Investigating daily fatigue scores during two-week offshore day shifts

Vanessa Riethmeister, Ute Bültmann, Marijke Gordijn, Sandra Brouwer, Michiel de Boer

University of Groningen, University Medical Center Groningen, Department of Health Sciences, Community and Occupational Medicine, Antonius Deusinglaan 1, 9713 AV Groningen, The Netherlands
Chrono@Work B.V., Groningen, Chronobiology Unit, Groningen Institute for Evolutionary Life Sciences, University of Groningen, Groningen, The Netherlands
VU University Amsterdam, Department of Health Sciences and the EMGO+ Institute for Health and Care Research, Faculty of Earth and Life Sciences, Amsterdam, The Netherlands

Keywords: Cortisol Fatigue risk management Melatonin Occupational health Safety Sleepiness

ABSTRACT

Objectives: This study examined daily scores of fatigue and circadian rhythm markers over two-week offshore day shift periods.

Methods: A prospective cohort study among N = 60 offshore day-shift workers working two-week offshore shifts was conducted. Offshore day shifts lasted from 07:00 – 19:00 h. Fatigue was measured objectively with pre- and post-shift scores of the 3-minute psychomotor vigilance tasks (PVT-B) parameters (reaction times, number of lapses, errors and false starts) and subjectively with pre- and post-shift Karolinska Sleepiness Scale (KSS) ratings.

Results: Complete data from N = 42 offshore day shift workers was analyzed. Daily parameters of objective fatigue, PVT-B scores (reaction times, average number of lapses, errors and false starts), remained stable over the course of the two-week offshore shifts. Daily subjective post-shift fatigue scores significantly increased over the course of the two-week offshore shifts. Each day offshore was associated with an increased post-shift subjective fatigue score of 0.06 points (95%CI: .03 -.09 p < .001). No significant statistical differences in subjective pre-shift fatigue scores were found. Neither a circadian rhythm phase shift of melatonin nor an effect on the pattern and levels of evening cortisol was found.

Conclusion: Daily parameters of objective fatigue scores remained stable over the course of the two-week offshore day shifts. Daily subjective post-shift fatigue scores significantly increased over the course of the two-week offshore shifts. No significant changes in circadian rhythm markers were found. Increased post-shift fatigue scores, especially during the last days of an offshore shift, should be considered and managed in (offshore) fatigue risk management programs and fatigue risk prediction models.

1. Introduction

Fatigue has been identified to be among the most important health and safety risk factors in the offshore oil and gas industry (Parkes, 2015; Ross, 2009). Some of the major offshore and industry disasters have been linked to human error, and more specifically fatigue (U.S. Chemical Safety and Hazard Investigation Board, 2007; U.S. Chemical Safety and Hazard Investigation Board, 2016). In industrial settings the terms fatigue and sleepiness are often used interchangeably although conceptual differences exist. Fatigue has been associated with impaired task performance resulting from physical or psychological strain, whereas sleepiness has been associated with the neurobiological need to sleep, resulting from physiological wake and sleep drives (Sadeghniiat-Haghighi and Yazdi, 2015). Although the causes of fatigue and sleepiness may vary, the consequences are similar. Both fatigue and sleepiness may cause mental and physical performance impairments, which can increase the likelihood of health and safety incidents. In this article, we will use the term ‘fatigue’ to refer to both fatigue and sleepiness constructs.

The offshore work conditions (e.g. remote shift work, limited light exposure, long periods of consecutive work days and 12-h shifts) are likely to predispose offshore workers to higher degrees of fatigue and fatigue-related work injuries and accidents. Previous research showed that shift work, long daily work hours and working more than 50 h per week increases the risk of work injuries related to poor sleep quality...
shift workers. These circadian rhythm phase shifts may negatively impact circadian rhythms, resulting in circadian rhythm phase shifts even in day behaviours and routines, can change the phase angles between sleep and recovery processes and fatigue in return.

In the offshore environment, poor sleep quality (Menezes et al., 2004; Parkes, 1994, 2016), short sleep periods (Menezes et al., 2004; Parkes, 2002, 2016), and high fatigue scores (Parkes, 1993; Riethmeister et al., 2016) have been identified. Although a few studies on fatigue have been conducted in the offshore industry, not much is known on daily fatigue scores during offshore shifts. The majority of existing offshore studies has focused on the effect of shift work (night and swing shifts) on fatigue, circadian rhythm adjustments as well as health and safety outcomes (Barnes et al., 1998; Bjorvatn et al., 2006; Harris et al., 2010). Yet, only a few studies have also identified fatigue and sleep problems in offshore day shift workers (Menezes et al., 2004; Parkes, 2016). Ignoring offshore day shift workers from occupational health and safety studies is of concern, as offshore day shift workers represent the largest workforce in the oil and gas industry. In addition, most existing offshore fatigue and sleep studies have not used longitudinal, repeated measures designs and have for the most part been conducted using small sample sizes (Harris et al., 2010; Waage et al., 2012) employing primarily self-reported measures (Harris et al., 2010; Parkes, 2002, 2016; Waage et al., 2012).

An important factor in preventing fatigue is a consolidated period of sleep. A consolidated sleep phase is possible when people have the opportunity to sleep long enough at the optimal circadian phase (Dijk and Czeisler, 1994). The high prevalence of fatigue offshore may be caused by a multitude of factors related to the nature of offshore work affecting sleep and circadian rhythms. For example, combinations of long offshore work periods, 12-h work days, early start times and offshore work evening behaviours and routines, can change the phase angles between sleep and circadian rhythms, resulting in circadian rhythm phase shifts even in day shift workers. These circadian rhythm phase shifts may negatively impact offshore workers sleep timing, duration and quality as well as daily recovery processes and fatigue in return.

A more thorough investigation of daily fatigue scores over two-week offshore day shifts is needed to better understand the course of fatigue over time spent offshore and the possible association with circadian rhythm markers. Moreover, detailed knowledge on daily fatigue scores over offshore day shift periods will help to improve the existing fatigue risk prediction models. Thus, the aims of this study were to examine daily fatigue scores and changes in circadian rhythm markers over the course of two-week offshore day shift periods.

2. Materials and method

2.1. Study population & design

A longitudinal observational study was conducted in N = 60 offshore day shift workers on four offshore platforms located in the Dutch Continental Shelf. This study is part of a larger investigation on sleep and fatigue parameters across full offshore day shift rotations, including both work and leave periods. The present study concerns the two-week offshore work period. The offshore work schedule consisted of two weeks of 12-h workdays. The day shifts lasted from 07:00–19:00 o’clock. During the study period, no overtime was officially requested nor recorded. Break times can vary between platforms. In this study, no data on break times was assessed.

The study was conducted between February and June 2015. Due to operational and logistic constraints, it was not possible for the investigators to be present on the offshore platforms for the conduction of the study. On each platform, a study supervisor was allocated to implement the study protocol. The implementation was mainly executed by the offshore medic or first aider. In addition, elaborate briefing sessions with the offshore platforms and the participating offshore workers were held to ensure correct conduction of the study tasks. Also, individualized study material (i.e. actigraphs) and procedures were sent to the offshore workers including detailed daily study timelines. One week before the start of the offshore shift period, all participating offshore workers received an electronic link, via e-mail, for a baseline questionnaire on demographic, work and health variables. In addition, offshore workers started to wear an actigraph (MotionWatch® Camntech) one week before the offshore work period commenced until one week after the offshore work period ended. This study concerns only the offshore work period.

Twice a day electronic questionnaires were used for the assessment of fatigue. Every morning before shift start and every evening post-shift, offshore workers received a personal electronic link, via e-mail, to the fatigue questionnaire. An online questionnaire portal was used to access, monitor and store fatigue recordings. Psychomotor vigilance task (PVT-B) testing took place in the accommodation block of the offshore platforms. Offshore workers were instructed to find a quiet room to complete the task. The online portal of the PVT-B app provider (Pulsar Informatics; Joggle Research®) was used to access, monitor and store PVT-B recordings in real-time. On days with saliva sampling, daily reminders were sent to the offshore platforms and offshore workers. Offshore workers were instructed to collect hourly saliva samples from 19:00 h until bedtime. Exposure to light, consumption of food and beverages other than water were forbidden during this period. All salivary samples were stored in the offshore freezers (−20 °C) until study sampling was completed. Upon study completion, all samples were sent to the laboratory of the University Medical Center Groningen, Groningen, The Netherlands for analyses.

2.3. Measurements

2.3.1. Fatigue

Reaction times and accurateness on simple reaction time tasks, objective proxies for fatigue, were measured before and after each shift with the 3-min IPad app version of the psychomotor vigilance task (PVT-B) (Pulsar Informatics; Joggle Research®) (Basner et al., 2011; Grant et al., 2016). Each platform was equipped with a maximum of four Ipads which were shared among offshore workers and were stored in the common room areas of the living quarters. The PVT-B has been...
successfully implemented in workplace settings to measure subcomponents of fatigue such as: alertness, sleepiness, and neurobehavioral performance (Basner et al., 2011; Lamond et al., 2005; Shattuck and Matsangas, 2015). Due to operational constraints, no PVT-B tests could be conducted on the offshore arrival day (day 1). The following PVT-B metrics were investigated: mean valid reaction times in milliseconds (reaction times > 100 ms), number of false starts (responses without a stimulus or reaction times < 100 ms), errors (pressing the wrong button or failing to release the button for 3s or longer), and lapses (reaction times ≥ 355 ms). The lapse threshold was adopted from suggested PVT-B scoring algorithms for 3-min versions (Basner et al., 2011).

Self-reported sleepiness, from now on referred to as subjective fatigue, was assessed pre- and post-shift (07:00 & 19:00 h) using the Karolinska Sleepiness Scale (KSS) (Akerstedt and Gillberg, 1990). The KSS consists of a nine-point Likert scale, rating sleepiness with (1) extremely alert, (2) very alert, (3) alert, (4) rather alert, (5) neither alert or sleepy, (6) some signs of sleepiness, (7) sleepy, but no effort to keep awake, (8) sleepy, some effort to keep awake (9) very sleepy, great effort to keep awake, fighting sleep (Akerstedt et al., 2014; Kaida et al., 2006). Higher KSS scores indicate higher subjective fatigue.

2.3.2. Circadian rhythm markers

Circadian rhythm markers were calculated based on salivary cortisol and melatonin levels in the evening. Saliva was collected using Salivettes® cotton rolls (Sarstedt) on three offshore days (day 2, 7 and 13) following the methodology of Harris and colleagues (Harris et al., 2010). Both, the pattern of evening cortisol concentration on the three investigated offshore days and the average cortisol concentration in the evening were used as a measure of circadian rhythmicity over the course of the two-week offshore day shifts. Dim light melatonin onset (DLMO) times were measured as phase markers of endogenous time. Cortisol and melatonin rhythms have been shown to be reliable circadian markers (Groeschl, 2008; Voultsios et al., 1997) and have been used in industrial settings to measure circadian disruption as a result of shift schedules and occupational exposures (Ferguson et al., 2012; Harris et al., 2010).

Saliva samples were analysed using liquid chromatography in combination with isotope dilution mass spectrometry, as described elsewhere (Booij et al., 2015; Bouwmans et al., 2015). The functional sensitivity was 200 pmol/L for cortisol and 3.0 pmol/L for melatonin. Salivary melatonin scores were used to obtain DLMO times. DLMO was defined as the moment at which the melatonin rhythm crossed the 11.01 pmol/L concentration by linearly interpolating the raw values around the 11.01 pmol/L concentration at the rising part of the curve, or that was within the first hour of extrapolation (Benloucif et al., 2008).

2.3.3. Covariates

Covariates included platform location, self-reported chronotype and time in bed (TIB). Offshore platforms varied in size, age, location, equipment and culture. Therefore, platform location was used as a covariate in all linear mixed models to adjust for possible cluster effects. Self-reported chronotype was included in all mixed models with circadian rhythm markers to adjust for offshore workers chronobiological inclination. Chronotype was defined as the midsleep point on days off-work corrected for sleep on working days and was assessed at baseline with the Munich Chronotype Questionnaire (Roenneberg et al., 2003; Zavada et al., 2005). The later the mean midsleep sleep-corrected time, the later the chronotype. The official scoring protocol was used (Juda et al., 2013).

TIB was assessed using daily actigraphy recordings from the MotionWatch®8, Camtech. The MotionWatch®8 is a wrist-worn actigraph, worn on the non-dominant hand, which has been shown to be a valid and reliable measure for sleep parameters, using tri-axial sensors data (Elbaz et al., 2012). Generated data consisted of 1-min epochs.

### Table 1

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Sample characteristics of the final study sample (N = 42).</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Age (years)</td>
<td>42</td>
</tr>
<tr>
<td>Job tenure (years)</td>
<td>6.6</td>
</tr>
<tr>
<td>Mean mid sleep-corrected (hh:mm)a</td>
<td>02:59</td>
</tr>
<tr>
<td>Time in bed (h:mm)b</td>
<td>07:32</td>
</tr>
</tbody>
</table>

a Mean mid sleep-corrected represents offshore workers chronotype.
b Time in Bed (TIB) is based on N = 41 offshore workers due to sickness of one offshore worker who left the platform after 5 days offshore.

2.4. Statistical analysis

Generalized and linear mixed model analyses were conducted to examine daily fatigue scores and changes in circadian rhythm markers over the two-week offshore day shifts. Linear mixed models were used for continuous outcomes (KSS scores, reaction times, cortisol and DLMO times). Log transformations were performed for pre- and post-shift reaction times and cortisol concentrations as the data was log-normally distributed. We chose to dichotomize the PVT-B variables: number of false starts, errors and lapses, because of the high number of zeros in these variables. For these outcome variables, we used generalized linear mixed models. PVT-B test observations were excluded if they showed reaction times higher than 1000 ms (1x), or if they had more than 20 lapses (7x), false start (2x) or errors (2x). Inclusion of random intercepts and/or slopes was based on lowest Akaiakes Information Criteria (AIC) values. Time (offshore days) was entered as a continuous variable and PVT-B scores (reaction times, number of lapses, number of errors, number of false starts), subjective fatigue (KSS), evening cortisol concentrations (timing and level) and DLMO times were entered as dependent variables. For both pre- and post-shift PVT-B and KSS scores, separate (generalized) linear mixed models were performed. All models were adjusted for platform location by entering platform as a fixed effect. Analyses with cortisol levels were additionally adjusted for self-reported chronotype. In addition, all mixed model analyses were repeated with adding TIB as an extra explanatory variable to assess whether TIB could (partly) explain possible trends over time (see appendix).

For circadian rhythm analyses, the average log-transformed cortisol concentration in the evening (main effect of days) and the pattern of average log-transformed evening cortisol concentration across the three sampling days (interaction between day and time of day) were investigated. The effect of time of day on average log transformed evening cortisol concentrations was fitted adding a quadratic function of time of day. For DLMO, the change in DLMO times across the three sampling days was examined. Missing values were assumed to be missing at random. Under this assumption, linear mixed models provide valid estimates, without data imputation (Twisk et al., 2013). All analyses were performed using SPSS version 23.

3. Results

3.1. Sample characteristics

The final sample consisted of N = 42 (70%) male offshore workers, after the exclusion of N = 8 offshore workers who worked night shifts during the study period. The spread of offshore workers across the platforms was as follows: Platform 1 (N = 15), platform 2 (N = 13), platform 3 (N = 9) and platform 4 (N = 5). About half of the offshore workers were contractors (N = 20, 48%). Complete data was obtained for PVT-B, KSS and circadian rhythm phase markers for N = 35, N = 42 and N = 39, respectively. Sample characteristics are displayed in Table 1.
Fig. 2. Outcomes of the pre- and post-shift objective fatigue metrics, obtained from the psychomotor vigilance task (PVT-B), over the course of the two-week offshore day shift periods. Means, standard errors and linear prediction lines are plotted for (1) reaction times, (2) number of lapses, (3) number of errors, (4) and number of false starts.

Fig. 3. Mean pre- and post-shift subjective fatigue scores and standard errors, measured with the Karolinska Sleepiness Scale (KSS), and trendlines over the course of the two-week offshore day shifts. Please note truncation of Y-axis.
3.2. Fatigue

Daily parameters of objective fatigue, PVT-B scores (reaction times, average number of lapses, errors and false starts), remained stable over the course of the two-week offshore day shifts (Fig. 2, Appendix Table A1). Daily post-shift subjective fatigue (KSS) scores significantly increased over the two-week offshore day shifts. Each day offshore was associated with an increase in post-shift KSS score of 0.06 points (95%CI: 0.03 - 0.09, p < .001). Adjustment for TIB, did not substantially change the results (Appendix Table A1). No significant changes of pre-shift subjective fatigue scores of the course of the two-week offshore day shifts were found (Fig. 3).

3.3. Circadian rhythm markers

In total, N = 243 saliva samples were analyzed. Four cortisol concentration measurements scored zero and were assigned the next smallest cortisol concentration value for the linear mixed model analyses. Absolute cortisol concentration values were not normally distributed. The absolute median cortisol concentration value was 0.73 pMol/l (IQR = 1.79) on day 2, 0.76 pMol/l (IQR = 1.82) on day 7 and 0.78 pMol/l (IQR = 1.90) on day 13, respectively. There was a significant main effect of time (b = −0.29, 95%CI: −0.40 to −0.18, p < .001) and the quadratic function time² (b = 0.07, 95%CI: 0.00 - 0.14, p = .036) on the pattern of average log-transformed cortisol concentration in the evening. Cortisol decreases over time, but this pattern over time was not significantly different between the three study days (p-value for interaction = 0.433) (Fig. 4, graph 1). No significant main effect of study day for average log-transformed evening cortisol concentration was found (p = .250). Mean predicted DLMO times were at 20:08 (0:58) for day 2, 20:08(0:59) for day 7 and 20:02 (1:03) for day 13 (Fig. 4, graph 2). The timing of DLMO did not differ significantly between the three study days (p = .832).

4. Discussion

Daily parameters of objective fatigue, PVT-B scores (reaction times, average number of lapses, errors and false starts), remained stable over the course of the two-week offshore day shifts. Post-shift subjective fatigue scores significantly increased over the course of the two-week offshore day shifts. In addition, no circadian rhythm phase shift was found over the course of the two-week offshore day shifts.

4.1. Fatigue

Daily objective fatigue (PVT-B) scores remained stable over the course of the two-week offshore shift periods. A potential learning effect may be excluded as an explanation for this finding, as the PVT-B has been found to only have minor learning effects (Dinges et al., 1997). Participants on one offshore platform reported that the PVT-B task turned into a competition in which offshore workers kept scores on who had the fastest reaction time. This competitive PVT-B task environment might have positively influenced the motivation and alertness levels of offshore workers and reduced reaction times, accordingly. In general, reaction times were fast compared to other working populations (Shattuck and Matsangas, 2015) and our scores align with previous reaction times found among other offshore workers (Harris et al., 2010).

Post-shift subjective fatigue scores, significantly increased over the course of the two-week offshore day shifts. It is important to note that although the daily increases of subjective fatigue seemed low, they might be relevant in practice. According to the Karolinska Sleepiness Scale (KSS) developers, daytime KSS ratings usually range between 3 and 4 (Akerstedt et al., 1998). Our findings indicate slightly higher daytime KSS ratings between 4 and 5. Even though a daily increase of 0.06 on the KSS is small, the average offshore worker already reports higher KSS scores and the additional accumulation of KSS scores over time may pose potential additional risks. Akerstedt et al. (2011) found that the relative risk of accident involvement doubles once KSS scores are equal to 5 (Akerstedt et al., 2011). Hence, the increase in post-shift KSS scores over the course of the two-week offshore day shifts is a relevant finding for fatigue risk management programs in offshore operations.

On average, post-shift subjective fatigue scores were higher compared to pre-shift subjective fatigue scores. Over the two-week offshore shifts, pre-shift subjective fatigue scores remained fairly constant. A possible explanation for the elevated post-shift fatigue scores might be that the ability to regulate the daily subjective fatigue scores decreases over the two-week offshore shifts. This could be due to the depletion processes like depleted energy resources or accumulating sleep debts during the two-week offshore shifts, preventing daily subjective fatigue recovery (Raslear et al., 2011). More research is needed to investigate the underlying causes and consequences of these daily recovery/regulatory mechanisms.

Another interesting observation is the peak of post-shift subjective fatigue scores on day ten (about three quarters of the offshore shift) rather than day fourteen (the end of the offshore shift). Earlier, Waage et al. (2012) investigated the course of subjective fatigue among three different offshore shift schedules (day, night and swing shifts). The authors present a figure of the mean subjective fatigue (KSS) values over the two-week offshore period and visual inspection of their data reveals a peak in subjective fatigue scores on day eleven for day shift
workers (Fig. 2, p.69). A potential explanation of this finding could be linked to psychosocial/motivational motives. In long-term space, military and Antarctica expeditions a related construct of significant psychological changes in mood and performance due to monotony, boredom and restricted social contacts has been termed the ‘third-quarter phenomenon’ (Bechtel and Berning, 1991; Kanas and Manzey, 2008). During this period expedition staff experienced more conflicts, anxiety, and demotivation. The third-quarter phenomenon most likely results from the realization that the expedition is only just more than half-way completed, and a rather long period of work and isolation still awaits. Although, to our knowledge, never been directly linked to subjective fatigue, psychosocial changes during day ten/eleven of a two-week offshore shift might account for the increased post-shift fatigue scores in this period. Future research needs to investigate the links between sleep and fatigue and the third-quarter phenomenon in more detail and whether this phenomenon has potential implications for fatigue risk management programs.

Differential findings between objective and subjective fatigue scores have previously been noted and explained by different underlying theoretical constructs (Dijk, 2014). Subjective fatigue ratings have been viewed as warning signs, signalling the brain that insufficient sleep was obtained and that preventative actions need to be initiated (Dijk, 2014). Only when the subjective warning signals are ignored objective fatigue indications are noticeable. Thus, subjective fatigue perceptions occur before objective fatigue performance deteriorations. More research on the differential findings between objective and subjective fatigue is needed to further confirm and validate the findings.

4.2. Circadian rhythm markers

The course of evening cortisol levels, the average values of evening cortisol concentration, and DLMO times did not differ between the three investigated offshore days (days 2, 7 and 13). Cortisol levels decreased on each of the investigated evenings in line with normal 24-h-cortisol rhythms (Chan and Debono, 2010). In addition, salivary evening cortisol concentrations of offshore workers were comparable to normal reference values of other populations, ranging from 0.5 to 9.9 nmol/L (Aardal and Holm, 1995; Cheung et al., 2016; Most et al., 2010).

No significant differences in DLMO times were found across the three investigated offshore days. These results imply that living and working offshore for two weeks, in a 12-h day shift schedule, did not induce a circadian rhythm phase shift of melatonin nor cortisol, nor did it induce a change in the level of evening cortisol concentration. This finding is in line with previous circadian rhythm investigations offshore, which showed that mainly night shift workers showed circadian misalignment (Fossum et al., 2013; Harris et al., 2010; Merkus et al., 2015). Considering these findings, it seems unlikely that the increase of fatigue scores of offshore day shift workers over the course of two-week offshore shifts is the result of changes in timing of circadian rhythms or is related to elevated cortisol levels. More research is needed to further investigate these relationships and underlying mechanisms to verify our results.

4.3. Strengths and limitations

A strength of this study is that multiple daily fatigue measurements were taken, over the course of two-week offshore shifts, in a real-life work setting in a relatively large cohort of offshore workers compared to previous offshore studies, e.g. (Harris et al., 2010; Waage et al., 2012). In addition, both objective and subjective measures of fatigue and circadian rhythms were used. Previous offshore studies included only limited measurement points and mostly either objective or subjective parameters to investigate sleep and fatigue parameters offshore (Waage et al., 2012). Another strength concerns the fact that this study included offshore workers from several offshore platforms and countries.

Study limitations mainly concern operational and logistic constraints, which could have led to information bias. For instance, the principal investigator was not able to be on the platforms for data collection as the study took place on all four platforms simultaneously. As a result, measurements were conducted under supervision of the appointed offshore study supervisor, who had to assure the correct application of study procedures and measurements. We cannot exclude e.g. that the competitive PVT-B task environment on one of the offshore platforms might have led to biased information. However, as the competition was only reported on one platform, and only a limited number of offshore workers participated in the study at a given time, the risk of bias is probably low. Other operational constraints (i.e. weather conditions, flight times, handovers) prohibited the conduction of the PVT-B on day 1. In the analyses, PVT-B estimates for the missing first offshore day were predicted. Also, due to operational constraints, no cortisol awakening response could be measured and our circadian rhythm sampling days were limited to the evening hours of three days. Furthermore, we cannot rule out residual confounding. Finally, the analyses included many statistical tests. Analyses were not adjusted for alpha levels, because this would reduce the power of the analyses. This means that the change over time in subjective post-shift fatigue might be the result of a type one error.

4.4. Implications

Elevated post-shift subjective fatigue scores may increase the risk of health and safety incidents among offshore workers. Being fatigued at the end of a shift is likely to increase the odds of making mistakes and/or errors, which could adversely impact the health and safety of offshore workers. Offshore work schedules should consider the potential adverse consequences of elevated post-shift fatigue scores (especially towards the end of a two-week offshore shift rotation) and plan work tasks accordingly. For instance, if possible, safety critical tasks should be avoided towards the end of a shift or appropriate additional fatigue mitigation/prooﬁng strategies should be put in place (i.e. buddy system/extra monitoring) (Dawson et al., 2012). Findings of this study might be applicable to other extended shift work environments in which workers accumulate fatigue over a prolonged period of time on shift. In shift work environments, road safety is a critical safety concern as increased subjective fatigue has been linked to an increased accident risks (Akerstedt et al., 2011). Thus, both offshore and general shift work employers and employees, should focus more on post-shift fatigue risks and potential consequences, especially towards the last days of an (offshore) shift rotation.

More research on the antecedents and consequences of fatigue development offshore is needed to improve fatigue risk management programs and policies. In particular, daily recovery processes and day-on-shift effects on fatigue parameters pose interesting research areas and should be further investigated. In addition, health and safety incidents reports should be analysed on day-on-shift and time-of-day effects and monitored accordingly to investigate whether post-shift fatigue levels are a potential causal factor for incidents. Further analyses of the health and safety incident reports is likely to support the improvement of current fatigue risk management programs and policies. Moreover, the differential results of the objective PVT-B and subjective KSS fatigue ratings should be further investigated. Finally, the focus of this study was on day shift workers, as this is a large, increasing and often neglected group of offshore shift workers. Therefore, the effects of long, remote, consecutive day shifts need to be explored to manage fatigue risks associated with offshore day shifts appropriately.

5. Conclusions

Daily parameters of objective fatigue, PVT-B scores, remained stable over the course of the two-week offshore day shifts. Post-shift subjective fatigue significantly increased over the course of two-week offshore day shifts.
shifts. No circadian rhythm phase shift was found over the course of the two-week offshore day shifts. Increased post-shift fatigue scores, especially during the last days of an offshore shift, should be considered and managed in (offshore) fatigue risk management programs and fatigue risk prediction models. Further research is needed to confirm our findings on daily fatigue scores and circadian rhythm markers during offshore shifts.

Funding
This study was supported by the Nederlandse Aardolie Maatschappij B.V. and Royal Dutch Shell, Assen, Drenthe, The Netherlands.

Conflicts of interest
Vanessa Riethmeister works full time as an insights analyst at the

APPENDIX

Table A1
Generalized linear (GLMM) and linear mixed model (LMM) results for pre- and post-shift subjective fatigue (KSS) scores, reaction times, average numbers of psychomotor vigilance tests (PVT-B) errors, false starts and lapses over the course of two-week offshore day shifts adjusted and unadjusted for time in bed (TIB). Subjective fatigue was measured with the Karolinska Sleepiness Scale (KSS) higher scores indicate higher subjective fatigue.

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted scores</th>
<th>Adjusted scores for TIB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Estimate</td>
</tr>
<tr>
<td>Karolinska Sleepiness Score (KSS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-shift</td>
<td>537</td>
<td>.01</td>
</tr>
<tr>
<td>Post-shift</td>
<td>540</td>
<td>.06</td>
</tr>
<tr>
<td>Reaction time (RT)a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-shift</td>
<td>374</td>
<td>1.00</td>
</tr>
<tr>
<td>Post-shift</td>
<td>382</td>
<td>1.00</td>
</tr>
<tr>
<td>Errors (E)a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-shift</td>
<td>375</td>
<td>1.07</td>
</tr>
<tr>
<td>Post-shift</td>
<td>380</td>
<td>1.03</td>
</tr>
<tr>
<td>False Starts (FS)a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-shift</td>
<td>375</td>
<td>1.04</td>
</tr>
<tr>
<td>Post-shift</td>
<td>380</td>
<td>1.03</td>
</tr>
<tr>
<td>Lapses (L)a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-shift</td>
<td>373</td>
<td>1.04</td>
</tr>
<tr>
<td>Post-shift</td>
<td>377</td>
<td>1.02</td>
</tr>
</tbody>
</table>

In the columns, 95% confidence intervals and p-values of significance are displayed. All models were adjusted for platform location and time in bed (TIB). Subjective fatigue was measured with the Karolinska Sleepiness Scale (KSS) higher scores indicate higher subjective fatigue.

a Log-normally distributed values were back-transformed.

Acknowledgements
This study was supported and funded by the Nederlandse Aardolie Maatschappij B.V. and Royal Dutch Shell. We would like to acknowledge the logistic and technical help of Mireille Folkerts in the set-up and conduction of the study.

References


Chan, S., Debono, M., 2010. Replication of cortisol circadian rhythm: new advances in...
Juda, M., Vetter, C., Roenneberg, T., 2013. The munich ChronoType questionnaire for

Harris, A., Waage, S., Ursin, H., Hansen, A.M., Bjorvatn, B., Eriksen, H.R., 2010. Cortisol,


Menezes, M., Pires, M., Benedito-Silva, A., Tu

Elbaz, M., Yauy, K., Metlaine, A., Martoni, M., Leger, D., 2012. Validation of a new ac-

Dijk, D., 2014. Subjective sleepiness: an undervalued early sign of insu


