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## Sleepiness of day shift workers and watchkeepers on board at high seas: a cross-sectional study

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4 **Sleepiness of day shift workers and watchkeepers on board at high seas: a cross-**  
5 **sectional study**  
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## ABSTRACT

### Objectives

To estimate the relevance of sleepiness on duty among day shift workers and watchkeepers on board.

### Design

Cross-sectional survey in a maritime field study.

### Setting

12 shipping companies with container vessels under German management.

### Participants

The whole crew (75 day shift workers and 123 watchkeepers) during 18 voyages on container ships.

### Outcome measures

Sleepiness on duty and efficiency of sleep by using pupillometry (in a cross-shift design) and SenseWear® armband activity monitor.

### Results

The watchkeepers showed significantly shorter sleep periods than day shift workers (5.5 h vs. 5.8 h). The average efficiency of sleep was 69.6% and significantly lower among watchkeepers (OR 0.48; 95% CI 0.26-0.88). 396 pupillometric examinations were carried out and revealed 88 study members (22.2%) with a pupillary unrest index (rPUI) in a range characterized as “unfit for duty” and 110 seafarers (27.8%) categorized as “particular attention required”. The average rPUI was similar between day shift workers and watchkeepers.

According to the Epworth Sleepiness Scale, the subjective judgement of 70 seafarers (35.4%) revealed recent daytime sleepiness, which was similarly often stated by day shift workers and watchkeepers. Based on the Stanford Sleepiness Scale (SSS), a measurable cross-shift increase in the SSS value during the examined shift could be objectified, especially among watchkeepers. The amount of time already spent on the vessel at the time of the present examination was significantly associated with the rPUI ( $p= 0.009$ ).

### Discussion

Sleep periods of both the day shift workers and the watchkeepers aboard vessels were alarmingly short and sleep efficiency was low. Sleepiness on duty is similarly prevalent

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3 among day shift workers and watchkeepers and seems to depend partly on the cumulative  
4 working period on the vessels.  
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## 6 **Conclusion**

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8 Preventive measures need to be taken by the shipping industry.  
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13 **Key words:** *occupational medicine, sleepiness, seafaring, pupillometry*  
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## 16 **Strengths and limitations of this study**

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19 ➤ The present maritime field study provides for the first time the relevance of seafarers'  
20 sleepiness on duty during the sea passage, with the distinction of crew members with and  
21 without watchkeeping duties.  
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23 ➤ The present study analysed seafarers' sleepiness on duty by applying both subjective and  
24 objective methods that are less dependent on the participants' motivation (pupillometry,  
25 armband activity monitor).  
26  
27 ➤ The study was carried out in a cross-sectional design that does not allow evaluation of  
28 long-time effects of sleepiness.  
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30 ➤ Due to the various occupational and ethnic groups on board, the crews are very  
31 heterogeneous; that makes the interpretation and comparison of sleeping behaviours  
32 difficult.  
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## 38 **INTRODUCTION**

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41 Long and irregular working hours each day, combined with sleep deficiency and long periods  
42 of work at sea, are crucial risk factors for increased sleepiness on duty among seafarers.[1,2]  
43 Strong weather conditions can also affect seafarers' performance, increase the risk of error  
44 and, consequently, cause injuries or fatalities to personnel. Psychological strain in maritime  
45 professions can also lead to psychosomatic diseases including burnout syndrome or  
46 exhaustion (fatigue).[3] It has been stated that shipping crews suffer from psychophysical  
47 exhaustion/strain due to stress and decreased periods and quality of sleep.[4] Thus, seafaring  
48 still ought to be considered a high-risk profession for psychophysical exhaustion.[5,6]  
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55 Three voyage episodes can be distinguished on board: stays in port, river passages and sea  
56 passages. During the first two voyage episodes, the seafarers are often exposed to high  
57 psychophysical stressors caused by unforeseeable and external demands that possibly need to  
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3 be addressed at chronobiologically adverse times (e.g. embarkation and disembarkation,  
4 loading and unloading, exchange of information with port authorities). During the sea passage,  
5 the engine room personnel, the electricians and the galley staff can often adhere to a regular  
6 working day of 8 hours (day shift workers). This is better suited to chronobiologically adapted  
7 sleep periods and can thus partially compensate for a potential sleep deficiency.[7] In contrast,  
8 due to obligatory navigation manoeuvres, nautical officers and a large number of the deck  
9 ratings are often required to work in a 24-hour shift system during sea passages  
10 (watchkeepers).  
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16 Nowadays, merchant ships operating internationally generally run on a 4/8-hour watch shift  
17 system. That means that three nautical officers alternate in a system, which includes four hours  
18 on duty and eight hours off for each of them. Van Leeuwen, Kircher et al. (2013)[8] measured  
19 the effect of a 4/8-hour watch shift system on the alertness of seafarers in a ship simulator.  
20 They observed that especially additional overtime was associated with a subjective and  
21 objective increase in sleepiness.  
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26 It has been described that watchkeeping, critical assignments during night time and irregular  
27 working periods can lead to disruptions of the crews' circadian rhythm as a precondition for  
28 sleepiness on board.[9] Dohrmann and Leppin (2017)[7] performed a systematic analysis and  
29 quality assessment of seafarers' fatigue. They observed that working nights was most fatiguing  
30 and that fatigue levels were higher toward the end of watch or shift. According to the review,  
31 particularly the psychosocial work environment (including day shift workers besides the  
32 watchkeepers) had received little attention. However, the monotonous noise of the vessel's  
33 engine, the smooth ship's vibrations and the continuous slow ship's movements (during calm  
34 weather conditions) can lead to sleepiness of the whole crew on board. Higher levels of  
35 exposition to noise and vibrations can also increase sleep troubles/problems and poorer sleep  
36 quality when impacting on employees throughout the day.[10]  
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45 Working in a maritime setting is characterized by a wide variety of occupations with numerous  
46 fatiguing physical and mental strains, depending on the type of job.[11] The available maritime  
47 fatigue studies have only focused on watch officers as crew members who typically also work  
48 during night hours.[2,8,12-14] Thus, there is a lack of knowledge about sleepiness at high seas  
49 among the other shipboard occupational groups, including the day shift workers. Knowing who  
50 is affected by severe sleepiness on board is of great importance to facilitate its prevention.  
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55 The present maritime field study analysed for the first time the relevance of seafarers'  
56 sleepiness on duty during the sea passage, with the distinction of day shift workers and  
57 watchkeepers on board.  
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## METHODS

### Study sample

A medically trained scientist accompanied 18 sea voyages on container ships operating in the Baltic Sea and examined the crew members on board. 206 out of 225 seafarers took part in the study (participation rate 91.6%). Only the results of those 198 seafarers were included who could be interviewed and examined (pupillometry) in a cross-shift design (both at the very beginning of their shift and at the end). Taking part in this study was voluntary and the individual data was pseudonymized. No patients were involved in this study. All participants gave their informed consent before taking part in this study. The study was approved by the Ethics Committee of the Hamburg Medical Association (no PV4395).

The 198 seafarers were classified into two occupational groups (75 day shift workers and 123 watchkeepers) (Tab. 1). Slightly more watchkeepers than day shift workers originated from Southeast Asian (109 from the Philippines and 4 from other Southeast Asian countries). The median age of the exclusively male study sample was 36.7 years (19 - 67 years) and significantly higher among the day shift workers. Furthermore, the day shift workers had a somewhat higher body weight than the watchkeepers. No differences were observed in the chronotype when comparing watchkeepers with day shift workers. The difference between the two occupational groups in terms of their marital status and the presence of children was not noteworthy. 49.0% of the seafarers either smoked or were former smokers.

|   | <b>Day shift workers</b><br><i>(54 engine room personnel,<br/>16 electricians, 5 galley staff)</i> | <b>Watchkeepers</b><br><i>(46 nautical officers, 77<br/>deck ratings)</i> |
|---|--|---|
| <b>Number; n (%)</b>                        | 75 (37.9%)   | 123 (62.1%)   |
| <b>Age; years (min-max)</b>                 | 44 (19-67)   | 35 (19-63)  |
| <b>BMI; median (min-max)</b>                | 26 (19-40)   | 24 (17-36)  |
| <b>Morning Evening Questionnaire, n (%)</b> |  |   |
| <i>Morning type</i>                         | 45 (60.0%)   | 68 (55.2%)  |
| <i>Intermediate type</i>                    | 24 (32.0%)   | 46 (37.4%)  |
| <i>Evening type</i>                         | 6 (8.0%)   | 9 (7.4%)  |
| <b>Origin; n (%)</b>                        |  |   |
| <i>European</i>                             | 38 (50.7%)   | 47 (38.2%)  |
| <i>Southeast Asian</i>                      | 37 (49.3%)   | 76 (61.8%)  |
| <b>Married; n (%)</b>                       | 53 (70.7%)   | 87 (70.7%)  |
| <b>Children; n (%)</b>                      | 53 (70.7%)   | 82 (66.7%)  |
| <b>Smoking status; n (%)</b>                |  |   |
| <i>Never smoked</i>                         | 36 (48.0%)   | 65 (52.8%)  |
| <i>Former smoker/smoker</i>                 | 39 (52.0%)   | 58 (47.2%)  |

**Tab. 1** Demographic and lifestyle parameters by occupational groups on board

To assess long-term effects on sleep during their current period on board, the participants were additionally grouped in respect of their stay on board at the time of examination (< 2 months, 2-5 months and > 5 months).



## Examination procedure

All seafarers taking part in the study were examined with the SenseWear® armband monitor and pupillometry both during shifts and during time off (including sleep time). The present study monitored the sleep of all seafarers in a continuous mode during a period of at least 72 hours of observation. The average period of wearing the armband monitor was 66.3 h (SD 14.8 h) (>92% of observation time) and did not differ between the occupational groups. The pupillometric examination took place within this observation period.

## Efficiency of sleep

The *SenseWear® armband activity monitor* is a device that weighs 82 g and is worn on the right upper arm just above the triceps muscle according to its validation requirements. The monitor is designed to analyse the profile of physical activity (movement, lying down or sleeping). The collected information allows the estimation of sleep efficiency by establishing the ratio of the duration of sleep and the time spent lying down. Thus, efficiency of sleep expresses the time spent actually sleeping while lying down.

The armband monitor has already been successfully applied in many studies as a detector of sleep.[15-19] Current studies reveal that the total sleep time and time in bed correlate significantly between the measurements of the armband monitor and the polysomnography ( $p < 0.001$ ); the armband has proved to be superior in comparison to other activity monitors.[16]

## Pupillometry

The device *Fit-For-Duty* by AmTech was used to conduct pupillometric examinations. The Pupillographic Sleepiness Test is considered an objective method for documenting sleepiness by monitoring spontaneous and unconscious oscillations of the pupil without stimulating light. The result is a pupillogram, which can be used to deduct the pupillary unrest index (rPUI). This parameter therefore is an objective measure for the variance of the diameter of the pupil. A recent study suggested the Pupillographic Sleepiness Test as a reliable measurement for detecting drowsiness-related impairment.[20]

The rPUI is compared to standard values. Results  $< 1.02$  are considered normal. "Particular attention required" is the characterization of results  $\geq 1.02$  und  $< 1.53$ . An index  $\geq 1.53$  is

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3 rated as “unfit for duty”. This methodology has repeatedly been used in scientific studies to  
4 assess sleepiness.[21-23]  
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7 During a sea passage, the pupillometric examination was performed twice according to a  
8 cross-shift design for all 198 seafarers included in the study sample. The chosen sea  
9 passages lasted for at least 24 hours and therefore allowed a regular operation of the vessel  
10 and predictable working procedures. The examination was performed within a timeframe of  
11 30 minutes at the beginning and before the end of a regular working shift period.  
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15 The engine room personnel, the electricians and the galley staff (without watchkeeping duties)  
16 were examined during an average work shift that lasted 8 hours (most likely from 8:00 h to  
17 17:00 h including a lunch break of 1 hour). The watchkeepers were randomly examined during  
18 one of the six shift periods (0-4 h, 4-8 h, 8-12 h, 12-16 h, 16-20 h und 20-24 h) with the aim of  
19 achieving an equal representation of the periods (about 20 watchkeepers/shift period).  
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## 27 **Questionnaire**

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29 In the framework of a standardized interview, all seafarers were asked about their  
30 demographic data, their subjective physical and mental stress level, their sleep period before  
31 the examined shift and their current working time. Additionally, chronic fatigue was estimated  
32 by using the Epworth Sleepiness Scale.[24] The Stanford Sleepiness Scale assessed the  
33 sleepiness before and after a shift. In order to identify the daily peak of alertness, the seafarers  
34 filled in the Morningness-Eveningness Questionnaire (rMEQ).[25] The findings allowed the  
35 allocation of the participants to chronotypes.  
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## 44 **Statistics**

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46 Statistic analysis was performed with SPSS (version 24, IBM Corporation). After investigation  
47 for normal distribution, the non-parametric tests (Mann Whitney-U test, Wilcoxon test) were  
48 used. The Chi-squared test was applied to analyse differences in frequencies of parameters.  
49 Crude odds ratio (OR) including 95% confidence intervals was calculated by binary logistic  
50 regression. For adjustment reasons, age, rank (officer vs. rating), the examination time of  
51 day and duration of stay on board at the time of examination were added. Furthermore,  
52 correlations were analysed by using the Spearman test. All indicated p-values were two-  
53 sided, and a p-value of < 0.05 was regarded as statistically significant.  
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## RESULTS

The number of months day time workers had already spent on the vessel at the time of examination and during their current contract was similar to that of watchkeepers. In particular, the stratification of the seafarers in tertile concerning their recent stay on board did not reveal any differences (Tab. 2).

The Epworth Sleepiness Scale (ESS) showed that 70 seafarers (35.4%) had recently been suffering from daytime sleepiness. Depending on a growing stay on board, the ESS value increased significantly ( $p= 0.004$ ). No differences were observed when differentiating according to the obligation to perform watchkeeping duties ( $p= 0.113$ ). Younger seafarers below the age median of 37 years indicated daytime sleepiness more often than older colleagues ( $p= 0.014$ ).

|   | Occupational groups                         |   | <i>p</i> |
|---|---|---|----------|
|   | <i>Day shift workers</i><br>( <i>n=75</i> ) | <i>Watchkeepers</i><br>( <i>n=123</i> ) |          |
| <b>Stay on board</b>                            |   |   |          |
| At the time of examination;<br>months (min-max) | 3 (1-12)                                    | 3 (0-11)                                | 0.837*   |
| Frequency according to<br>tertile; n (%)        |   |   |          |
| ≤ 2 months                                      | 28 (37.3%)                                  | 45 (36.6%)                              |          |
| > 2 and ≤ 5 months                              | 28 (37.3%)                                  | 45 (36.3%)                              | 0.973#   |
| > 5 months                                      | 19 (25.3%)                                  | 33 (26.8%)                              |          |
| Scheduled (min-max)                             | 7 (2-13)                                    | 8 (1-12)                                | 0.719*   |
| <b>Epworth Sleepiness Scale (ESS)</b>           |   |   |          |
| Score value (SD) <sup>1</sup>                   | 8 (0-15)                                    | 8 (0-21)                                | 0.113#   |
| ≥ Cut off value (10), n (%)                     | 26 (34.7%)                                  | 44 (35.8%)                              | 0.875#   |

\*Mann Whitney-U test #Chi-squared test <sup>1</sup>sleepiness scale from 0 ("no chance to doze in") up to 24 ("maximum chance to doze in")

**Tab. 2** Stay on board and subjective assessment for daytime sleepiness

### Cross-shift examinations

To analyse the recent alertness attributed to a representative shift, 198 seafarers were asked to participate in a cross-shift examination. According to the results of the armband monitor, the sleep time before the examined shift lasted for 5.6 hours (SD 1.0) per 24 h period, while watchkeepers had significantly shorter sleep durations compared to the day shift workers (Tab. 3). The working hours during the current shift did not differ between these groups. Concerning their subjective stress level during the shift examined, significantly more watchkeepers experienced mental demands than day shift workers (OR 2.35; 95% CI 1.24-4.44). After adjustment for age, ranking, examination time of day and recent number of months at the time of investigation, this elevated risk for mental stress remained significant among watchkeepers.

During the examined shift, the average sleep efficiency was 69.3% and was significantly lower among watchkeeping seafarers than day shift workers (OR 0.48; 95% CI 0.26-0.88). This finding was independent of the age, ranking, time of day of the examination and the recent duration of shipboard stay.

Before their shift, the mean value on the Stanford Sleepiness Scale (SSS) was 2.6 (SD 1.4) (2= "functioning at high levels, but not fully alert"; 3= "awake, but relaxed; responsive but not fully alert"); after the work shift, the level of sleepiness was significantly higher (3.2 (SD 1.8)) (Wilcoxon test:  $p= 0.001$ ) indicating a measurable increase in the subjective sleepiness in the course of a shift. This was especially true for watchkeepers (Tab. 3). Consequently, more watchkeepers reported current sleepiness than day shift workers after the examined shift.

A remarkable number of 35 seafarers (17.7%) reported a level of sleepiness on duty of 6/7 on the SSS (6= "sleepy, woozy, fighting sleep, prefer to lie down"; 7= "no longer fighting sleep; sleep onset soon; having dream-like thoughts") at the end of their shift. According to SSS, it turned out that more young seafarers considered themselves to be tired (cross-shift SSS of all crew members below and above the median age of 37 years: 3.1 vs. 2.6;  $p= 0.011$ ). Focusing on the group of watchkeeping seafarers, those who were on duty between 00:00-04:00 h and 04:00-08:00 h more often displayed severe sleepiness on duty at the end of their shift (SSS $\geq$  5) (50.0% and 72.2% respectively).

The 396 pupillometric examinations (during the first and the last 30 minutes of a shift) revealed that the change in rPUI values during the cross-shift observation did not reach a significant level in intra-individual comparison (mean rPUI before vs. after the working shift: 1.14 vs. 1.19;

cross-shift rPUI change:  $p=0.355$ ). After stratification, the intra-individual cross-shift change in rPUI values was also not dependent on the occupational groups (Tab. 3).

The objective sleepiness on duty in the study sample was not dependent on age (only a slight tendency for younger seafarers after shift;  $p=0.064$ ). During the examination, 12 seafarers fell asleep and therefore were assigned to the group “unfit for duty”. The pupillary unrest index in 88 examinations showed the seafarers were “unfit for duty”; additionally “particular attention required” was classified in 110 cases (27.8%). Therefore, only half of the examinations were “normal”. No differences were observed in the pupillary unrest index between seafarers with and without watchkeeping duties.

In concordance to their subjective self-report in SSS, watchkeepers displayed somewhat higher rPUI values after the shift than day shift workers (Tab. 3). The analysis of the correlation of the subjective assessment of sleepiness on duty (SSS) with the objective measures of pupillometry only revealed a very weak correlation after the shift ( $r=0.185$ ;  $p=0.009$ ).

Within the group of watchkeepers, stronger sleepiness on duty ( $rPUI \geq 1.2$ ) after a shift lasting from 00:00-04:00 h and from 04:00-08:00 h could be objectified (75.0% and 55.6% respectively).

|   | Occupational groups             |                             |                           |                              |
|---|---------------------------------|-----------------------------|---------------------------|------------------------------|
|   | <i>Day shift workers</i> (n=75) | <i>Watchkeepers</i> (n=123) | <i>Crude OR*</i> (95% CI) | <i>Adjusted OR#</i> (95% CI) |
| <b>Time periods in the context of the current pupillometric examination, hours (SD)</b> |                                 |                             |                           |                              |
| Sleep period before <sup>1</sup>  | 5.8 (1.1)                       | 5.5 (1.0)                   | <b>2.05 (1.10-3.83)</b>   | <b>2.32 (1.21-4.47)</b>      |
| Working hours   | 9.5 (1.5)                       | 9.6 (1.8)                   | 1.02 (0.55-1.88)          | 0.74 (0.38-1.44)             |
| <b>Subjective stress level during examined shift, n (SD)</b>                            |                                 |                             |                           |                              |
| Physical <sup>2</sup>   | 48 (64.0%)                      | 78 (63.4%)                  | 0.96 (0.52-1.79)          | 0.51 (0.24-1.08)             |
| Mental <sup>3</sup>   | 41 (54.7%)                      | 94 (76.4%)                  | <b>2.35 (1.24-4.44)</b>   | <b>2.18 (1.08-4.40)</b>      |
| <b>Sleep efficiency<sup>1</sup></b>   |                                 |                             |                           |                              |
| - Mean (%)  | 72.7% (11.8%)                   | 67.9% (12.2%)               | <b>0.48 (0.26-0.88)</b>   | <b>0.48 (0.25-0.91)</b>      |

**Stanford Sleepiness Scale (SSS)<sup>4</sup>****Cross-shift,**

|                          |           |           |                  |                  |
|--------------------------|-----------|-----------|------------------|------------------|
| - Mean (SD) <sup>5</sup> | 2.6 (1.4) | 3.1 (1.7) | 0.73 (0.48-1.10) | 0.84 (0.55-1.29) |
|--------------------------|-----------|-----------|------------------|------------------|

**Time depending**

|                                 |           |           |                  |                  |
|---------------------------------|-----------|-----------|------------------|------------------|
| - At the beginning of the shift | 2.5 (1.4) | 2.6 (1.5) | 1.07 (0.59-1.95) | 0.91 (0.49-1.70) |
|---------------------------------|-----------|-----------|------------------|------------------|

|                   |           |           |                         |                  |
|-------------------|-----------|-----------|-------------------------|------------------|
| - After the shift | 2.8 (1.4) | 3.5 (1.9) | <b>1.81 (1.01-3.25)</b> | 1.25 (0.66-2.37) |
|-------------------|-----------|-----------|-------------------------|------------------|

**Pupillary unrest index (rPUI)****Cross-shift,**

|                          |             |             |                  |                  |
|--------------------------|-------------|-------------|------------------|------------------|
| - Mean <sup>5</sup> (SD) | 1.14 (0.66) | 1.18 (0.65) | 0.92 (0.61-1.40) | 1.05 (0.70-1.61) |
|--------------------------|-------------|-------------|------------------|------------------|

**Time depending**

|                                 |             |             |                  |                  |
|---------------------------------|-------------|-------------|------------------|------------------|
| - At the beginning of the shift | 1.14 (0.67) | 1.12 (0.62) | 0.96 (0.52-1.74) | 0.86 (0.46-1.61) |
|---------------------------------|-------------|-------------|------------------|------------------|

|                   |             |             |                  |                  |
|-------------------|-------------|-------------|------------------|------------------|
| - After the shift | 1.13 (0.66) | 1.23 (0.65) | 1.55 (0.85-2.84) | 1.31 (0.70-2.46) |
|-------------------|-------------|-------------|------------------|------------------|

**Level (n=396) of sleepiness on duty<sup>5</sup> n (%)**

|                     |            |             |  |  |
|---------------------|------------|-------------|--|--|
| - None <sup>6</sup> | 78 (52.0%) | 120 (48.8%) |  |  |
|---------------------|------------|-------------|--|--|

|  |            |            |       |  |
|--|------------|------------|-------|--|
| - Particular attention required <sup>7</sup> | 39 (26.0%) | 71 (28.9%) | 0.789 |  |
|--|------------|------------|-------|--|

|                               |            |            |  |  |
|-------------------------------|------------|------------|--|--|
| - Unfit for duty <sup>8</sup> | 33 (22.0%) | 55 (22.3%) |  |  |
|-------------------------------|------------|------------|--|--|

<sup>†</sup>the crude OR bases on the median of parameters and includes differences between occupational groups and the examination time of day <sup>#</sup>adjusted for age, rank (officer vs. rating) and duration of stay on board at the time of examination

<sup>1</sup>according to measurements with the armband monitor, related to an average 24 hour period

<sup>2</sup>"have you experienced physical stress during the examined shift?" <sup>3</sup>"have you experienced mental stress during the examined shift?"

<sup>4</sup>SSS-scale from 1 ("feel active and vital") up to 7 ("almost dreaming/falling asleep")

<sup>5</sup>all values exploited (before and after the shift) <sup>6</sup>rPUI < 1.02 <sup>7</sup>rPUI ≥ 1.02 and < 1.53 <sup>8</sup>rPUI ≥ 1.53

**Tab. 3 Cross-shift examination concerning sleep characteristics**

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3 Regardless of the occupational groups, the objective sleepiness on duty (rPUI) did not  
4 correlate to the sleep period before the examined shift, the sleep efficiency, the current  
5 working hours and the objective assessment of the ship's motion according to the ship's  
6 journal parameters. An association was observed, however, between the duration of time  
7 already spent on board at the time of the seafarers' examination and the rPUI ( $p= 0.009$ ).  
8 The stratification according to the duration of stay on board indicates that the association  
9 was especially true for those seafarers with a longer stay on the vessels (pre-shift rPUI after  
10 stay of less than 2 months, 2-5 months and more than 5 months: 1.06, 1.09 and - much  
11 higher - 1.32). The bivariate grouping of the crew in their stay of less vs. more than 5 months  
12 showed significant pre-shift differences in rPUI (1.08 vs. 1.32;  $p= 0.002$ ).  
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## 22 **DISCUSSION**

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24 Being a seafarer requires strong mental stability and a robust physical constitution, along  
25 with an adaptive and flexible attitude. However, stress and fatigue can hinder maritime  
26 professionals in performing effectively.[26] Seafarers spend both their working and leisure  
27 time over a couple of months in the restricted shipboard environment that can impact sleep  
28 quality and lead to sleepiness.[5] In the present study, a significantly lower sleep efficiency  
29 averaging at 69.3% and a higher subjective sleepiness assessment (SSS) after the shift  
30 were found among watchkeepers compared to day shift workers. In addition, the  
31 examinations carried out on board objectified critically short durations of the seafarers' sleep  
32 average (5.6 h per 24 h) particularly among watchkeepers.  
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39 Especially the short sleeping times correspond very well with the results of international  
40 studies.[27] Sleep periods on board are often interrupted (potentially due to ship's  
41 movements or sudden noise evoked by the handling of containers in harbours).[28] These  
42 interruptions are often an inevitable consequence of the watch shift requirements with two 4-  
43 h working shifts per day. Thus, on any watch system it is common that seafarers have  
44 several sleep episodes per 24-h period. Daytime sleep is usually much less efficient than  
45 sleep obtained at the circadian nadir.  
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50 Although this study has not proven that sleepiness on duty depends directly on disturbances  
51 of the sea during passages, we measured low sleep efficiency. This means that not only the  
52 amount, but also the quality of sleep is insufficient among the examined seafarers on board.  
53 Frequent sleep disruptions can impair alertness to a great degree and consequently lead to  
54 an increased risk of accident on board.[29]  
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3 In contrast to a similar physical stress level and working hours per day, the crew members  
4 with watchkeeping duties experienced mental stress subjectively more frequently than day  
5 shift workers. This was probably due to their reduced and interrupted sleep time as well as  
6 their high job responsibility, which represents a distinct mental stressor. Correspondingly, the  
7 watchkeepers starting with a similar subjective sleepiness level compared with the day shift  
8 workers had a significantly more pronounced increase of their sleepiness after the cross-shift  
9 examination. Although no significance level was reached, the cross-shift pupillometry of  
10 watchkeepers also indicated a higher level of objective sleepiness after the shift than that of  
11 day shift workers.  
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18 According to Wilhelm (2008)[30], severe sleepiness is displayed by drivers who did not sleep  
19 during the chronobiologically relevant time frame (0:00 h - 05:00 h). In the maritime setting,  
20 this especially applies to watchkeepers. These crew members, who are on duty during the  
21 inconvenient time frames between 0:00-04:00 h and 04:00-08:00 h, reported the expected  
22 subjective severe sleepiness, which could also be objectified by pupillometric measurements.  
23 In this context, it has to be taken into account that most fatigue-induced shipping disasters  
24 take place in these time frames.[8]  
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Watchkeepers are habitual shift workers, often experiencing circadian misalignment due to  
their irregular work/rest schedules. This might be one explanation as to why the small  
number of available maritime field studies about seafarers' fatigue has exclusively focused  
on watchkeepers. Importantly, this study demonstrates that day shift workers also often  
experience severe sleepiness; more than 20% of both the watchkeepers and the day shift  
workers were characterized as "unfit for duty" during their regular shift and only every second  
pupillary measurement was regarded normal. The fact that 12 seafarers had fallen asleep  
during the 11-min pupillary examination and that 35 crew members regarded themselves as  
very sleepy post-shift ( $SSS \geq 6$ ) confirms these alarming pupillometric results. In light of the  
strong impact on the ships' safety, further studies are urgently needed to examine and  
counteract the sleepiness of both the shipboard watchkeepers and the day shift workers.

The period already spent on the vessel at the time of the examination seems to influence  
sleepiness on duty. Officers, generally coming from European countries, normally have far  
shorter periods on board than ratings (averaging 2.5 vs. 4.1 months in a row). It is most likely  
that the differences detected in sleepiness on duty related to recent shipboard stay are  
mainly being caused by the cumulative working time on board. Daily sleepiness as a  
consequence of high work strain lasting for many months seems to be plausible. According  
to the present results, working periods below five months in a row seem to be reasonable for



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3 seafarers. Further studies are required to determine recommendations for maximum working  
4 periods on board.  
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7 Subjective assessments of sleepiness only displayed a weak correlation with the results of  
8 the pupillometry that could be objectified. This could lead to a misjudgement of their current  
9 psychophysical performance, which might also have safety implications. Younger and less  
10 experienced crew members reported more severe sleepiness on duty but did not display  
11 differences in their pupillometric measurements. In view of the frequently described high  
12 prevalence of fatigue-related accidents in seafaring, a high level of psychophysical stress,  
13 but also a misjudgement of their alertness is assumed. Thus, it is recommended to use  
14 complementary objective methods besides questionnaires in studies to determine the level of  
15 fatigue among examined employees.  
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19 Recent studies have described a difference in the circadian rhythm among various ethnic  
20 groups, for example more Africans were allocated to “morning type” compared to a fair-  
21 skinned reference group.[31,32] In the present study, the Morningness-Eveningness  
22 Questionnaire also revealed significant chronotypical differences between the members of  
23 this study sample when they were grouped according to their origin (data not shown);  
24 Southeast Asians were more frequently assigned to the morning type than Europeans (65.4%  
25 vs. 32.2%;  $p < 0.001$ ). Therefore, it is possibly easier for Southeast Asians than for  
26 Europeans to perform work duties at times considered to be chronobiologically inconvenient  
27 (e.g., from 04:00 h to 08:00 h). Future studies should explore possibilities and evaluate  
28 acceptance by the crew to develop more flexible shift scheduling that allows the  
29 consideration of chronotype and, possibly, individual preferences of the watchkeeping  
30 seafarers.  
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### 43 **Limitations**

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45 The present analysis has some limitations that need to be addressed. Firstly, the sample size of  
46 this study is rather small, but in comparison to other available maritime studies the examined  
47 seafarer population is far larger. Secondly, the study was carried out in a cross-sectional design  
48 that does not allow the evaluation of long-time effects of sleepiness. Due to the permanently  
49 changing shipping crews on the vessels, it is hardly possible to arrange long-time follow-up  
50 examinations of a noteworthy proportion of seafarers. Thirdly, due to the various occupational  
51 and ethnic groups on board, the crews are very heterogeneous and that makes the  
52 interpretation and comparison of sleeping behaviours difficult, also when considering the large  
53 inter-individual and intra-individual variability in sleep. Fourthly, the present study design does  
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3 not provide information about the seafarers' sleep architecture. Sleep loss is generally  
4 compensated by changing the sleep architecture towards more so-called slow-wave sleep.  
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6 Despite these limitations, the present study analyses for the first time the relevance of  
7  
8 sleepiness in seafarers with and without watchkeeping duties that require further confirmation in  
9  
10 a larger cohort. Furthermore, the present maritime field study analysed the relevance of  
11  
12 seafarers' sleepiness on duty by applying various subjective and objective methods. Up to now,  
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14 most maritime studies about seafarers' sleepiness have not been carried out on board of  
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16 vessels and only rely on subjective methods.[33] Questionnaires are, however, subjective  
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18 instruments, consequently depending on self-reported data, so that underreporting might have  
19  
20 occurred.[34] Additionally, these subjective instruments do not reveal biophysiological  
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22 differences that might promote the understanding of sleepiness on board.[20,35]

23  
24 Nowadays, a variety of subjective and objective instruments exist for assessment of  
25  
26 excessive daytime sleepiness, including structured sleep history, sleep logs and sleep  
27  
28 questionnaires. The multiple sleep latency test, for example, is often used as an objective  
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30 measurement to evaluate sleep propensity. However, in view of the large overlap between  
31  
32 healthy subjects and subjects with sleep disorders, its use to assess sleepiness is  
33  
34 questionable.[36] Furthermore, its results are often jeopardized by motivational influences  
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36 and the last nap effect.[35] Consequently, a feasible and convenient method that is less  
37  
38 dependent on motivation - such as the pupillometry used in this study - seems to constitute  
39  
40 an enrichment in field studies.[20,36]

### 41 **Implications for clinicians and policy makers**

42  
43 Fatigue in the maritime setting could be counteracted by strict compliance with and monitoring  
44  
45 of the obligatory rest and sleep times. According to Allen, Wadsworth et al. (2007)[34] it is not  
46  
47 uncommon in seafaring for legal obligations to be neglected, for example by ignoring the  
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49 minimum safety levels for crewing on board. To reduce the seafarers' workload on board during  
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51 the vessel's stay in the port, some job duties could be transferred to land-based workers ashore.

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53 In light of the frequently objectified sleepiness on duty within the study sample, training  
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55 should be offered for shipboard crews to improve sleep hygiene and techniques to support  
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57 short-term recreation, such as power napping. This training should be accompanied by the  
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59 strengthening of the seafarers' individual resources (e.g. training to cope with stress for  
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health promotion[37]) to enable them to compensate for the inevitable psychophysical strain  
on board. Considering the present results, limiting the work periods of seafarers (perhaps to  
a maximum of five months) might be an essential preventive measure in a maritime setting.

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### **Contributors**

MO and HJJ gave substantial contributions to the conception or design of the work or the acquisition, analysis or interpretation of data. They were equally involved in drafting the work or revising it critically for important intellectual content. Both authors gave their final approval of the version published.

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### **Conflict of interest**

Both authors declare no conflicts of interest.

### **Patient consent**

Not required.

### **Ethics approval**

The study was approved by the Ethics Committee of the Hamburg Medical Association (no. PV4395).

### **Data sharing statement**

No additional data are available.

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STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

|                              | Item No | Recommendation   | Page No |
|------------------------------|---------|--|---------|
| <b>Title and abstract</b>    | 1       | (a) Indicate the study's design with a commonly used term in the title or the abstract   | 1       |
|                              |         | (b) Provide in the abstract an informative and balanced summary of what was done and what was found  | 2       |
| <b>Introduction</b>          |         |  |         |
| Background/rationale         | 2       | Explain the scientific background and rationale for the investigation being reported   | 3-4     |
| Objectives                   | 3       | State specific objectives, including any prespecified hypotheses   | 4       |
| <b>Methods</b>               |         |  |         |
| Study design                 | 4       | Present key elements of study design early in the paper  | 5       |
| Setting                      | 5       | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection  | 5,7     |
| Participants                 | 6       | (a) Give the eligibility criteria, and the sources and methods of selection of participants  | 5,6     |
| Variables                    | 7       | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable   | 7,8     |
| Data sources/<br>measurement | 8*      | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group                         | 7,8     |
| Bias                         | 9       | Describe any efforts to address potential sources of bias  | 8       |
| Study size                   | 10      | Explain how the study size was arrived at  | 5       |
| Quantitative variables       | 11      | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why   | 6       |
| Statistical methods          | 12      | (a) Describe all statistical methods, including those used to control for confounding  | 8       |
|                              |         | (b) Describe any methods used to examine subgroups and interactions  | 8       |
|                              |         | (c) Explain how missing data were addressed  |         |
|                              |         | (d) If applicable, describe analytical methods taking account of sampling strategy   |         |
|                              |         | (e) Describe any sensitivity analyses  |         |
| <b>Results</b>               |         |  |         |
| Participants                 | 13*     | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed            | 9       |
|                              |         | (b) Give reasons for non-participation at each stage   |         |
|                              |         | (c) Consider use of a flow diagram   |         |
| Descriptive data             | 14*     | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders   | 9       |
|                              |         | (b) Indicate number of participants with missing data for each variable of interest  |         |
| Outcome data                 | 15*     | Report numbers of outcome events or summary measures   | 9       |
| Main results                 | 16      | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 10-12   |



|                          |    |  |           |
|--------------------------|----|--|-----------|
|                          |    | (b) Report category boundaries when continuous variables were categorized  |           |
|                          |    | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   | 11        |
| Other analyses           | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses   |           |
| <b>Discussion</b>        |    |  |           |
| Key results              | 18 | Summarise key results with reference to study objectives   | 13        |
| Limitations              | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias                 | 15-<br>16 |
| Interpretation           | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 15-<br>16 |
| Generalisability         | 21 | Discuss the generalisability (external validity) of the study results  | 16        |
| <b>Other information</b> |    |  |           |
| Funding                  | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based              | 17        |

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

# BMJ Open

## Sleepiness of day workers and watchkeepers on board at high seas: a cross-sectional study

|                                 |   |
|---------------------------------|---|
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| <b>Primary Subject Heading</b>: | Occupational and environmental medicine   |
| Secondary Subject Heading:      | Occupational and environmental medicine   |
| Keywords:                       | occupational medicine, sleepiness, seafaring, pupillometry  |
|                                 |   |

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4 1 **Sleepiness of day workers and watchkeepers on board at high seas: a cross-sectional**  
5 2 **study**

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7 3 Marcus Oldenburg, Hans-Joachim Jensen

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9 4 Institute for Occupational and Maritime Medicine Hamburg (ZfAM), University Medical Center  
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24 16 ***Word count: 5,005 words***

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3 17 **ABSTRACT**  
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5 18 **Objectives**  
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7 19 To estimate the prevalence of sleepiness on duty among day workers and watchkeepers on  
8 20 board.

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11 21 **Design**  
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13 22 Cross-sectional survey in a maritime field study.  
14

15 23 **Setting**  
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17 24 10 shipping companies with container vessels under German management.  
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19 25 **Participants**  
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21 26 The whole crew (75 day workers and 123 watchkeepers) during 18 voyages on 18 different  
22 27 container ships.  
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25 28 **Outcome measures**  
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27 29 Sleepiness on duty and efficiency of sleep using pupillometry (in a cross-shift design) and the  
28 30 SenseWear® armband activity monitor.  
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31 31 **Results**  
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33 32 The watchkeepers showed significantly shorter sleep periods than day workers (5.5 h vs. 5.8  
34 33 h). The average efficiency of sleep was 69.6% and significantly lower among watchkeepers  
35 34 (OR 0.48; 95% CI 0.26-0.88). 396 pupillometric examinations were carried out and revealed  
36 35 88 study members (22.2%) with a pupillary unrest index (rPUI) in a range characterised as  
37 36 “unfit for duty” and 110 seafarers (27.8%) categorised as “particular attention required”. The  
38 37 average rPUI was similar between day workers and watchkeepers.  
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41 38 The Epworth Sleepiness Scale revealed recent daytime sleepiness in 70 seafarers, which  
42 39 was similarly often stated by day workers and watchkeepers. Based on the Stanford  
43 40 Sleepiness Scale (SSS), a measurable cross-shift increase in the SSS value during the  
44 41 examined shift was observed, especially among watchkeepers. The amount of time already  
45 42 spent on the vessel at the time of the present examination was significantly associated with  
46 43 the rPUI (p= 0.009).  
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49 50  
51 52 **Conclusion**  
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54 55 Sleep periods of both the day workers and the watchkeepers aboard vessels were alarmingly  
55 56 short and sleep efficiency was low. Sleepiness on duty is similarly prevalent among day  
56 57 workers and watchkeepers and seems to depend partly on the cumulative working period on  
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3 48 the vessels. Preventive measures need to be taken by the shipping industry to counteract  
4 49 fatigue (e.g. through compliance with the obligatory rest and sleep times).  
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9 51 **Key words:** *occupational medicine, sleepiness, seafaring, pupillometry*  
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11 52

### 12 13 53 **Strengths and limitations of this study**

- 14  
15 54 ➤ The present maritime field study provides for the first time the prevalence of seafarers'  
16 55 sleepiness on duty during the sea passage, drawing a distinction between crew members  
17 56 with and without watchkeeping duties.  
18  
19 57 ➤ The present study analysed seafarers' sleepiness on duty by applying both subjective and  
20 58 objective methods that are less dependent on the participants' motivation (pupillometry,  
21 59 armband activity monitor).  
22  
23 60 ➤ The study was carried out in a cross-sectional design that does not allow evaluation of  
24 61 long-time effects of sleepiness.  
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26 62 ➤ Due to the various occupational and ethnic groups on board, the crews are very  
27 63 heterogeneous; that makes the interpretation and comparison of sleeping behaviours  
28 64 difficult.  
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### 34 66 **INTRODUCTION**

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37 67 Long and irregular working hours each day, combined with sleep deficiency and long periods  
38 68 of work at sea, are crucial risk factors for increased sleepiness on duty among seafarers.[1,2]  
39 69 Strong weather conditions can also affect seafarers' performance, increase the risk of error  
40 70 and, consequently, cause injuries or fatalities to personnel. Psychological strain in maritime  
41 71 professions can also lead to psychosomatic diseases including burnout syndrome or  
42 72 exhaustion.[3] Some studies have stated that shipping crews suffer from psychophysical  
43 73 exhaustion/strain due to stress and decreased periods and quality of sleep.[4] Thus, seafaring  
44 74 still ought to be considered a high-risk profession for psychophysical exhaustion.[5,6]

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47 75 Three voyage episodes can be distinguished on board: stays in port, river passages and sea  
48 76 passages. During the first two voyage episodes, the seafarers are often exposed to high  
49 77 psychophysical stressors caused by unforeseeable and external demands that possibly need to  
50 78 be addressed at chronobiologically adverse times (e.g. embarkation and disembarkation,  
51 79 loading and unloading, exchange of information with port authorities). During the sea passage,  
52 80 the engine room personnel, the electricians and the galley staff can often adhere to a regular  
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3 81 working day of 8 hours (day workers). This is better suited to chronobiologically adapted sleep  
4 82 periods and can thus partially compensate for a potential sleep deficiency.[7] In contrast, due to  
5 83 obligatory navigation manoeuvres, nautical officers and a large number of the deck ratings are  
6 84 often required to work in a 24-hour shift system during sea passages (watchkeepers).  
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10 85 Nowadays, merchant ships operating internationally generally run on a 4/8-hour watch shift  
11 86 system. That means that three nautical officers alternate in a system which includes four hours  
12 87 on duty and eight hours off for each of them. Van Leeuwen, Kircher et al. (2013)[8] measured  
13 88 the effect of a 4/8-hour watch shift system on the alertness of seafarers in a ship simulator.  
14 89 They observed that especially additional overtime was associated with a subjective and  
15 90 objective increase in sleepiness. The authors also showed sleepiness increasing with time on  
16 91 watch and peaking at the end of a watch.  
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22 92 It has been described that watchkeeping, critical assignments during night time and irregular  
23 93 working periods can lead to disruptions of the crews' circadian rhythm as a precondition for  
24 94 sleepiness on board.[9] Dohrmann and Leppin (2017)[7] performed a systematic analysis and  
25 95 quality assessment of seafarers' fatigue. They observed that working nights was most fatiguing  
26 96 and that fatigue levels were higher toward the end of a watch or shift. According to the review,  
27 97 particularly the psychosocial work environment (including day workers besides the  
28 98 watchkeepers) had received little attention. However, the monotonous noise of the vessel's  
29 99 engine, the smooth ship's vibrations and the continuous slow ship's movements (during calm  
30 100 weather conditions) can lead to sleepiness of the whole crew on board. Higher levels of  
31 101 exposure to noise and vibrations can also increase sleep troubles/problems and poorer sleep  
32 102 quality when impacting on employees throughout the day.[10]  
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40 103 Working in a maritime setting is characterised by a wide variety of occupations with numerous  
41 104 fatiguing physical and mental strains, depending on the type of job.[11] The available maritime  
42 105 fatigue studies have only focused on watch officers as crew members who typically also work  
43 106 during night hours.[2,8,12,13] Thus, there is a lack of knowledge about sleepiness on the high  
44 107 seas among the other shipboard occupational groups, including the day workers. Knowing who  
45 108 is affected by severe sleepiness on board is of great importance to facilitate its prevention.  
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50 109 The present maritime field study analysed for the first time the prevalence of seafarers'  
51 110 sleepiness on duty during the sea passage, with a distinction between day workers and  
52 111 watchkeepers on board.  
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## 113 **METHODS**

### 114 **Study sample**

115 A medically trained scientist accompanied 18 sea voyages on 18 different container ships  
116 operating in the Baltic Sea and examined the crew members on board. 206 out of 225  
117 seafarers took part in the study (participation rate 91.6%). Only the results of those 198  
118 seafarers were included who could be interviewed and examined (pupillometry) in a cross-  
119 shift design (both before the beginning and after the end of their shift). Taking part in this  
120 study was voluntary and the individual data was pseudonymised. No patients were involved  
121 in this study. All participants gave their written informed consent before taking part in this  
122 study. The study was approved by the Ethics Committee of the Hamburg Medical  
123 Association (no PV4395).

124 The 198 seafarers were classified into two occupational groups (75 day workers and 123  
125 watchkeepers) (Tab. 1). The median age of the exclusively male study sample was 36.7  
126 years (19 - 67 years) and significantly higher among the day workers. Furthermore, the day  
127 workers had a somewhat higher body weight than the watchkeepers. No differences were  
128 observed in the circadian preference when comparing watchkeepers with day workers. The  
129 difference between the two occupational groups in terms of their marital status and the  
130 presence of children was not noteworthy. 49.0% of the seafarers either smoked or were  
131 former smokers.

132

### 133 **Patient and Public Involvement**

134 The present study focused on the sleepiness of shipboard crews; patients and/or public were  
135 not the target group of this study. Previous studies revealed that sleepiness constitutes one  
136 of the major problems amongst seafarers. All German shipping companies owning container  
137 ships were invited to participate in this study. 10 shipping companies agreed and put 18  
138 different container ships at our disposal.

139 All seafarers on board of these vessels were informed about our study design, aim and  
140 content and were encouraged to participate. After completion of our board examination, an  
141 individual medical report was created and sent to each of the accepting seafarers to their  
142 home address.

143

|   | <b>Day workers</b><br><i>(54 engine room personnel,<br/>16 electricians, 5 galley staff)</i> | <b>Watchkeepers</b><br><i>(46 nautical officers, 77<br/>deck ratings)</i> |
|---|--|---|
| <b>Number; n (%)</b>                        | 75 (37.9%)   | 123 (62.1%)   |
| <b>Age; median years (min-max)</b>          | 44 (19-67)   | 35 (19-63)  |
| <b>BMI; median (min-max)</b>                | 26 (19-40)   | 24 (17-36)  |
| <b>Morning Evening Questionnaire, n (%)</b> |  |   |
| <i>Morning type</i>                         | 45 (60.0%)   | 68 (55.2%)  |
| <i>Intermediate type</i>                    | 24 (32.0%)   | 46 (37.4%)  |
| <i>Evening type</i>                         | 6 (8.0%)   | 9 (7.4%)  |
| <b>Origin; n (%)</b>                        |  |   |
| <i>European</i>                             | 38 (50.7%)   | 47 (38.2%)  |
| <i>Southeast Asian</i>                      | 37 (49.3%)   | 76 (61.8%)  |
| <b>Married; n (%)</b>                       | 53 (70.7%)   | 87 (70.7%)  |
| <b>Children; n (%)</b>                      | 53 (70.7%)   | 82 (66.7%)  |
| <b>Smoking status; n (%)</b>                |  |   |
| <i>Never smoked</i>                         | 36 (48.0%)   | 65 (52.8%)  |
| <i>Former smoker/smoker</i>                 | 39 (52.0%)   | 58 (47.2%)  |

144 **Tab. 1** Demographic and lifestyle parameters by occupational groups on board

145

146 To assess long-term effects on sleep during their current period on board, the participants  
 147 were additionally grouped in respect of their stay on board at the time of examination (< 2  
 148 months, 2-5 months and > 5 months).

149



## 150 **Examination procedure**

151 All seafarers taking part in the study were examined with the SenseWear® armband monitor  
152 and pupillometry both during shifts and during time off (including sleep time). These devices  
153 were selected because they did not considerably disturb the crew's daily routines (low  
154 weight, no cable connection, easy use), which was a precondition. The present study  
155 monitored the sleep of all seafarers in a continuous mode during a period of at least 72 hours  
156 of observation. An observation time of at least 3 days during the sea passage was chosen  
157 because of the known variations of sleep quality on a daily basis.

158 The average period of wearing the armband monitor was 66.3 h (SD 14.8 h) (>92% of  
159 observation time) and did not differ between the occupational groups. The pupillometric  
160 examination took place within this observation period.

161

## 162 **Efficiency of sleep**

163 The *SenseWear® armband activity monitor* is a device that weighs 82 g and is worn on the  
164 right upper arm just above the triceps muscle according to its validation requirements. While  
165 wearing the armband monitor, the seafarers could easily operate the device for themselves  
166 without support from the shipboard examiner. The monitor is designed to analyse the profile  
167 of physical activity (movement, lying down or sleeping). The collected information allows the  
168 estimation of sleep efficiency by establishing the ratio of the duration of sleep and the time  
169 spent lying down. Thus, efficiency of sleep expresses the time spent actually sleeping while  
170 lying down.

171 The armband monitor has already been successfully applied in many studies as a detector of  
172 sleep.[14-19] Current studies reveal that the total sleep time and time in bed correlate  
173 significantly between the measurements of the armband monitor and the polysomnography  
174 ( $p < 0.001$ ); the armband has proved to be superior in comparison to other commercially  
175 available activity monitors.[16]

176

## 177 **Pupillometry**

178 The device *Fit-For-Duty* by AmTech was used to conduct pupillometric examinations [20].  
179 The Pupillographic Sleepiness Test is considered an objective method for documenting  
180 sleepiness by monitoring spontaneous and unconscious oscillations of the pupil without

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3 181 stimulating light. The result is a pupillogram, which can be used to deduct the pupillary unrest  
4 182 index (rPUI). This parameter therefore is an objective measure for the variance of the  
5 183 diameter of the pupil. A recent study suggested the Pupillographic Sleepiness Test as a  
6 184 reliable measurement for detecting drowsiness-related impairment.[21]

9  
10 185 The rPUI is compared to standard values. Results  $< 1.02$  are considered normal. "Particular  
11 186 attention required" is the characterisation of results  $\geq 1.02$  and  $< 1.53$ . An index  $\geq 1.53$  is  
12 187 rated as "unfit for duty". This methodology has repeatedly been used in scientific studies to  
13 188 assess sleepiness.[22-24]

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17 189 During a sea passage, the pupillometric examination was performed twice according to a  
18 190 cross-shift design for all 198 seafarers included in the study sample. The chosen sea  
19 191 passages lasted for at least 24 hours and therefore allowed a regular operation of the vessel  
20 192 and predictable working procedures. The pupillometric cross-shift examination took place 15  
21 193 minutes before the respective shift started and directly after it ended so that that shift was  
22 194 neither shortened nor disturbed by this examination. In general, it is not likely that the  
23 195 seafarers were distinctly disturbed by the examination with the chosen devices or by the  
24 196 presence of the medical staff on board.

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31 197 The engine room personnel, the electricians and the galley staff (without watchkeeping duties)  
32 198 were examined during an average work shift that lasted 8 hours (most likely from 8:00 h to  
33 199 17:00 h including a lunch break of 1 hour). As watchkeepers have two work units per day –  
34 200 each of them about 4 h (six shift periods: 0-4 h, 4-8 h, 8-12 h, 12-16 h, 16-20 h and 20-24 h) – a  
35 201 split sleeping time is often observed in this occupational group. The watchkeepers were  
36 202 examined during a randomly selected shift period with the aim of achieving an equal  
37 203 representation of these periods (about 20 watchkeepers/shift period). For the assessment of  
38 204 cross-shift reactions, it was unavoidable to compare the PUI and SSS between two  
39 205 occupational groups with different lengths of working times.

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## 47 48 207 **Questionnaire**

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50 208 In the framework of a standardised interview, all seafarers were asked about their  
51 209 demographic data, their subjective physical and mental stress level, their sleep period before  
52 210 the examined shift and their current working time. Additionally, daytime sleepiness was  
53 211 estimated by using the Epworth Sleepiness Scale.[25] The Stanford Sleepiness Scale  
54 212 assessed the sleepiness before and after a shift. For the assessment of the circadian  
55 213 preference, the seafarers filled in the Morningness-Eveningness Questionnaire (rMEQ).[26]

## 214 **Statistics**

215 Statistic analysis was performed with SPSS (version 24, IBM Corporation). The Shapiro-Wilk  
216 test was used to test for normal distribution of data. Where variables were not normally  
217 distributed, non-parametric tests (Mann Whitney-U test, Wilcoxon test) were used. The Chi-  
218 squared test was applied to analyse differences in frequencies of parameters. Crude odds  
219 ratio (OR) including 95% confidence intervals was calculated by binary logistic regression.  
220 For adjustment reasons, age, rank (officer vs. rating), the examination time of day and  
221 duration of stay on board at the time of examination were added. Furthermore, correlations  
222 were analysed by using the Spearman test.

223 All indicated p-values were two-sided, and a p-value of  $< 0.05$  was regarded as statistically  
224 significant.

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226

## 227 **RESULTS**

228 The number of months day workers had already spent on the vessel at the time of examination  
229 and during their current contract was similar to that of watchkeepers. In particular, the  
230 stratification of the seafarers in tertiles concerning their recent stay on board did not reveal any  
231 differences (Tab. 2).

232 The Epworth Sleepiness Scale (ESS) showed that 70 seafarers (35.4%) had recently been  
233 suffering from daytime sleepiness. The ESS value increased significantly ( $p= 0.004$ ) with the  
234 length of stay on board. No differences were observed when differentiating according to the  
235 obligation to perform watchkeeping duties ( $p= 0.113$ ). Younger seafarers below the age  
236 median of 37 years indicated daytime sleepiness more often than older colleagues ( $p= 0.014$ ).

237

|   | Occupational groups                   |   | <i>p</i> |
|---|---------------------------------------|---|----------|
|   | <i>Day workers</i><br>( <i>n</i> =75) | <i>Watchkeepers</i><br>( <i>n</i> =123) |          |
| <b>Stay on board</b>                                    |                                       |   |          |
| At the time of examination;<br>median months (min-max)  | 3 (1-12)                              | 3 (0-11)                                | 0.837*   |
| Frequency according to<br>tertile; <i>n</i> (%)         |                                       |   |          |
| ≤ 2 months  | 28 (37.3%)                            | 45 (36.6%)                              |          |
| > 2 and ≤ 5 months                                      | 28 (37.3%)                            | 45 (36.3%)                              | 0.973#   |
| > 5 months  | 19 (25.3%)                            | 33 (26.8%)                              |          |
| Scheduled (min-max)                                     | 7 (2-13)                              | 8 (1-12)                                | 0.719*   |
| <b>Epworth Sleepiness Scale (ESS), median (min-max)</b> |                                       |   |          |
| Score value (SD) <sup>1</sup>                           | 8 (0-15)                              | 8 (0-21)                                | 0.113*   |
| ≥ Cut off value (10), <i>n</i> (%)                      | 26 (34.7%)                            | 44 (35.8%)                              | 0.875#   |

238 \*Mann Whitney-U test #Chi-squared test <sup>1</sup>sleepiness scale from 0 ("no chance to doze in")  
 239 up to 24 ("maximum chance to doze in")

240 **Tab. 2** *Stay on board and subjective assessment for daytime sleepiness*

### 242 Cross-shift examinations

243 To analyse the recent alertness attributed to a representative shift, 198 seafarers were asked  
 244 to participate in a cross-shift examination. According to the results of the armband monitor,  
 245 the cumulative sleep time before the examined shift (including split sleep episodes) lasted for  
 246 5.6 hours (SD 1.0) per 24 h period, while watchkeepers had significantly shorter sleep  
 247 durations compared to the day workers (Tab. 3). The working hours during the examined  
 248 shift were significantly lower amongst watchkeepers. Concerning their subjective stress level  
 249 during the shift examined, significantly more watchkeepers experienced mental demands  
 250 than day workers (OR 2.35; 95% CI 1.24-4.44). After adjustment for age, ranking,  
 251 examination time of day and recent number of months at the time of investigation, this  
 252 elevated risk for mental stress remained significant among watchkeepers.

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3 253 During the examined shift, the average sleep efficiency was 69.3% and was significantly  
4 254 lower among watchkeeping seafarers than day workers (OR 0.48; 95% CI 0.26-0.88). This  
5 255 finding was independent of the age, ranking, time of day of the examination and the recent  
6 256 duration of shipboard stay. 63.7% of the participating seafarers stated that they had  
7 257 consumed coffee within the past 4 hour before our pupillometric examination on board  
8 258 irrespective of their occupational group.

13 259 Before their shift, the mean value on the Stanford Sleepiness Scale (SSS) was 2.6 (SD 1.4)  
14 260 (2= "functioning at high levels, but not fully alert"; 3= "awake, but relaxed; responsive but not  
15 261 fully alert"); after the work shift, the level of sleepiness was significantly higher (3.2 (SD 1.8))  
16 262 (Wilcoxon test:  $p= 0.001$ ) indicating a measurable increase in the subjective sleepiness in the  
17 263 course of a shift. This was especially true for watchkeepers although the length of their  
18 264 working time was much shorter than that of day workers (Tab. 3). Consequently, more  
19 265 watchkeepers reported current sleepiness than day workers after the examined shift.

25 266 A remarkable number of 35 seafarers (17.7%) reported a level of sleepiness on duty of 6/7  
26 267 on the SSS (6= "sleepy, woozy, fighting sleep, prefer to lie down"; 7= "no longer fighting  
27 268 sleep; sleep onset soon; having dream-like thoughts") after their shift. According to SSS,  
28 269 more young seafarers considered themselves to be tired (cross-shift SSS of all crew  
29 270 members below and above the median age of 37 years: 3.1 vs. 2.6;  $p= 0.011$ ). Focusing on  
30 271 the group of watchkeeping seafarers, those who were on duty between 00:00-04:00 h and  
31 272 04:00-08:00 h more often displayed severe sleepiness on duty after their shift (SSS $\geq 5$ ) (72.2%  
32 273 and 50.0% respectively).

38 274 The 396 pupillometric examinations (15 minutes before and after a shift) revealed that the  
39 275 change in rPUI values during the cross-shift observation did not reach a significant level in  
40 276 intra-individual comparison (mean rPUI before vs. after the working shift: 1.14 vs. 1.19; cross-  
41 277 shift rPUI change:  $p= 0.355$ ). After stratification, the intra-individual cross-shift change in rPUI  
42 278 values was also not dependent on the occupational groups (Tab. 3), while the different length  
43 279 of working time has to be taken into account.

48 280 The objective sleepiness on duty in the study sample was not dependent on age (only a  
49 281 slight tendency for younger seafarers after shift;  $p= 0.064$ ). During the examination, 12  
50 282 seafarers fell asleep and therefore were assigned to the group "unfit for duty". The pupillary  
51 283 unrest index in 88 examinations showed the seafarers were "unfit for duty"; additionally  
52 284 "particular attention required" was classified in 110 cases (27.8%). Therefore, only half of the  
53 285 examinations were "normal". No differences were observed in the pupillary unrest index  
54 286 between seafarers with and without watchkeeping duties.

287 In concordance to their subjective self-report in SSS, watchkeepers displayed somewhat  
 288 higher rPUI values after the shift than day workers (Tab. 3). The analysis of the correlation of  
 289 the subjective assessment of sleepiness on duty (SSS) with the objective measures of  
 290 pupillometry only revealed a weak correlation after the shift ( $r= 0.185$ ;  $p= 0.009$ ).

291 Within the group of watchkeepers, stronger sleepiness on duty ( $rPUI \geq 1.2$ ) after a shift  
 292 lasting from 00:00-04:00 h and from 04:00-08:00 h was observed (75.0% and 55.6%  
 293 respectively).

|  | <b>Occupational groups</b>            |   |                              |                                 |
|--|---------------------------------------|---|------------------------------|---------------------------------|
|  | <b>Day workers</b><br>( <i>n</i> =75) | <b>Watchkeepers</b><br>( <i>n</i> =123) | <b>Crude OR*</b><br>(95% CI) | <b>Adjusted OR#</b><br>(95% CI) |
| <b>Time periods in the context of the current pupillometric examination, mean hours (SD)</b> |                                       |   |                              |                                 |
| Sleep period before <sup>1</sup>   | 5.8 (1.1)                             | 5.5 (1.0)                               | <b>0.85 (0.78-0.92)</b>      | <b>0.88 (0.80-0.95)</b>         |
| Working hours examined   | 9.5 (1.5)                             | 4.9 (1.6)                               | <b>0.56 (0.43-0.88)</b>      | <b>0.57 (0.46-0.92)</b>         |
| <b>Subjective stress level during examined shift, n (SD)</b>                                 |                                       |   |                              |                                 |
| Physical <sup>2</sup>  | 48 (64.0%)                            | 78 (63.4%)                              | 0.96 (0.52-1.79)             | 0.51 (0.24-1.08)                |
| Mental <sup>3</sup>  | 41 (54.7%)                            | 94 (76.4%)                              | <b>2.35 (1.24-4.44)</b>      | <b>2.18 (1.08-4.40)</b>         |
| <b>Sleep efficiency<sup>1</sup></b>  |                                       |   |                              |                                 |
| - Mean (%)   | 72.7% (11.8%)                         | 67.9% (12.2%)                           | <b>0.48 (0.26-0.88)</b>      | <b>0.48 (0.25-0.91)</b>         |
| <b>Stanford Sleepiness Scale (SSS)<sup>4</sup>, mean (SD)</b>                                |                                       |   |                              |                                 |
| <b>Cross-shift<sup>5</sup></b>   | 2.6 (1.4)                             | 3.1 (1.7)                               | 0.73 (0.48-1.10)             | 0.84 (0.55-1.29)                |
| <b>Time depending</b>  |                                       |   |                              |                                 |
| - Before the shift   | 2.5 (1.4)                             | 2.6 (1.5)                               | 1.07 (0.59-1.95)             | 0.91 (0.49-1.70)                |
| - After the shift  | 2.8 (1.4)                             | 3.5 (1.9)                               | <b>1.81 (1.01-3.25)</b>      | 1.25 (0.66-2.37)                |
| <b>Pupillary unrest index (rPUI), mean (SD)</b>  |                                       |   |                              |                                 |
| <b>Cross-shift<sup>5</sup></b>   | 1.14 (0.66)                           | 1.18 (0.65)                             | 0.92 (0.61-1.40)             | 1.05 (0.70-1.61)                |
| <b>Time depending</b>  |                                       |   |                              |                                 |
|  | 1.14 (0.67)                           | 1.12 (0.62)                             | 0.96 (0.52-1.74)             | 0.86 (0.46-1.61)                |

1  
2  
3  
4 - Before the shift

5  
6 - After the shift 1.13 (0.66) 1.23 (0.65) 1.55 (0.85-2.84) 1.31 (0.70-2.46)

7  
8 **Level (n=396) of sleepiness on duty<sup>5</sup> n (%)**

9  
10 - None<sup>6</sup> 78 (52.0%) 120 (48.8%)

11  
12 - Particular attention  
13 required<sup>7</sup> 39 (26.0%) 71 (28.9%) 0.789

14  
15 - Unfit for duty<sup>8</sup> 33 (22.0%) 55 (22.3%)

16  
17 294 \*the crude OR bases on the median of parameters and includes differences between occupational  
18  
19 295 groups and the examination time of day #adjusted for age, rank (officer vs. rating) and duration of  
20  
21 296 stay on board at the time of examination

22  
23 297 <sup>1</sup>according to measurements with the armband monitor, related to an average 24 hour period

24  
25 298 <sup>2</sup>"have you experienced physical stress during the examined shift?" <sup>3</sup>"have you experienced  
26  
27 299 mental stress during the examined shift?"

28  
29 300 <sup>4</sup>SSS-scale from 1 ("feel active and vital") up to 7 ("almost dreaming/falling asleep")

30  
31 301 <sup>5</sup>all values exploited (before and after the shift) <sup>6</sup>rPUI < 1.02 <sup>7</sup>rPUI ≥ 1.02 and < 1.53 <sup>8</sup>rPUI ≥ 1.53

32  
33 302 **Tab. 3 Cross-shift examination concerning sleep characteristics**

34  
35  
36 304 Regardless of the occupational groups, the objective sleepiness on duty (rPUI) did not  
37  
38 305 correlate to the cumulative sleep over a 24-h period before the examined shift, the sleep  
39  
40 306 efficiency and the objective assessment of the ship's motion according to the ship's journal  
41  
42 307 parameters. An association was observed, however, between the duration of time already  
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44 308 spent on board at the time of the seafarers' examination and the rPUI (p= 0.009). The  
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46 309 stratification according to the duration of stay on board indicates that the association was  
47  
48 310 especially true for those seafarers with a longer stay on the vessels (pre-shift rPUI after stay  
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50 311 of less than 2 months, 2-5 months and more than 5 months: 1.06, 1.09 and - much higher -  
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52 312 1.32). The bivariate grouping of the crew according to their stay of less vs. more than 5  
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54 313 months showed significant pre-shift differences in rPUI (1.08 vs. 1.32; p= 0.002).

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## 315 **DISCUSSION**

316 Being a seafarer requires strong mental stability and a robust physical constitution, along  
317 with an adaptive and flexible attitude. However, stress and fatigue can hinder maritime  
318 professionals in performing effectively.[27] Seafarers spend both their working and leisure  
319 time over a couple of months in the restricted shipboard environment that can impact sleep  
320 quality and lead to sleepiness.[5] In the present study, a significantly lower sleep efficiency  
321 averaging at 69.3% and a higher subjective sleepiness assessment (SSS) after the shift  
322 were found among watchkeepers compared to day workers. In addition, the examinations  
323 carried out on board objectified critically short durations of the seafarers' sleep average (5.6  
324 h per 24 h) particularly among watchkeepers.

325 Especially the short sleeping times correspond very well with the results of international  
326 studies.[28] Sleep periods on board are often interrupted (potentially due to ship's  
327 movements or sudden noise evoked by the handling of containers in harbours).[29] These  
328 effects can explain why many seafarers, including day workers, suffer from sleepiness on the  
329 high seas. The sleep interruptions are particularly often an inevitable consequence of the  
330 watch shift requirements with two 4-h working shifts per day. Thus, on any watch system it is  
331 common that seafarers have several sleep episodes per 24-h period. Daytime sleep is  
332 usually much less efficient than sleep obtained at the circadian nadir. It can be assumed that  
333 some watchkeepers have problems falling asleep after a stressful working day (with scarcely  
334 any opportunities for sleep); this results in decreased sleep efficiency. Split sleep among  
335 watchkeepers can also not be excluded as the cause of this low sleep efficiency.

336 Although this study has not proved that sleepiness on duty depends directly on disturbances  
337 of the sea during passages, we measured generally low sleep efficiency. This means that not  
338 only the amount, but also the quality of sleep is insufficient among the examined seafarers  
339 on board. Frequent sleep disruptions can impair alertness to a great degree and  
340 consequently lead to an increased risk of accident on board.[30]

341 Despite similar physical stress levels, the crew members with watchkeeping duties  
342 experienced mental stress subjectively more frequently than day workers. This was probably  
343 due to their reduced and interrupted sleep time as well as their high job responsibility, which  
344 represents a distinct mental stressor. Correspondingly, the watchkeepers starting with a  
345 subjective sleepiness level similar to that of the day workers had a significantly more  
346 pronounced increase in their sleepiness level after the cross-shift examination. Although no  
347 significance level was reached, the cross-shift pupillometry of watchkeepers also indicated a  
348 higher level of objective sleepiness after the shift than that of day workers. In this context, the



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3 349 difference in the length of examined working time between day workers and watchkeepers  
4 350 has to be highlighted. The watchkeepers' higher value for SSS and, by trend, for PUI after  
5 351 the examined shift is remarkable as they had worked a considerably shorter time than the  
6 352 day workers. Thus, these differences are surely underestimated in this study.

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10 353 According to Wilhelm (2008)[31], severe sleepiness is displayed by drivers who did not sleep  
11 354 during the chronobiologically relevant time frame (0:00 h - 05:00 h). In the maritime setting,  
12 355 this especially applies to watchkeepers. These crew members, who are on duty during the  
13 356 inconvenient time frames between 0:00-04:00 h and 04:00-08:00 h, reported the expected  
14 357 subjective severe sleepiness, which was also objectively measured using pupillometry. In  
15 358 this context, it has to be taken into account that most fatigue-induced shipping disasters take  
16 359 place in these time frames.[32]

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18 360 Watchkeepers are habitual shift workers, often experiencing circadian misalignment due to  
19 361 their irregular work/rest schedules. This might be one explanation as to why the small  
20 362 number of available maritime field studies about seafarers' fatigue has exclusively focused  
21 363 on watchkeepers. Importantly, this study demonstrates that day workers also often  
22 364 experience severe sleepiness; more than 20% of both the watchkeepers and the day  
23 365 workers were characterised as "unfit for duty" during their regular shift and only every second  
24 366 pupillary measurement was regarded normal. The fact that 12 seafarers had fallen asleep  
25 367 during the 11-min pupillary examination and that 35 crew members regarded themselves as  
26 368 very sleepy post-shift ( $SSS \geq 6$ ) confirms these alarming pupillometric results. In light of the  
27 369 strong impact on the ships' safety, further studies are urgently needed to examine and  
28 370 counteract the sleepiness of both the shipboard watchkeepers and the day workers.

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30 371 Furthermore, this study observed that the duration already spent on the vessel at the time of  
31 372 the examination correlated with the PUI. This finding could indicate a cumulative effect on the  
32 373 seafarers' sleepiness. Officers normally have far shorter periods on board than ratings  
33 374 (averaging 2.5 vs. 4.1 months in a row). Daily sleepiness as a consequence of high work  
34 375 strain lasting for many months seems to be plausible. According to the present results,  
35 376 working periods below five months in a row seem to be reasonable for seafarers. Further  
36 377 studies are required to evaluate this hypothesis and to determine recommendations for  
37 378 maximum working periods on board.

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39 379 Subjective assessments of sleepiness only displayed a weak correlation with the objective  
40 380 pupillometric results. This could lead to a misjudgement of the seafarers' current  
41 381 psychophysical performance, which might also have safety implications. Younger and less  
42 382 experienced crew members reported more severe sleepiness on duty but did not display  
43 383 differences in their pupillometric measurements. In view of the frequently described high

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3 384 prevalence of fatigue-related accidents in seafaring, a high level of psychophysical stress,  
4 385 but also a misjudgement of their alertness is assumed. Thus, it is recommended to use  
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6 386 complementary objective methods besides questionnaires in studies to determine the level of  
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8 387 fatigue among examined employees. Future studies should also explore possibilities and  
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10 388 evaluate acceptance by the crew to develop more flexible shift scheduling that allows the  
11 389 consideration of circadian preferences and, possibly, individual preferences of the  
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13 390 watchkeeping seafarers.

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## 16 392 **Limitations**

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19 393 The present analysis has some limitations that need to be addressed. Firstly, the sample size of  
20 394 this study is rather small, but in comparison to other available maritime studies the examined  
21 395 seafarer population is far larger. Secondly, the study was carried out in a cross-sectional design  
22 396 that does not allow the evaluation of long-time effects of sleepiness. Due to the permanently  
23 397 changing shipping crews on the vessels, it is hardly possible to arrange long-time follow-up  
24 398 examinations of a noteworthy proportion of seafarers. Thirdly, due to the various occupational  
25 399 and ethnic groups on board, the crews are very heterogeneous and that makes the  
30 400 interpretation and comparison of sleeping behaviours difficult, also when considering the large  
31 401 inter-individual and intra-individual variability in sleep. Fourthly, the present study design does  
32 402 not provide information about the seafarers' sleep architecture. Sleep loss is generally  
33 403 compensated by changing the sleep architecture towards more so-called slow-wave sleep.

36 404 The armband monitor used has only a limited informative value about sleep architecture, which  
37 405 is normally measured in sleep laboratories ashore, e.g. using polysomnographic techniques [33].  
38 406 In maritime field studies, however, the use of such extensive examinations (only one  
39 407 measurement per night) does not appear to be very suitable on board. Furthermore, the  
40 408 determination of lying time with this monitor may be somewhat imprecise so that an  
41 409 underestimation of the sleep efficiency cannot be excluded. In addition, the frequently used  
42 410 sleep diaries for sleep assessment are only subjective procedures and require a survey period  
43 411 of at least 2 weeks, particularly as the shipboard measurements in this study were only to take  
44 412 place during the sea passage.

51 413 Moreover, pupillometry has yet not been established as a reliable screening test for sleepiness  
52 414 [34]. Particularly sleep latency or sleep architecture are the domains of extensive examinations  
53 415 in sleep laboratories ashore and were not the focus of the present maritime field study.  
54 416 Additionally, the PUI correlated with the seafarers' subjective statements. Further studies are  
55 417 recommended to evaluate the validity of these devices for their use in maritime field settings as  
56 418 well as to check their suitability on board and their acceptance by the seafarers on the high seas.

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3 419 Despite these limitations, the present study analyses for the first time the prevalence of  
4 420 sleepiness in seafarers with and without watchkeeping duties; the findings require further  
5 421 confirmation in a larger cohort. Furthermore, the present maritime field study analysed the  
6 422 prevalence of seafarers' sleepiness on duty by applying various subjective and objective  
7 423 methods. Up to now, most maritime studies about seafarers' sleepiness have not been carried  
8 424 out on board vessels and only rely on subjective methods.[35] Questionnaires are, however,  
9 425 subjective instruments, consequently depending on self-reported data, so that underreporting  
10 426 might have occurred.[36] Additionally, these subjective instruments do not reveal  
11 427 biophysiological differences that might promote the understanding of sleepiness on  
12 428 board.[21,37]

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20 429 Nowadays, a variety of subjective and objective instruments exist for assessment of  
21 430 excessive daytime sleepiness, including structured sleep history, sleep logs and sleep  
22 431 questionnaires. The multiple sleep latency test, for example, is often used as an objective  
23 432 measurement to evaluate sleep propensity. However, in view of the large overlap between  
24 433 healthy subjects and subjects with sleep disorders, its use to assess sleepiness is  
25 434 questionable. Furthermore, its results are often jeopardised by motivational influences and  
26 435 the last nap effect.[35] Consequently, a feasible and convenient method that is less  
27 436 dependent on motivation – such as the pupillometry used in this study – seems to constitute  
28 437 an enrichment in field studies.[21]

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### 36 37 439 **Implications for clinicians and policy makers**

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39 440 Fatigue in the maritime setting could be counteracted by strict compliance with and monitoring  
40 441 of the obligatory rest and sleep times. According to Allen, Wadsworth et al. (2007)[35], it is not  
41 442 uncommon in seafaring for legal obligations to be neglected, for example by ignoring the  
42 443 minimum safety levels for crewing on board. To reduce the seafarers' workload on board during  
43 444 the vessel's stay in port, some job duties could be transferred to land-based workers ashore.

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47 445 In light of the frequently observed sleepiness on duty within the study sample, training should  
48 446 be offered for shipboard crews to improve sleep hygiene and techniques to support short-  
49 447 term relaxation, such as power napping. This training should be accompanied by the  
50 448 strengthening of the seafarers' individual resources (e.g. training to cope with stress for  
51 449 health promotion) to enable them to compensate for the inevitable psychophysical strain on  
52 450 board. Considering the present results, limiting the work periods of seafarers (perhaps to a  
53 451 maximum of five months) might be an essential preventive measure in a maritime setting.

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4

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34 470 **Conflict of interest**  
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36 471 Both authors declare no conflicts of interest.  
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40 473 **Patient consent**  
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42 474 Not required.  
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47 476 **Ethics approval**  
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49 477 The study was approved by the Ethics Committee of the Hamburg Medical Association (no.  
50 478 PV4395).  
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54 480 **Data sharing statement**  
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56 481 No additional data are available.  
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60STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

|                              | Item No | Recommendation   | Page No |
|------------------------------|---------|--|---------|
| <b>Title and abstract</b>    | 1       | (a) Indicate the study's design with a commonly used term in the title or the abstract   | 1       |
|                              |         | (b) Provide in the abstract an informative and balanced summary of what was done and what was found  | 2       |
| <b>Introduction</b>          |         |  |         |
| Background/rationale         | 2       | Explain the scientific background and rationale for the investigation being reported   | 3-4     |
| Objectives                   | 3       | State specific objectives, including any prespecified hypotheses   | 4       |
| <b>Methods</b>               |         |  |         |
| Study design                 | 4       | Present key elements of study design early in the paper  | 5       |
| Setting                      | 5       | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection  | 5,7     |
| Participants                 | 6       | (a) Give the eligibility criteria, and the sources and methods of selection of participants  | 5,6     |
| Variables                    | 7       | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable   | 7,8     |
| Data sources/<br>measurement | 8*      | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group                         | 7,8     |
| Bias                         | 9       | Describe any efforts to address potential sources of bias  | 8       |
| Study size                   | 10      | Explain how the study size was arrived at  | 5       |
| Quantitative variables       | 11      | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why   | 6       |
| Statistical methods          | 12      | (a) Describe all statistical methods, including those used to control for confounding  | 8       |
|                              |         | (b) Describe any methods used to examine subgroups and interactions  | 8       |
|                              |         | (c) Explain how missing data were addressed  |         |
|                              |         | (d) If applicable, describe analytical methods taking account of sampling strategy   |         |
|                              |         | (e) Describe any sensitivity analyses  |         |
| <b>Results</b>               |         |  |         |
| Participants                 | 13*     | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed            | 9       |
|                              |         | (b) Give reasons for non-participation at each stage   |         |
|                              |         | (c) Consider use of a flow diagram   |         |
| Descriptive data             | 14*     | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders   | 9       |
|                              |         | (b) Indicate number of participants with missing data for each variable of interest  |         |
| Outcome data                 | 15*     | Report numbers of outcome events or summary measures   | 9       |
| Main results                 | 16      | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 10-12   |

|                          |    |  |       |
|--------------------------|----|--|-------|
|                          |    | (b) Report category boundaries when continuous variables were categorized  |       |
|                          |    | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   | 11    |
| Other analyses           | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses   |       |
| <b>Discussion</b>        |    |  |       |
| Key results              | 18 | Summarise key results with reference to study objectives   | 13    |
| Limitations              | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias                 | 15-16 |
| Interpretation           | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 15-16 |
| Generalisability         | 21 | Discuss the generalisability (external validity) of the study results  | 16    |
| <b>Other information</b> |    |  |       |
| Funding                  | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based              | 17    |

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

# BMJ Open

## Sleepiness of day workers and watchkeepers on board at high seas: a cross-sectional study

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4 1 **Sleepiness of day workers and watchkeepers on board at high seas: a cross-sectional**  
5 2 **study**

6  
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23 15

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2  
3 17 **ABSTRACT**

4  
5 18 **Objectives**

6  
7 19 To estimate the prevalence of sleepiness on duty among day workers and watchkeepers on  
8  
9 20 board.

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11 21 **Design**

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13 22 Cross-sectional survey in a maritime field study.

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15 23 **Setting**

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17 24 10 shipping companies with container vessels under German management.

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19 25 **Participants**

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21 26 The whole crew (75 day workers and 123 watchkeepers) during 18 voyages on 18 different  
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23 27 container ships.

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25 28 **Outcome measures**

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27 29 Sleepiness on duty and efficiency of sleep using pupillometry (in a cross-shift design) and the  
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29 30 SenseWear® armband activity monitor.

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31 31 **Results**

32  
33 32 The watchkeepers showed significantly shorter sleep periods than day workers (5.5 h vs. 5.8  
34  
35 33 h). The average efficiency of sleep was 69.6% and significantly lower among watchkeepers  
36  
37 34 (OR 0.48; 95% CI 0.26-0.88). 396 pupillometric examinations were carried out and revealed  
38  
39 35 88 study members (22.2%) with a pupillary unrest index (rPUI) in a range characterised as  
40  
41 36 “unfit for duty” and 110 seafarers (27.8%) categorised as “particular attention required”. The  
42  
43 37 average rPUI was similar between day workers and watchkeepers.

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45 38 The Epworth Sleepiness Scale revealed recent daytime sleepiness in 70 seafarers, which  
46  
47 39 was similarly often stated by day workers and watchkeepers. Based on the Stanford  
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49 40 Sleepiness Scale (SSS), a measurable cross-shift increase in the SSS value during the  
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51 41 examined shift was observed, especially among watchkeepers. The amount of time already  
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53 42 spent on the vessel at the time of the present examination was significantly associated with  
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55 43 the rPUI (p= 0.009).

56  
57 44 **Conclusion**

58  
59 45 Sleep periods of both the day workers and the watchkeepers aboard vessels were alarmingly  
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46 short and sleep efficiency was low. Sleepiness on duty is similarly prevalent among day  
47 workers and watchkeepers and seems to depend partly on the cumulative working period on

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3 48 the vessels. Preventive measures need to be taken by the shipping industry to counteract  
4 49 fatigue (e.g.by enabling sufficient rest and sleep times).  
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8  
9 51 **Key words:** *occupational medicine, sleepiness, seafaring, pupillometry*  
10  
11 52

### 12 13 53 **Strengths and limitations of this study**

- 14  
15 54 ➤ The present maritime field study shows for the first time the prevalence of seafarers'  
16 55 sleepiness on duty during the sea passage, drawing a distinction between crew members  
17 56 with and without watchkeeping duties.  
18  
19 57 ➤ The present study analysed seafarers' sleepiness on duty by applying both subjective and  
20 58 objective methods that are less dependent on the participants' motivation (pupillometry,  
21 59 armband activity monitor).  
22  
23 60 ➤ The study was carried out in a cross-sectional design that does not allow evaluation of  
24 61 long-time effects of sleepiness.  
25  
26 62 ➤ Due to the various occupational groups on board, the crews are very heterogeneous; that  
27 63 makes the interpretation and comparison of sleeping behaviours difficult.  
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### 32 33 65 **INTRODUCTION**

34  
35 66 Long and irregular working hours each day, combined with sleep deficiency and long periods  
36 67 of work at sea, are crucial risk factors for increased sleepiness on duty among seafarers.[1,2]  
37  
38 68 Strong weather conditions can also affect seafarers' performance, increase the risk of error  
39 69 and, consequently, cause injuries or fatalities to personnel. Psychological strain in maritime  
40 70 professions can also lead to psychosomatic diseases including burnout syndrome or  
41 71 exhaustion.[3] Some studies have stated that shipping crews suffer from psychophysical  
42 72 exhaustion/strain due to stress and decreased periods and quality of sleep.[4] Thus, seafaring  
43 73 still ought to be considered a high-risk profession for psychophysical exhaustion.[5,6]

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49 74 Three voyage episodes can be distinguished on board: stays in port, river passages and sea  
50 75 passages. During the first two voyage episodes, the seafarers are often exposed to high  
51 76 psychophysical stressors caused by unforeseeable and external demands that possibly need to  
52 77 be addressed at chronobiologically adverse times (e.g. embarkation and disembarkation,  
53 78 loading and unloading, exchange of information with port authorities). During the sea passage,  
54 79 the engine room personnel, the electricians and the galley staff can often adhere to a regular  
55 80 working day of 8 hours (day workers). This is better suited to chronobiologically adapted sleep  
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3 81 periods and can thus partially compensate for a potential sleep deficiency.[7] In contrast, due to  
4 82 obligatory navigation manoeuvres, nautical officers and a large number of the deck ratings are  
5 83 often required to work in a 24-hour shift system during sea passages (watchkeepers).

6  
7  
8 84 Nowadays, merchant ships operating internationally generally run on a 4/8-hour watch shift  
9 85 system. That means that three nautical officers alternate in a system which includes four hours  
10 86 on duty and eight hours off for each of them. Van Leeuwen, Kircher et al. (2013)[8] measured  
11 87 the effect of a 4/8-hour watch shift system on the alertness of seafarers in a ship simulator.  
12 88 They observed that especially additional overtime was associated with a subjective and  
13 89 objective increase in sleepiness. The authors also showed sleepiness increasing with time on  
14 90 watch and peaking at the end of a watch.

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20 91 It has been described that watchkeeping, critical assignments during night time and irregular  
21 92 working periods can lead to disruptions of the crews' circadian rhythm as a precondition for  
22 93 sleepiness on board.[9] Dohrmann and Leppin (2017)[7] performed a systematic analysis and  
23 94 quality assessment of seafarers' fatigue. They observed that working nights was most fatiguing  
24 95 and that fatigue levels were higher toward the end of a watch or shift. According to the review,  
25 96 particularly the psychosocial work environment (including day workers besides the  
26 97 watchkeepers) had received little attention. However, the monotonous noise of the vessel's  
27 98 engine, the smooth ship's vibrations and the continuous slow ship's movements (during calm  
28 99 weather conditions) can lead to sleepiness of the whole crew on board. Higher levels of  
29 100 exposure to noise and vibrations can also increase sleep troubles/problems and poorer sleep  
30 101 quality when impacting on employees throughout the day.[10]

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39 102 Working in a maritime setting is characterised by a wide variety of occupations with numerous  
40 103 fatiguing physical and mental strains, depending on the type of job.[11] The available maritime  
41 104 fatigue studies have only focused on watch officers as crew members who typically also work  
42 105 during night hours.[2,8,12,13] Thus, there is a lack of knowledge about sleepiness on the high  
43 106 seas among the other shipboard occupational groups, including the day workers. Knowing who  
44 107 is affected by severe sleepiness on board is of great importance to facilitate its prevention.

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49 108 The present maritime field study analysed for the first time the prevalence of seafarers'  
50 109 sleepiness on duty during the sea passage, with a distinction between day workers and  
51 110 watchkeepers on board.

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## 112 **METHODS**

### 113 **Study sample**

114 A medically trained scientist accompanied 18 sea voyages on 18 different container ships  
115 operating in the Baltic Sea and examined the crew members on board. 206 out of 225  
116 seafarers took part in the study (response rate 91.6%). Only the results of those 198  
117 seafarers were included who could be interviewed and examined (pupillometry) in a cross-  
118 shift design (both before the beginning and after the end of their shift). Taking part in this  
119 study was voluntary and the individual data was pseudonymised. No patients were involved  
120 in this study. All participants gave their written informed consent before taking part in this  
121 study. The study was approved by the Ethics Committee of the Hamburg Medical  
122 Association (no PV4395).

123 The 198 seafarers were classified into two occupational groups (75 day workers and 123  
124 watchkeepers) (Tab. 1). The median age of the exclusively male study sample was 36.7  
125 years (19 - 67 years) and significantly higher among the day workers. Furthermore, the day  
126 workers had a somewhat higher body weight than the watchkeepers. No differences were  
127 observed in the circadian preference when comparing watchkeepers with day workers. The  
128 difference between the two occupational groups in terms of their marital status and the  
129 presence of children was not noteworthy. 49.0% of the seafarers either smoked or were  
130 former smokers.

131

### 132 **Patient and Public Involvement**

133 The present study focused on the sleepiness of shipboard crews; patients and/or public were  
134 not the target group of this study. Previous studies revealed that sleepiness constitutes one  
135 of the major problems amongst seafarers. All German shipping companies owning container  
136 ships were invited to participate in this study. 10 shipping companies agreed and put 18  
137 different container ships at our disposal (the proportion of ships was four times one, four  
138 times two and twice three vessels per shipping company).

139 All seafarers on board of these vessels were informed about our study design, aim and  
140 content and were encouraged to participate (participation rate 88.0%). After completion of  
141 our board examination, an individual medical report was created and sent to each of the  
142 accepting seafarers to their home address.

143



|   | <b>Day workers</b><br><i>(54 engine room personnel,<br/>16 electricians, 5 galley staff)</i> | <b>Watchkeepers</b><br><i>(46 nautical officers, 77<br/>deck ratings)</i> |
|---|--|---|
| <b>Number; n (%)</b>                        | 75 (37.9%)   | 123 (62.1%)   |
| <b>Age; median years (min-max)</b>          | 44 (19-67)   | 35 (19-63)  |
| <b>BMI; median (min-max)</b>                | 26 (19-40)   | 24 (17-36)  |
| <b>Morning-Evening-Questionnaire, n (%)</b> |  |   |
| <i>Morning type</i>                         | 45 (60.0%)   | 68 (55.2%)  |
| <i>Intermediate type</i>                    | 24 (32.0%)   | 46 (37.4%)  |
| <i>Evening type</i>                         | 6 (8.0%)   | 9 (7.4%)  |
| <b>Origin; n (%)</b>                        |  |   |
| <i>European</i>                             | 38 (50.7%)   | 47 (38.2%)  |
| <i>Southeast Asian</i>                      | 37 (49.3%)   | 76 (61.8%)  |
| <b>Married; n (%)</b>                       | 53 (70.7%)   | 87 (70.7%)  |
| <b>Children; n (%)</b>                      | 53 (70.7%)   | 82 (66.7%)  |
| <b>Smoking status; n (%)</b>                |  |   |
| <i>Never smoked</i>                         | 36 (48.0%)   | 65 (52.8%)  |
| <i>Former smoker/smoker</i>                 | 39 (52.0%)   | 58 (47.2%)  |

144 **Tab. 1** Demographic and lifestyle parameters by occupational groups on board

145

146 To assess long-term effects on sleep during their current period on board, the participants  
 147 were additionally grouped in respect of their stay on board at the time of examination (< 2  
 148 months, 2-5 months and > 5 months).

149

## 150 **Examination procedure**

151 All seafarers taking part in the study were examined with the SenseWear® armband monitor  
152 and pupillometry both during shifts and during time off (including sleep time). These devices  
153 were selected because they did not considerably disturb the crew's daily routines (low  
154 weight, no cable connection, easy use), which was a precondition. The present study  
155 monitored the sleep of all seafarers in a continuous mode during a period of at least 72 hours  
156 of observation. An observation time of at least 3 days during the sea passage was chosen  
157 because of the known variations of sleep quality on a daily basis.

158 The average period of wearing the armband monitor was 66.3 h (SD 14.8 h) (>92% of  
159 observation time) and did not differ between the occupational groups. The pupillometric  
160 examination took place within this observation period.

161

## 162 **Efficiency of sleep**

163 The *SenseWear® armband activity monitor* is a device that weighs 82 g and is worn on the  
164 right upper arm just above the triceps muscle according to its validation requirements. While  
165 wearing the armband monitor, the seafarers could easily operate the device for themselves  
166 without support from the shipboard examiner. The monitor is designed to analyse the profile  
167 of physical activity (movement, lying down or sleeping). The collected information allows the  
168 estimation of sleep efficiency by establishing the ratio of the duration of sleep and the time  
169 spent lying down. Thus, efficiency of sleep expresses the time spent actually sleeping while  
170 lying down.

171 The armband monitor has already been successfully applied in many studies as a detector of  
172 sleep.[14-19] Current studies reveal that the total sleep time and time in bed correlate  
173 significantly between the measurements of the armband monitor and the polysomnography  
174 ( $p < 0.001$ ); the armband has proved to be superior in comparison to other commercially  
175 available activity monitors.[16]

176

## 177 **Pupillometry**

178 The device *Fit-For-Duty* by AmTech was used to conduct pupillometric examinations [20].  
179 The Pupillographic Sleepiness Test is considered an objective method for documenting  
180 sleepiness by monitoring spontaneous and unconscious oscillations of the pupil without

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3 181 stimulating light. The result is a pupillogram, which can be used to deduct the pupillary unrest  
4 182 index (rPUI). This parameter therefore is an objective measure for the variance of the  
5 183 diameter of the pupil. A recent study suggested the Pupillographic Sleepiness Test as a  
6 184 reliable measurement for detecting drowsiness-related impairment.[21]

9  
10 185 The rPUI is compared to standard values. Results  $< 1.02$  are considered normal. "Particular  
11 186 attention required" is the characterisation of results  $\geq 1.02$  and  $< 1.53$ . An index  $\geq 1.53$  is  
12 187 rated as "unfit for duty". This methodology has repeatedly been used in scientific studies to  
13 188 assess sleepiness.[22-24]

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17 189 During a sea passage, the pupillometric examination was performed twice according to a  
18 190 cross-shift design for all 198 seafarers included in the study sample. The chosen sea  
19 191 passages lasted for at least 24 hours and therefore allowed a regular operation of the vessel  
20 192 and predictable working procedures. The pupillometric cross-shift examination took place 15  
21 193 minutes before the respective shift started and directly after it ended so that that shift was  
22 194 neither shortened nor disturbed by this examination. In general, it is not likely that the  
23 195 seafarers were distinctly disturbed by the examination with the chosen devices or by the  
24 196 presence of the medical staff on board.

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31 197 The engine room personnel, the electricians and the galley staff (without watchkeeping duties)  
32 198 were examined during an average work shift that lasted 8 hours (most likely from 8:00 h to  
33 199 17:00 h including a lunch break of 1 hour). As watchkeepers have two work units per day –  
34 200 each of them about 4 h (six shift periods: 0-4 h, 4-8 h, 8-12 h, 12-16 h, 16-20 h and 20-24 h) – a  
35 201 split sleeping time is often observed in this occupational group. The watchkeepers were  
36 202 examined during a randomly selected shift period with the aim of achieving an equal  
37 203 representation of these periods (about 20 watchkeepers/shift period). For the assessment of  
38 204 cross-shift reactions, it was unavoidable to compare the PUI and SSS between two  
39 205 occupational groups with different lengths of working times.

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## 47 48 207 **Questionnaire**

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51 208 In the framework of a standardised interview, all seafarers were asked about their  
52 209 demographic data, their subjective physical and mental stress level, their sleep period before  
53 210 the examined shift and their current working time. Additionally, daytime sleepiness was  
54 211 estimated by using the Epworth Sleepiness Scale.[25]. This is a self-administered  
55 212 questionnaire which is shown to provide a measurement of the subject's general level of  
56 213 daytime sleepiness. Retrospectively, the probability of nodding off or falling asleep in eight

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3 214 typical everyday situations is investigated. Furthermore, the Stanford Sleepiness Scale was  
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5 215 used as a self-rating scale to quantify progressive stages of sleepiness.[26] Individual  
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7 216 circadian fluctuations in sleepiness and alertness can be determined through repetition in  
8  
9 217 intervals. In the present study, this scale assessed the sleepiness before and after a shift.  
10  
11 218 Finally, the seafarers filled in the Morning-Evening-Questionnaire (rMEQ) for the assessment  
12  
13 219 of the circadian preference.[27, 28] This questionnaire evaluates against individual differences  
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15 220 in the circadian rhythm. Responses to the questions are combined to form a composite score  
16  
17 221 that indicates the degree to which the respondent favours morning versus evening.  
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### 223 **Statistics**

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Statistic analysis was performed with SPSS (version 24, IBM Corporation). The Shapiro-Wilk test was used to test for normal distribution of data. Where variables were not normally distributed, non-parametric tests (Mann Whitney-U test, Wilcoxon test) were used. The Chi-squared test was applied to analyse differences in frequencies of parameters. Crude odds ratio (OR) including 95% confidence intervals was calculated by binary logistic regression. For adjustment reasons, age, rank (officer vs. rating), the examination time of day and duration of stay on board at the time of examination were added. Furthermore, correlations were analysed by using the Spearman test.

All indicated p-values were two-sided, and a p-value of < 0.05 was regarded as statistically significant.

## 235 **RESULTS**

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The number of months day workers had already spent on the vessel at the time of examination and during their current contract was similar to that of watchkeepers. In particular, the stratification of the seafarers in tertiles concerning their recent stay on board did not reveal any differences (Tab. 2).

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The Epworth Sleepiness Scale (ESS) showed that 70 seafarers (35.4%) had recently been suffering from daytime sleepiness. The ESS value increased significantly ( $p=0.004$ ) with the length of stay on board. No differences were observed when differentiating according to the obligation to perform watchkeeping duties ( $p=0.113$ ). Younger seafarers below the age median of 37 years indicated daytime sleepiness more often than older colleagues ( $p=0.014$ ).

|   | Occupational groups                   |   | <i>p</i> |
|---|---------------------------------------|---|----------|
|   | <i>Day workers</i><br>( <i>n</i> =75) | <i>Watchkeepers</i><br>( <i>n</i> =123) |          |
| <b>Stay on board</b>                                    |                                       |   |          |
| At the time of examination;<br>median months (min-max)  | 3 (1-12)                              | 3 (0-11)                                | 0.837*   |
| Frequency according to<br>tertile; <i>n</i> (%)         |                                       |   |          |
| ≤ 2 months  | 28 (37.3%)                            | 45 (36.6%)                              |          |
| > 2 and ≤ 5 months                                      | 28 (37.3%)                            | 45 (36.3%)                              | 0.973#   |
| > 5 months  | 19 (25.3%)                            | 33 (26.8%)                              |          |
| Scheduled (min-max)                                     | 7 (2-13)                              | 8 (1-12)                                | 0.719*   |
| <b>Epworth Sleepiness Scale (ESS), median (min-max)</b> |                                       |   |          |
| Score value (SD) <sup>1</sup>                           | 8 (0-15)                              | 8 (0-21)                                | 0.113*   |
| ≥ Cut off value (10), <i>n</i> (%)                      | 26 (34.7%)                            | 44 (35.8%)                              | 0.875#   |

\*Mann Whitney-U test #Chi-squared test <sup>1</sup>sleepiness scale from 0 ("no chance to doze in") up to 24 ("maximum chance to doze in")

**Tab. 2** Stay on board and subjective assessment for daytime sleepiness

### Cross-shift examinations

To analyse the recent alertness attributed to a representative shift, 198 seafarers were asked to participate in a cross-shift examination. According to the results of the armband monitor, the cumulative sleep time before the examined shift (including split sleep episodes) lasted for 5.6 hours (SD 1.0) per 24 h period, while watchkeepers had significantly shorter sleep durations compared to the day workers (Tab. 3). The working hours during the examined shift were significantly lower amongst watchkeepers. Concerning their subjective stress level during the shift examined, significantly more watchkeepers experienced mental demands than day workers (OR 2.35; 95% CI 1.24-4.44). After adjustment for age, ranking, examination time of day and recent number of months at the time of investigation, this elevated risk for mental stress remained significant among watchkeepers.

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3 260 During the examined shift, the average sleep efficiency was 69.3% and was significantly  
4 261 lower among watchkeeping seafarers than day workers (OR 0.48; 95% CI 0.26-0.88). This  
5 262 finding was independent of the age, ranking, time of day of the examination and the recent  
6 263 duration of shipboard stay. 63.7% of the participating seafarers stated that they had  
7 264 consumed coffee within the past 4 hour before our pupillometric examination on board  
8 265 irrespective of their occupational group.

12  
13 266 Before their shift, the mean value on the Stanford Sleepiness Scale (SSS) was 2.6 (SD 1.4)  
14 267 (2= "functioning at high levels, but not fully alert"; 3= "awake, but relaxed; responsive but not  
15 268 fully alert"); after the work shift, the level of sleepiness was significantly higher (3.2 (SD 1.8))  
16 269 (Wilcoxon test:  $p= 0.001$ ) indicating a measurable increase in the subjective sleepiness in the  
17 270 course of a shift. This was especially true for watchkeepers although the length of their  
18 271 working time was much shorter than that of day workers (Tab. 3). Consequently, more  
19 272 watchkeepers reported current sleepiness than day workers after the examined shift.

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25 273 A remarkable number of 35 seafarers (17.7%) reported a level of sleepiness on duty of 6/7  
26 274 on the SSS (6= "sleepy, woozy, fighting sleep, prefer to lie down"; 7= "no longer fighting  
27 275 sleep; sleep onset soon; having dream-like thoughts") after their shift. According to SSS,  
28 276 more young seafarers considered themselves to be tired (cross-shift SSS of all crew  
29 277 members below and above the median age of 37 years: 3.1 vs. 2.6;  $p= 0.011$ ). Focusing on  
30 278 the group of watchkeeping seafarers, those who were on duty between 00:00-04:00 h and  
31 279 04:00-08:00 h more often displayed severe sleepiness on duty after their shift (SSS $\geq 5$ ) (72.2%  
32 280 and 50.0% respectively).

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35 281 The 396 pupillometric examinations (15 minutes before and after a shift) revealed that the  
36 282 change in rPUI values during the cross-shift observation did not reach a significant level in  
37 283 intra-individual comparison (mean rPUI before vs. after the working shift: 1.14 vs. 1.19; cross-  
38 284 shift rPUI change:  $p= 0.355$ ). After stratification, the intra-individual cross-shift change in rPUI  
39 285 values was also not dependent on the occupational groups (Tab. 3), while the different length  
40 286 of working time has to be taken into account.

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43 287 The objective sleepiness on duty in the study sample was not dependent on age (only a  
44 288 slight tendency for younger seafarers after shift;  $p= 0.064$ ). During the examination, 12  
45 289 seafarers fell asleep and therefore were assigned to the group "unfit for duty". The pupillary  
46 290 unrest index in 88 examinations showed the seafarers were "unfit for duty"; additionally  
47 291 "particular attention required" was classified in 110 cases (27.8%). Therefore, only half of the  
48 292 examinations were "normal". No differences were observed in the pupillary unrest index  
49 293 between seafarers with and without watchkeeping duties.

294 In concordance to their subjective self-report in SSS, watchkeepers displayed somewhat  
 295 higher rPUI values after the shift than day workers (Tab. 3). The analysis of the correlation of  
 296 the subjective assessment of sleepiness on duty (SSS) with the objective measures of  
 297 pupillometry only revealed a weak correlation after the shift ( $r= 0.185$ ;  $p= 0.009$ ).

298 Within the group of watchkeepers, stronger sleepiness on duty ( $rPUI \geq 1.2$ ) after a shift  
 299 lasting from 00:00-04:00 h and from 04:00-08:00 h was observed (75.0% and 55.6%  
 300 respectively).

301

|  | <b>Occupational groups</b> |                     |                         |                         |
|--|----------------------------|---------------------|-------------------------|-------------------------|
|  | <b>Day workers</b>         | <b>Watchkeepers</b> | <b>Crude OR*</b>        | <b>Adjusted OR#</b>     |
|  | <i>(n=75)</i>              | <i>(n=123)</i>      | <i>(95% CI)</i>         | <i>(95% CI)</i>         |
| <b>Time periods in the context of the current pupillometric examination, mean hours (SD)</b> |                            |                     |                         |                         |
| Sleep period before <sup>1</sup>   | 5.8 (1.1)                  | 5.5 (1.0)           | <b>0.85 (0.78-0.92)</b> | <b>0.88 (0.80-0.95)</b> |
| Working hours examined   | 9.5 (1.5)                  | 4.9 (1.6)           | <b>0.56 (0.43-0.88)</b> | <b>0.57 (0.46-0.92)</b> |
| <b>Subjective stress level during examined shift, n (SD)</b>                                 |                            |                     |                         |                         |
| Physical <sup>2</sup>  | 48 (64.0%)                 | 78 (63.4%)          | 0.96 (0.52-1.79)        | 0.51 (0.24-1.08)        |
| Mental <sup>3</sup>  | 41 (54.7%)                 | 94 (76.4%)          | <b>2.35 (1.24-4.44)</b> | <b>2.18 (1.08-4.40)</b> |
| <b>Sleep efficiency<sup>1</sup></b>  |                            |                     |                         |                         |
| - Mean (%)   | 72.7% (11.8%)              | 67.9% (12.2%)       | <b>0.48 (0.26-0.88)</b> | <b>0.48 (0.25-0.91)</b> |
| <b>Stanford Sleepiness Scale (SSS)<sup>4</sup>, mean (SD)</b>                                |                            |                     |                         |                         |
| <b>Cross-shift<sup>5</sup></b>   | 2.6 (1.4)                  | 3.1 (1.7)           | 0.73 (0.48-1.10)        | 0.84 (0.55-1.29)        |
| <b>Time depending</b>  |                            |                     |                         |                         |
| - Before the shift   | 2.5 (1.4)                  | 2.6 (1.5)           | 1.07 (0.59-1.95)        | 0.91 (0.49-1.70)        |
| - After the shift  | 2.8 (1.4)                  | 3.5 (1.9)           | <b>1.81 (1.01-3.25)</b> | 1.25 (0.66-2.37)        |
| <b>Pupillary unrest index (rPUI), mean (SD)</b>  |                            |                     |                         |                         |
| <b>Cross-shift<sup>5</sup></b>   | 1.14 (0.66)                | 1.18 (0.65)         | 0.92 (0.61-1.40)        | 1.05 (0.70-1.61)        |

**Time depending**

|                    |             |             |                  |                  |
|--------------------|-------------|-------------|------------------|------------------|
| - Before the shift | 1.14 (0.67) | 1.12 (0.62) | 0.96 (0.52-1.74) | 0.86 (0.46-1.61) |
| - After the shift  | 1.13 (0.66) | 1.23 (0.65) | 1.55 (0.85-2.84) | 1.31 (0.70-2.46) |

**Level (n=396) of sleepiness on duty<sup>5</sup> n (%)**

|   |            |             |       |  |
|---|------------|-------------|-------|--|
| - None <sup>6</sup>                             | 78 (52.0%) | 120 (48.8%) |       |  |
| - Particular attention<br>required <sup>7</sup> | 39 (26.0%) | 71 (28.9%)  | 0.789 |  |
| - Unfit for duty <sup>8</sup>                   | 33 (22.0%) | 55 (22.3%)  |       |  |

\*the crude OR bases on the median of parameters and includes differences between occupational groups and the examination time of day #adjusted for age, rank (officer vs. rating) and duration of stay on board at the time of examination

<sup>1</sup>according to measurements with the armband monitor, related to an average 24 hour period  
<sup>2</sup>"have you experienced physical stress during the examined shift?" <sup>3</sup>"have you experienced mental stress during the examined shift?"

<sup>4</sup>SSS-scale from 1 ("feel active and vital") up to 7 ("almost dreaming/falling asleep")

<sup>5</sup>all values exploited (before and after the shift) <sup>6</sup>rPUI < 1.02 <sup>7</sup>rPUI ≥ 1.02 and < 1.53 <sup>8</sup>rPUI ≥ 1.53

**Tab. 3 Cross-shift examination concerning sleep characteristics**

Regardless of the occupational groups, the objective sleepiness on duty (rPUI) did not correlate to the cumulative sleep over a 24-h period before the examined shift, the sleep efficiency and the objective assessment of the ship's motion according to the ship's journal parameters. An association was observed, however, between the duration of time already spent on board at the time of the seafarers' examination and the rPUI (p= 0.009). The stratification according to the duration of stay on board indicates that the association was especially true for those seafarers with a longer stay on the vessels (pre-shift rPUI after stay of less than 2 months, 2-5 months and more than 5 months: 1.06, 1.09 and - much higher - 1.32). The bivariate grouping of the crew according to their stay of less vs. more than 5 months showed significant pre-shift differences in rPUI (1.08 vs. 1.32; p= 0.002).



## DISCUSSION

Being a seafarer requires strong mental stability and a robust physical constitution, along with an adaptive and flexible attitude. However, stress and fatigue can hinder maritime professionals in performing effectively.[29] Seafarers spend both their working and leisure time over a couple of months in the restricted shipboard environment that can impact sleep quality and lead to sleepiness.[5] In the present study, a significantly lower sleep efficiency averaging at 69.3% and a higher subjective sleepiness assessment (SSS) after the shift were found among watchkeepers compared to day workers. In addition, the examinations carried out on board objectified critically short durations of the seafarers' sleep average (5.6 h per 24 h) particularly among watchkeepers.

Especially the short sleeping times correspond very well with the results of international studies.[30] Sleep periods on board are often interrupted (potentially due to ship's movements or sudden noise evoked by the handling of containers in harbours).[31] These effects can explain why many seafarers, including day workers, suffer from sleepiness on the high seas. The sleep interruptions are particularly often an inevitable consequence of the watch shift requirements with two 4-h working shifts per day. Thus, on any watch system it is common that seafarers have several sleep episodes per 24-h period. Daytime sleep is usually much less efficient than sleep obtained at the circadian nadir. It can be assumed that some watchkeepers have problems falling asleep after a stressful working day (with scarcely any opportunities for sleep); this results in decreased sleep efficiency. Split sleep among watchkeepers can also not be excluded as the cause of this low sleep efficiency.

Although this study has not proved that sleepiness on duty depends directly on disturbances of the sea during passages, we measured generally low sleep efficiency. This means that not only the amount, but also the quality of sleep is insufficient among the examined seafarers on board. Frequent sleep disruptions can impair alertness to a great degree and consequently lead to an increased risk of accident on board.[32]

Despite similar physical stress levels, the crew members with watchkeeping duties experienced mental stress subjectively more frequently than day workers. This was probably due to their reduced and interrupted sleep time as well as their high job responsibility, which represents a distinct mental stressor. Correspondingly, the watchkeepers starting with a subjective sleepiness level similar to that of the day workers had a significantly more pronounced increase in their sleepiness level after the cross-shift examination. Although no significance level was reached, the cross-shift pupillometry of watchkeepers also indicated a higher level of objective sleepiness after the shift than that of day workers. In this context, the

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3 357 difference in the length of examined working time between day workers and watchkeepers  
4 358 has to be highlighted. The watchkeepers' higher value for SSS and, by trend, for PUI after  
5 359 the examined shift is remarkable as they had worked a considerably shorter time than the  
6 360 day workers. Thus, these differences are surely underestimated in this study.

9  
10 361 According to Wilhelm (2008)[33], severe sleepiness is displayed by drivers who did not sleep  
11 362 during the chronobiologically relevant time frame (0:00 h - 05:00 h). In the maritime setting,  
12 363 this especially applies to watchkeepers. These crew members, who are on duty during the  
13 364 inconvenient time frames between 0:00-04:00 h and 04:00-08:00 h, reported the expected  
14 365 subjective severe sleepiness, which was also objectively measured using pupillometry. In  
15 366 this context, it has to be taken into account that most fatigue-induced shipping disasters take  
16 367 place in these time frames.[34]

17  
18 368 According to the results of the Morning-Evening-Questionnaire in the present study, the  
19 369 morning type was overrepresented in the study group. Due to the fact that their work shifts  
20 370 on board often begin early in the morning over several months in a stretch, many seafarers  
21 371 are surely adapted to this daily rhythm and subjectively feel particularly fit in the early  
22 372 morning-hours. This is a hypothesis for the skewed distribution towards the morning type in  
23 373 our study that needs confirmation in further field studies on board.

24  
25 374 Watchkeepers are habitual shift workers, often experiencing circadian misalignment due to  
26 375 their irregular work/rest schedules. This might be one explanation as to why the small  
27 376 number of available maritime field studies about seafarers' fatigue has exclusively focused  
28 377 on watchkeepers. Importantly, this study demonstrates that day workers also often  
29 378 experience severe sleepiness; more than 20% of both the watchkeepers and the day  
30 379 workers were characterised as "unfit for duty" during their regular shift and only every second  
31 380 pupillary measurement was regarded normal. The fact that 12 seafarers had fallen asleep  
32 381 during the 11-min pupillary examination and that 35 crew members regarded themselves as  
33 382 very sleepy post-shift ( $SSS \geq 6$ ) confirms these alarming pupillometric results. In light of the  
34 383 strong impact on the ships' safety, further studies are urgently needed to examine and  
35 384 counteract the sleepiness of both the shipboard watchkeepers and the day workers.

36  
37 385 Furthermore, this study observed that the duration already spent on the vessel at the time of  
38 386 the examination correlated with the PUI. This finding could indicate a cumulative effect on the  
39 387 seafarers' sleepiness. Officers normally have far shorter periods on board than ratings  
40 388 (averaging 2.5 vs. 4.1 months in a row). Daily sleepiness as a consequence of high work  
41 389 strain lasting for many months seems to be plausible. According to the present results,  
42 390 working periods below five months in a row seem to be reasonable for seafarers. Further

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3 391 studies are required to evaluate this hypothesis and to determine recommendations for  
4 392 maximum working periods on board.

6 393 Subjective assessments of sleepiness only displayed a weak correlation with the objective  
7 394 pupillometric results. This could lead to a misjudgement of the seafarers' current  
8 395 psychophysical performance, which might also have safety implications. Younger and less  
9 396 experienced crew members reported more severe sleepiness on duty but did not display  
10 397 differences in their pupillometric measurements. In view of the frequently described high  
11 398 prevalence of fatigue-related accidents in seafaring, a high level of psychophysical stress,  
12 399 but also a misjudgement of their alertness is assumed. Thus, it is recommended to use  
13 400 complementary objective methods besides questionnaires in studies to determine the level of  
14 401 fatigue among examined employees. Future studies should also explore possibilities and  
15 402 evaluate acceptance by the crew to develop more flexible shift scheduling that allows the  
16 403 consideration of circadian preferences and, possibly, individual preferences of the  
17 404 watchkeeping seafarers.

18 405

## 28 406 **Limitations**

29 407 The present study has some limitations that need to be addressed. Firstly, the sample size of  
30 408 this study is rather small, but in comparison to other available maritime studies the examined  
31 409 seafarer population is far larger. Secondly, the study was carried out in a cross-sectional design  
32 410 that does not allow the evaluation of long-time effects of sleepiness. Due to the permanently  
33 411 changing shipping crews on the vessels, it is hardly possible to arrange long-time follow-up  
34 412 examinations of a noteworthy proportion of seafarers. Thirdly, due to the various occupational  
35 413 groups on board, the crews are very heterogeneous and that makes the interpretation and  
36 414 comparison of sleeping behaviours difficult, also when considering the large inter-individual and  
37 415 intra-individual variability in sleep. Fourthly, the present study design does not provide  
38 416 information about the seafarers' sleep architecture. Sleep loss is generally compensated by  
39 417 changing the sleep architecture towards more so-called slow-wave sleep.

40 418 The armband monitor used is mainly suitable for measuring bed rest[35] and has only a limited  
41 419 informative value about sleep architecture, which is normally measured in sleep laboratories  
42 420 ashore, e.g. using polysomnographic techniques.[36] In maritime field studies, however, the use  
43 421 of such extensive examinations (only one measurement per night) does not appear to be very  
44 422 suitable on board. Furthermore, the determination of lying time with this monitor may be  
45 423 somewhat imprecise so that an underestimation of the sleep efficiency cannot be excluded.  
46 424 Although the sleep diaries frequently used for sleep assessment are only subjective procedures,

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3 425 in further studies the armband monitor examination should be accompanied by the use of sleep  
4 426 diaries as they allow checking the start and end times of sleep.  
5  
6 427 Moreover, pupillometry has yet not been established as a reliable screening test for sleepiness  
7  
8 428 [36]. Particularly sleep latency or sleep architecture are the domains of extensive examinations  
9  
10 429 in sleep laboratories ashore and were not the focus of the present maritime field study.  
11 430 Additionally, the PUI correlated with the seafarers' subjective statements. Further studies are  
12  
13 431 recommended to evaluate the validity of these devices for their use in maritime field settings as  
14  
15 432 well as to check their suitability on board and their acceptance by the seafarers on the high seas.

16  
17 433 Despite these limitations, the present study analyses for the first time the prevalence of  
18  
19 434 sleepiness in seafarers with and without watchkeeping duties; the findings require further  
20  
21 435 confirmation in a larger cohort. Furthermore, the present maritime field study analysed the  
22  
23 436 prevalence of seafarers' sleepiness on duty by applying various subjective and objective  
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25 437 methods. Up to now, most maritime studies about seafarers' sleepiness have not been carried  
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27 438 out on board vessels and only rely on subjective methods.[37] Questionnaires are, however,  
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29 439 subjective instruments, consequently depending on self-reported data, so that underreporting  
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31 440 might have occurred.[38] Additionally, these subjective instruments do not reveal  
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33 441 biophysiological differences that might promote the understanding of sleepiness on  
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35 442 board.[21,39]

36  
37 443 Nowadays, a variety of subjective and objective instruments exist for assessment of  
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39 444 excessive daytime sleepiness, including structured sleep history, sleep logs and sleep  
40  
41 445 questionnaires. The multiple sleep latency test, for example, is often used as an objective  
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43 446 measurement to evaluate sleep propensity. However, in view of the large overlap between  
44  
45 447 healthy subjects and subjects with sleep disorders, its use to assess sleepiness is  
46  
47 448 questionable. Furthermore, its results are often jeopardised by motivational influences and  
48  
49 449 the last nap effect.[37] Consequently, a feasible and convenient method that is less  
50  
51 450 dependent on motivation – such as the pupillometry used in this study – seems to constitute  
52  
53 451 an enrichment in field studies.[21]

54  
55 452

### 56 453 **Implications for clinicians and policy makers**

57 454 Fatigue in the maritime setting could be counteracted by strict compliance with and monitoring  
58  
59 455 of the obligatory rest and sleep times. According to Allen, Wadsworth et al. (2007)[37], it is not  
60  
456 uncommon in seafaring for legal obligations to be neglected, for example by ignoring the  
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458 minimum safety levels for crewing on board. To reduce the seafarers' workload on board during  
the vessel's stay in port, some job duties could be transferred to land-based workers ashore.

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3 459 In light of the frequently observed sleepiness on duty within the study sample, training should  
4 460 be offered for shipboard crews to improve sleep hygiene and techniques to support short-  
5 461 term relaxation, such as power napping. This training should be accompanied by the  
6 462 strengthening of the seafarers' individual resources (e.g. training to cope with stress for  
7 463 health promotion) to enable them to compensate for the inevitable psychophysical strain on  
8 464 board. Considering the present results, limiting the work periods of seafarers (perhaps to a  
9 465 maximum of five months) might be an essential preventive measure in a maritime setting.  
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27  
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## 46 483 47 484 **Conflict of interest**

48  
49 485 Both authors declare no conflicts of interest.  
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## 53 486 54 487 **Patient consent**

55  
56 488 Not required.  
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3 490 **Ethics approval**

4  
5 491 The study was approved by the Ethics Committee of the Hamburg Medical Association (no.  
6  
7 492 PV4395).

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11 494 **Data sharing statement**

12  
13 495 No additional data are available.

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60STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

|                              | Item No | Recommendation   | Page No |
|------------------------------|---------|--|---------|
| <b>Title and abstract</b>    | 1       | (a) Indicate the study's design with a commonly used term in the title or the abstract   | 1       |
|                              |         | (b) Provide in the abstract an informative and balanced summary of what was done and what was found  | 2       |
| <b>Introduction</b>          |         |  |         |
| Background/rationale         | 2       | Explain the scientific background and rationale for the investigation being reported   | 3-4     |
| Objectives                   | 3       | State specific objectives, including any prespecified hypotheses   | 4       |
| <b>Methods</b>               |         |  |         |
| Study design                 | 4       | Present key elements of study design early in the paper  | 5       |
| Setting                      | 5       | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection  | 5,7     |
| Participants                 | 6       | (a) Give the eligibility criteria, and the sources and methods of selection of participants  | 5,6     |
| Variables                    | 7       | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable   | 7,8     |
| Data sources/<br>measurement | 8*      | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group                         | 7,8     |
| Bias                         | 9       | Describe any efforts to address potential sources of bias  | 8       |
| Study size                   | 10      | Explain how the study size was arrived at  | 5       |
| Quantitative variables       | 11      | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why   | 6       |
| Statistical methods          | 12      | (a) Describe all statistical methods, including those used to control for confounding  | 8       |
|                              |         | (b) Describe any methods used to examine subgroups and interactions  | 8       |
|                              |         | (c) Explain how missing data were addressed  |         |
|                              |         | (d) If applicable, describe analytical methods taking account of sampling strategy   |         |
|                              |         | (e) Describe any sensitivity analyses  |         |
| <b>Results</b>               |         |  |         |
| Participants                 | 13*     | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed            | 9       |
|                              |         | (b) Give reasons for non-participation at each stage   |         |
|                              |         | (c) Consider use of a flow diagram   |         |
| Descriptive data             | 14*     | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders   | 9       |
|                              |         | (b) Indicate number of participants with missing data for each variable of interest  |         |
| Outcome data                 | 15*     | Report numbers of outcome events or summary measures   | 9       |
| Main results                 | 16      | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 10-12   |

|                          |    |  |       |
|--------------------------|----|--|-------|
|                          |    | (b) Report category boundaries when continuous variables were categorized  |       |
|                          |    | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   | 11    |
| Other analyses           | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses   |       |
| <b>Discussion</b>        |    |  |       |
| Key results              | 18 | Summarise key results with reference to study objectives   | 13    |
| Limitations              | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias                 | 15-16 |
| Interpretation           | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 15-16 |
| Generalisability         | 21 | Discuss the generalisability (external validity) of the study results  | 16    |
| <b>Other information</b> |    |  |       |
| Funding                  | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based              | 17    |

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

# BMJ Open

## Sleepiness of day workers and watchkeepers on board at high seas: a cross-sectional study

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| Keywords:                       | occupational medicine, sleepiness, seafaring, pupillometry  |
|                                 |   |

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4 1 **Sleepiness of day workers and watchkeepers on board at high seas: a cross-sectional**  
5 2 **study**

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24 16 ***Word count: 5,639 words***

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3 17 **ABSTRACT**

4  
5 18 **Objectives**

6  
7 19 To estimate the prevalence of sleepiness on duty among day workers and watchkeepers on  
8 20 board.

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11 21 **Design**

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13 22 Cross-sectional survey in a maritime field study.

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15 23 **Setting**

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17 24 10 shipping companies with container vessels under German management.

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19 25 **Participants**

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21 26 The whole crew (75 day workers and 123 watchkeepers) during 18 voyages on 18 different  
22 27 container ships.

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25 28 **Outcome measures**

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27 29 Sleepiness on duty and efficiency of sleep using pupillometry (in a cross-shift design) and the  
28 30 SenseWear® armband activity monitor.

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31 31 **Results**

32  
33 32 The watchkeepers showed significantly shorter sleep periods than day workers (5.5 h vs. 5.8  
34 33 h). The average efficiency of sleep was 69.6% and significantly lower among watchkeepers  
35 34 (OR 0.48; 95% CI 0.26-0.88). 396 pupillometric examinations were carried out and revealed  
36 35 88 study members (22.2%) with a pupillary unrest index (rPUI) in a range characterised as  
37 36 “unfit for duty” and 110 seafarers (27.8%) categorised as “particular attention required”. The  
38 37 average rPUI was similar between day workers and watchkeepers.

39  
40 38 The Epworth Sleepiness Scale revealed recent daytime sleepiness in 70 seafarers, which  
41 39 was similarly often stated by day workers and watchkeepers. Based on the Stanford  
42 40 Sleepiness Scale (SSS), a measurable cross-shift increase in the SSS value during the  
43 41 examined shift was observed, especially among watchkeepers. The amount of time already  
44 42 spent on the vessel at the time of the present examination was significantly associated with  
45 43 the rPUI (p= 0.009).

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48 44 **Conclusion**

49  
50 45 Sleep periods of both the day workers and the watchkeepers aboard vessels were alarmingly  
51 46 short and sleep efficiency was low. Sleepiness on duty is similarly prevalent among day  
52 47 workers and watchkeepers and seems to depend partly on the cumulative working period on

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3 48 the vessels. Preventive measures need to be taken by the shipping industry to counteract  
4 49 fatigue (e.g.by enabling sufficient rest and sleep times).  
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9 51 **Key words:** *occupational medicine, sleepiness, seafaring, pupillometry*  
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### 12 13 53 **Strengths and limitations of this study**

- 14  
15 54 ➤ The present maritime field study shows for the first time the prevalence of seafarers'  
16 55 sleepiness on duty during the sea passage, drawing a distinction between crew members  
17 56 with and without watchkeeping duties.  
18  
19 57 ➤ The present study analysed seafarers' sleepiness on duty by applying both subjective and  
20 58 objective methods that are less dependent on the participants' motivation (pupillometry,  
21 59 armband activity monitor).  
22  
23 60 ➤ The study was carried out in a cross-sectional design that does not allow evaluation of  
24 61 long-time effects of sleepiness.  
25  
26 62 ➤ Due to the various occupational groups on board, the crews are very heterogeneous; that  
27 63 makes the interpretation and comparison of sleeping behaviours difficult.  
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### 32 33 65 **INTRODUCTION**

34  
35 66 Long and irregular working hours each day, combined with sleep deficiency and long periods  
36 67 of work at sea, are crucial risk factors for increased sleepiness on duty among seafarers.[1,2]  
37  
38 68 Strong weather conditions can also affect seafarers' performance, increase the risk of error  
39 69 and, consequently, cause injuries or fatalities to personnel. Psychological strain in maritime  
40 70 professions can also lead to psychosomatic diseases including burnout syndrome or  
41 71 exhaustion.[3] Some studies have stated that shipping crews suffer from psychophysical  
42 72 exhaustion/strain due to stress and decreased periods and quality of sleep.[4] Thus, seafaring  
43 73 still ought to be considered a high-risk profession for psychophysical exhaustion.[5,6]  
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49 74 Three voyage episodes can be distinguished on board: stays in port, river passages and sea  
50 75 passages. During the first two voyage episodes, the seafarers are often exposed to high  
51 76 psychophysical stressors caused by unforeseeable and external demands that possibly need to  
52 77 be addressed at chronobiologically adverse times (e.g. embarkation and disembarkation,  
53 78 loading and unloading, exchange of information with port authorities). During the sea passage,  
54 79 the engine room personnel, the electricians and the galley staff can often adhere to a regular  
55 80 working day of 8 hours (day workers). This is better suited to chronobiologically adapted sleep  
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3 81 periods and can thus partially compensate for a potential sleep deficiency.[7] In contrast, due to  
4 82 obligatory navigation manoeuvres, nautical officers and a large number of the deck ratings are  
5 83 often required to work in a 24-hour shift system during sea passages (watchkeepers).

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8 84 Nowadays, merchant ships operating internationally generally run on a 4/8-hour watch shift  
9 85 system. That means that three nautical officers alternate in a system which includes four hours  
10 86 on duty and eight hours off for each of them. Van Leeuwen, Kircher et al. (2013)[8] measured  
11 87 the effect of a 4/8-hour watch shift system on the alertness of seafarers in a ship simulator.  
12 88 They observed that especially additional overtime was associated with a subjective and  
13 89 objective increase in sleepiness. The authors also showed sleepiness increasing with time on  
14 90 watch and peaking at the end of a watch.

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20 91 It has been described that watchkeeping, critical assignments during night time and irregular  
21 92 working periods can lead to disruptions of the crews' circadian rhythm as a precondition for  
22 93 sleepiness on board.[9] Dohrmann and Leppin (2017)[7] performed a systematic analysis and  
23 94 quality assessment of seafarers' fatigue. They observed that working nights was most fatiguing  
24 95 and that fatigue levels were higher toward the end of a watch or shift. According to the review,  
25 96 particularly the psychosocial work environment (including day workers besides the  
26 97 watchkeepers) had received little attention. However, the monotonous noise of the vessel's  
27 98 engine, the smooth ship's vibrations and the continuous slow ship's movements (during calm  
28 99 weather conditions) can lead to sleepiness of the whole crew on board. Higher levels of  
29 100 exposure to noise and vibrations can also increase sleep troubles/problems and poorer sleep  
30 101 quality when impacting on employees throughout the day.[10]

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39 102 Working in a maritime setting is characterised by a wide variety of occupations with numerous  
40 103 fatiguing physical and mental strains, depending on the type of job.[11] The available maritime  
41 104 fatigue studies have only focused on watch officers as crew members who typically also work  
42 105 during night hours.[2,8,12,13] Thus, there is a lack of knowledge about sleepiness on the high  
43 106 seas among the other shipboard occupational groups, including the day workers. Knowing who  
44 107 is affected by severe sleepiness on board is of great importance to facilitate its prevention.

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49 108 The present maritime field study analysed for the first time the prevalence of seafarers'  
50 109 sleepiness on duty during the sea passage, with a distinction between day workers and  
51 110 watchkeepers on board.

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## 112 **METHODS**

### 113 **Study sample**

114 A medically trained scientist accompanied 18 sea voyages on 18 different container ships  
115 operating in the Baltic Sea and examined the crew members on board. 206 out of 225  
116 seafarers took part in the study (response rate 91.6%). Only the results of those 198  
117 seafarers were included who could be interviewed and examined (pupillometry) in a cross-  
118 shift design (both before the beginning and after the end of their shift). Taking part in this  
119 study was voluntary and the individual data was pseudonymised. No patients were involved  
120 in this study. All participants gave their written informed consent before taking part in this  
121 study. The study was approved by the Ethics Committee of the Hamburg Medical  
122 Association (no PV4395).

123 The 198 seafarers were classified into two occupational groups (75 day workers and 123  
124 watchkeepers) (Tab. 1). The median age of the exclusively male study sample was 36.7  
125 years (19 - 67 years) and significantly higher among the day workers. Furthermore, the day  
126 workers had a somewhat higher body weight than the watchkeepers. No differences were  
127 observed in the circadian preference when comparing watchkeepers with day workers. The  
128 difference between the two occupational groups in terms of their marital status and the  
129 presence of children was not noteworthy. 49.0% of the seafarers either smoked or were  
130 former smokers.

### 131 132 **Patient and Public Involvement**

133 The present study focused on the sleepiness of shipboard crews; patients and/or public were  
134 not the target group of this study. Previous studies revealed that sleepiness constitutes one  
135 of the major problems amongst seafarers. All German shipping companies owning container  
136 ships were invited to participate in this study. 10 shipping companies agreed and put 18  
137 different container ships at our disposal (1 ship of companies A, B, C, and D, 2 ships of  
138 companies E, F, G, and H, and 3 ships of companies I and J participated).

139 All seafarers on board of these vessels were informed about our study design, aim and  
140 content and were encouraged to participate (participation rate 88.0%). After completion of  
141 our board examination, an individual medical report was created and sent to each of the  
142 accepting seafarers to their home address.

143

|   | <b>Day workers</b><br><i>(54 engine room personnel,<br/>16 electricians, 5 galley staff)</i> | <b>Watchkeepers</b><br><i>(46 nautical officers, 77<br/>deck ratings)</i> |
|---|--|---|
| <b>Number; n (%)</b>                        | 75 (37.9%)   | 123 (62.1%)   |
| <b>Age; median years (min-max)</b>          | 44 (19-67)   | 35 (19-63)  |
| <b>BMI; median (min-max)</b>                | 26 (19-40)   | 24 (17-36)  |
| <b>Morning-Evening-Questionnaire, n (%)</b> |  |   |
| <i>Morning type</i>                         | 45 (60.0%)   | 68 (55.2%)  |
| <i>Intermediate type</i>                    | 24 (32.0%)   | 46 (37.4%)  |
| <i>Evening type</i>                         | 6 (8.0%)   | 9 (7.4%)  |
| <b>Origin; n (%)</b>                        |  |   |
| <i>European</i>                             | 38 (50.7%)   | 47 (38.2%)  |
| <i>Southeast Asian</i>                      | 37 (49.3%)   | 76 (61.8%)  |
| <b>Married; n (%)</b>                       | 53 (70.7%)   | 87 (70.7%)  |
| <b>Children; n (%)</b>                      | 53 (70.7%)   | 82 (66.7%)  |
| <b>Smoking status; n (%)</b>                |  |   |
| <i>Never smoked</i>                         | 36 (48.0%)   | 65 (52.8%)  |
| <i>Former smoker/smoker</i>                 | 39 (52.0%)   | 58 (47.2%)  |

144 **Tab. 1** Demographic and lifestyle parameters by occupational groups on board

145

146 To assess long-term effects on sleep during their current period on board, the participants  
 147 were additionally grouped in respect of their stay on board at the time of examination (< 2  
 148 months, 2-5 months and > 5 months).

149

## 150 **Examination procedure**

151 All seafarers taking part in the study were examined with the SenseWear® armband monitor  
152 and pupillometry both during shifts and during time off (including sleep time). These devices  
153 were selected because they did not considerably disturb the crew's daily routines (low  
154 weight, no cable connection, easy use), which was a precondition. The present study  
155 monitored the sleep of all seafarers in a continuous mode during a period of at least 72 hours  
156 of observation. An observation time of at least 3 days during the sea passage was chosen  
157 because of the known variations of sleep quality on a daily basis.

158 The average period of wearing the armband monitor was 66.3 h (SD 14.8 h) (>92% of  
159 observation time) and did not differ between the occupational groups. The pupillometric  
160 examination took place within this observation period.

161

## 162 **Efficiency of sleep**

163 The *SenseWear® armband activity monitor* is a device that weighs 82 g and is worn on the  
164 right upper arm just above the triceps muscle according to its validation requirements. While  
165 wearing the armband monitor, the seafarers could easily operate the device for themselves  
166 without support from the shipboard examiner. The monitor is designed to analyse the profile  
167 of physical activity (movement, lying down or sleeping). The collected information allows the  
168 estimation of sleep efficiency by establishing the ratio of the duration of sleep and the time  
169 spent lying down. Thus, efficiency of sleep expresses the time spent actually sleeping while  
170 lying down.

171 The armband monitor has already been successfully applied in many studies as a detector of  
172 sleep.[14-19] Current studies reveal that the total sleep time and time in bed correlate  
173 significantly between the measurements of the armband monitor and the polysomnography  
174 ( $p < 0.001$ ); the armband has proved to be superior in comparison to other commercially  
175 available activity monitors.[16]

176

## 177 **Pupillometry**

178 The device *Fit-For-Duty* by AmTech was used to conduct pupillometric examinations [20].  
179 The Pupillographic Sleepiness Test is considered an objective method for documenting  
180 sleepiness by monitoring spontaneous and unconscious oscillations of the pupil without

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3 181 stimulating light. The result is a pupillogram, which can be used to deduct the pupillary unrest  
4 182 index (rPUI). This parameter therefore is an objective measure for the variance of the  
5 183 diameter of the pupil. A recent study suggested the Pupillographic Sleepiness Test as a  
6 184 reliable measurement for detecting drowsiness-related impairment.[21]

9  
10 185 The rPUI is compared to standard values. Results  $< 1.02$  are considered normal. "Particular  
11 186 attention required" is the characterisation of results  $\geq 1.02$  and  $< 1.53$ . An index  $\geq 1.53$  is  
12 187 rated as "unfit for duty". This methodology has repeatedly been used in scientific studies to  
13 188 assess sleepiness.[22-24]

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17 189 During a sea passage, the pupillometric examination was performed twice according to a  
18 190 cross-shift design for all 198 seafarers included in the study sample. The chosen sea  
19 191 passages lasted for at least 24 hours and therefore allowed a regular operation of the vessel  
20 192 and predictable working procedures. The pupillometric cross-shift examination took place 15  
21 193 minutes before the respective shift started and directly after it ended so that that shift was  
22 194 neither shortened nor disturbed by this examination. In general, it is not likely that the  
23 195 seafarers were distinctly disturbed by the examination with the chosen devices or by the  
24 196 presence of the medical staff on board.

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27 197 The engine room personnel, the electricians and the galley staff (without watchkeeping duties)  
28 198 were examined during an average work shift that lasted 8 hours (most likely from 8:00 h to  
29 199 17:00 h including a lunch break of 1 hour). As watchkeepers have two work units per day –  
30 200 each of them about 4 h (six shift periods: 0-4 h, 4-8 h, 8-12 h, 12-16 h, 16-20 h and 20-24 h) – a  
31 201 split sleeping time is often observed in this occupational group. The watchkeepers were  
32 202 examined during a randomly selected shift period with the aim of achieving an equal  
33 203 representation of these periods (about 20 watchkeepers/shift period). For the assessment of  
34 204 cross-shift reactions, it was unavoidable to compare the PUI and SSS between two  
35 205 occupational groups with different lengths of working times.

36 206

## 37 207 **Questionnaire**

38  
39 208 In the framework of a standardised interview, all seafarers were asked about their  
40 209 demographic data, their subjective physical and mental stress level, their sleep period before  
41 210 the examined shift and their current working time. Additionally, daytime sleepiness was  
42 211 estimated by using the Epworth Sleepiness Scale.[25]. This is a self-administered  
43 212 questionnaire which is shown to provide a measurement of the subject's general level of  
44 213 daytime sleepiness. Retrospectively, the probability of nodding off or falling asleep in eight

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3 214 typical everyday situations is investigated. Furthermore, the Stanford Sleepiness Scale was  
4  
5 215 used as a self-rating scale to quantify progressive stages of sleepiness.[26] Individual  
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7 216 circadian fluctuations in sleepiness and alertness can be determined through repetition in  
8  
9 217 intervals. In the present study, this scale assessed the sleepiness before and after a shift.  
10  
11 218 Finally, the seafarers filled in the Morning-Evening-Questionnaire (rMEQ) for the assessment  
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13 219 of the circadian preference.[27, 28] This questionnaire evaluates against individual differences  
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15 220 in the circadian rhythm. Responses to the questions are combined to form a composite score  
16  
17 221 that indicates the degree to which the respondent favours morning versus evening.  
18

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### 223 **Statistics**

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22 224 Statistic analysis was performed with SPSS (version 24, IBM Corporation). The Shapiro-Wilk  
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24 225 test was used to test for normal distribution of data. Where variables were not normally  
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26 226 distributed, non-parametric tests (Mann Whitney-U test, Wilcoxon test) were used, otherwise  
27  
28 227 the T-test was applied in the case of normal distribution. The Chi-squared test was used to  
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30 228 analyse differences in frequencies of parameters. Crude odds ratio (OR) including 95%  
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32 229 confidence intervals was calculated by binary logistic regression. For adjustment reasons,  
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34 230 age, rank (officer vs. rating), the examination time of day and duration of stay on board at the  
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36 231 time of examination were added. Furthermore, correlations were analysed by using the  
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38 232 Spearman test.

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40 233 All indicated p-values were two-sided, and a p-value of < 0.05 was regarded as statistically  
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42 234 significant.

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### 236 **RESULTS**

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45 237 The number of months day workers had already spent on the vessel at the time of examination  
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47 238 and during their current contract was similar to that of watchkeepers. In particular, the  
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49 239 stratification of the seafarers in tertiles concerning their recent stay on board did not reveal any  
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51 240 differences (Tab. 2).

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53 241 The Epworth Sleepiness Scale (ESS) showed that 70 seafarers (35.4%) had recently been  
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55 242 suffering from daytime sleepiness. The ESS value increased significantly ( $p=0.004$ ) with the  
56  
57 243 length of stay on board. No differences were observed when differentiating according to the  
58  
59 244 obligation to perform watchkeeping duties ( $p=0.113$ ). Younger seafarers below the age  
60  
245 median of 37 years indicated daytime sleepiness more often than older colleagues ( $p=0.014$ ).

|   | Occupational groups                   |   | <i>p</i> |
|---|---------------------------------------|---|----------|
|   | <i>Day workers</i><br>( <i>n</i> =75) | <i>Watchkeepers</i><br>( <i>n</i> =123) |          |
| <b>Stay on board</b>                                    |                                       |   |          |
| At the time of examination;<br>median months (min-max)  | 3 (1-12)                              | 3 (0-11)                                | 0.837*   |
| Frequency according to<br>tertile; <i>n</i> (%)         |                                       |   |          |
| ≤ 2 months  | 28 (37.3%)                            | 45 (36.6%)                              |          |
| > 2 and ≤ 5 months                                      | 28 (37.3%)                            | 45 (36.3%)                              | 0.973#   |
| > 5 months  | 19 (25.3%)                            | 33 (26.8%)                              |          |
| Scheduled (min-max)                                     | 7 (2-13)                              | 8 (1-12)                                | 0.719*   |
| <b>Epworth Sleepiness Scale (ESS), median (min-max)</b> |                                       |   |          |
| Score value (SD) <sup>1</sup>                           | 8 (0-15)                              | 8 (0-21)                                | 0.113*   |
| ≥ Cut off value (10), <i>n</i> (%)                      | 26 (34.7%)                            | 44 (35.8%)                              | 0.875#   |

\*Mann Whitney-U test #Chi-squared test <sup>1</sup>sleepiness scale from 0 ("no chance to doze in") up to 24 ("maximum chance to doze in")

**Tab. 2** *Stay on board and subjective assessment for daytime sleepiness*

### Cross-shift examinations

To analyse the recent alertness attributed to a representative shift, 198 seafarers were asked to participate in a cross-shift examination. According to the results of the armband monitor, the cumulative sleep time before the examined shift (including split sleep episodes) lasted for 5.6 hours (SD 1.0) per 24 h period, while watchkeepers had significantly shorter sleep durations compared to the day workers (Tab. 3). The working hours during the examined shift were significantly lower amongst watchkeepers. Concerning their subjective stress level during the shift examined, significantly more watchkeepers experienced mental demands than day workers (OR 2.35; 95% CI 1.24-4.44). After adjustment for age, ranking, examination time of day and recent number of months at the time of investigation, this elevated risk for mental stress remained significant among watchkeepers.

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3 261 During the examined shift, the average sleep efficiency was 69.3% and was significantly  
4 262 lower among watchkeeping seafarers than day workers (OR 0.48; 95% CI 0.26-0.88). This  
5 263 finding was independent of the age, ranking, time of day of the examination and the recent  
6 264 duration of shipboard stay. 63.7% of the participating seafarers stated that they had  
7 265 consumed coffee within the past 4 hour before our pupillometric examination on board  
8 266 irrespective of their occupational group.

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13 267 Before their shift, the mean value on the Stanford Sleepiness Scale (SSS) was 2.6 (SD 1.4)  
14 268 (2= "functioning at high levels, but not fully alert"; 3= "awake, but relaxed; responsive but not  
15 269 fully alert"); after the work shift, the level of sleepiness was significantly higher (3.2 (SD 1.8))  
16 270 (Wilcoxon test:  $p= 0.001$ ) indicating a measurable increase in the subjective sleepiness in the  
17 271 course of a shift. This was especially true for watchkeepers although the length of their  
18 272 working time was much shorter than that of day workers (Tab. 3). Consequently, more  
19 273 watchkeepers reported current sleepiness than day workers after the examined shift.

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25 274 A remarkable number of 35 seafarers (17.7%) reported a level of sleepiness on duty of 6/7  
26 275 on the SSS (6= "sleepy, woozy, fighting sleep, prefer to lie down"; 7= "no longer fighting  
27 276 sleep; sleep onset soon; having dream-like thoughts") after their shift. According to SSS,  
28 277 more young seafarers considered themselves to be tired (cross-shift SSS of all crew  
29 278 members below and above the median age of 37 years: 3.1 vs. 2.6;  $p= 0.011$ ). Focusing on  
30 279 the group of watchkeeping seafarers, those who were on duty between 00:00-04:00 h and  
31 280 04:00-08:00 h more often displayed severe sleepiness on duty after their shift (SSS $\geq$  5) (72.2%  
32 281 and 50.0% respectively).

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39 282 The 396 pupillometric examinations (15 minutes before and after a shift) revealed that the  
40 283 change in rPUI values during the cross-shift observation did not reach a significant level in  
41 284 intra-individual comparison (mean rPUI before vs. after the working shift: 1.14 vs. 1.19; cross-  
42 285 shift rPUI change:  $p= 0.355$ ). After stratification, the intra-individual cross-shift change in rPUI  
43 286 values was also not dependent on the occupational groups (Tab. 3), while the different length  
44 287 of working time has to be taken into account.

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49 288 The objective sleepiness on duty in the study sample was not dependent on age (only a  
50 289 slight tendency for younger seafarers after shift;  $p= 0.064$ ). During the examination, 12  
51 290 seafarers fell asleep and therefore were assigned to the group "unfit for duty". The pupillary  
52 291 unrest index in 88 examinations showed the seafarers were "unfit for duty"; additionally  
53 292 "particular attention required" was classified in 110 cases (27.8%). Therefore, only half of the  
54 293 examinations were "normal". No differences were observed in the pupillary unrest index  
55 294 between seafarers with and without watchkeeping duties.

295 In concordance to their subjective self-report in SSS, watchkeepers displayed somewhat  
 296 higher rPUI values after the shift than day workers (Tab. 3). The analysis of the correlation of  
 297 the subjective assessment of sleepiness on duty (SSS) with the objective measures of  
 298 pupillometry only revealed a weak correlation after the shift ( $r= 0.185$ ;  $p= 0.009$ ).

299 Within the group of watchkeepers, stronger sleepiness on duty ( $rPUI \geq 1.2$ ) after a shift  
 300 lasting from 00:00-04:00 h and from 04:00-08:00 h was observed (75.0% and 55.6%  
 301 respectively).

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|  | <b>Occupational groups</b> |                     |                         |                         |
|--|----------------------------|---------------------|-------------------------|-------------------------|
|  | <b>Day workers</b>         | <b>Watchkeepers</b> | <b>Crude OR*</b>        | <b>Adjusted OR#</b>     |
|  | <i>(n=75)</i>              | <i>(n=123)</i>      | <i>(95% CI)</i>         | <i>(95% CI)</i>         |
| <b>Time periods in the context of the current pupillometric examination, mean hours (SD)</b> |                            |                     |                         |                         |
| Sleep period before <sup>1</sup>   | 5.8 (1.1)                  | 5.5 (1.0)           | <b>0.85 (0.78-0.92)</b> | <b>0.88 (0.80-0.95)</b> |
| Working hours examined   | 9.5 (1.5)                  | 4.9 (1.6)           | <b>0.56 (0.43-0.88)</b> | <b>0.57 (0.46-0.92)</b> |
| <b>Subjective stress level during examined shift, n (SD)</b>                                 |                            |                     |                         |                         |
| Physical <sup>2</sup>  | 48 (64.0%)                 | 78 (63.4%)          | 0.96 (0.52-1.79)        | 0.51 (0.24-1.08)        |
| Mental <sup>3</sup>  | 41 (54.7%)                 | 94 (76.4%)          | <b>2.35 (1.24-4.44)</b> | <b>2.18 (1.08-4.40)</b> |
| <b>Sleep efficiency<sup>1</sup></b>  |                            |                     |                         |                         |
| - Mean (%)   | 72.7% (11.8%)              | 67.9% (12.2%)       | <b>0.48 (0.26-0.88)</b> | <b>0.48 (0.25-0.91)</b> |
| <b>Stanford Sleepiness Scale (SSS)<sup>4</sup>, mean (SD)</b>                                |                            |                     |                         |                         |
| <b>Cross-shift<sup>5</sup></b>   | 2.6 (1.4)                  | 3.1 (1.7)           | 0.73 (0.48-1.10)        | 0.84 (0.55-1.29)        |
| <b>Time depending</b>  |                            |                     |                         |                         |
| - Before the shift   | 2.5 (1.4)                  | 2.6 (1.5)           | 1.07 (0.59-1.95)        | 0.91 (0.49-1.70)        |
| - After the shift  | 2.8 (1.4)                  | 3.5 (1.9)           | <b>1.81 (1.01-3.25)</b> | 1.25 (0.66-2.37)        |
| <b>Pupillary unrest index (rPUI), mean (SD)</b>  |                            |                     |                         |                         |
| <b>Cross-shift<sup>5</sup></b>   | 1.14 (0.66)                | 1.18 (0.65)         | 0.92 (0.61-1.40)        | 1.05 (0.70-1.61)        |



**Time depending**

|                    |             |             |                  |                  |
|--------------------|-------------|-------------|------------------|------------------|
| - Before the shift | 1.14 (0.67) | 1.12 (0.62) | 0.96 (0.52-1.74) | 0.86 (0.46-1.61) |
| - After the shift  | 1.13 (0.66) | 1.23 (0.65) | 1.55 (0.85-2.84) | 1.31 (0.70-2.46) |

**Level (n=396) of sleepiness on duty<sup>5</sup> n (%)**

|  |            |             |       |  |
|--|------------|-------------|-------|--|
| - None <sup>6</sup>                          | 78 (52.0%) | 120 (48.8%) |       |  |
| - Particular attention required <sup>7</sup> | 39 (26.0%) | 71 (28.9%)  | 0.789 |  |
| - Unfit for duty <sup>8</sup>                | 33 (22.0%) | 55 (22.3%)  |       |  |

<sup>303</sup> \*the crude OR bases on the median of parameters and includes differences between occupational  
<sup>304</sup> groups and the examination time of day <sup>305</sup> #adjusted for age, rank (officer vs. rating) and duration of  
stay on board at the time of examination

<sup>306</sup> <sup>1</sup>according to measurements with the armband monitor, related to an average 24 hour period  
<sup>307</sup> <sup>2</sup>"have you experienced physical stress during the examined shift?" <sup>308</sup> <sup>3</sup>"have you experienced  
mental stress during the examined shift?"

<sup>309</sup> <sup>4</sup>SSS-scale from 1 ("feel active and vital") up to 7 ("almost dreaming/falling asleep")

<sup>310</sup> <sup>5</sup>all values exploited (before and after the shift) <sup>6</sup>rPUI < 1.02 <sup>7</sup>rPUI ≥ 1.02 and < 1.53 <sup>8</sup>rPUI ≥ 1.53

**Tab. 3 Cross-shift examination concerning sleep characteristics**

Regardless of the occupational groups, the objective sleepiness on duty (rPUI) did not correlate to the cumulative sleep over a 24-h period before the examined shift, the sleep efficiency and the objective assessment of the ship's motion according to the ship's journal parameters. An association was observed, however, between the duration of time already spent on board at the time of the seafarers' examination and the rPUI (p= 0.009). The stratification according to the duration of stay on board indicates that the association was especially true for those seafarers with a longer stay on the vessels (pre-shift rPUI after stay of less than 2 months, 2-5 months and more than 5 months: 1.06, 1.09 and - much higher - 1.32). The bivariate grouping of the crew according to their stay of less vs. more than 5 months showed significant pre-shift differences in rPUI (1.08 vs. 1.32; p= 0.002).

## 324 DISCUSSION

325 Being a seafarer requires strong mental stability and a robust physical constitution, along  
326 with an adaptive and flexible attitude. However, stress and fatigue can hinder maritime  
327 professionals in performing effectively.[29] Seafarers spend both their working and leisure  
328 time over a couple of months in the restricted shipboard environment that can impact sleep  
329 quality and lead to sleepiness.[5] In the present study, a significantly lower sleep efficiency  
330 averaging at 69.3% and a higher subjective sleepiness assessment (SSS) after the shift  
331 were found among watchkeepers compared to day workers. In addition, the examinations  
332 carried out on board objectified critically short durations of the seafarers' sleep average (5.6  
333 h per 24 h) particularly among watchkeepers.

334 Especially the short sleeping times correspond very well with the results of international  
335 studies.[30] Sleep periods on board are often interrupted (potentially due to ship's  
336 movements or sudden noise evoked by the handling of containers in harbours).[31] These  
337 effects can explain why many seafarers, including day workers, suffer from sleepiness on the  
338 high seas. The sleep interruptions are particularly often an inevitable consequence of the  
339 watch shift requirements with two 4-h working shifts per day. Thus, on any watch system it is  
340 common that seafarers have several sleep episodes per 24-h period. Daytime sleep is  
341 usually much less efficient than sleep obtained at the circadian nadir. It can be assumed that  
342 some watchkeepers have problems falling asleep after a stressful working day (with scarcely  
343 any opportunities for sleep); this results in decreased sleep efficiency. Split sleep among  
344 watchkeepers can also not be excluded as the cause of this low sleep efficiency.

345 Although this study has not proved that sleepiness on duty depends directly on disturbances  
346 of the sea during passages, we measured generally low sleep efficiency. This means that not  
347 only the amount, but also the quality of sleep is insufficient among the examined seafarers  
348 on board. Frequent sleep disruptions can impair alertness to a great degree and  
349 consequently lead to an increased risk of accident on board.[32]

350 Despite similar physical stress levels, the crew members with watchkeeping duties  
351 experienced mental stress subjectively more frequently than day workers. This was probably  
352 due to their reduced and interrupted sleep time as well as their high job responsibility, which  
353 represents a distinct mental stressor. Correspondingly, the watchkeepers starting with a  
354 subjective sleepiness level similar to that of the day workers had a significantly more  
355 pronounced increase in their sleepiness level after the cross-shift examination. Although no  
356 significance level was reached, the cross-shift pupillometry of watchkeepers also indicated a  
357 higher level of objective sleepiness after the shift than that of day workers. In this context, the

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3 358 difference in the length of examined working time between day workers and watchkeepers  
4 359 has to be highlighted. The watchkeepers' higher value for SSS and, by trend, for PUI after  
5 360 the examined shift is remarkable as they had worked a considerably shorter time than the  
6 361 day workers. Thus, these differences are surely underestimated in this study.

9  
10 362 According to Wilhelm (2008)[33], severe sleepiness is displayed by drivers who did not sleep  
11 363 during the chronobiologically relevant time frame (0:00 h - 05:00 h). In the maritime setting,  
12 364 this especially applies to watchkeepers. These crew members, who are on duty during the  
13 365 inconvenient time frames between 0:00-04:00 h and 04:00-08:00 h, reported the expected  
14 366 subjective severe sleepiness, which was also objectively measured using pupillometry. In  
15 367 this context, it has to be taken into account that most fatigue-induced shipping disasters take  
16 368 place in these time frames.[34]

17  
18 369 According to the results of the Morning-Evening-Questionnaire in the present study, the  
19 370 morning type was overrepresented in the study group. Due to the fact that their work shifts  
20 371 on board often begin early in the morning over several months in a stretch, many seafarers  
21 372 are surely adapted to this daily rhythm and subjectively feel particularly fit in the early  
22 373 morning-hours. This is a hypothesis for the skewed distribution towards the morning type in  
23 374 our study that needs confirmation in further field studies on board.

24  
25 375 Watchkeepers are habitual shift workers, often experiencing circadian misalignment due to  
26 376 their irregular work/rest schedules. This might be one explanation as to why the small  
27 377 number of available maritime field studies about seafarers' fatigue has exclusively focused  
28 378 on watchkeepers. Importantly, this study demonstrates that day workers also often  
29 379 experience severe sleepiness; more than 20% of both the watchkeepers and the day  
30 380 workers were characterised as "unfit for duty" during their regular shift and only every second  
31 381 pupillary measurement was regarded normal. The fact that 12 seafarers had fallen asleep  
32 382 during the 11-min pupillary examination and that 35 crew members regarded themselves as  
33 383 very sleepy post-shift (SSS  $\geq$  6) confirms these alarming pupillometric results. In light of the  
34 384 strong impact on the ships' safety, further studies are urgently needed to examine and  
35 385 counteract the sleepiness of both the shipboard watchkeepers and the day workers.

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37 386 Furthermore, this study observed that the duration already spent on the vessel at the time of  
38 387 the examination correlated with the PUI. This finding could indicate a cumulative effect on the  
39 388 seafarers' sleepiness. Officers normally have far shorter periods on board than ratings  
40 389 (averaging 2.5 vs. 4.1 months in a row). Daily sleepiness as a consequence of high work  
41 390 strain lasting for many months seems to be plausible. According to the present results,  
42 391 working periods below five months in a row seem to be reasonable for seafarers. Further

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3 392 studies are required to evaluate this hypothesis and to determine recommendations for  
4 393 maximum working periods on board.

6 394 Subjective assessments of sleepiness only displayed a weak correlation with the objective  
7 395 pupillometric results. This could lead to a misjudgement of the seafarers' current  
8 396 psychophysical performance, which might also have safety implications. Younger and less  
9 397 experienced crew members reported more severe sleepiness on duty but did not display  
10 398 differences in their pupillometric measurements. In view of the frequently described high  
11 399 prevalence of fatigue-related accidents in seafaring, a high level of psychophysical stress,  
12 400 but also a misjudgement of their alertness is assumed. Thus, it is recommended to use  
13 401 complementary objective methods besides questionnaires in studies to determine the level of  
14 402 fatigue among examined employees. Future studies should also explore possibilities and  
15 403 evaluate acceptance by the crew to develop more flexible shift scheduling that allows the  
16 404 consideration of circadian preferences and, possibly, individual preferences of the  
17 405 watchkeeping seafarers.

18 406

## 19 407 **Limitations**

20 408 The present study has some limitations that need to be addressed. Firstly, the sample size of  
21 409 this study is rather small, but in comparison to other available maritime studies the examined  
22 410 seafarer population is far larger. Secondly, the study was carried out in a cross-sectional design  
23 411 that does not allow the evaluation of long-time effects of sleepiness. Due to the permanently  
24 412 changing shipping crews on the vessels, it is hardly possible to arrange long-time follow-up  
25 413 examinations of a noteworthy proportion of seafarers. Thirdly, due to the various occupational  
26 414 groups on board, the crews are very heterogeneous and that makes the interpretation and  
27 415 comparison of sleeping behaviours difficult, also when considering the large inter-individual and  
28 416 intra-individual variability in sleep. Fourthly, the present study design does not provide  
29 417 information about the seafarers' sleep architecture. Sleep loss is generally compensated by  
30 418 changing the sleep architecture towards more so-called slow-wave sleep.

31 419 The armband monitor used is mainly suitable for measuring bed rest[35] and has only a limited  
32 420 informative value about sleep architecture, which is normally measured in sleep laboratories  
33 421 ashore, e.g. using polysomnographic techniques.[36] In maritime field studies, however, the use  
34 422 of such extensive examinations (only one measurement per night) does not appear to be very  
35 423 suitable on board. Furthermore, the determination of lying time with this monitor may be  
36 424 somewhat imprecise so that an underestimation of the sleep efficiency cannot be excluded.  
37 425 Although the sleep diaries frequently used for sleep assessment are only subjective procedures,

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3 426 in further studies the armband monitor examination should be accompanied by the use of sleep  
4 427 diaries as they allow checking the start and end times of sleep.  
5  
6 428 Moreover, pupillometry has yet not been established as a reliable screening test for sleepiness  
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8 429 [36]. Particularly sleep latency or sleep architecture are the domains of extensive examinations  
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10 430 in sleep laboratories ashore and were not the focus of the present maritime field study.  
11 431 Additionally, the PUI correlated with the seafarers' subjective statements. Further studies are  
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13 432 recommended to evaluate the validity of these devices for their use in maritime field settings as  
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15 433 well as to check their suitability on board and their acceptance by the seafarers on the high seas.

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17 434 Despite these limitations, the present study analyses for the first time the prevalence of  
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19 435 sleepiness in seafarers with and without watchkeeping duties; the findings require further  
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21 436 confirmation in a larger cohort. Furthermore, the present maritime field study analysed the  
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23 437 prevalence of seafarers' sleepiness on duty by applying various subjective and objective  
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25 438 methods. Up to now, most maritime studies about seafarers' sleepiness have not been carried  
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27 439 out on board vessels and only rely on subjective methods.[37] Questionnaires are, however,  
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29 440 subjective instruments, consequently depending on self-reported data, so that underreporting  
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31 441 might have occurred.[38] Additionally, these subjective instruments do not reveal  
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33 442 biophysiological differences that might promote the understanding of sleepiness on  
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35 443 board.[21,39]

36  
37 444 Nowadays, a variety of subjective and objective instruments exist for assessment of  
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39 445 excessive daytime sleepiness, including structured sleep history, sleep logs and sleep  
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41 446 questionnaires. The multiple sleep latency test, for example, is often used as an objective  
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43 447 measurement to evaluate sleep propensity. However, in view of the large overlap between  
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45 448 healthy subjects and subjects with sleep disorders, its use to assess sleepiness is  
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47 449 questionable. Furthermore, its results are often jeopardised by motivational influences and  
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49 450 the last nap effect.[37] Consequently, a feasible and convenient method that is less  
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51 451 dependent on motivation – such as the pupillometry used in this study – seems to constitute  
52  
53 452 an enrichment in field studies.[21]

54  
55 453

#### 56 454 **Implications for clinicians and policy makers**

57 455 Fatigue in the maritime setting could be counteracted by strict compliance with and monitoring  
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59 456 of the obligatory rest and sleep times. According to Allen, Wadsworth et al. (2007)[37], it is not  
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457 uncommon in seafaring for legal obligations to be neglected, for example by ignoring the  
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459 minimum safety levels for crewing on board. To reduce the seafarers' workload on board during  
the vessel's stay in port, some job duties could be transferred to land-based workers ashore.

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3 460 In light of the frequently observed sleepiness on duty within the study sample, training should  
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5 461 be offered for shipboard crews to improve sleep hygiene and techniques to support short-  
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7 462 term relaxation, such as power napping. This training should be accompanied by the  
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9 463 strengthening of the seafarers' individual resources (e.g. training to cope with stress for  
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11 464 health promotion) to enable them to compensate for the inevitable psychophysical strain on  
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13 465 board. Considering the present results, limiting the work periods of seafarers (perhaps to a  
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15 466 maximum of five months) might be an essential preventive measure in a maritime setting.

16 467

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24 472

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26  
27  
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29  
30 475 acquisition, analysis or interpretation of data. They were equally involved in drafting the work  
31  
32 476 or revising it critically for important intellectual content. Both authors gave their final approval  
33  
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42  
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44  
45 483 paper for publication.

46 484

### 47 485 **Conflict of interest**

48  
49  
50 486 Both authors declare no conflicts of interest.

51 487

### 52 488 **Patient consent**

53  
54  
55 489 Not required.

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2  
3 491 **Ethics approval**

4  
5 492 The study was approved by the Ethics Committee of the Hamburg Medical Association (no.  
6  
7 493 PV4395).

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11 495 **Data sharing statement**

12  
13 496 No additional data are available.

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60STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

|                              | Item No | Recommendation   | Page No |
|------------------------------|---------|--|---------|
| <b>Title and abstract</b>    | 1       | (a) Indicate the study's design with a commonly used term in the title or the abstract   | 1       |
|                              |         | (b) Provide in the abstract an informative and balanced summary of what was done and what was found  | 2       |
| <b>Introduction</b>          |         |  |         |
| Background/rationale         | 2       | Explain the scientific background and rationale for the investigation being reported   | 3-4     |
| Objectives                   | 3       | State specific objectives, including any prespecified hypotheses   | 4       |
| <b>Methods</b>               |         |  |         |
| Study design                 | 4       | Present key elements of study design early in the paper  | 5       |
| Setting                      | 5       | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection  | 5,7     |
| Participants                 | 6       | (a) Give the eligibility criteria, and the sources and methods of selection of participants  | 5,6     |
| Variables                    | 7       | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable   | 7,8     |
| Data sources/<br>measurement | 8*      | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group                         | 7,8     |
| Bias                         | 9       | Describe any efforts to address potential sources of bias  | 8       |
| Study size                   | 10      | Explain how the study size was arrived at  | 5       |
| Quantitative variables       | 11      | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why   | 6       |
| Statistical methods          | 12      | (a) Describe all statistical methods, including those used to control for confounding  | 8       |
|                              |         | (b) Describe any methods used to examine subgroups and interactions  | 8       |
|                              |         | (c) Explain how missing data were addressed  |         |
|                              |         | (d) If applicable, describe analytical methods taking account of sampling strategy   |         |
|                              |         | (e) Describe any sensitivity analyses  |         |
| <b>Results</b>               |         |  |         |
| Participants                 | 13*     | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed            | 9       |
|                              |         | (b) Give reasons for non-participation at each stage   |         |
|                              |         | (c) Consider use of a flow diagram   |         |
| Descriptive data             | 14*     | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders   | 9       |
|                              |         | (b) Indicate number of participants with missing data for each variable of interest  |         |
| Outcome data                 | 15*     | Report numbers of outcome events or summary measures   | 9       |
| Main results                 | 16      | (a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 10-12   |

|                          |    |  |       |
|--------------------------|----|--|-------|
|                          |    | (b) Report category boundaries when continuous variables were categorized  |       |
|                          |    | (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period   | 11    |
| Other analyses           | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses   |       |
| <b>Discussion</b>        |    |  |       |
| Key results              | 18 | Summarise key results with reference to study objectives   | 13    |
| Limitations              | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias                 | 15-16 |
| Interpretation           | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 15-16 |
| Generalisability         | 21 | Discuss the generalisability (external validity) of the study results  | 16    |
| <b>Other information</b> |    |  |       |
| Funding                  | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based              | 17    |

\*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).