescent enzyme immunoassay kits, while alpha-amylase (sAA), immunoglobulin A (sIgA) were analyzed by Konelab 20XTi (Thermo Fisher Scientific, Vantaa, Finland) using the enzyme photometric measurement method. The sensitivity and interassay coefficients of variance for these assays were 10.9 nmol/l and 6.02% for sCOR, 0.08 g/L and 4.35% for sDHEA, 4 U/L and 6.32% for sAA 5 μg·mL−1, and 1.2 pg/mL and 1.56% for sIgA.

Orthostatic test

An orthostatic test was performed daily because it was used as a measurement point for the heart rate variability (HRV) measurements. The execution of the orthostatic test was performed daily for both watch sections so that all subjects on the same watch section completed the test simultaneously. Instructions how to perform the orthostatic test were announced by the vessel's on-board communication system. To obtain reliable results, the participants were instructed to avoid any other activity during the orthostatic test.

Cognitive tests

Cognitive tests (SART, N-Back) were conducted to assess the participants' cognitive performance. The Sustained Attention to Response Task (SART) is a measure developed to evaluate sustained attention and inhibitory control (Robertson et al. 1997). The n-back task (N-Back) is a continuous performance task that is considered useful for experimental research in working memory and is also considered to predict inter-individual differences in fluid intelligence (Jaeggi et al. 2010). During the study weeks, the participants performed the cognitive tests with laptop computers using the index finger of the dominant hand. To obtain reliable results, laptop computers were situated on tables, an unused new keyboard was attached to every computer and the participants performed the tests using the same keyboard and computer in both data collection periods. Completing the SART required approximately 5 min and the test consisted of numbers 1–9 appearing 225 times in random order. The participants attempted to respond to the appearance of each number by pressing a button on the keyboard, except when the number 3 appeared, which happened 25 times during the test. Completing the N-Back test required approximately 10 min and the test consisted of appearing letters. The participants attempted to respond to each letter that appeared instructed N items ago by pressing a button on the keyboard. In this study, the N-Back test was modified so that it consisted only of trials N = 0, N = 1 and N = 2. Trial N = 3 was left out of the N-Back in this study to shorten the duration of the test.

Heart rate variability (HRV)

HRV is characterized as the fluctuation of the length of hearth beat intervals and can be used to indirectly study the changes in the activity of the autonomic nervous system (ANS). Current neurobiological evidence supports the use of HRV as an objective marker to assess psychological stress (Kim et al. 2018). In this study, the HRV was recorded using the Bodyguard 2 device (Firstbeat Technologies Ltd., Jyväskylä, Finland) which recorded R to R waves measures at a sampling frequency of 1000 Hz. The HRV was assessed during a daily orthostatic test (5 min supine, 5 min standing). To obtain a steady signal and reliable time- and frequency-domain parameters, there was a 1-min baseline recording in supine and standing positions so that in both positions only the last 4 min of HRV were used for analysis (Bourdillon et al. 2017). This daily short-term (4 min supine + 4 min standing) HRV was analyzed using the Kubios HRV Standard program (version 3.4.3, Kubios Ltd., Kuopio, Finland).

Three time-domain measures and five frequency-domain measures were utilized. The time-domain measures were the mean heart rate (HRmean) (bpm), standard deviation of NN intervals (SDNN) (ms), and the root mean square of successive RR interval differences (RMSSD) (ms). The frequency-domain measures were the absolute total power (TP) (ms2), absolute power of the very low-frequency band (VLF) (0.003–0.04 Hz) (ms2), absolute power of the low-frequency band (LF) (0.05–0.15 Hz) (ms2), absolute power of the high-frequency band (HF) (0.15–0.40 Hz) (ms2), and the ratio of LF to HF power (LF/HF).

Statistical analysis

A statistical analysis was performed using the SPSS statistical software (SPSS version 27.0.1.0; SPSS Inc., Chicago, IL). A Shapiro–Wilk test was used to assess the normal distribution of the data. Prior to the statistical analysis transformations were used for non-normally distributed variables. Log-transformations were used with the saliva sample variables (sAA, sCor, sIgA, and sDHEA) and with some of the HRV variables (SDNN, RMSSD, TP, VLF, LF, HF, and LF/HF). A 1/x-transformation was used with one SART variable

(Mean RT) and an x2-transformation was used with another SART variable (Errors). Appropriate transformations were not found for the N-Back variables (Total hits, Errors) and a nonparametric test was used. Comparisons of normally distributed and transformed variables between the study weeks of 4:4 and 4:4/6:6 watch systems were performed using a linear mixed model to account for the repeated measurements of the participants. A linear mixed model was also used to evaluate the mean changes day by day from the first day of each watch system. To evaluate the baseline values at the beginning of the data collection periods, a paired samples T-test was used. Variables in the N-Back were analyzed using a nonparametric Wilcoxon signed rank test. P-values lower than 0.05 were considered statistically significant.

Results

The Karolinska sleepiness scale (KSS)

The KSS was overall significantly lower during the second data collection period with the 4:4/6:6 watch system. There were statistically no significant differences between the first baseline values (1. day at 08:00) of the data collection periods regarding KSS. The mean KSS level concerning all data collection points was 4.2 during the 4:4 watch system and 3.7 during the 4:4/6:6 watch system ($p < .001$) (Figure 2). The highest KSS values were observed at night at 04:00 h or 02:00 h depending on the watch system. The mean KSS score for data collection points at 04:00 h vs. 02:00 h was 5.1 during the 4:4 watch system and 4.5 during the 4:4/6:6 watch system ($p < .001$) (Figure 2). There was also a significant difference in the KSS score at 16:00–18:00 h when all other data collections were performed. The mean level of the KSS at 16:00–18:00 h was 3.8 during the 4:4 watch system and 3.4 during the 4:4/6:6 watch system ($p = .046$) (Figure 3). The daily mean level of the KSS at 16:00–18:00 h compared to the first day of the study week was significantly higher on the last 4 days during the 4:4 watch system and last 3 days during the 4:4/6:6 watch system (Figure 3).

Saliva samples

Results of the mean level of sAA, sCor, sIgA, and sDHEA during study weeks are shown in Table 2. The mean level of salivary alpha-amylase was significantly lower during the data collection period with the 4:4/6:6 watch system ($p = .025$). In contrast, the mean level of salivary IgA was significantly higher ($p = .003$), respectively. Between the study weeks, no significant differences in the mean levels of sCor or sDHEA were observed. Neither any statistically significant differences in the analyzed saliva biomarkers between the baseline values (1. day values) were noticed.

Cognitive tests

Concerning cognitive tests (SART, N-Back), there were statistically no significant differences between the study weeks. Neither were there any statistically significant differences between the baseline values (1. day values) of the data collection periods. Regarding SART, the mean reaction times for the correct response trials and

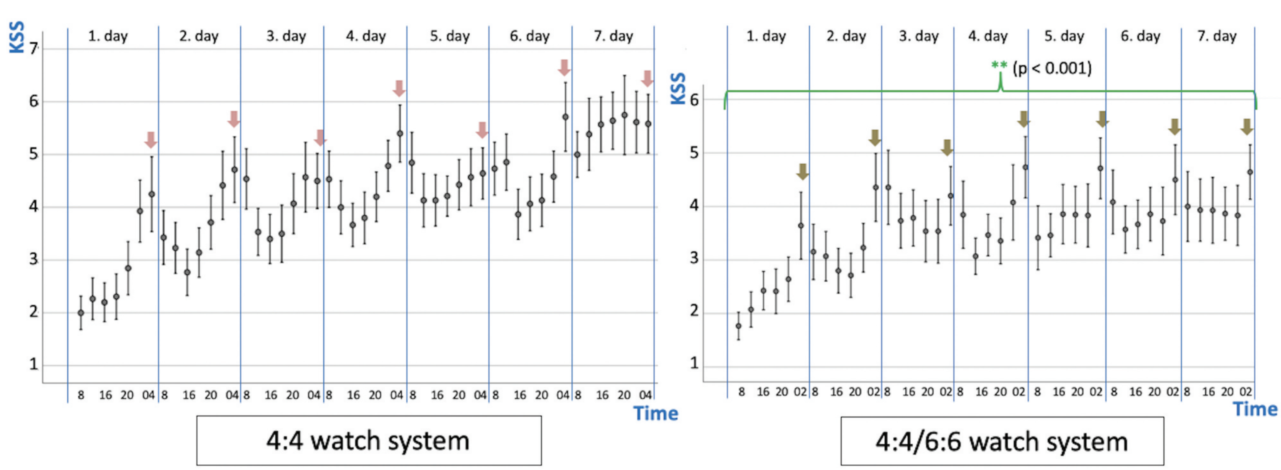

Figure 2. The mean Karolinska sleepiness scale (KSS) level for all data collection points during the study weeks.
Means and standard errors are shown. Comparisons were performed using a linear mixed model. **Significant difference in the mean KSS level concerning all data collection points of the compared 4:4 and 4:4/6:6 watch systems. Arrows point out the high night-time levels of KSS (at 04.00 h during 4:4 system and at 02.00 h during 4:4/6:6 system). Missing values for all data collection points: 7.1% (4:4 system) and 9.4% (4:4/6:6 system). Missing values for night-time data collection points: 9.5% (4:4 system) and 4.8% (4:4/6:6 system).

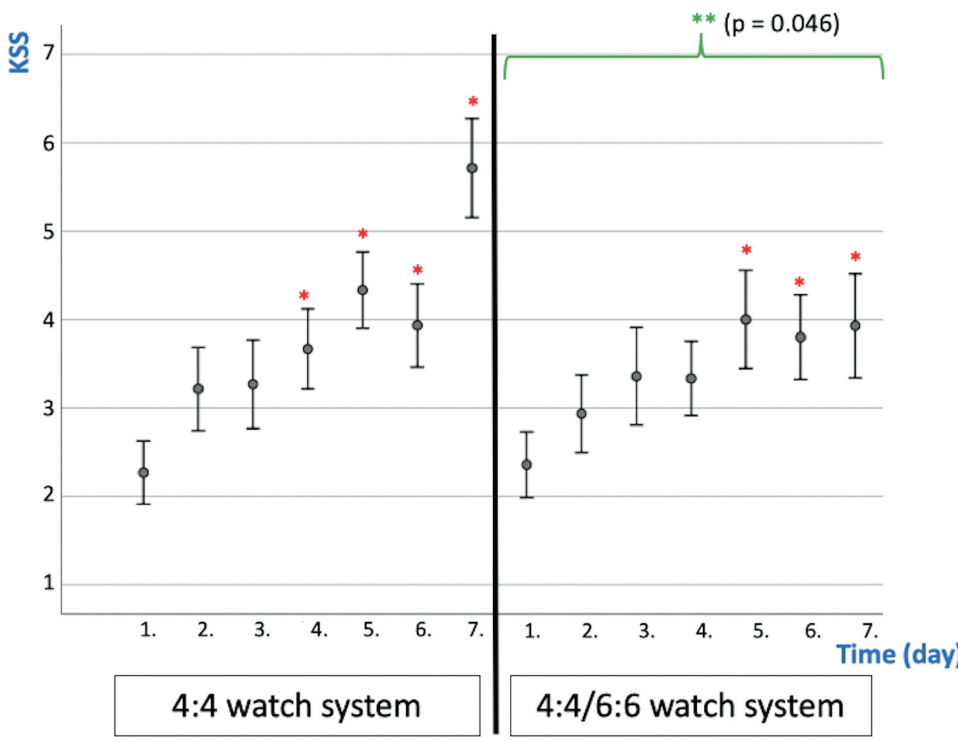

Figure 3. The mean the Karolinska sleepiness scale (KSS) level concerning data collection points at 16.00–18.00 h during the study weeks. Means and standard errors are shown. Comparisons were performed using a linear mixed model. ** Significant difference in the mean KSS level concerning all data collection points at 16.00–18.00 h of the compared 4:4 and 4:4/6:6 watch systems. * Significant difference in the daily KSS level at 16.00–18.00 h compared to the result of first day of the study week. Missing values for all data collection points at 16.00–18.00 h: 1.9% (4:4 system) and 3.8% (4:4/6:6 system).

Table 2. Mean (± SD), medians, and interquartile ranges (IQR) of salivary alpha-amylase (sAA), cortisol (sCor), immunoglobulin A (sIgA), and dehydroepiandosterone (sDHEA) during the study weeks.

	4:4 watch system		4:4/6:6 watch system		
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	p-value
sAA (U/ml)	106 ± 86	74 (89)	95 ± 74	73 (62)	0.025*
sCor (mmol/l)	11 ± 10	8 (6)	11 ± 16	7 (6)	0.776
sIgA (mg/l)	92 ± 44	84 (40)	110 ± 81	83 (59)	0.003*
sDHEA (ng/ml)	2.4 ± 2.3	1.3 (2.4)	3.2 ± 4.0	2.0 (3.1)	0.134

Prior to the statistical analyses a log-transformation was used with all variables due to a skewed distribution. Comparisons were made using a linear mixed model. * Significant difference in the mean level of the variable between 4:4 and 4:4/6:6 watch systems. Missing values concerning saliva samples: 1.0% (4:4 system) and 0.0% (4:4/6:6 system).

commission errors were assessed. In terms of the N-Back scores, the number of correct responses and commission errors were assessed. More detailed results of the cognitive test are displayed in Table 3.

Table 3. Mean (± SD), medians, and interquartile ranges (IQR) of the cognitive test results during the study weeks.

	4:4 watch system		4:4/6:6 watch system		
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	p-value
SART					
Mean RT (ms)	353 ± 108	321 (108)	358 ± 99	324 (94)	0.213
Errors (no.)	16 ± 7	18 (12)	16 ± 7	16 (9)	0.116
N-Back					
Total hits (no.)	28 ± 3	29 (2)	27 ± 5	29 (5)	0.233
Errors (no.)	1.6 ± 0.8	1.3 (1.0)	1.5 ± 1.0	1.1 (1.6)	0.582

For the Sustained Attention to Response Task (SART) the mean RT is defined as the mean reaction time in the correct response trials. Errors are defined as the no. of commission errors (in other words no-go trial responses). For the n-back task (N-Back) the total hits are defined as the no. of correct responses. Errors are defined as the no. of commission errors (in other words responses to nontargets). Prior to the statistical analyses in SART, a 1/x-transformation was used with the mean RT, and an x^2-transformation was used with errors due to the skewed distribution. Comparisons regarding the SART variables were performed with a linear mixed model. Variables in the N-Back results were analyzed using a nonparametric Wilcoxon signed rank test. Missing values concerning SART were 1.0% (4:4 system) and 0.0% (4:4/6:6 system). Missing values concerning N-Back were 6.7% (4:4 system) and 3.8% (4:4/6:6 system).

HRV during orthostatic test

Results of HRV in supine and standing positions are shown in Table 4. From the time-domain measures, the mean HRmean was significantly lower in both supine and standing positions during the data collection period with the 4:4/6:6 watch system. However, in the supine and standing position, the HRmean differed statistically significantly between the baseline values (1. day

Table 4. Mean (± SD), medians, and interquartile ranges (IQR) of the heart rate variability (HRV) in supine and standing positions during orthostatic tests in both study weeks.

Supine					
	4:4 watch system		4:4/6:6 watch system		
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	p-value
HRmean (bpm)	66 ± 11	66 (10)	64 ± 9	64 (12)	0.045*
SDNN (ms)	53 ± 25	48 (24)	50 ± 21	44 (24)	0.406
RMSSD (ms)	57 ± 33	49 (32)	58 ± 33	49 (33)	0.573
TP (ms^2)	3102 ± 3974	2008 (2251)	2689 ± 2945	1558 (2026)	0.525
VLF (ms^2)	126 ± 125	95 (119)	117 ± 136	75 (94)	0.150
LF (ms^2)	1572 ± 2983	817 (1330)	1248 ± 1233	756 (1076)	0.998
HF (ms^2)	1374 ± 1711	828 (1324)	1322 ± 1846	644 (921)	0.690
LF/HF (%)	1.90 ± 1.75	1.33 (2.18)	1.79 ± 1.89	1.30 (1.35)	0.808
Standing					
	4:4 watch system		4:4/6:6 watch system		
	Mean ± SD	Median (IQR)	Mean ± SD	Median (IQR)	p-value
HRmean (bpm)	82 ± 9	82 (11)	78 ± 7	78 (8)	< 0.001*
SDNN (ms)	46 ± 18	43 (24)	45 ± 14	45 (18)	0.345
RMSSD (ms)	31 ± 18	26 (21)	30 ± 12	28 (16)	0.516
TP (ms^2)	2211 ± 1832	1928 (2082)	2122 ± 1378	1656 (1699)	0.101
VLF (ms^2)	155 ± 135	110 (180)	154 ± 125	135 (112)	0.357
LF (ms^2)	1673 ± 1613	1169 (1419)	1647 ± 1197	1327 (1328)	0.045*
HF (ms^2)	383 ± 566	190 (411)	316 ± 334	186 (272)	0.610
LF/HF (%)	8.32 ± 7.33	6.53 (7.87)	9.16 ± 8.96	6.76 (8.54)	0.274

* Significant difference in the mean level of the variable between the 4:4 and 4:4/6:6 watch systems. Eight HRV measures were utilized. Three time-domain measures: mean heart rate (HRmean), standard deviation of NN intervals (SDNN) (ms), and root mean square of successive RR interval differences (RMSSD). Five frequency-domain measures: absolute total power (TP), absolute power of the very low-frequency band (VLF), absolute power of the low-frequency band (LF), absolute power of the high-frequency band (HF), and the ratio of LF to HF power (LF/HF). From the variables the HRmean was normally distributed. Prior to the statistical analyses a log-transformation was used with all other variables (SDNN, RMSSD, TP, VLF, LF, HF, LF/HF) due to a skewed distribution. Comparisons were performed using a mixed linear model. Missing values concerning HRV were 10.0% for the supine position and 11.1% for the standing position (4:4 system), 11.1% for the supine position and 11.1% for the standing position (4:4/6:6 system).

values). An analysis of other time-domain measures (SDNN, RMSSD) did not reveal any statistically significant differences between the study weeks.

From the frequency-domain measures, the mean LF value was significantly higher in the standing position during the data collection period with the 4:4/6:6 watch system. There were no statistically significant differences in the baseline (1. day values) for the LF values in the standing position. However, the baseline (1. day value) for the LF values in the supine position was statistically significantly higher on the data collection period with the 4:4/6:6 watch system. An analysis of the mean values of other frequency-domain measures (TP, VLF, HF, and LF/HF) did not reveal any statistically significant differences between the study weeks.

Discussion

The 4:4/6:6 watch system enables a 2 h longer daily continuous sleeping period than the 4:4 watch system, which could be beneficial in terms of sleepiness, fatigue, and stress responses. The studied 4:4/6:6 system was also a fixed system and in a previous study rotating shifts have been found to be more fatiguing than fixed watch schedules (Arulanandam and Tsing 2009). Previous research points out that rotating watch systems can cause interrupted sleep and disturb physiological rhythms (Colquhoun 1985; Colquhoun et al. 1968; Shattuck and Matsangas 2016).

In this study, the difference regarding sleepiness and fatigue between the study weeks was most visible in the subjective KSS, which clearly favored the 4:4/6:6 system. Previous studies regarding the effects of the time of watch have reported significant differences between night shifts (00:00–04:00 h/04:00–08:00 h) and day shifts in terms of sleepiness and fatigue (Colquhoun et al. 1987; Harma et al. 2008; Leung et al. 2006; Lutzhoft et al. 2010). Furthermore, in this study, the mean level of the subjects' sleepiness was clearly higher during night shifts compared to day shifts according to the KSS results. However, there was a significant difference also at night (04:00 h vs. 02:00 h) in the mean level of the KSS results in favor of the 4:4/6:6 system. Especially during longer working periods these kinds of differences in sleepiness between the watch systems could have considerable operational significance.

The present results of the sAA and sIgA tests suggest that the participants were psychologically less stressed during the data collection period with the 4:4/6:6 watch system. Previous literature points out that sAA increases as a response to psychological stress, and it can be implicated as an additional sympathetic stress marker in all age groups (Strahler et al. 2010). Some previous studies, investigating the link between the secretion of sIgA and psychological stress, have found that there is a significant reduction in levels of sIgA in conditions that generate psychological stress (Afrisham et al. 2016; Deinzer et al. 2000; Jemmott and Magloire 1988; Lowe et al. 2000). On the contrary, in this study, the mean sAA level was significantly lower and the mean sIgA level was significantly higher during the study week with the 4:4/6:6 watch system compared to the 4:4 system.

According to the cognitive test results (SART, N-Back), there was overall no significant difference in the participants' cognitive capacity during the study weeks or between the study weeks. Nevertheless, the level of difficulty of the cognitive tests seemed to be adequate, because the participants repeatedly made errors in both tests during the study weeks.

The HRV data during the daily orthostatic tests was inconclusive. The mean level of the HRmean was significantly lower during the study week with the 4:4/6:6 watch system but there was also a similar significant difference regarding the baseline values. The mean LF was significantly higher in the standing position during the study week with the 4:4/6:6 watch system, while no significant difference was observed in the baseline values for the standing position. This finding may suggest that the participants had less stress during the study week with the 4:4/6:6 watch system. A previous study assessing stress during an orthostatic test showed that higher incidence of stress symptoms was significantly associated with a lower HRV (Hynynen et al. 2011). On the other hand, a frequently reported factor regarding HRV and stress is low parasympathetic activity, which is characterized by a decrease in HF and increase in LF power (Kim et al. 2018). Nevertheless, there was no significant difference in HF during or between the study weeks in the present study. Although it has been discovered that in long term ambulatory recordings the LF power increases within sympathetic activity, this does not seem to happen in short term resting recordings (Axelrod et al. 1987; Shaffer et al. 2014). In short term resting recordings LF power increases by slower breathing and it is almost totally vagally mediated and therefore parasympathetic activity (Shaffer et al. 2014).

Strengths and limitations

This study contributes to the prior comparative studies investigating sleepiness and fatigue in different watch systems. The use of multiple measures makes it quite unique compared to previous studies and provides us more knowledge about the stress responses and the level of cognitive capacity during patrolling at sea using different watch systems.

As a limitation of the study, the assessment between the 4:4 and 4:4/6:6 watch system was only based on the participants who worked in one vessel. During the study weeks with these watch systems, it was impossible to achieve laboratory-like conditions. There were always minor variations, for example, in weather or in the operational status of the vessel between the study weeks. The vessel performed different missions during the two data collection periods, but there were no major differences in the operational tempo of the crew. There were minor differences in the duration of sleep of the participants before the study weeks. It still did not have any major or significant difference in the baseline values of the subjective KSS regarding sleepiness. During the study weeks, the amount of sleepiness was not high enough to affect to the results of the cognitive tests (SART, N-Back). Nevertheless, the level of difficulty of the cognitive tests seemed to be adequate, because the participants repeatedly made errors in both tests during the study weeks. For further research, additional studies which include larger samples representing more ship departments are needed.

Conclusion

The present study suggests that in surface navy operations working with the fixed 4:4/6:6 watch system causes less sleepiness, fatigue, and psychological stress than working with the rotating 4:4 watch system. The study results are well in line with previous literature in which it has commonly been found that one daily rest period of up to 8 h minimizes the development of sleepiness and fatigue in watch systems that consist of two watch sections (Paul and Love 2021; Størkersen et al. 2011). According to current literature, fixed watch schedules have also been found more recommendable in terms of sleepiness and fatigue than rotating watch systems (Arulanandam and Tsing 2009).

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References

Afrisham R, Aberomand M, Soliemanifar O, Kooti W, Ashtary-Larky D, Alamiri F, Najjar-Asl S, Khaneh-Keshi A, and Sadegh-Nejadi S. 2016. Levels of salivary immunoglobulin A under psychological stress and its relationship with rumination and five personality traits in medical students. Eur J Psychiat. [Accessed 2021 May 20]; 30: 41–53. http://scielo.isciii.es/scielo.php?script=sci_arttext&pid=S0213-61632016000100003&lng=en

Akerstedt T, Gillberg M. 1990. Subjective and objective sleepiness in the active individual. Int J Neurosci. 52:29–37. PMID: 2265922.

Akerstedt T, Knutsson A, Westerholm P, Theorell T, Alfredsson L, Kecklund G. 2004. Mental fatigue, work and sleep. J Psychosom Res. 57:427–433. PMID: 15581645.

Akerstedt T. 2007. Altered sleep/wake patterns and mental performance. Physiol Behav. 90:209–218. PMID: 17049569.

Arulanandam S, Tsing GC. 2009. Comparison of alertness levels in ship crew. An experiment on rotating versus fixed watch schedules. Int Marit Health. 60:6–9. PMID: 20205120.

Axelrod S, Lishner M, Oz O, Bernheim J, Ravid M. 1987. Spectral analysis of fluctuations in heart rate: An objective evaluation of autonomic nervous control in chronic renal failure. Nephron. 45:202–206. PMID: 3574569.

Bourdillon N, Schmitt L, Yazdani S, Vesin JM, Millet GP. 2017. Minimal window duration for accurate HRV recording in athletes. Front Neurosci. 11:456. PMID: 28848382.

Colquhoun WP, Blake MJ, Edwards RS. 1968. Experimental studies of shift-work I: A comparison of 'rotating' and 'stabilized' 4-hour shift systems. Ergonomics. 11:437–453. PMID: 5682413.

Colquhoun WP. 1985. Hours at work at sea: Watchkeeping schedules, circadian rhythms and efficiency. Ergonomics. 28:637–653. PMID: 4018013.

Colquhoun WP, Watson KJ, Gordon DS. 1987. A shipboard study of a four-crew rotating watchkeeping system. Ergonomics. 30:1341–1352. doi:10.1080/00140138708966028

Deinzer R, Kleineidam C, Stiller-Winkler R, Idel H, Bachg D. 2000. Prolonged reduction of salivary immunoglobulin A (sIgA) after a major academic exam. Int J Psychophysiol. 37:219–232. PMID: 10858568.

Goel N, Rao H, Durmer JS, Dinges DF. 2009. Neurocognitive consequences of sleep deprivation. Semin Neurol. 29:320–339. PMID: 19742409.

Harma M, Partinen M, Repo R, Sorsa M, Siivonen P. 2008. Effects of 6/6 and 4/8 watch systems on sleepiness among bridge officers. Chronobiol Int. 25:413–423. PMID: 18484371.

Hellhammer DH, Wüst S, Kudielka BM. 2009. Salivary cortisol as a biomarker in stress research. Psychoneuroendocrinology. 34:163–171. PMID: 19095358.

Hynynen E, Konttinen N, Kinnunen U, Kyröläinen H, Rusko H. 2011. The incidence of stress symptoms and heart rate variability during sleep and orthostatic test. Eur J Appl Physiol. 111:733–741. PMID: 20972879.

Izawa S, Sugaya N, Shirotsuki K, Yamada KC, Ogawa N, Ouchi Y, Nagano Y, Suzuki K, Nomura S. 2008. Salivary dehydroepiandrosterone secretion in response to acute psychosocial stress and its correlations with biological and psychological changes. Biol Psychol. 79:294–298. PMID: 18706968.

Jaeggi SM, Buschkuehl M, Perrig WJ, Meier B. 2010. The concurrent validity of the N-back task as a working memory measure. Memory. 18:394–412. PMID: 20408039.

Jemmott JB, Magloire K. 1988. Academic stress, social support, and secretory immunoglobulin A. J Pers Soc Psychol. 55:803. PMID: 3210147.

Kaida K, Takahashi M, Akerstedt T, Nakata A, Otsuka Y, Haratani T, Fukasawa K. 2006. Validation of the Karolinska sleepiness scale against performance and EEG variables. Clin Neurophysiol. 117:1574–1581. PMID: 16679057.

Kim HG, Cheon EJ, Bai DS, Lee YH, Koo BH. 2018. Stress and heart rate variability: a meta-analysis and review of the literature. Psychiatry Investig. 15:235–245. PMID: 29486547.

Leung AWS, Chan CCH, Jjm N, Wong PCC. 2006. Factors contributing to officers' fatigue in high-speed maritime craft operations. Appl Ergon. 37:565–576. PMID: 16368069.

Lowe G, Urquhart J, Greenman J, Lowe G. 2000. Academic stress and secretory immunoglobulin A. Psychol Rep. 87:721–722. PMID: 11191373.

Lutzhoft M, Dahlgren A, Kircher A, Thorslund B, and Gillberg M. (2010). Fatigue at sea in Swedish shipping: A field study. Am J Ind Med 2010. 53:733–740. doi:10.1002/ajim.20814 PMID: 20187001.

Paul MA, and Love RJ. 2021. Comparison of royal Canadian navy watchstanding schedules. Mil Med. 187(3-4):e418-e425. doi:10.1093/milmed/usab047 PMID: 33591312.

Raby M, McCallum MC. 1997. Procedures for investigating and reporting fatigue contributions to marine casualties. Proc Hum Factors Ergon Soc Annu Meet. 41:988–992. doi:10.1177/107118139704100259

Robertson IH, Manly T, Andrade J, Baddeley BT, Yiend J. 1997. 'Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. Neuropsychologia. 35:747–758. PMID: 9204482.

Shaffer F, McCraty R, Zerr CL. 2014. A healthy heart is not a metronome: An integrative review of the heart's anatomy and heart rate variability. Front Psychol. 5:1040. PMID: 25324790.

Shattuck NL, Matsangas P. 2016. Operational assessment of the 5-h on/10-h off watchstanding schedule on a US navy ship: Sleep patterns, mood and psychomotor vigilance performance of crewmembers in the nuclear reactor department. Ergonomics. 59:657–664. PMID: 26360772.

Størkersen K, Kongsvik T, Hansen J 2011. The possible impact of different watch keeping regimes at sea on sleep, fatigue, and safety. Paper presented at the 2011 European Safety and Reliability Conference; Troyes; FR.

Strahler J, Mueller A, Rosenloecher F, Kirschbaum C, Rohleder N. 2010. Salivary alpha-amylase stress reactivity across different age groups. Psychophysiology. 47:587–595. PMID: 20070573.