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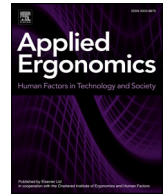
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Time-of-day and days-on-shift predict increased fatigue over two-week offshore day-shifts



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ABSTRACT

Objectives: The purpose of this study was to investigate the accumulation of fatigue over a two-week offshore period. In particular, the effects of (1) time-of-day and days-on-shift as well as (2) acute and chronic sleep loss on the rate at which fatigue accumulates were investigated.

Methods: 42 day-shift offshore workers were examined. Fatigue was measured using pre- and post-shift scores on the Karolinska Sleepiness Scale (KSS). Total sleep time was measured using actigraphy (Motionwatch8, Camntech). Data was analyzed using a linear mixed model analyses.

Results: Average sleep loss per night was 92 min (95%CI: 89.6–94.0; $p < .001$). Mean cumulative sleep loss across the study was 21:20hrs (SD = 08:10hrs) over the 14 days. Chronic sleep loss was significantly related to a modest increase in sleepiness (KSS) across the shift (95%CI: 0.01–0.17; $p = .020$) and in post-shift scores (95%CI: 0.07–0.19; $p < .001$). Time-of-day (95%CI: 0.63 to -0.01 ; $p = .042$) and days-on-shift (95%CI: 0.03–0.08; $p < .001$) as well as their interaction (95%CI: 0.08 to -0.00 ; $p = .027$) influenced the rate at which fatigue accumulated over a two-week offshore period.

Conclusions: Pre- and post-shift fatigue accumulate in different ways over the two-week offshore period. The accumulation of post-shift fatigue scores was positively related to successive days-on-shift and chronic sleep loss. Our results suggest that prolonging offshore periods will likely result in elevated fatigue risk. Accumulating fatigue and sleep loss over two-week offshore periods should be considered in fatigue risk management plans and systems.

1. Introduction

Fatigue is a well-established occupational hazard, particularly relevant in shift work environments (Folkard et al., 2005; Williamson et al., 2011). The offshore oil and gas industry represents a high-risk shift work environment, in which effective fatigue risk management can help prevent disasters like the 2010 Deep Water Horizon incident (U.S. Chemical Safety and Hazard Investigation Board, 2016). Offshore stints vary in length with shift durations ranging from one to four weeks. Both, high levels of fatigue and reports of increased sleeping problems have been well-documented amongst offshore workers (Fossum et al., 2013; Menezes et al., 2004; Parkes, 1994, 2015, 2017; Ross, 2009). During offshore shifts, offshore workers sleep less, feel less rested upon

waking, perceive their overall sleep quality as worse, and report high levels of fatigue and sleepiness compared with leave periods (Merkus et al., 2015; Parkes, 1994; Riethmeister et al., 2016). Moreover, research by our group found that fatigue scores in the evening (after shift completion) increased during the course of an offshore deployment and more than a third of the investigated offshore population reported a ‘high risk’ Karolinska Sleepiness Scale (KSS) score (> 6) by day ten of their shift sequence (Riethmeister et al., 2016, 2018). This finding implies that both, time-of-day and days-on-shift may influence the rate at which fatigue accumulates.

One of the major causes of fatigue is the interaction between two physiological drives: the circadian and the homeostatic sleep/wake drive (Borbely et al., 2016). The circadian drive is regulated by the

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circadian pacemaker, located in the suprachiasmatic nucleus of the hypothalamus, which generates circadian 24-hr rhythms of core bodily functions and controls brain alerting signals. The homeostatic system, involves neural systems in the brain stem and basal forebrain, which control sleep/wake regulation. During the day, the propensity to fall asleep is controlled by homeostatic sleep/wake drives and is counteracted by the increasing wake propensity, controlled by the circadian drive (Dijk and Czeisler, 1994). This synergistic relationship between circadian and homeostatic sleep/wake drives is a major contributor to individuals' levels of alertness and performance as well as rest-activity patterns during a day (Borbely et al., 2016; Pilcher et al., 2002). Other potential contributors may be psychosocial factors, such as an individual's level of motivation, resilience, and perceptions of workload (Magnavita and Gabarino, 2017; Dawson et al., 2011).

Sleep and wake have previously been defined as separate states, which are both influenced by prior sleep debt (Carskadon and Dement, 2011). Sleep debt, the cumulative effect of not getting enough sleep with respect to a subject-specific daily need for sleep, can stem from acute and chronic sleep loss (Van Dongen et al., 2003). Extensive laboratory and field research has demonstrated the adverse effects of acute sleep loss and time-of-day on fatigue (Akerstedt et al., 2013; Matthews et al., 2012a, 2012b). Yet, less research has focused on fatigue caused by the effects of cumulative sleep loss over several days-on-shift – sometimes referred to as chronic sleep loss (Van Dongen et al., 2003). In addition, there is a lack of research investigating the interaction between acute and chronic sleep loss and in particular the interaction between time-of-day and days-on-shift. These interactions might also influence the rate at which fatigue accumulates during shift work.

Previously, it has been suggested that the rate at which fatigue accumulates across the day varies as a function of prior sleep loss, consistent with the principles that: (1) acute and chronic sleep loss increase fatigue levels and that (2) high sleep loss increases the rate at which fatigue accumulates across the waking period (Matthews et al., 2012b). Some recently published laboratory studies have suggested that this increased fatigue accumulation rate is due to an interaction between circadian and homeostatic sleep/wake drives (Kosmadopoulos et al., 2017; Matthews et al., 2012a, 2012b; Zhou et al., 2010). Moreover, these studies suggest that considering this interaction is necessary for the development of better fatigue-risk prediction models. To date, fatigue risk management systems (FRMS) that use bio-mathematical algorithms to predict fatigue, are said to be over-simplistic as they lack e.g. the interaction between circadian and homeostatic sleep-wake drives and mainly focus on e.g. hours of service, the time-of-day, sleep opportunity, and sleep in the past 24/48 h (Dawson and McCulloch, 2005; Dawson et al., 2017). Forced desynchrony laboratory studies, i.e. studies that disentangle endogenous and activity-related effects on daily rhythms to demonstrate that the homeostatic and circadian systems interact, have further investigated this interaction (Matthews et al., 2012a, 2012b; Zhou et al., 2010, 2011). In particular, forced desynchrony laboratory studies have shown that the disruption of circadian factors (e.g. the light-dark cycle), as well as acute and chronic sleep loss produce only small impairments of alertness and performance by themselves. However, when combining the factors, they resulted in more substantial alertness and performance deficits and, by inference, heightened occupational risk (i.e. involvement in occupational incidents and/or accidents) (Matthews et al., 2012b). Thus, only two of the three fatiguing factors (the circadian and the acute and chronic homeostatic sleep/wake drives) need to be present to decrease alertness. Therefore, we hypothesize that even day-shift workers will struggle with fatigue problems if they accumulate *enough* sleep debt over a consecutive number of days-on-shift and factoring in the time-of-day. In other words, even when no pressing circadian drive to be sleepy exists, day-shift workers will experience fatigue when enough acute and chronic sleep loss is accumulated across an offshore shift rotation.

The main objective of this study was to investigate the accumulation

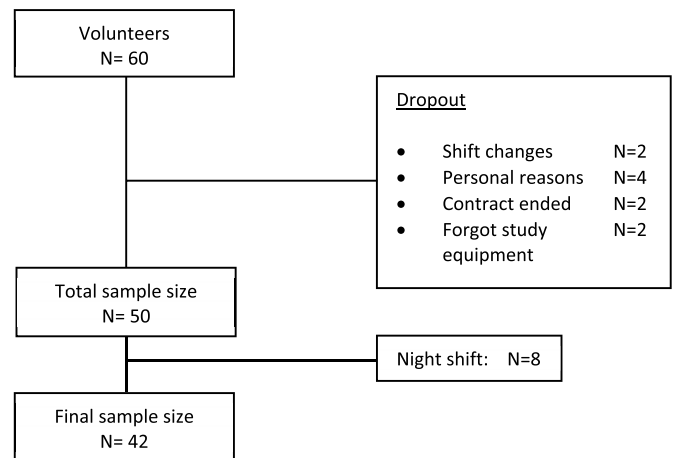


Fig. 1. Flowchart of study sample. Previously published in Riethmeister et al. (2018).

of fatigue over a two-week offshore period. In particular, we examine the effects of (1) time-of-day and days-on-shift as well as the effects of (2) acute and chronic sleep loss on the rate at which fatigue accumulates. Main and interaction effects will be investigated.

2. Materials and methods

2.1. Participants

Data from an existing prospective cohort study among $N = 42$ offshore day-shift workers was used (Riethmeister et al., 2018). (Fig. 1) Study recruitment was done via electronic study waivers, which were sent via company email accounts, and posters and banners displayed at the heliport and on the offshore platforms. Both permanent staff and contractors were asked to participate. Offshore work arrangements consisted of fourteen consecutive days of twelve-hour day-shifts (07:00–19:00 o'clock), on four remote gas production platforms in the Dutch Central North Sea. Each day, offshore workers wore actigraphs to determine sleep behavior and filled in electronic sleep diaries to assess their subjective level of fatigue at 7am (pre-shift) and 7pm (post-shift). Ethical approval for this study was granted by the ethics committee of the University Medical Center Groningen, The Netherlands (reference number: M14.165646). A more elaborate study (design) description was provided elsewhere (Riethmeister et al., 2018).

2.2. Measures

Fatigue was assessed pre- and post-shift using the Karolinska Sleepiness Scale (KSS) (Akerstedt and Gillberg, 1990). Sleepiness, the drive to fall asleep due to insufficient sleep (Dement and Carskadon, 1982), has been used extensively as a proxy for fatigue and is used in many fatigue risk prediction models (Dawson et al., 2011, 2017). The KSS is a valid and reliable measure of sleepiness that has previously been used for the investigation of fatigue among offshore workers (Kaida et al., 2007; Waage et al., 2012). The KSS consists of a one-item Likert scale, asking participants to rate their level of sleepiness from (1) Extremely alert to (9) Very sleepy, great effort to keep awake, fighting sleep (Akerstedt et al., 2014). KSS scores are strongly associated with time-of-day and sleep quality (Akerstedt et al., 2017). Offshore workers with a KSS score of > 6 were classified as suffering from severe sleepiness, i.e. high fatigue (Härmä et al., 2002). Pre- and post-shift KSS scores as well as their difference scores (post-shift KSS subtracted by pre-shift KSS scores) were examined.

Sleep duration was assessed using actigraph recordings (MotionWatch8[®], CamnTech). The MotionWatch8[®] is a light-weight, waterproof, wrist-worn actigraph, which has been shown to be a valid

and reliable measure for the investigation of sleep parameters, using tri-axial sensors data (Cellini et al., 2013; Elbaz et al., 2012). Generated data consist of 1-min epochs. Sleep loss for each night (acute sleep loss) was calculated by subtracting the actual/total sleep time (TST), total time spent in sleep per epoch-by-epoch sleep/wake categorization, from eight-hours of recommended sleep duration. Recommended sleep durations usually range between seven and nine hours for healthy adults (Hirshkowitz et al., 2015). To determine sleep loss, eight-hours of sleep duration was used as a reference point, based on the average value of recommended sleep durations and our earlier finding of 08:14 h of average time in bed during leave periods. Chronic sleep loss was calculated by adding the hours of acute sleep loss over the offshore period (i.e. days-on-shift).

Demographic and work variables included offshore workers' self-reported: age, gender, height and weight, used to calculate participants body mass indices (BMI: kg/m²), chronotype and job tenure (years in current function). Offshore workers chronotype was assessed using the Munich Chronotype Questionnaire (MCTQ) (Roenneberg et al., 2003; Juda et al., 2013). Prior sleep quality was assessed with the Pittsburgh sleep quality index (PSQI) (Buysse et al., 1989; Carpenter and Andrykowski, 1998). The PSQI assesses sleep quality and disturbances during the previous four weeks, here including work and leave periods. The PSQI cannot be split to represent sleep quality in work and leave periods. Scores range from 0 to 21, with higher scores indicating worse sleep quality. PSQI scores ≥ 5 indicate poor sleepers.

2.3. Statistical analysis

Linear mixed model (LMM) analyses were performed to assess the accumulation of fatigue (pre-/post-shift, and daily difference scores) over the two-week offshore period. In addition, random intercept LMMs were used to examine how (1) time-of-day and days-on-shift as well as (2) acute and chronic sleep loss influenced the rate at which fatigue accumulated over a two-week offshore period. Main and interaction effects between time-of-day and days-on-shift as well as acute and chronic sleep loss were examined. One-hour bins of acute sleep and four-hour bins of chronic sleep loss were investigated. Chronic sleep loss was clustered into four-hour bins to ease readability and interpretability of the effect of chronic sleep loss on pre- and post-shift fatigue scores over time. Platform location was entered as a fixed effect to the LMM analyses to adjust for possible cluster effects. Missing values in the field study were regarded to be random.

3. Results

Six participants were excluded because of substantial missing data. The final sample with complete data consisted of $N = 36$ (85.7%) male participants (Table 1). Elaborate description of the courses of pre- and

Table 1
Sample characteristics of the final study sample.

	N	Mean	SD	Range
Age (years)	36	43.4	11.8	21.2–62.8
BMI	35	26.6	3.3	20.9–36.3
Years in current function	35	6.8	6.6	1–27
Prior sleep quality (PSQI)	33	6.5	1.6	4–12
Mean midsleep sleep-corrected (hh:mm) ^a	33	02:59	00:35	02:02–04:17
Actual/Total sleep time (hh:mm)	35	06:28	00:52	03:30–10:31
Acute sleep loss	36	01:32	00:52	–02:31–04:30
Chronic sleep loss	36	21:20	08:10	05:53–39:31
KSS				
Pre-shift	36	3.9	1.6	1–9
Post-shift	34	4.5	1.8	1–9

Body Mass Index (BMI), Pittsburgh Sleep Quality Index (PSQI), Karolinska Sleepiness Scale (KSS).

^a Mean midsleep sleep-corrected represents offshore workers chronotype.

post-shift KSS scores can be found in Riethmeister et al. (2018). During the two-week offshore period, pre-shift KSS scores were significantly lower than post-shift KSS scores ($M_{\text{difference}} = -0.32$; 95%CI: 0.63 to -0.01 ; $p = .042$). The interaction between time-of-day and days-on-shift showed that pre- and post-shift fatigue scores increased differentially over the course of the two-week offshore period ($b = -0.04$; 95%CI: 0.08 – 0.00; $p = .027$). Each day on shift, pre-shift fatigue scores increased by 0.01 points (95%CI: 0.01 – 0.04; $p = .201$) and post-shift fatigue scores increased by 0.05 points (95%CI: 0.03–0.08; $p < .001$). Compared to pre-shift fatigue scores, post-shift fatigue scores accumulated at a faster pace. Mean KSS difference score increased by 0.03 points per day (95%CI: 0.00–0.07; $p = .037$). (Fig. 2).

Over the course of the two-week offshore period, average total sleep time (TST) was 6:28hrs (SD = 0:52hrs) per day. Each day on shift, acute sleep loss significantly accumulated by an average of 92 min each night (95%CI: 88.6–94.9), creating an average chronic sleep loss of 21:20:hrs (SD = 08:10hrs) over the course of a two-week offshore period (Fig. 3). Acute sleep loss did not change during the two-week offshore period ($b = -.19$; 95%CI: 1.12 - 0.73; $p = .679$). When investigating the effect of acute sleep loss on fatigue over the two-week offshore period, results showed that one hour less sleep was related to a 0.22 points increase in KSS pre-shift scores (95%CI: .09–0.36; $p = .001$), a 0.23 points decrease in post-shift (95%CI -0.038 to -0.08 ; $p = .004$) and a 0.44 point decrease in difference scores (95%CI: 0.0.63 to -0.025 ; $p < .001$). When investigating the effects of chronic sleep loss (four-hour bins) on the rate at which fatigue accumulates over the two-week offshore period, significant differences were found for KSS difference ($b = .09$; 95%CI: 0.01–0.17; $p = .020$) and KSS post-shift scores ($b = 0.13$; 95%CI: .07–0.19; $p < .001$) but not for KSS pre-shift scores ($b = 0.03$; 95%CI ($-0.03 - 0.08$); $p = .318$) (Fig. 4). We found no evidence of interactions between acute and chronic sleep loss on the rate at which either daily average, pre-/post-shift, or daily difference KSS scores accumulate.

4. Discussion

Fatigue accumulated in different ways over the course of a two-week offshore day-shift period. An interaction effect between time-of-day and days-on-shift on fatigue accumulation was observed in which post-shift fatigue scores increased faster than pre-shift fatigue scores. In addition, an acute effect was observed whereby within each shift day, post-shift fatigue levels were higher compared to pre-shift levels. Furthermore, cumulative effects were observed in which post-shift fatigue scores increased over days-on-shift and with chronic sleep loss. No interaction effect between acute and chronic sleep loss was found.

Throughout the two-week offshore period, post-shift fatigue scores were higher compared to pre-shift fatigue scores. This finding can be partially explained by three main components: the influence of circadian rhythms, daily executed work tasks and prior/extended wake. Circadian rhythms (e.g. diurnal rhythms of cortisol) alert us in the morning hours (pre-shift) but cause us to feel fatigued as cortisol concentrations gradually decline over the course of the day (post-shift) (Kumari et al., 2009). Daily work tasks being executed whilst on shift can add to the levels of perceived post-shift fatigue scores. Both physical and mental work tasks have been found to increase fatigue at work (Akerstedt et al., 2002). Adding to these two factors, are the hours of prior wakefulness at the time of the post-shift fatigue measure. Prior wake is part of the homeostatic sleep/wake drive and may cause workers to feel more fatigued with increasing hours spent awake (Matthews et al., 2012a). The construct of time-of-day is related to prior wake as it gives an indication of the time awake. However, prior wake is more specific as it is based on individual sleep times. Although the absolute increase in post-shift KSS scores is small, the underlying trends should not go unnoticed as we show that more than a third of the investigated offshore population reported a 'high risk' Karolinska Sleepiness Scale score (KSS > 6) at the end of their offshore shift on day ten.

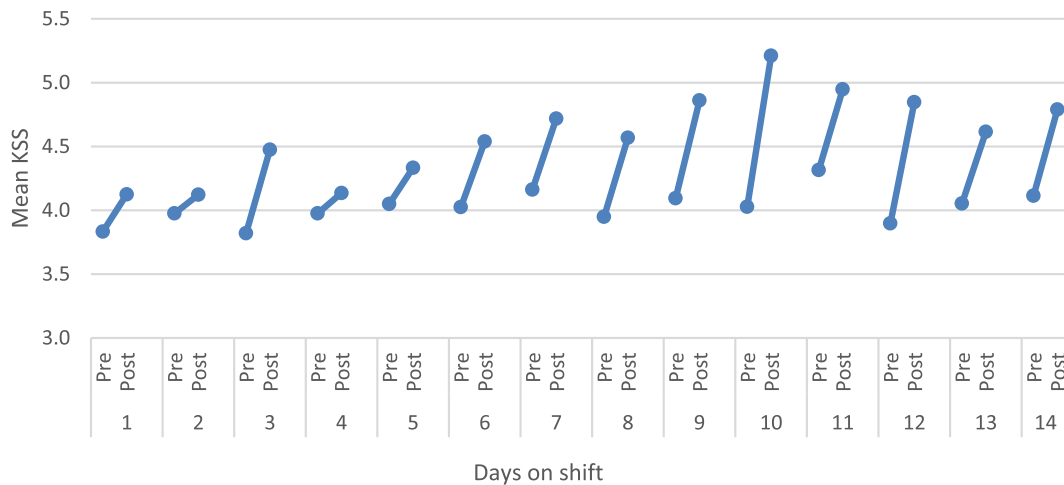


Fig. 2. Accumulation of pre- and post-shift fatigue (Karolinska Sleepiness Scale: KSS) difference scores over two-week offshore shifts. Note truncation of y-axis.

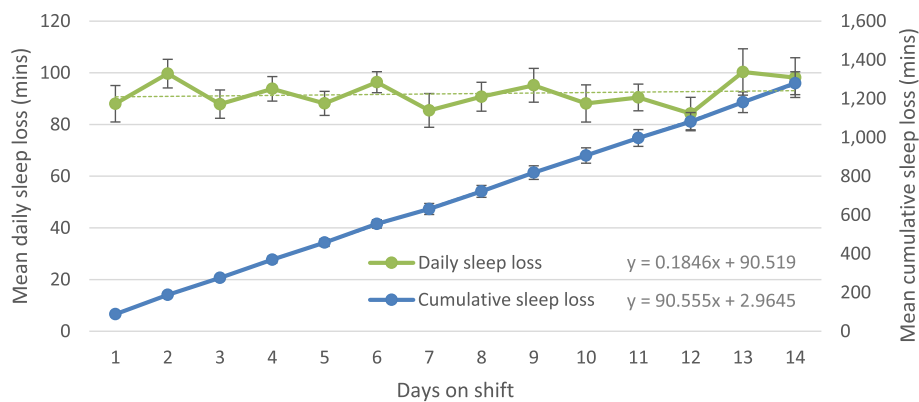


Fig. 3. Average acute (daily) and chronic sleep loss with standard errors over the two-week offshore shifts.

These findings are to be considered in FRMS after confirmation in further longitudinal research in the real-life setting.

Over the course of the two-week offshore period additional lasting effects on the rates of pre- and post-shift fatigue accumulation were observed. As previously noted, post-shift fatigue scores significantly increased over the course of the two-week offshore period, whereas pre-shift fatigue scores remained fairly constant (Riethmeister et al., 2018). One possible explanation could be the influence of homeostatic sleep/wake drives (acute and chronic sleep loss) on the rate at which fatigue accumulates over the two-week offshore period. Each day on shift, offshore workers experienced an average acute sleep loss of 92 min per

night impacting their pre- and post-shift sleepiness scores. This acute sleep loss was consistent over successive offshore days and resulted in a chronic sleep loss of 21:20 h at the end of the two-week offshore period. In other words, offshore workers lost > 2.5 nights of consolidated sleep during the two-week offshore period (disregarding the effect of increased homeostatic sleep drive). This significant amount of sleep loss has the potential to adversely impact offshore workers health and safety. Previous sleep loss studies have shown that chronic moderate sleep restriction of ≤6 h can potentially impair health and neurobehavioral functioning in healthy adults (Pejovic et al., 2013; Van Dongen et al., 2003; Vgontzas et al., 2004). Although these studies were

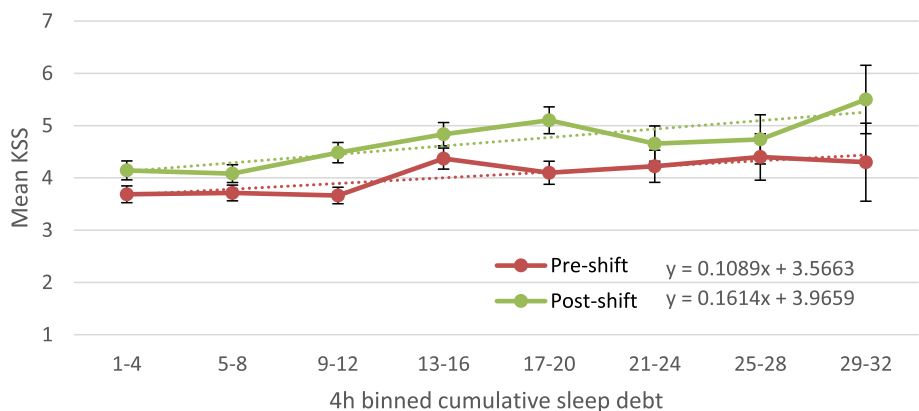


Fig. 4. Effect of chronic sleep loss on pre- and post-shift mean fatigue (Karolinska Sleepiness Scale: KSS) scores and standard errors. Four-hour bins with less than ten observations were excluded (N = 6 observations with > 32 h of sleep debt). Note truncation of y-axis.

conducted in a controlled sleep laboratory environment, results showed that fatigue increased, cognitive performance declined and the release of proinflammatory cytokines increased, potentially leading to long-term health effects, such as cardiovascular events (Pejovic et al., 2013; Van Dongen et al., 2003; Vgontzas et al., 2004).

When investigating the effects of acute sleep loss on fatigue accumulation differences for pre- and post-shift scores were found. Acute sleep loss was related to an increase in pre-shift fatigue scores but a decrease in post-shift and difference fatigue scores. The decreases in post-shift and difference fatigue scores is a paradoxical finding which should be further investigated. Acute sleep loss might not be a sensitive measure to investigate daily post-shift fatigue scores as other health, lifestyle and work variables might influence the results. When investigating the influence of chronic sleep loss on fatigue accumulation, similar patterns for pre- and post-shift fatigue scores were observed as for days-on-shift. Post-shift fatigue scores increased with increasing chronic sleep loss whereas pre-shift fatigue scores did not. This finding is conflicting with previous assumptions that acute and chronic sleep loss increase overall fatigue levels (Matthews et al., 2012b). Moreover, we did not find an interaction between acute and chronic sleep loss when predicting fatigue levels. This might indicate that acute and chronic sleep loss constitute separate predictors estimating fatigue levels. Yet, these are exploratory research findings as, to our knowledge, this is the first time this has been investigated in a real-life work setting. Thus, further replication and validation studies are needed to confirm the results. Our findings show that it might not be overall fatigue levels that increase, but that the ability to cope with fatigue during the day decreases with the number of days spent on shift, resulting in elevated post-shift fatigue levels. Furthermore, possible work intensification towards the end of an offshore period would be an additional contributing factor influencing post-shift fatigue scores (Bhattacharya and Tang, 2013). A time-on-task effect might be present in which workload increased, negatively influencing post-shift fatigue scores (Lorist et al., 2005). Thus, it is likely to assume that if offshore shift durations were to be extended, the ability to cope with daily fatigue experiences will decrease and the likelihood of fatigue related incidences increases as offshore workers will eventually be presented with a high fatigue risk ($KSS > 6$). This notion is further supported by the observed interaction effect between time-of-day and days-on-shift, in which the difference between pre- and post-shift fatigue scores increased with the number of successive shift days. In other words, with increasing sleep loss, the difference between pre- and post-shift fatigue scores increased as well, replicating previous forced desynchrony laboratory study findings (Matthews et al., 2012b). Furthermore, this finding implies that the interaction between time-of-day and days-on-shift could predict the rate at which fatigue accumulates over days-on-shift and how fatigued offshore workers become during the course of an offshore period. Nevertheless, more research is needed to replicate, confirm and verify our findings.

Recently, the debate on whether it is safe to extend offshore shift rotations has obtained increased attention due to economic pressures to produce more for less. Extending offshore shifts to three-rather than two-weeks would be a substantial cost-saving in terms of crew changes (i.e. helicopter commutes) and staff counts and at the same time decrease the risks of commuting. To date, scientifically sound investigations on the health and safety outcomes of extended offshore shift rotations are lacking. In absolute terms, our results show that fatigue scores increased only a little despite the considerable amount of accumulated sleep loss.

4.1. Strength & limitations

To our knowledge, this is the first offshore study to investigate the effects of homeostatic sleep/wake drives on the accumulation of fatigue over two-week offshore day-shift periods. A strength of the study is the use of both subjective, self-reported (KSS) and objective (actigraph)

measures to investigate fatigue and sleep parameters. Using both subjective and objective measures provides a more detailed and valid insight into individual sleep and fatigue experiences. In addition, we were able to replicate previous forced desynchrony laboratory study findings in a sample of real offshore workers.

One of the limitations of this study is the relatively small sample size due to logistic and material constraints. For example, our study material was limited to thirty actigraphs, which we had to alternate between offshore workers. In addition, due to the varying offshore platforms and starting days some offshore workers were affected by external weather conditions (such as delayed helicopter flights) more than others. Furthermore, we were not able to measure and analyze 'normal' sleep durations of participants and had to use recommended industry sleeping guidelines to calculate acute and chronic sleep loss. This will have influenced the reliability of our findings to some extent. Future studies should aim to extend study periods to include several leave periods to measure 'normal' baseline sleep durations. Additionally, a different subjective sleep quality rating scale might be used to differentiate between experienced sleep quality in work and leave periods, as the PSQI cannot be split into work and leave periods. Furthermore, it is important to note that additional health (e.g. sleep disorders), lifestyle (e.g. smoking), work (e.g. workload) and/or organizational/cultural factors (e.g. offshore group behaviors) might have influenced the results. Suffering from sleep disorders, smoking and increased work load have been shown to negatively affect sleep and fatigue parameters (McNamara et al., 2014; Magnavita and Gabarino, 2017; Murawski et al., 2018). Moreover, as no data on workload and work intensification during the offshore work period was available, no potential time-on-task-effects and effect modification could be investigated. Confounding effects of organizational (e.g. working conditions) and/or cultural factors (e.g. religion/praying times; social norms/activities) could have also been present, either positively or negatively affecting the relationship between sleep loss and fatigue parameters (Knutson, 2013). For example, positive group norms could have led to good participation and compliances rates whereas an existing 'macho-culture' could have underestimated sleep and fatigue problems offshore (Riethmeister et al., 2016). Another study limitation is the exclusively male study population. Having only males in the study potentially limits the generalizability of our results as a gender effects might be present. The average number of female offshore workers is very low and thus the results reflect current offshore work environments. However, gender differences of fatigue accumulation during offshore shifts might exist and should be investigated in future studies.

4.2. Implications

Findings from the current study aid in the understanding, prediction and management of fatigue in offshore shift work environments. Future longitudinal repeated measures studies should investigate whether the inclusion of the interaction between time-of-day and days-on-shift adds to the improvement of bio-mathematical algorithms used in FRMS to more accurately predict fatigue during work shifts. Alternatively, the potential interaction effect between prior wake and days-on-shift should be investigated to compare the accuracy with acute time-of-day results. Our data show that sleep debt is associated with fatigue levels irrespective of the number of days-on-shift. Thus, if the number of successive days-on-shift increases, less sleep will be obtained by (offshore) workers and fatigue levels will likely increase. More scientific and economic research, including cost-benefit analyses, are needed to test these assumptions, confirm presented results and investigate whether the decreased commuting risk and potential cost-savings outweigh the cumulative fatigue risks of extended offshore shift rotations. Moreover, long-term follow-up repeated measures studies should evaluate and compare the health and safety effects of different offshore rosters (e.g. night-/swing-shifts). Other health, lifestyle, work and organizational/cultural factors should also be investigated to test their

potential mitigating effects on the described relationships between homeostatic and circadian sleep/wake drives. The resulting research findings may inform policy and practice how to adapt fatigue risk management plans and systems to better predict and manage fatigue risk.

Our results concerning the interaction between time-of-day and days-on-shift effects as well the cumulative sleep loss effect provide suggestive evidence to adapt existing bio-mathematical algorithms currently used in FRMS. Future FRMS need to consider the effects of accumulating sleep loss over extended shift days. In particular, that the effects of single days may not be sufficient to predict multiple days. Occupational health and safety programs that use these adapted FRMS are likely to improve health and safety statistics by better understanding, predicting and managing fatigue risk (Dawson et al., 2011, 2017). Economic, health, safety and performance indicators are important aspects to be considered when discussing optimal lengths of (offshore) shifts. Our data provide suggestive evidence that the extension of (offshore) shift lengths may not be recommended as high fatigue scenarios are likely to increase with prolonged successive days-on-shift. These findings have implications for general (non-offshore) industries. Any industry that operates extended consecutive work shifts, e.g. mining operations, might benefit from considering accumulating sleep loss and incorporating the interaction between time-of-day and days-on-shift in their work scheduling processes.

5. Conclusions

The objective of this study was to investigate the accumulation of fatigue over a two-week offshore period, by considering both the effects of (1) time-of-day and days-on-shift as well as the effects of (2) acute and chronic sleep loss on the rate at which fatigue accumulates. Every day offshore, post-shift fatigue levels were higher compared to pre-shift levels. Moreover, post-shift fatigue scores increased over days-on-shift and with chronic sleep loss, whereas pre-shift fatigue scores did not. Pre-shift fatigue scores did however increase with acute sleep loss. An interaction effect between time-of-day and days-on-shift on fatigue accumulation was observed in which the difference between pre- and post-shift fatigue scores increased with the number of successive shift days. Bio-mathematical algorithms currently used in FRMS should consider these findings to examine whether they better predict fatigue at work. If confirmed in larger, longitudinal and experimental studies, the findings may help to define recommendations and guidelines on shift durations, specifically the maximum threshold for consecutive days-on-shift.

Disclosure statement

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