A Final Report to the UK Maritime and Coastguard Agency:

"Investigation of the 8-hours on/8-hours off Seafarer Watch Keeping System"

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EXECUTIVE SUMMARY

The UK Maritime and Coastguard Agency (MCA) wished to investigate the 8 hours on/8 hours off watch keeping system, with the aim of providing an answer to the following question:

What is the effect of working an 8 hours on/8 hours off watch keeping system on seafarer fatigue, performance and safety?

The following methodology was adopted, which included the following elements:

- An onboard study to collect sleep and fatigue data from a selection of officer and rating watch keepers on 5 of the company's vessels;
- A theoretical study to compare different watch permutations using the MARTHA fatigue prediction software tool; and
- The analysis of quantitative and qualitative data

Some problems were encountered in the data collection phase. These were mostly due to the type of operations these vessels undertake. Although an optimal set of data was not achieved, it is possible to come to some definitive conclusions about the 8/8 system.

However, because of the special nature of the operations conducted by these vessels, the conclusions reached in this report may not be generalizable to other 8/8 situations and further testing is recommended on a case by case basis.

Theoretical and empirical evidence obtained in the project point in the same direction: the 6/6 watch keeping regime is worse than the 8/8 watch keeping regime in terms of the quantity and quality of sleep obtained. Both more and better sleep is obtained when working under 8/8 conditions and the levels of experienced sleepiness, stress, and fatigue are lower. Concerning sleep and sleepiness, these observations were also predicted by the model. Although correlational analyses between theory and practice may point to the fact that participants may have had the intention of letting the 8/8 system look better, it does not weaken the overall conclusion that both theory and practice point significantly into one and the same direction.

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1. INTRODUCTION

1.1 Aims and Objectives

The UK Maritime and Coastguard Agency (MCA) wished to investigate the 8 hours on/8 hours off watch keeping system, particularly in relation to the following:

1. the effect of 8 hours on/8 hours off on seafarer fatigue and performance;
2. the likely impact on maritime safety;
3. a comparison with other typical watch keeping systems (for example, 4/8 and 6/6);
4. its suitability as an “acceptable” watch keeping system under controlled conditions.

The aim of this project was to answer the following question:

What is the effect of working an 8 hours on/8 hours off watch keeping system on seafarer fatigue, performance and safety?

To satisfy the requirement, MCA identified the following objectives:

i. to conduct a scientifically robust investigation into the 8/8 watch keeping system using an appropriate blend of quantitative and qualitative methods;

ii. from the results of that investigation, to undertake an assessment of the impact of 8/8 on seafarer fatigue, cognitive and physical performance, health, wellbeing and maritime safety;

iii. to make a comparison of the impact of 8/8 with other watch keeping regimes. (In this project, the comparison has been made empirically between the 8/8 and the current 6/6 regimes, and through the MARTHA software for modelling both these regimes.)

2 METHODOLOGY

2.1 The proposed methodology and work plan.

2.1.1 Introduction

In order to achieve the aim and objectives of the study, the MCA had suggested the following programme of work, with certain specific features:

i. A theoretical assessment of 8/8 and other watch keeping regimes, through modelling or a similar approach;

ii. An onboard study on selected vessels;

   The data is to be collected in real time from seafarers carrying out their normal daily duties. This will include quantitative data e.g., by electronic measuring devices and qualitative data e.g., personal diaries and self-reporting.

   The project will involve dredgers working a 3 week on and 3 week tour of duty.

iii. Quantitative and qualitative data will be analysed and a report produced.

Following a successful proposal, the research team agreed the following methodology with the MCA, which included the following elements:

- An onboard study to collect sleep and fatigue data from a selection of officer and able seamen (ABs) watch keepers on 5 of the company's dredgers;
- A theoretical study to compare different watch permutations using the MARTHA fatigue prediction software tool;
- The analysis of quantitative and qualitative data
- The production of a final report.
- A powerpoint presentation summarising the project findings and a written paper for publication in a maritime journal.

2.2 The Onboard study

2.2.1 General design

In the onboard, experimental part of the project, a randomly assigned cross-over design was adopted, half of the participating watch keepers first working under a 6/6 regime followed by an 8/8 regime. The other half worked first under an 8/8 regime and then under a 6/6 regime. The purpose of this design was to even out any possible ordering effects. Data collection, both of Actiwatch data and from diaries, continued during the leave periods following the periods of work on board, in order to investigate recovery following each of the different watch keeping regimes.

2.2.2 Design and participants

A total of 5 vessels were involved with participation sought from the entire deck watch keeping crew (i.e., two watch keeping officers and ABs and their relief crews, making a total of 8 participants from each vessel), therefore making a total of 40 watch keepers. In fact, a total of 39 volunteers agreed to take part in the study, with only one refusal. Participation started with crew answering a short background questionnaire containing questions that were relevant for their health, sleep, fatigue and performance whilst on board (for instance, diurnal type[1] (Torsvall and Akerstedt 1980), subjective health, mental health, body mass index (BMI), etc.).

Participants then started working either under a 6/6 regime (half the group) or under an 8/8 regime (half the group) for a period of 3 weeks. After these 3 weeks, measures continued during the crews' 3 weeks leave period, although the requested reporting was less intense. After the leave period, crew were on board again for another 3 weeks and under the other watch keeping regime. Hence, those who worked 6/6 prior to their leave now started working 8/8 and vice versa. After this second working period, measures continued again during the subsequent 3 weeks leave. A schematic view of the research design is shown in Figure 1.

2.2.3 Measures

During the time on board, the following measures were taken. The measures were carefully selected in order to interfere with work on board as little as possible:

- **Actigraphy** was assessed by selected participants wearing an actiwatch. This a scientifically validated method to objectively qualify and quantify sleep (Cole, Kripke, Gruen, Mullaney, & Gillin, 1992). 30 watches were available, so each vessel could use a maximum of six each. The principle adopted was that both

[1] Diurnal type refers to the categorisation of people into "Morning" and "evening" types. For example, "morning" types are likely to be more alert in the morning and perform better than "evening" types.

sets of two watch keeper officers would wear a watch plus volunteer ratings. In practice, the number of watch wearers was 28. The numbers of participants, Actiwatch wearers and diary return distribution across the ranks is shown in Appendix 1.

- **A Sleep diary (KSD)** to be filled out for every sleep episode. The diary contained questions on both the quantity and quality of sleep (Torbjörn Akerstedt, Hume, Minors, & Waterhouse, 1994);

- **Sleepiness, fatigue and stress** was assessed at two hourly intervals (even hours, i.e. 08:00, 10:00, 12:00, etc.) by means of a scientifically validated scale for each time. Of the various scales available, the Karolinska Sleepiness Scale (KSS) was chosen, and this rating scale assesses sleepiness on a 1-9 scale (T Akerstedt & Gillberg, 1990).

- **Fatigue counter-measures** were asked for at the end of each watch, where participants were to indicate which, if any, countermeasures they used during the watch to keep alert.

During the time on leave, the following measures were taken, but in a slightly less intensive way, in order not to interfere with their time on leave:

- **Actigraphy** assessment was continued as under time at work;
- **The Sleep diary** continued during the leave period, but it only recorded sleep quantity;
- **Sleepiness, fatigue and stress ratings** were assessed by requesting an average rating for the period 07:00-11:00, 11:00-15:00, as well as 15:00-19:00.

2.2.4 Analysis

The two watch systems were compared using a "within subjects'" analysis (i.e., repeated measures of Analysis of Variance - ANOVA). Such a "within subjects" design will make the comparison of the highest possible scientific quality, having sufficient statistical power with a relative low total number of participants.

2.2.5 Data Collection

All participants received written instructions on completing forms and scales. Researchers were to visit the vessel prior to departure on its first study voyage, to provide briefings, advice and forms and deliver the Actiwatches to each vessel. Researchers were to return to the vessel at crew turnover periods to check Actiwatch batteries and remove paper forms. Finally, at the end of the study on each vessel, researchers were to remove all Actiwatches and survey instruments.

As it turned out, logistical problems prevented the research team from doing this on all occasions. All data is confidential and anonymised. It was assumed that all watch keepers were relieved at the crew change-overs every three weeks. This did happen on most occasions, but sickness and other reasons meant that sometimes, the study period for each participant was not completed (see Appendix A).

Table 1 shows the crew change-over dates for each vessel, and who visited the ship. In the event, visits to the ships did not necessarily occur on the planned dates, as sometimes crew changes occurred when weather and other circumstances permitted.

Table 1: Crew Change over dates

Vessel and visitor	Regime 1 On board Date and port	Regime 2 On Leave Date and port	Regime 3 On board Date and port	Regime 4 On Leave Date and port	Finish Crew 1	Finish Crew 2
Vessel 1	30/12/2015 Shoreham	20/01/2016 Shoreham	10/02/2016 Shoreham Battery: 62%	02/03/2016 Portsmouth Battery change	23/03/2016 Shoreham	13/04/2016
Research team	Yes	No	No	Yes	Yes	
Crew Manager	No	Yes	No	No	No	Sent from ship
Vessel 2	06/01/2016 W Thurrock,	27/01/2016 Liverpool	17/02/2016 Liverpool	09/03/2016 Chatham	30/03/2016 Rochester	20/04/2016
Research team	Yes	No	No	Yes	Yes	No
Crew Manager	No	Yes	Yes	No	No	Sent from ship
Vessel 3	24/01/2016 In Sunderland	05/02/2016 Thames	24/02/2016 Southampton	16/03/2016 Southampton	06/04/2016	27/04/2016
Research team	No	No	Yes	No		
Crew Manager	Yes	Yes	No	Yes	Sent from ship	Sent from ship
Vessel 4	13/01/2016 Dagenham	03/02/2016 Dagenham	26/02/2016 Dagenham	16/03/2016 Dagenham	06/04/2016	27/04/2016
Research team	Yes	Yes	No	Yes		
Crew Manager	No	No	Yes	Yes	Sent from ship	Sent from ship
Vessel 5	14/01/2016 Cardiff	03/02/2016 Cardiff	18/02/2016 Cardiff	16/03/2016 Cardiff	06/04/2016 Bridgewater	27/04/2016
Research team	No	No	No	No	Yes	
Crew Manager	Yes	Yes	Yes	Yes	No	Sent from ship

2.3 Theoretical Study

In the theoretical part of the study, the experimentally obtained sleep and sleepiness data from the on-board study will be compared to sleep and sleepiness as predicted by the software MARTHA model, based on the widely validated three process model of alertness regulation (TPMA; (T Akerstedt & Folkard, 1995, 1996; Torbjörn Akerstedt, Folkard, & Portin, 2004; Ingre et al., 2014).

Comparisons have been made in two different ways, using both an uninformed model as well as an informed model to predict sleep and sleepiness in the two watch systems.

2.3.1 Uninformed model comparison

Under the uninformed model comparisons, MARTHA has used only the working hours (i.e. the watch regime) as an input. Based on this, sleep and sleepiness has been predicted for the period that reflects the on-board study. Such a comparison answers the question as to which of the two watch systems has the best sleep opportunities as well as which of the two systems is associated with the highest levels of sleepiness and thus will theoretically include the highest safety risk.

2.3.2 Informed model comparison

The informed model comparison uses the individuals own sleep times collected during the on-board study, thereby producing a sleepiness plot taking the individuals own sleep into account. These informed model predictions have been compared to the uninformed model predictions and should ideally be identical. The magnitude of the deviation between uninformed and informed model predictions indicates to what extent the individuals are capable of optimizing their own sleep and alertness. Another comparison made is with the obtained sleepiness ratings. Informed model predictions should be deviating in a similar way from the actual sleepiness ratings. If one or the other watch systems show a much bigger deviation here, it is likely that the participants may have systematically under- or overestimated their sleepiness in one of the two watch systems, possibly due to a strong personal preference for one or the other system.

2.4 Discussion on the method and work plan

2.4.1 Introduction

Although it is believed by the research team that sufficient data has been collected to allow a robust and scientifically rigorous study of the 8/8 watch keeping system, and its comparison with other schedules, a number of unplanned issues has meant that the data collection process was less than optimal. This section describes the more significant issues and their impact on the quantity and quality of data obtained.

2.4.2 Location of the vessels for visits

Although the MCA's Specification document suggested that the vessels selected for the study are "operating in the English Channel", this proved not to be the case in several instances. This meant that locations for crew change overs included ports such as Sunderland, Liverpool and Cardiff as well as the Thames River, which were far beyond the researchers' logistical plans and budget.

Due to the efforts of the Crew Manager, the ships did get visited in these ports and watches were delivered and diaries distributed, and collected again, as per the work plan. However, this logistical problem had an impact on the quality of the data obtained in three important respects:

1 To ensure consistency of understanding and activity, it is usually essential to ensure that all participants receive the same briefing from the same researcher. However, due to the ships' operations, the research team was not on hand to answer questions or give advice on every change over. Despite the best efforts of the Crew Manager, he was not able to see all ships on changeover day, which meant that when he visited, half the crew were turned in, and therefore he had to rely on those he did see to disseminate the message. It is possible this had an impact on the successful completion of diaries - especially the completion rate during the leave periods.

2 At the outset of the study, it was understood by the research team that all vessels had been notified of the forthcoming project to ensure "buy-in" from volunteers. This did not always seem to be the case when researchers actually visited the vessels. Despite receiving an e mail with an outline of the study, some crew claimed to the researchers that they were unaware of the study. Having said that, with the exception of one officer, all those who were asked to take part did so willingly, and signed a letter of consent to that effect.

3 The logistical problems outlined above also meant that the researchers were not always able to check the Actiwatch batteries on every change over. This problem was exacerbated by the fact that, although the time of the change over was always given as 1200, often researchers would arrive at the ship well before then, only to find that the crew going home had already gone! This means that the Actiwatch data may be affected by loss of battery power towards the end of the 12 week study period for each participant, and this will be covered in later sections.

2.4.3 Vessel operations

The specific operations of these vessels did mean that each vessel tended to operate quite independently. Although some of the five vessels were sisters, the operations could be quite different in different locations, with the newer vessels managing to shift cargoes two or even three times a day.

The practical operations of these vessels had two significant impacts on the data collected:

1 The study was conducted during the winter months when the weather was often bad. Operations are suspended under these conditions and consequently, the vessels are laid up in port, awaiting more favourable conditions. In these circumstances, the watch keeping crew members revert to day work. It was decided at the time of the first visit, when this situation became apparent, that the solution for the study was to accept these delays, and the consequent change of watch scheduling, as “random operational events” which could affect any watch keeping regime equally. Therefore, no attempt was made to require crew to remain on either 6/6 or 8/8 when these conditions prevailed. These events occurred quite frequently in the earlier stages of the data collection period and the switch from watch keeping to day work and back again, within a three week tour, may have had an impact on the results.

2 Another issue which may have had a similar impact was the noticeable frequency of stoppages due to repair or maintenance requirements. The nature of these operations means that there is intense ”wear and tear” on cargo and deck equipment. Two of the vessels underwent repairs lasting up to two weeks during the data collection period, and others had to suspend normal operations for a day or two while repairs were effected. It was acknowledged by shore management that this high toll is typical of the trade. The impact on the quality of data is the same as the weather, i.e. during these, sometimes

prolonged, periods, the watch keeping crew revert to day work. Any comparisons of watch systems is almost bound to be ”evened out” by these frequent breaks of watch keeping service.

One interesting aspect of changing watches is also noted in that one vessel did operate outside UK waters and therefore had to revert to a 6/6 regime from the 8/8. The impact of switching watches like this appears to be high and is discussed further in the findings of the project in Section 3.

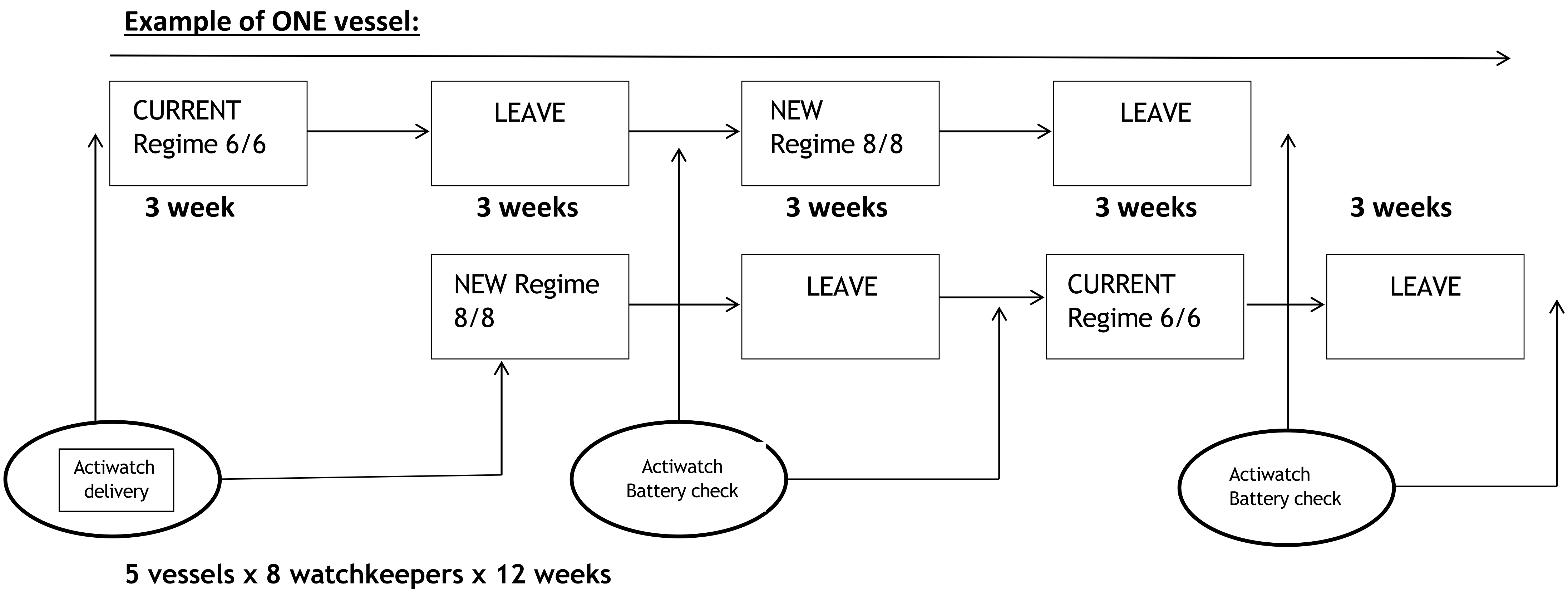
2.4.4 Watch keeping patterns

Due probably to the independent nature of each vessel and its specific operation, the watch keeping schedule adopted on each vessel also appeared to be “peculiar” to that vessel and indeed to the individual Master on any particular tour. Consequently, the watch keeping routines were not quite as expected. Although officers tended to be either on 6/6 or 8/8 as requested, the ratings often worked a different system – most commonly a 12/12 system. This would operate from 1200 to midnight and midnight to 1200. Because the permanent crews relieved each other, they switched round on a voyage by voyage basis to overcome the disadvantage of the midnight to 1200 routine. There was some evidence too that individual Masters helped watch keepers, during normal operations, by relieving them on the bridge at certain times.

Although the amount of usable data is less than optimal, and the above factors explain some of the reasons for this, it is possible to come to some definitive conclusions about the 8/8 system.

Section 3 describes these results.

Figure 1: Investigation of the 8 hours on/8 hours off Seafarer Watchkeeping System – Research Design



3 THE RESULTS

3.1 Introduction

This Results chapter is in three parts.

The first part describes the three watch systems 6on6off (6/6), 8on8off (8/8) and 12on12off (12/12) from a theoretical point of view. Although all three systems are characterised by being two watch keeper regimes, and consist of 50% working time and 50% time off, there are obvious differences between them. The possible “sleepiness-inducing” effect of time on task is most prominent in the 12/12 system where work shifts are 12 hours in length, and least prominent in the 6/6 system where periods of work are only 6 hours long. However, the opportunity to have a full and restorative sleep is another major factor in determining the relative efficiency of each regime from a fatigue point of view. In that case, it is the 12/12 system that would in theory provide the best opportunities to enjoy what is considered to be a normal 8 hours daily sleep during the 12 hours off watch, whereas the 6/6 regime prevents any such period. The 8/8 system may thus form a compromise between these two regimes. The first part of this section will arrive at the conclusion of which of the three watch keeping regimes are in theory the most and the least fatiguing.

The second part of this chapter describes the on-board study where a substantial number of the seafarers on-board the vessels studied were working under both 6/6 watches for 3 week tours as well as under an 8/8 regime for 3 weeks. In between these work periods, a 3 week leave period occurred, which has the effect of allowing recovery from any fatigue that may have built up during the periods of watch keeping. Moreover, the order of doing the different watch regimes was randomised, so that half the study populations would first work 6/6, and the other half worked the 8/8 regime first. This second part will arrive at the conclusion of which of these two systems is in practice the most fatiguing.

The third section briefly considers to what extent the theory and the practice match each other. Will both theory and practice point to the same conclusion, or will there be any major differences in the results? If so, what may be the possible causes and consequences of these differences?

3.2 The Theoretical Study

In the theoretical study, the three most widely used watch systems on these vessels were compared. These two watch keeper systems are the 8/8 regime, the 6/6 regime and the 12/12 regime. This comparison used the three process model of alertness regulation (TPMA) hereafter referred to as the “model” with settings especially adapted to seafaring operations, similar to the software MARTHA. The key adaptation is that the proximity to work setting is changed compared to the setting used in shore work, being reduced to 45 minutes. This number indicates, based on findings from project HORIZON, that the average time seafarers would need between the end of work and the start of sleep is 45 minutes. Due to the 24/7 nature of work at sea, the comparisons also take diurnal type into account. Hence, extreme morning types, morning types, neutral types, evening types, and extreme evening types are modelled separately. The first 48 hours of each watch system and each watch team is illustrated in Figure 2.

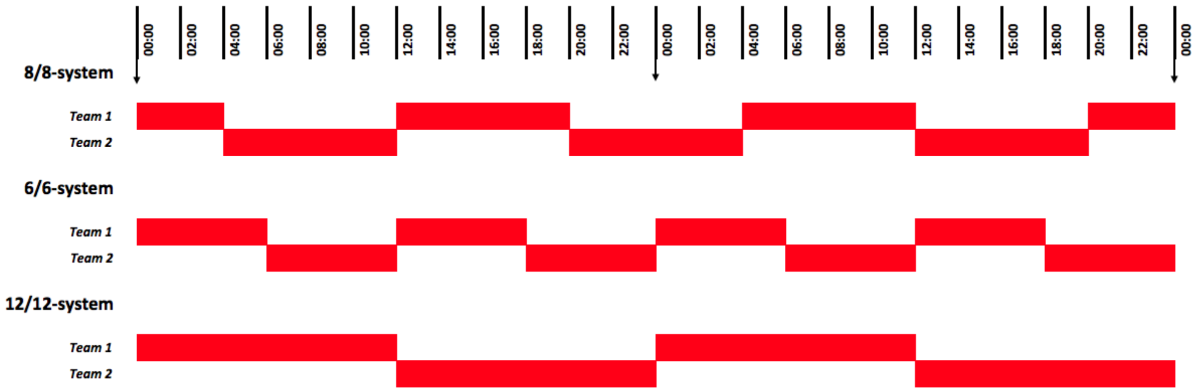


Figure 2. The three watch systems under theoretical investigation. Only the first 48 hours are shown during which all watch teams do work for a total of 24 hours, shaded in red. The entire comparison was carried out for a total of 42 days i.e. 3 weeks, followed by a 21 days (3 week) period of leave.

3.2.1 Sleep opportunities

The possibility to sleep outside the conventional night time hours, that is between 23:00 and 07:00, is strongly determined by diurnal type. Whereas morning types will have relatively little problems going to sleep earlier than 23:00, they will encounter difficulties obtaining sleep when coming off watch at 06:00 or 08:00. For evening types, the problem is the other way around, as their main difficulty will lie in obtaining any sleep before entering the night watch at 00:00, or even at 04:00. Predicted opportunities for sleep in each diurnal type are shown in Table 2 for the 8/8 system, in Table 3 for the 6/6 system, and in Table 4 for the 12/12 system.

Table 2. Sleep opportunities during each off-watch period as per diurnal type in the 8/8-system.

	Off-watch period			**Average sleep per 24h period**
	12:00 – 20:00	**20:00 – 04:00**	**04:00 – 12:00**	
Extreme morning	No sleep	21:29 – 03:15	04:56 – 10:34	05 h 42 m
Morning	No sleep	21:41 – 03:15	04:56 – 10:42	05 h 40 m
Neutral	No sleep	22:17 – 03:15	04:56 – 11:03	05 h 32 m
Evening	No sleep	23:12 – 03:15	04:55 – 11:15	05 h 11 m
Extreme evening	12:57 – 16:08	01:35 – 03:15	04:56 – 11:15	05 h 35 m

Table 3. Sleep opportunities during each off watch period as per diurnal type in the 6/6 system.

	Off-watch period				**Average sleep per 24h period**
	00:00 – 06:00	**06:00 – 12:00**	**12:00 – 18:00**	**18:00 – 00:00**	
Extreme morning		06:57 – 10:41		21:23 – 23:15	5 h 36 m
	00:55 – 05:15		12:59 – 14:45[1]		4 h 41 m
Morning		06:57 – 10:55		21:41 – 23:15	5 h 33 m
	00:56 – 05:15		12:59 – 14:40[2]		4 h 29 m
Neutral		06:56 – 11:15		22:05 – 23:15	5 h 29 m
	00:56 – 05:15		13:00 – 14:47[3]		4 h 55 m
Evening		06:56 – 11:15		22:35 – 23:15	4 h 59 m
	00:57 – 05:15		12:59 – 14:51[4]		5 h 14 m
Extreme evening		06:55 – 11:15		No sleep	4 h 20 m
	01:23 – 05:15		12:59 – 15:01		5 h 54 m

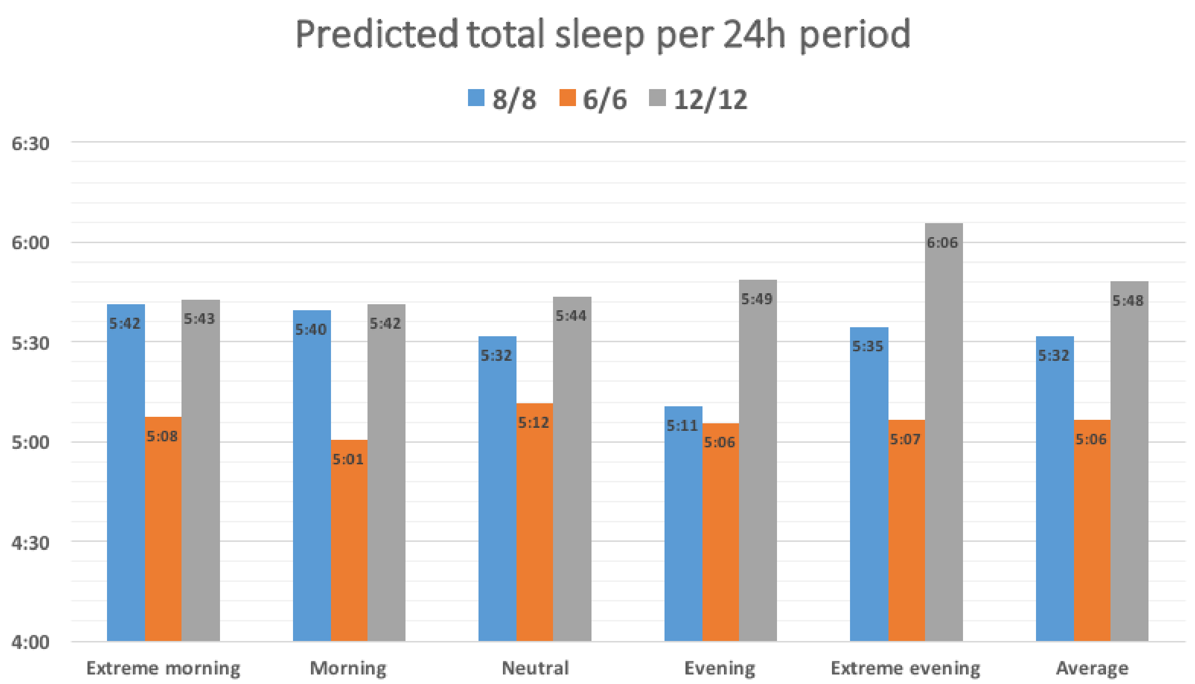
[1] Afternoon sleep predicted to be successfully taking place only once every 5 days
[2] Afternoon sleep predicted to be successfully taking place only once every 4 days
[3] Afternoon sleep predicted to be successfully taking place only once every 3 days
[4] Afternoon sleep predicted to be successfully taking place only once every 2 days

Table 4. Sleep opportunities during each off watch period as per diurnal type in the 12/12 system.

	Off watch period		**Sleep per 24h period**
	00:00 – 12:00	**12:00 – 00:00**	
Extreme morning		12:58 – 15:35 & 20:53 – 23:15	4 h 59 m
	00:56 – 07:24		6 h 28 m
Morning		12:58 – 15:45 & 21:11 – 23:15	4 h 51 m
	00:57 – 07:30		6 h 33 m
Neutral		12:58 – 16:06 & 21:41 – 23:15	4 h 42 m
	00:57 – 07:44		6 h 47 m
Evening		12:57 – 16:54 & 22:53 – 23:15	4 h 20 m
	00:58 – 08:16		7 h 18 m
Extreme evening		12:56 – 17:24	4 h 28 m
	01:59 – 09:44		7 h 45 m

An overall comparison of the amount of sleep that is predicted to successfully take place under the different watch keeping regimes is illustrated in Figure 3.

Figure 3. Total amount of sleep predicted to take place under the different watch keeping regimes for each of the five diurnal types as well as the overall average at the right hand side.



3.2.2`Sleepiness on watch

A Karolinska Sleepiness Scale (KSS) value exceeding 7 is associated with physiological signs of sleepiness including the occurrence of so called micro sleeps. Micro sleeps can be very short and occur without the person in question being aware of it. The risk, however, lies in the fact that one is entirely unresponsive to environmental input. Moreover, micro sleeps can transfer into "real" sleeps that can last for many minutes. Therefore, time spent under a predicted KSS level of 7 or higher is considered as time at risk.

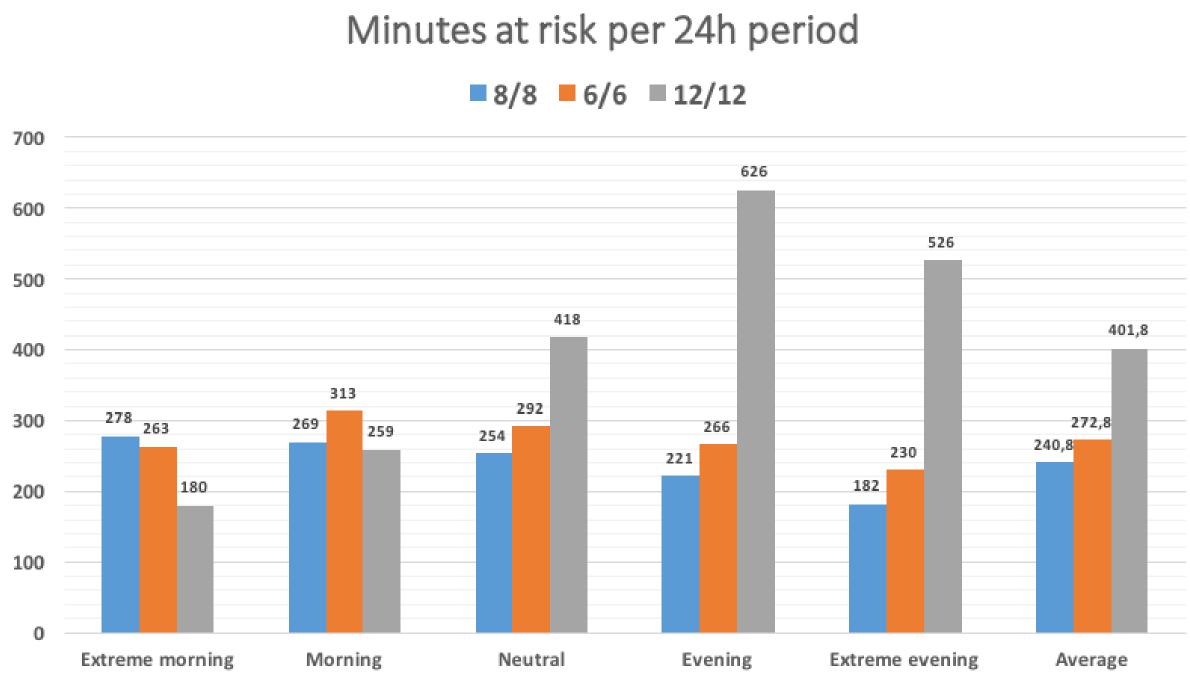
Table 5 therefore shows the time, as expressed as a percentage of the total watch time, that a watch keeper might be under significant risk of falling asleep for the three watch systems.

Table 5. Relative time at risk (%) per watch for the five different diurnal types. Time at risk is defined by a KSS rating 7 or higher.

System	**Watch**	**% of time at risk**				
		Extreme morning	morning	Neutral	evening	Extreme evening
8/8	12:00 – 20:00	0	0	0	0	0
	20:00 – 04:00	58	56	53	46	7
	04:00 – 12:00	0	0	0	0	31
6/6	00:00 – 06:00	46	66	71	74	64
	06:00 – 12:00	0	0	0	0	0
	12:00 – 18:00	0	0	0	0	0
	18:00 – 00:00	27 (13-34)	21 (9-29)	10 (0-18)	0	0
12/12	00:00 – 12:00	25	36	58	87	73
	12:00 – 00:00	0	0	0	0	0

More relevant from a risk related perspective than % of time on watch, however, is the absolute number of minutes spent in a condition of severe sleepiness with the risk of falling asleep on duty. These minutes are plotted in Figure 4.

Figure 4. Minutes at risk per 24-hour period when operating 8/8, 6/6, and 12/12. Five different diurnal types are shown (from extreme morning to extreme evening) as well as the overall average at the right hand side.



3.2.3 Conclusions

The amount of sleep per day is clearly least under a 6/6 regime, irrespective of diurnal type (Figure 3). This is mainly due to the fact that sleep is very difficult to obtain when a a watch keeper is off watch from 12:00 to 18:00. Overall, the 8/8 and especially the 12/12 regime do provide the highest average possibilities for sleep. However, those being off watch from midnight to midday have a strong advantage compared to those being off watch from midday to midnight.

The total number of minutes per day with severe levels of sleepiness (KSS>7) is a strong indicator of the risk of falling asleep. Here, the clear disadvantage of the 12/12 system can be observed (Figure 4), where the midnight to midday watch is in 3 out of 5 diurnal types creating a very considerable number of minutes at risk. The 6/6 and 8/8 systems are more closely together in risk, but the 8/8 system is associated with less minutes at risk in all diurnal types except the extreme morning type.

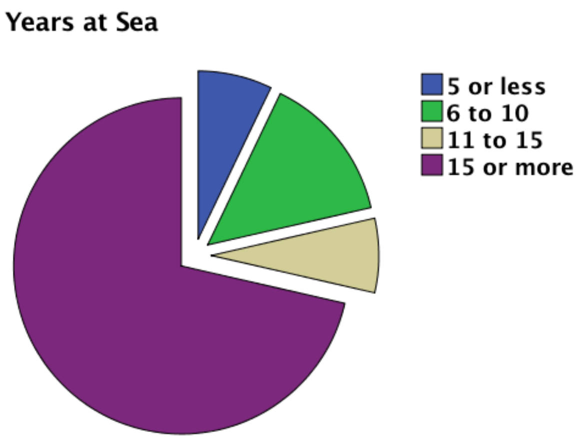
In summary, the 8/8 system is associated with the smallest risk of falling asleep and with very reasonable amounts of sleep opportunities.

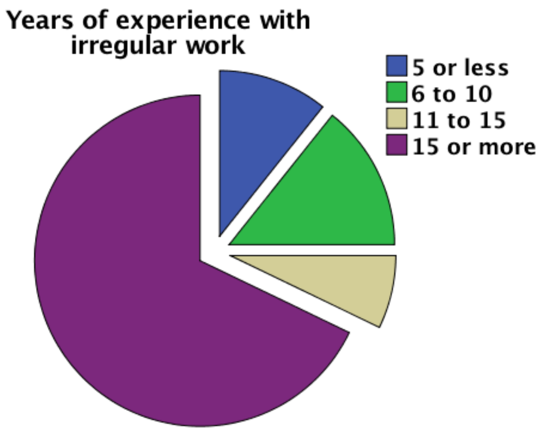
3.3 The On-board study

3.3.1 Participants

39 people participated in the on-board study. 4 participants only completed the 6/6 part and 7 only the 8/8 part. Of the remaining 28 participants, 14 completed first the 6/6 part and then, after their leave, the 8/8 part, whereas the remaining 14 first completed the 8/8 part and concluded with the 6/6 part. Only the 28 participants that have completed both parts will be used in the comparative analyses (mean age ¤ standard deviation = 48 ± 12). These were highly experienced seafarers, as illustrated in Figure 5.

Figure 5. An experienced group of participants took part in the on board studies, both with respect to years at sea (figure at the top) as well as to years of experience with irregular work (figure at the bottom)





Furthermore, none of the participants had a substantial problem with either working during the night or sleeping during the day, both factors being crucial components when working either 6/6 or 8/8 (Figure 6).

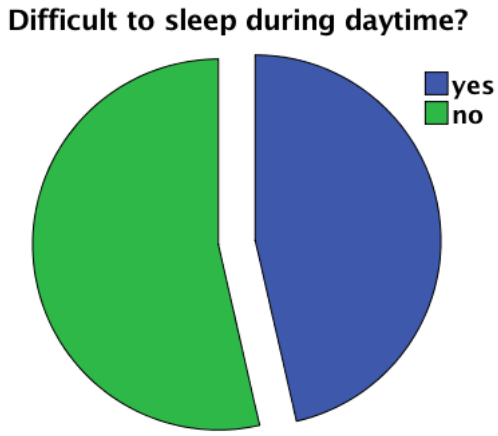
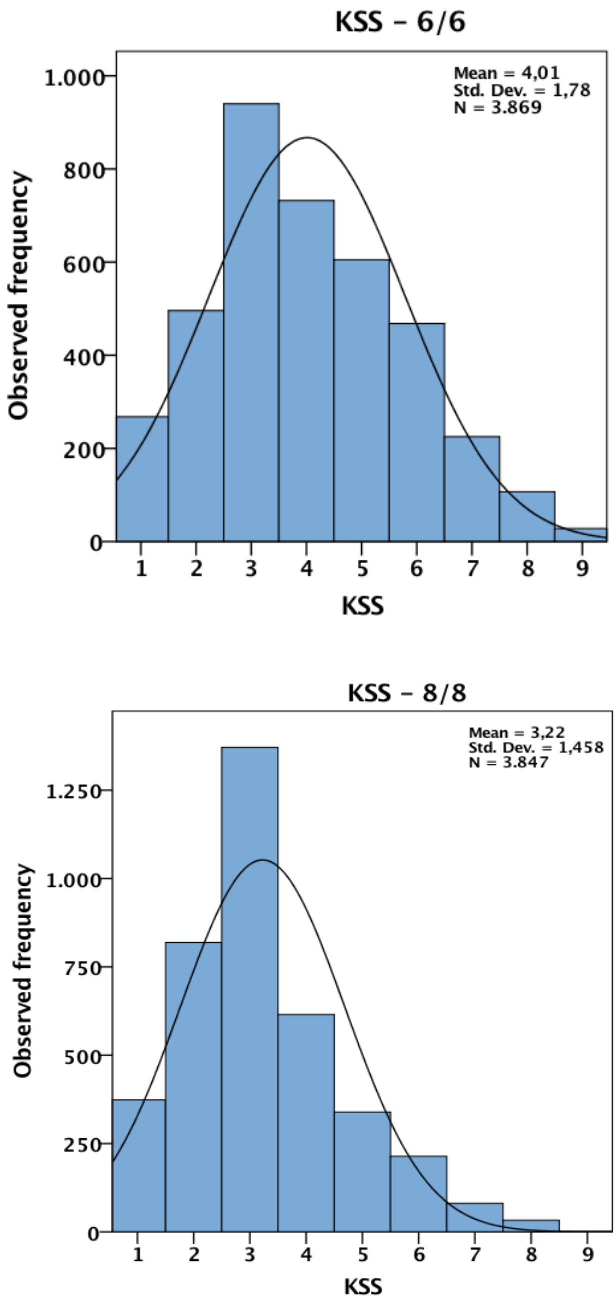


Figure 6.Sleep quality at night and during the day. A majority of the participants had no problem with working at night (figure at the left) or sleeping during the day (figure at the right).

3.3.2 Sleepiness at work

The 28 participants have in total collected 3,869 sleepiness (KSS) ratings while under a 6/6 regime and 3,847 sleepiness ratings while under an 8/8 regime. However, both regimes included occasional periods with other working schedules. Because these arrangements are typical for this type of operation, they were not excluded. Figure 7 illustrates how all these ratings were distributed. The mean of all KSS scores observed under the 6/6 regime is slightly higher than under the 8/8 regime (4.01 ± 1.78 versus 3.22 ± 1.46). Even the proportion of KSS values indicative of time at risk is considerably higher under the 6/6 regime (9.3%) than under the 8/8 regime (3.0%; ±2(1)=132,084, p<.0001). Similar patterns were observed for stress and fatigue. Stress levels were lower under the 8/8 regime (2.5 ± 1.2) than under the 6/6 (2.9 ± 1.6) and so were fatigue levels (2.8 ± 1.1 versus 3.4 ± 1.3).

Figure 7. Distribution of KSS ratings under the 6/6-regime (top panel) and 8/8-regime (bottom panel). See text for details.



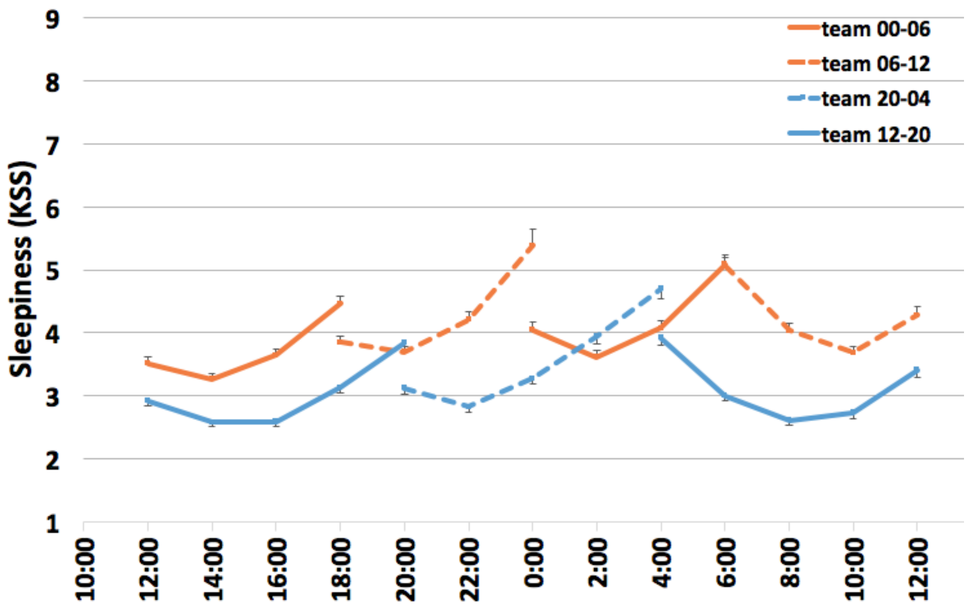
A closer look at the different watches under each regime is presented in Table 6, where it can be easily observed that both the mean KSS values as well as the time at risk are greater under the 6/6 regime than under the 8/8.

Table 6. Mean sleepiness (KSS) levels as well as time at risk (KSS≥7) during each of the watches in the two watch keeping regimes.

Regime	Watch	Observations	Mean KSS ± sd	Time at risk
6/6	00:00 to 06:00	654	4,2 ± 1,7	8,4 %
	06:00 to 12:00	806	4,3 ± 1,8	11,0 %
	12:00 to 18:00	697	3,7 ± 1,4	2,3 %
	18:00 to 00:00	669	4,0 ± 1,6	6,6 %
8/8	12:00 to 20:00	979	3,0 ± 1,3	1,2 %
	20:00 to 04:00	913	3,5 ± 1,6	5,3 %
	04:00 to 12:00	931	3,1 ± 1,4	2,3 %

Sleepiness levels during an average day under both watch keeping regimes is shown in Figure 8.

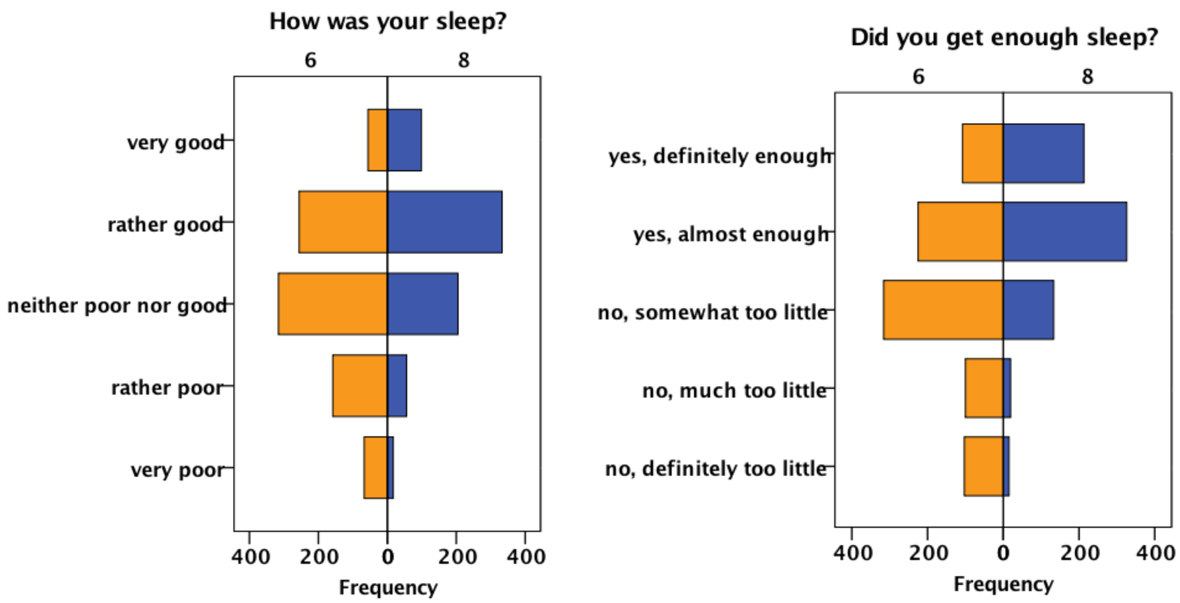
Figure 8. Sleepiness levels (± standard error) during an average day under a 6/6 regime (orange lines) and 8/8 regime (blue lines).



3.3.3 Sleep diaries

All items of the sleep diary indicated better sleep under the 8/8 regime than under the 6/6 regime (all p values <.001). In other words, sleep quality was better, sleep was calmer, it was easier to fall asleep, and easier to wake up under the 8/8 regime. Moreover, the feeling of waking up too early was less evident under the 8/8 regime and participants felt better rested upon waking up with a feeling of a higher sleep efficiency. The response distribution for two of those questions, related to quality and quantity of sleep, are shown in Figure 9.

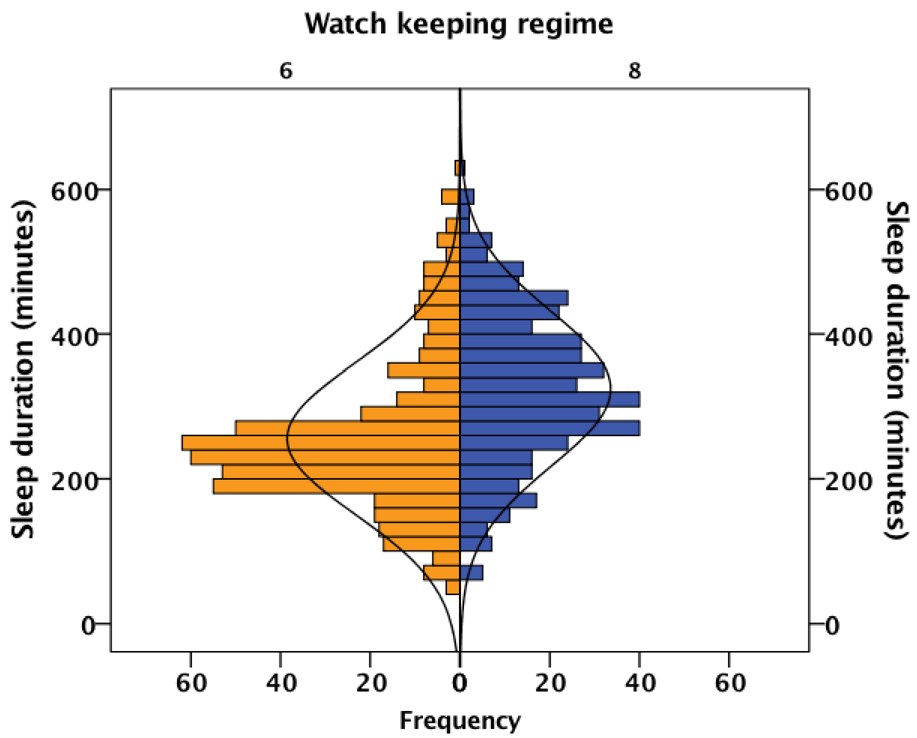
Figure 9. Both subjective sleep quality (left panel) and sleep quantity (right panel) are better under the 8/8 regime (blue bars) than under the 6/6 regime (orange bars).



3.3.4 Actigraphy results

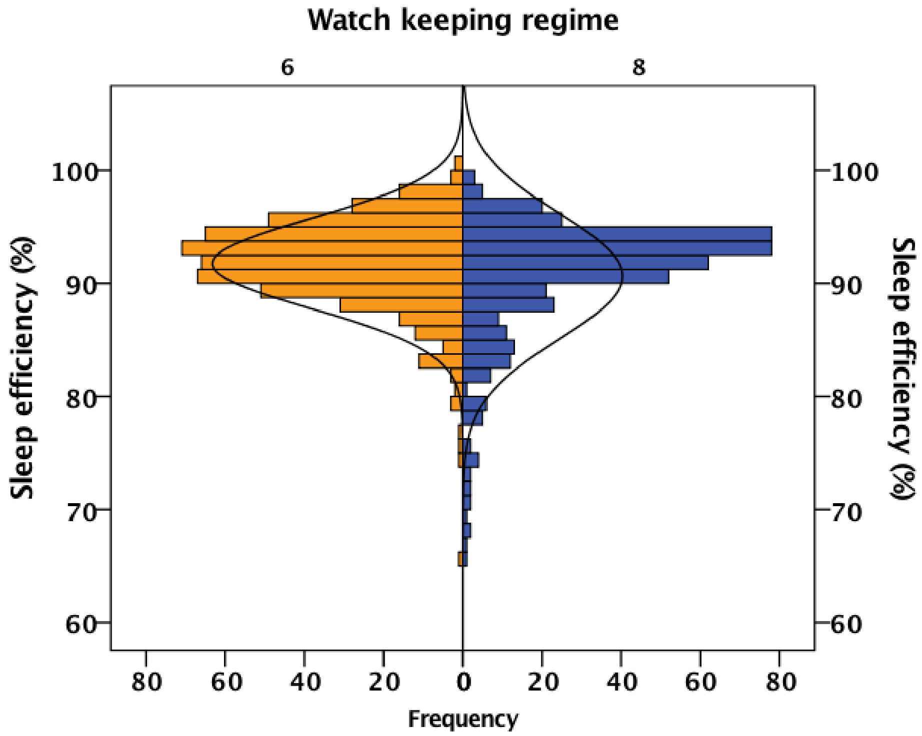
Although the sleep diary results as described above do provide us with crucial subjective information about several sleep parameters, it is always good to combine such parameters with an objective measure of sleep, in this case, actigraphy. In this study, we have recorded a very large amount of 1672 sleeps by using actigraphy. 953 of these sleeps were included in the current analyses as they represented sleeps for the same people under the two different watch regimes. There were a variety of reasons which accounted for the reduction in usable sleeps: some simply did not do both watches, actiwatches broke down or stopped recording, some recordings were not usable. 953 is a considerable number for analysis, however, especially given the fact that the research design is the strongest possible (i.e., a “crossed over within subjects" design).The remaining sleeps were recorded in individuals that did not take part in both parts of the study (i.e., both 6/6 and 8/8). 505 of these 953 sleeps took place under a 6/6 regime (mean length ± standard deviation being 256 ± 105 minutes). The remaining 448 sleeps took place under a 8/8 regime and had an average length of 324 ± 106 minutes. Figure 10 shows how these sleeps were distributed under both regimes. It should be noted, however, that this does not necessarily imply that longer ***daily*** sleep took place, since the values reflect the duration per sleep, not per day.

Figure 10. Distribution of the recorded sleep durations under 6/6 (orange) and 8/8 (blue).



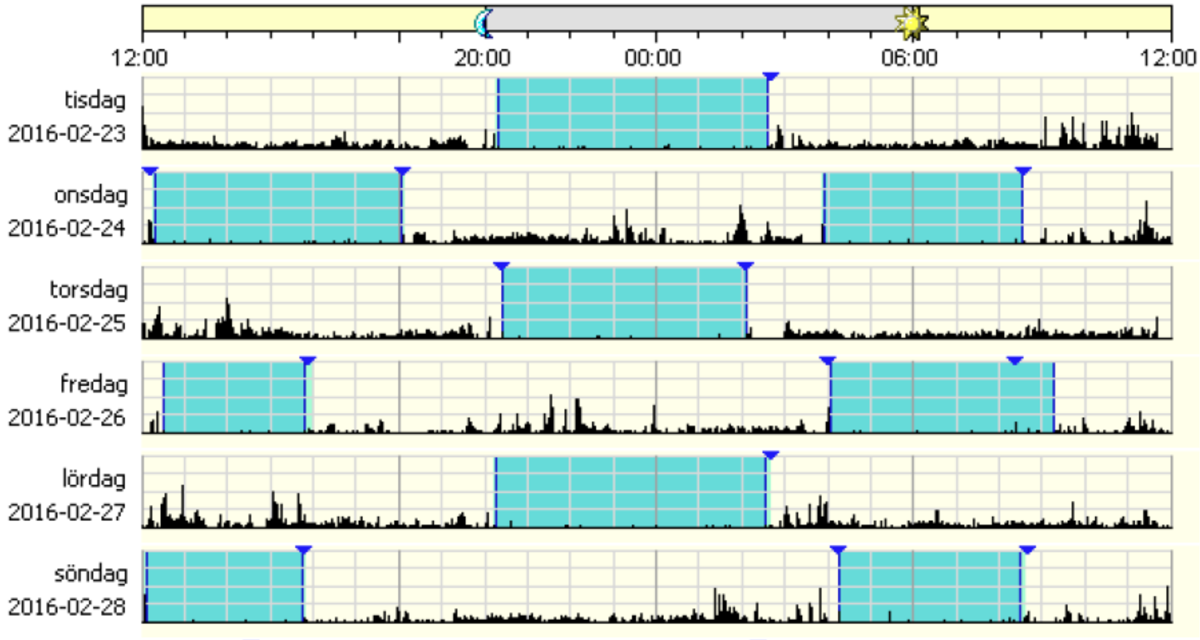
Sleep efficiency, i.e., the percentage of time that one is really asleep during a period of sleep, shows to be relatively good. All sleep efficiencies of 85% or higher are considered normal, and Figure 11 illustrates that the vast majority of sleeps under both watch keeping regimes reach that level. The notion that the average sleep efficiency under the 6/6 regime may seem slightly higher can be seen as a direct consequence of the smaller amount of sleep obtained. With high sleep pressure but little time to sleep, the sleep efficiency will always look slightly better.

Figure 11. Distribution of the recorded sleep efficiencies under 6/6 (orange) and 8/8 (blue).



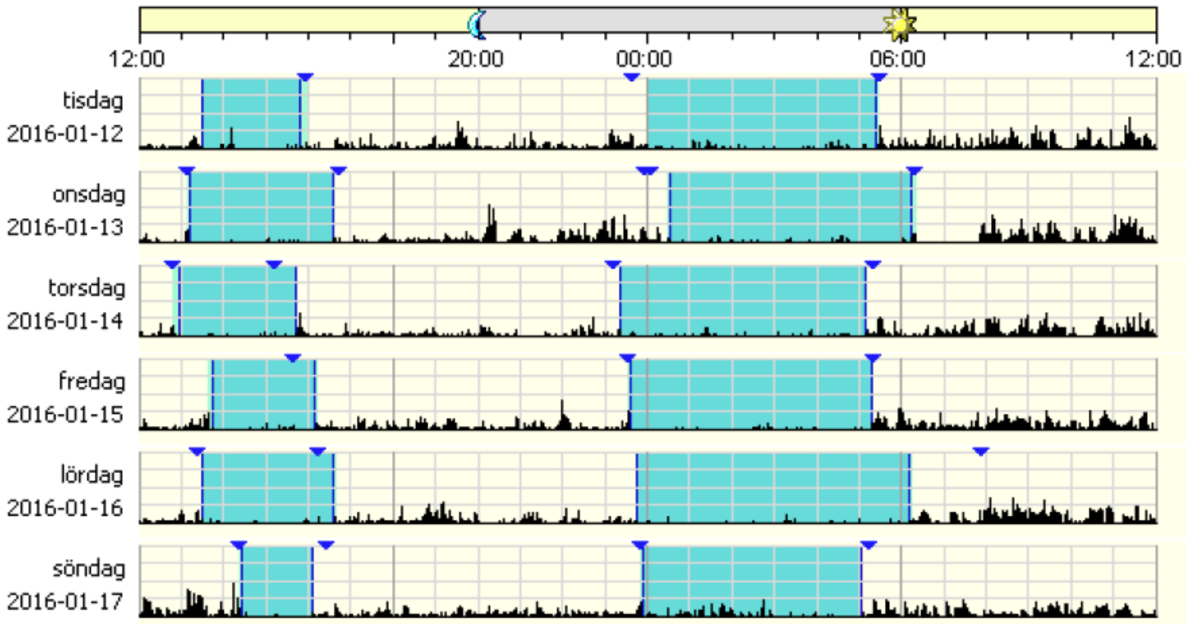
A typical actogram (activity plot with sleep shaded in blue) for a participant working under an 8/8 regime and getting very decent amounts of sleep is shown in Figure 12. Here, it can also be seen that participants sometimes forget to press the event marker button (used for indicating bed-time and rise-time) and sometimes continue snoozing after having indicated a wake up (e.g. at about 08:00 AM on the 27th of February).

Figure 12. Six days of a typical sleep wake pattern under an 8/8 regime. Areas shaded in blue indicate sleep and the little blue triangles indicate when the participant pressed the event marker button on the watch.



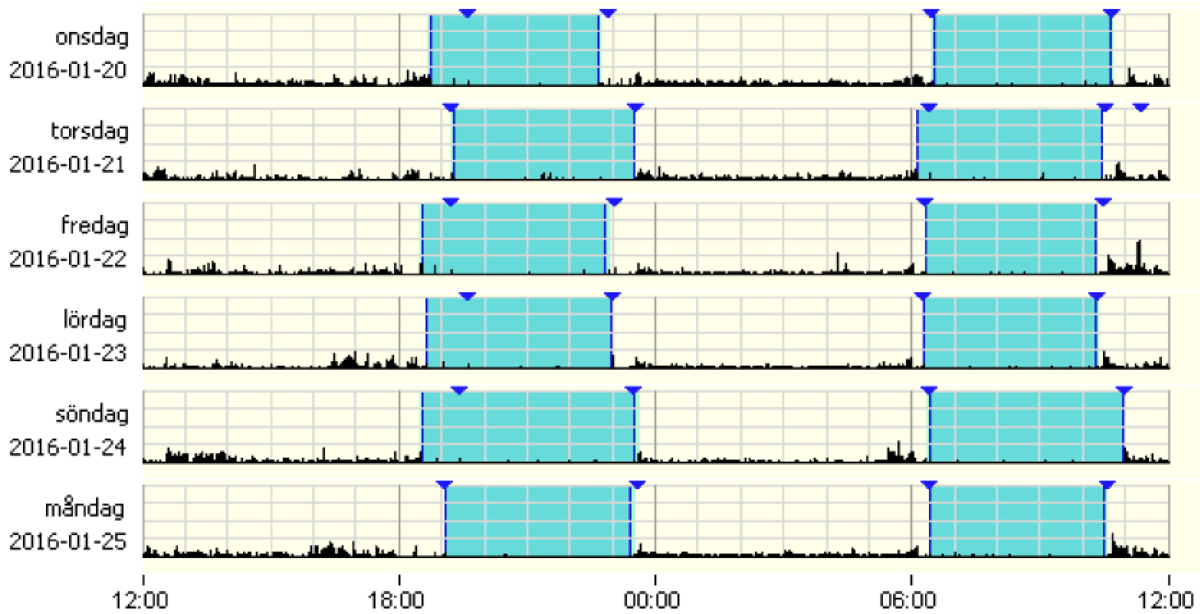
For those working 06:00 to 12:00 and 18:00 to 00:00 under a 6/6 regime, a typical actogram is shown in Figure 13. In this case, the watch keeper appears to be able to get regular sleep during the off watch period in the middle of the day. It should be noted, however, that this ability is by no means observed in all watch keepers working this regime.

Figure 13. Six days of a typical sleep wake pattern under an 6/6 regime (work between 06:00-12:00 & 18:00-00:00). Areas shaded in blue indicate sleep and the little blue triangles indicate when the participant pressed the event marker button on the watch.



A final example of an actogram is shown in Figure 14, again working under a 6/6 regime, but in this case working 00:00 to 06:00 and 12:00 to 18:00. Again a pattern that indicates sufficient amounts of sleep on a daily basis, which is rather unique. It should furthermore be noted that these quantities of sleep do not provide any information on the quality of sleep nor on its recuperative value.

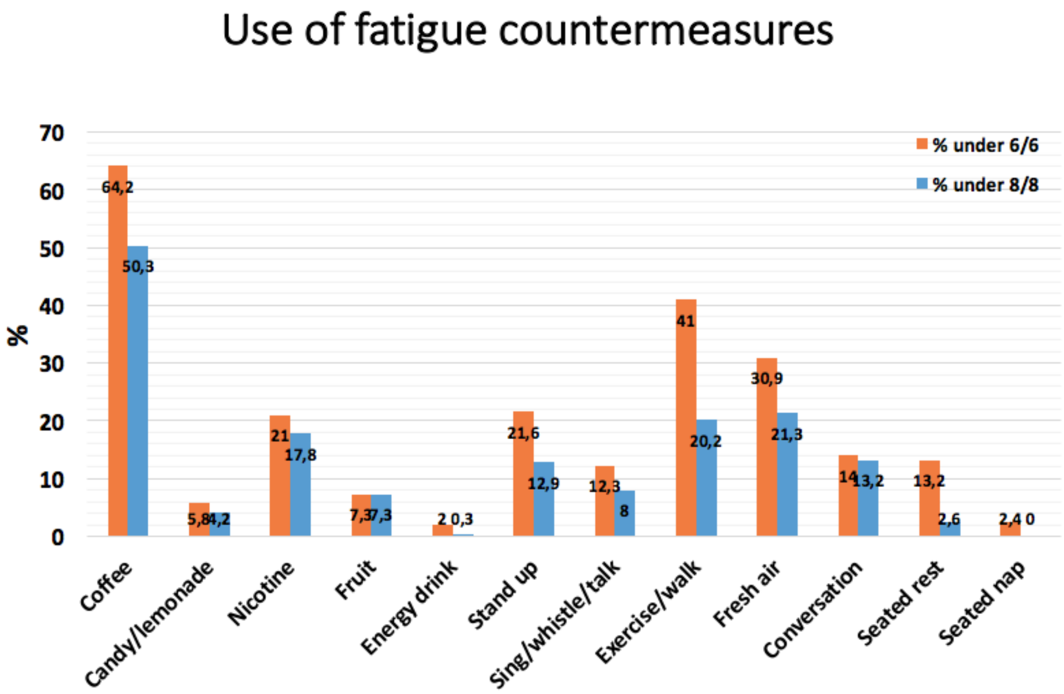
Figure 14. Six days of a typical sleep wake pattern under an 6/6 regime (work between 00:00-06:00 & 12:00-18:00). Areas shaded in blue indicate sleep and the little blue triangles indicate when the participant pressed the event marker button on the watch.



3.3.5 Countermeasure use

Another indicator of how fatiguing a given working schedule is, is the extent to which people look for ways to fight fatigue. Coffee is by far the most widely known fatigue countermeasure people use to try to regain alertness, but several more countermeasures were sought from the participants. As can be seen in Figure 14, all countermeasures except eating fruit were more frequently used under the 6/6 regime than under the 8/8 regime. As expected, coffee was the most widely used countermeasure under both regimes: it was used on 64.2% of the days when working under 6/6 and on 50.3% of the days when working 8/8 (Figure 14).

Figure 15. Percentage of days that each of the mentioned fatigue countermeasures were used under both watch keeping regimes.



3.3.6 Conclusions

All measures used in the on-board study point consistently to the fact that a 6/6 regime is associated with higher levels of sleepiness, and thus, is more fatiguing than the 8/8 regime. Reported sleepiness levels are almost at all time points during the day higher under a 6/6 regime than under an 8/8 regime. It is only between 02:00 and 04:00 at night that sleepiness levels are higher under the 8/8 regime (Figure 8), This 02:00 to 04:00 time interval result is quite revealing, since those working 8/8 have been awake since 20:00, while those working 6/6 only since 00:00. Hence, less sleep pressure has built up in those working 6/6 between these time points. The story is completely opposite for the 04:00 to 06:00 time interval. Here, 8/8 watch keepers would have been very fresh as they have just woken up, while 6/6 ones are very tired as they have been awake since midnight. Clear peaks in sleepiness are observed when the end of watch coincides with hours in the night and early morning, i.e., at midnight at the end of the 18:00 to 00:00 watch, at 04:00 at the end of the 20:00 to 04:00 watch, and at 06:00 at the end of the 00:00 to 06:00 watch.

Although mean sleepiness values never reached the risk cut off of KSS≥7, quite a substantial amount of such risky values were recorded during this study, the percentages being consistently higher under the 6/6 regime than under the 8/8 regime. In addition, the fact that all kinds of fatigue countermeasures were applied more frequently under the 6/6 regime provide indirect evidence that it is indeed the 6/6 regime that is associated with higher levels of fatigue. In addition, sleep under an 8/8 regime appears to be of higher quality and longer sleep episodes can be enjoyed.

3.4 Comparing theory with the on-board study

Figures 16 and 17 plot both model predicted levels of sleepiness as well as the actual observed levels in the on-board study. A clear picture arises that KSS scores as recorded on board are at almost all time points, in both watch keeping regimes, considerably lower than that predicted by the model. It is, however, not the first time that this phenomenon is observed, for example, as Project HORIZON made clear, seafarers tend to report extremely low sleepiness levels in general.

Figure 16. Comparing the ratings collected during the 6/6 part of the on-board study (blue lines) with the predicted ratings for different diurnal types (extreme morning type in red, neutral type in black, and extreme evening type in green) shows that self-reported sleepiness is considerably lower than predicted at virtually all time points.

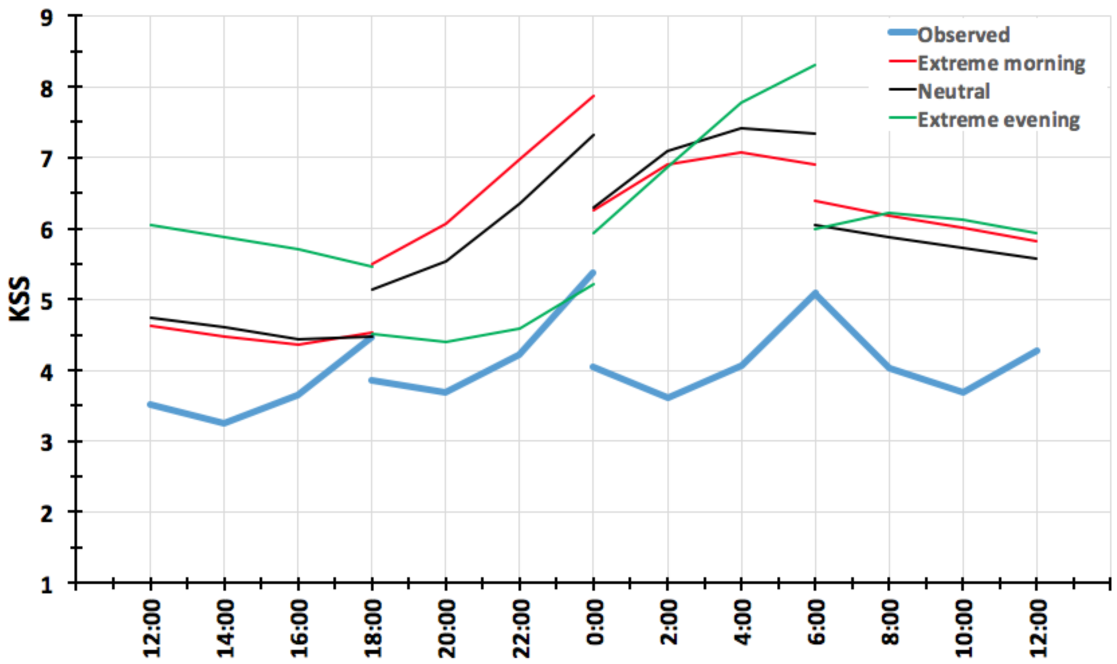
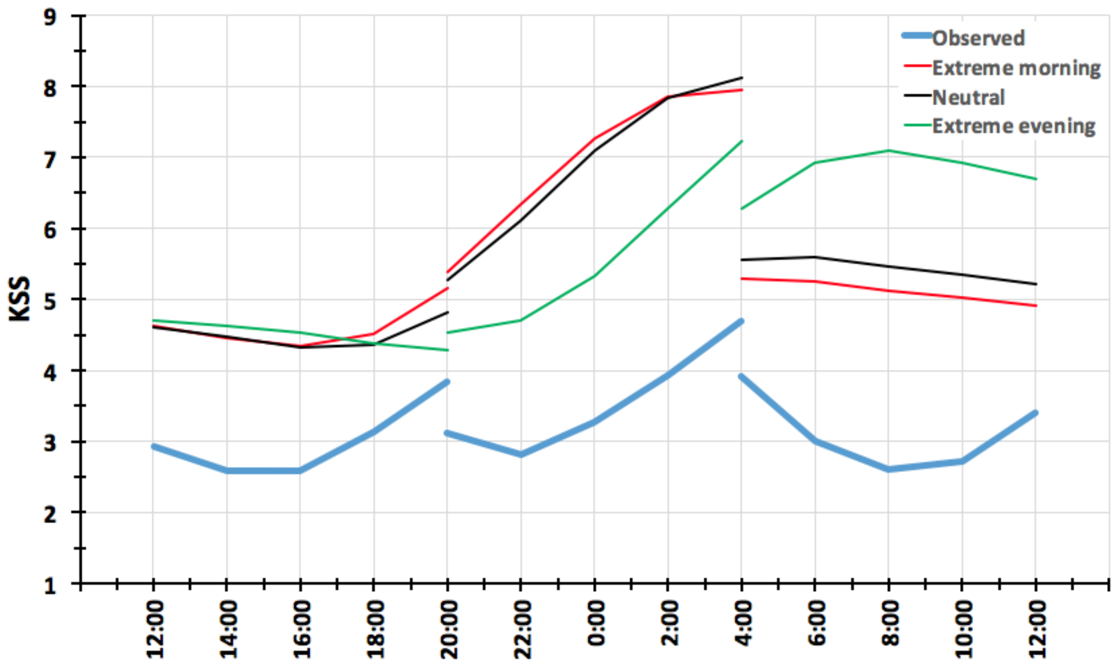
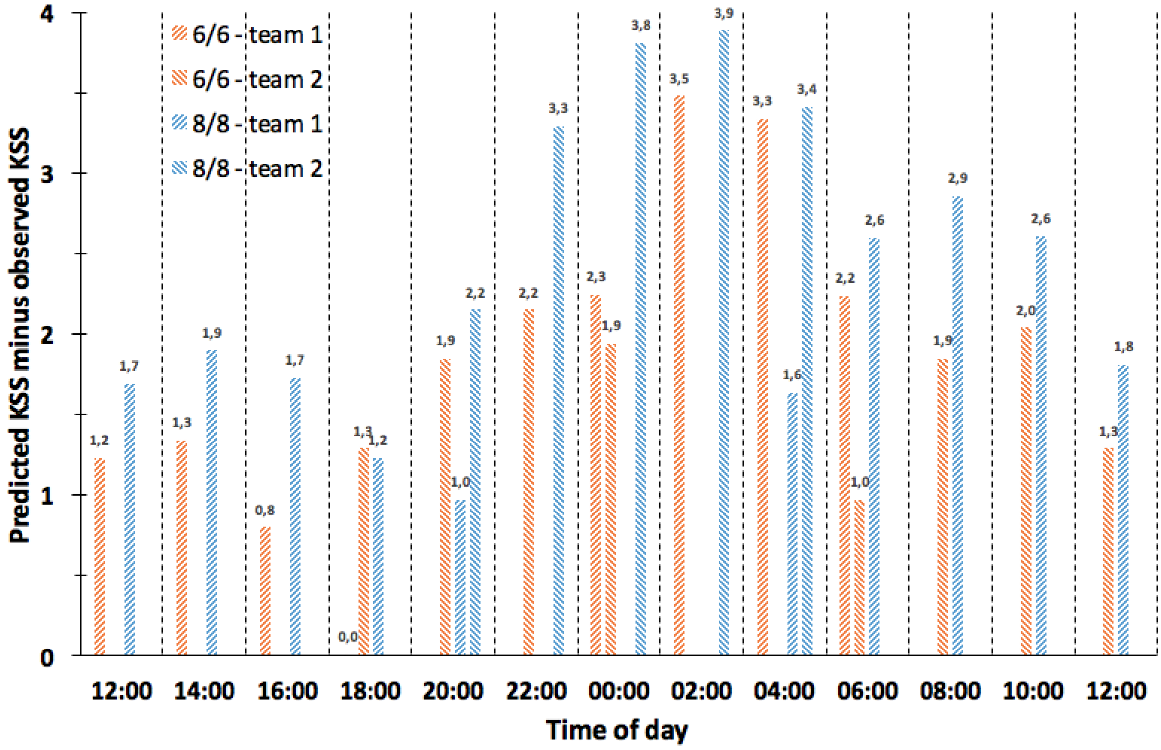


Figure 17. Comparing the ratings collected during the 8/8 part of the on-board study (blue lines) with the predicted ratings for different diurnal types (extreme morning type in red, neutral type in black, and extreme evening type in green) shows that self-reported sleepiness is considerably lower than predicted at virtually all time points.



Of particular interest in the current study is whether the observed difference between KSS ratings collected in the on-board study, versus those as predicted by the model, is larger under any of the two watch keeping regimes. Focusing on a neutral diurnal type only (assumed to represent a larger proportion of the study population than any of the extreme diurnal types), it can indeed be observed that the discrepancy between observed and predicted sleepiness is larger under the 8/8 regime (on average 2,4 KSS points) than under the 6/6 regime (on average 1,8 KSS points). This may either indicate that the model somehow is better at predicting under 6/6 conditions than under 8/8 conditions or it may indicate that participants, obviously not blinded for the watch keeping regime they were working under, did in fact try to make things look even better under 8/8 than under 6/6. When plotting these differences for all time points (Figure 18), a highly interesting picture arises, where the discrepancies tend to peak at the most vulnerable time points during the day, that is between 22:00 and 06:00. Again, this could be a consequence of the model having reduced capabilities of predicting under extreme conditions. A more likely explanation, however, is that this phenomenon is a consequence of suffering from high levels of sleepiness. Introspective capabilities are known to be reduced under conditions of severe sleepiness, making the accuracy of KSS ratings as recorded under these conditions less accurate.

Figure 18. Differences between predicted and observed KSS values as a function of time of day. Positive values (all) indicate that observed KSS was lower than predicted.



4 CONCLUSIONS`

Some problems were encountered in the data collection phase. These were mostly due to the type of operations these vessels undertake. Although an optimal set of data was not achieved, and the factors described in the text explain some of the reasons for this, it is possible to come to some definitive conclusions about the 8/8 system.

However, because of the special nature of the operations conducted by these vessels, the conclusions reached in this report may not be generalizable to other 8/8 situations and further testing is recommended on a case by case basis.

Theoretical and empirical evidence obtained in the project point in the same direction: the 6/6 watch keeping regime is worse than the 8/8 watch keeping regime in terms of the quantity and quality of sleep obtained. Both more and better sleep is obtained when working under 8/8 conditions and the levels of experienced sleepiness, stress, and fatigue are lower. Concerning sleep and sleepiness, these observations were also predicted by the model. Although correlational analyses between theory and practice may point to the fact that participants may have had the intention of letting the 8/8 system look better, it does not weaken the overall conclusion that both theory and practice point significantly into one and the same direction.

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APPENDIX A: Participants

39 participants agreed to take part, with only one refusal. 38 participants actually returned useable diaries. 30 Actiwatches were distributed, but two were lost.

	Chief Officer	Second Officer	Able Seaman	Totals
Diaries (40)	10	9	18	37
Actiwatches (30)	10	7	10	28

Notes:

2 lost watches (AB and 2/0)
1 refusal (2/O)
2 agreed to participate , but did not return diaries (AB)