Chapter 07

General Discussion
The overall goal of the thesis was to better understand sleep and fatigue parameters during full 2on/2off offshore day-shift rotation periods. The specific aims were to investigate the courses of sleep and fatigue parameters during offshore shift rotations and the prevalence of fatigue. In addition, various explanatory variables and predictors of sleep and fatigue parameters offshore were investigated. In this chapter, a summary of the main findings of the thesis will be presented (Figure 1), followed by a discussion of the findings and the methodological considerations as well as the implications for policy, practice and research will be provided.

**MAIN FINDINGS**

The main findings are summarized per research question.

**Research question 1 (Chapter 2): What are the needs and suitable program objectives for a healthy ageing at work program offshore?**

An intervention mapping (IM) framework was used to answer the research question. We applied a mixed method design, in which we collected qualitative and quantitative data and performed the first two, out of six, IM steps: (1) a needs assessment and (2) defining suitable program objectives. Work, food and sleep/fatigue management were identified as the most important program objectives for a healthy ageing at work program offshore. The need for further detailed studies on sleep and fatigue parameters among offshore workers was identified as the prevalence of perceived fatigue was high (73%) and only limited research on sleep and fatigue parameters among offshore workers existed. The findings inspired the design of a rigorous sleep and fatigue follow-up study, using intensive longitudinal repeated measures, to investigate sleep and fatigue parameters during offshore shift rotations. The following chapters and research questions were based on these findings.

**Research question 2 (Chapter 3): What are the courses of sleep quality and sleepiness parameters in full 2on/2off offshore day-shift rotations (including pre-offshore, offshore, and post-offshore work periods)?**

Differences in the courses of sleep quality and sleepiness scores across full 2on/2off offshore day-shift rotation periods were found. In the pre-offshore work period, sleep efficiency percentages significantly decreased. During the offshore work period, sleep efficiency percentages were higher compared to pre- and post-offshore work periods, although offshore workers slept less. Moreover, offshore workers’ perceived sleep quality and level of rest after awakening was lower, and morning sleepiness scores were higher during the offshore work period, compared to the pre- and post-offshore work periods. In addition, evening sleepiness scores increased during the offshore work period and decreased again in the post-offshore work period. Yet, evening sleepiness scores were highest in the post-offshore work period. No differences in sleep latency onset times were observed across the full 2on/2off offshore day-shift rotation periods.
Figure 1. Fatigue risk heat map across the 28-day offshore shift rotation cycle.

Findings in Figure 1 are displayed in a heat map, with darker colours representing higher fatigue risk, i.e. potential fatigue risk prone periods. Heat indications are based on the Karolinska Sleepiness Scores (KSS) and acute/chronic sleep loss findings of this thesis.

Sleep efficiency percentage (SE%); Body Mass Index (BMI); Psychomotor Vigilance Test (PVT-B)

*Compared to pre- and post-offshore work periods
Research question 3 (Chapter 4): What are the courses of daily fatigue scores and changes in circadian rhythm markers over two-week offshore day-shift periods?

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-shift period. No changes in daily subjective pre-shift (morning) fatigue scores were found over the course of the two-week offshore day-shift period. Daily subjective post-shift (evening) fatigue scores increased. Furthermore, a peak in subjective post-shift fatigue scores was observed on day 10 of a fourteen-day offshore shift period. Neither a circadian rhythm phase shift of melatonin nor an effect on the pattern and levels of evening cortisol were found.

Research question 4 (Chapter 5): How does fatigue accumulate over a two-week offshore period? In particular, what are the effects of (1) time-of-day and days-on-shift and the effects of (2) acute and chronic sleep loss on the rate at which fatigue accumulates?

Pre- and post-shift fatigue scores and the difference between pre- and post-shift fatigue scores increased over a two-week offshore period. Every day offshore, post-shift fatigue levels were higher compared to pre-shift fatigue levels. Acute sleep loss accumulated by an average of 92 minutes each offshore night, creating an average chronic sleep loss of 21:20h (> 2.5 nights of consolidated sleep) over the two-week offshore day-shift period. An interaction effect between time-of-day and days-on-shift on fatigue accumulation was observed; 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. No significant interaction effect between acute and chronic sleep loss was found.

Research question 5 (Chapter 6): What are the individual courses of (1) sleepiness and (2) daily prevalences of severe sleepiness in offshore day-shift workers? (3) What are their potential predictors?

On average, individual post-shift sleepiness scores were higher and increased more over the two-week offshore day-shift rotation periods, compared to pre-shift sleepiness scores. Additionally, daily prevalences of severe sleepiness were also higher in post-shift (19%) compared to pre-shift (10%) periods and peaked towards the end of the two-week offshore day-shift rotation periods. Suggestive evidence for differential demographic, lifestyle and health predictors for pre- and post-shift individual sleepiness courses as well as for daily prevalences of severe sleepiness scores during two-week offshore day-shift rotation periods were found. Increasing individual pre-shift fatigue courses were predicted by low pre-offshore shift rotation fatigue scores, older age, earlier chronotypes, smoking and poor level of mental and physical health. Increasing post-shift fatigue courses were predicted by low pre-offshore shift rotation fatigue scores, younger age, good mental and poor physical health. Older age and a high BMI were associated with lower daily prevalences of pre-shift severe sleepiness scores.
DISCUSSION OF THE MAIN FINDINGS

The most important findings concerning the investigated sleep and fatigue parameters during the full 2on/2off offshore day-shift rotation periods pertain to: (1) the accumulation of sleep and fatigue-related problems during two-week offshore day-shift rotations and (2) the identification of potential fatigue risk prone periods during full 2on/2off offshore day-shift rotation periods. Both findings are discussed in detail below.

The accumulation of sleep and fatigue-related problems

When looking at the courses of sleep and fatigue parameters, a general lack of sleep and increases of sleep loss and fatigue during offshore day-shift rotation periods was found. It is important to note, that although an accumulation of sleep loss and fatigue during a two-week offshore work period was found, on average, fatigue scores did not reach safety critical levels of 7 – 9 KSS points. In detail, time in bed was shorter during offshore work periods compared to pre- and post-offshore work periods (chapter 3); total sleep time was below the general recommended sleep duration of 7 – 9 hours a night (chapter 3); and chronic sleep loss increased across the two-week offshore day-shift rotation periods (chapter 5). To date, the chronic effect of both reduced sleep quantity and quality over days-on-shift has largely been ignored in scientific research although it has been suggested that individuals can develop a chronic sleep debt despite apparent full recovery from acute sleep loss. Previous offshore studies also found shorter sleep periods (acute sleep loss) during offshore work periods compared to leave periods. Previous non-offshore studies have shown the negative impacts of chronic sleep loss on individuals' cognition, performance, mood and biological pathways, leading to potential increases in occupational health and safety risks. In line with the accumulation of sleep problems over time spent offshore, another offshore study found that towards the end of a two-week offshore shift rotation period poorer sleep and more records of insomnia were observed. Thus, chronic sleep deficiency effects, compared to acute sleep deficiency effects, might appear subtler towards the beginning of an offshore shift but are more severe towards the end of an offshore shift period.

Apart from an accumulation of chronic sleep loss, an accumulation of fatigue (sleepiness) across offshore day-shift rotation periods was found (chapters 3 & 6). In particular, increases in post-shift fatigue scores and daily prevalences of severe fatigue scores were observed. Overall, the prevalence of fatigue was high with 73% of offshore workers reporting prolonged fatigue (chapter 2) and 1 in 7 offshore workers (14%) reporting severe sleepiness each offshore day (chapter 6). Across the offshore shift rotation period, the average daily prevalence of severe sleepiness was 10% in pre-shift and 19% in post-shift measures. To our knowledge, the accumulation of post-shift fatigue scores (i.e. an end-of shift effect) is a novel finding. The increase in post-shift fatigue scores might be related to the accumulation of chronic sleep loss. Recovery after each sleep phase seemed to be sufficient despite shorter sleep durations (acute sleep loss) (chapter 5). Yet, the capacity to stay alert across each
offshore day seems to decline over days-on-shift. This may potentially explain the increases in post-shift fatigue but not pre-shift fatigue scores. Furthermore, a previous offshore study also found increases in fatigue over two-week offshore shift rotation periods. However, that study, as well as the majority of existing offshore research, focused on the adverse effects of offshore night- and swing-shifts, and mainly used fixed day-shifts as a comparison group. Consequently, in-depth data on fatigue among offshore day-shift workers is missing.

Furthermore, differences between subjective, self-reported, and objective fatigue parameters across offshore day-shift rotation periods were found. On average, objective fatigue scores did not change over the course of offshore work periods, whereas subjective fatigue estimates increased over time. Similar results were found in previous offshore studies, showing that subjective fatigue measures varied over offshore days, whereas objective fatigue measures (e.g. PVT-B) did not. These differential findings have previously been explained by different underlying theoretical constructs. Subjective fatigue ratings have been viewed as warning signs, signalling the brain that insufficient sleep has been obtained and that preventive actions need to be initiated. Only when the subjective warning signals are ignored objective fatigue indications, i.e. performance deteriorations, become noticeable. Thus, subjective fatigue might be seen as a precursor of objective fatigue deteriorations, as physiological changes are not likely to occur until extreme perceptions of fatigue are encountered.

Potential Offshore Fatigue Risk Prone Periods

Whilst investigating the courses and prevalences of sleep and fatigue parameters, potential fatigue risk prone periods were identified, in which fatigue scores peaked and fatigue risk substantially increased (chapters 3 – 6). Fatigue risk prone periods are a relatively new concept in offshore sleep and fatigue research. Previous offshore research has described specific days on which fatigue is high and increased safety risk might exist, such as e.g.: the first offshore day, the first day on night-shift, the first day after switching shift patterns, crew-change days, and the first day of leave. These results are mainly based on offshore night- and swing-shift workers and fail to acknowledge fixed day-shift rotations.

Next to these specific days, our study identified an additional fatigue risk prone period, namely a third-quarter phenomenon, characterized by a peak of fatigue on day 10/11 of a fourteen-day offshore shift, after which fatigue scores slowly declined. This third-quarter phenomenon was observed in both the initiator study (chapter 2) as well as in the offshore sleep and fatigue study (chapters 3 – 6). No circadian changes were found to account for the increases in fatigue scores (chapter 4). It can be hypothesized that this third-quarter phenomenon is a psychosocial construct in which motivation, emotions and (time) perception are key drivers. Accordingly, it might not be the 10th or 11th day of a two-week offshore shift, but rather the moment offshore workers realize that they have been at work for a substantial period of time, i.e. three-quarters of an offshore shift rotation. After this experienced peak of time spent
offshore, a change in perspective may take place, in which the focus shifts from the previously completed offshore days to the few offshore days left before returning home and positive emotions lead to increased motivation levels.\textsuperscript{20,21} In extended shift work environments this would mean that, if e.g. three-week offshore shift rotations would be deployed, the third-quarter phenomenon is likely to occur just after the second offshore week is completed. In addition, it would be interesting to know what the level of perceived fatigue is across various (offshore) shift rotation durations. Although no offshore literature on a potential third-quarter phenomenon exists, data from extended space, polar and military missions have shown that psychosocial changes take place three-quarters into a mission, negatively affecting e.g. motivation, mood and anxiety levels of employees.\textsuperscript{22,23} Increased rates of emotional outbursts, deviant behaviours, conflicts, requests for marital counselling and accidents have been noted during space and polar expeditions.\textsuperscript{22,24} It has been argued that these changes are due to psychosocial factors rather than the environment and that mental components are relevant in the development of the third-quarter phenomenon.

In addition to the third-quarter phenomenon, another potential fatigue risk prone period was identified. An end-of-shift effect, with elevated and increasing post-shift fatigue scores compared to pre-shift fatigue scores was found in chapters 4 – 6. Thus, marking the end of a shift as a potential fatigue risk prone period. Diurnal and circadian differences of sleep and fatigue measures across the day were expected, yet the magnitude of the differences was unexpected. To our knowledge, only one other study among seafarers exist, investigating the diurnal/circadian differences of fatigue parameters at work.\textsuperscript{25} This seafarer study found contradicting results, namely that pre-shift fatigue scores might be a more sensitive measure of emerging cumulative fatigue as post-shift measures reflect acute fatigue after work.\textsuperscript{25} However, based on our results, post-shift fatigue scores could still be a more sensitive measure of fatigue as the acute recuperative effects of sleep phase substantially influence pre-shift fatigue scores, which are not acknowledged in the seafarer study. Thus, more research is needed to confirm pre- and post-shift effects on fatigue. Other, unidentified, (daily) fatigue risk prone periods might exist, which were not captured by the bi-daily fatigue measurements. More research on potential (daily) fatigue risk prone periods using multiple daily fatigue measurements is needed to fully understand and identify fatigue risk offshore.

Fatigue risk prone periods may also derive from spill-over effects between pre-, offshore, and post-offshore work periods, i.e. work periods affecting leave periods and vice versa. Spill-over effects of both sleep and fatigue estimates were observed, pointing towards offshore preparation and recovery periods (chapters 2 & 3). In the pre-offshore work periods, sleep efficiency percentages decreased, whereas sleep durations and sleep onset latency times increased, pointing towards inefficient sleep banking practices. In the post-offshore work period, the highest (post-shift) fatigue scores were identified, with declining fatigue courses and increasing sleep durations over time (chapter 3). In addition, one-third of the offshore
workers reported a need for recovery after having completed a two-week offshore shift rotation period (chapter 2). Most existing research on spill-over effects focuses on the (re-)adaptation of night- and swing-shift offshore workers.\textsuperscript{10,12,18,26,27} Although several studies do include day-shift workers, these individuals are mainly used as a comparison group, as the effects of day-shift spill-over effects are generally smaller among day-shift workers compared to night-/swing-shift workers.\textsuperscript{10} Consequently, spill-over effects among day-shift offshore workers have been largely ignored or overlooked. One offshore study demonstrated that offshore workers reported poor sleep quality during the first and the last days at home, independent of the shift pattern at work.\textsuperscript{28} Offshore shift rotation spill-over effects may negatively affect offshore workers health, safety, performance and interpersonal relationships.\textsuperscript{29-31} For example, elevated fatigue scores combined with long, stressful commutes at unfavourable times of the day (e.g. early morning hours) might put offshore workers at a higher risk of being involved in a car accidents.\textsuperscript{29-31} Road safety is a key risk area in the oil and gas industry as driving-related incidents are historically the single largest cause of fatalities.\textsuperscript{32} By considering sleep and fatigue-related parameters, e.g. spill-over effects, companies might be able to better predict, manage fatigue risk and subsequently reduce road accidents.

\textbf{METHODOLOGICAL CONSIDERATIONS}

In this section, the methodological considerations and their potential influence on reliability, validity and generalizability of the main findings will be discussed.

\textbf{Study sample}

This thesis was conducted on several offshore platforms located in the Dutch Central North Sea. Both contractors and permanent staff were invited to participate to get a more reliable and representative estimate of the offshore workforce. Overall, good participation and low attrition rates were observed contributing to the quality and validity of the data. Although in absolute terms, the sample sizes were small, compared to previous offshore studies, the sample sizes were relatively large, nearly doubling the average offshore sample sizes of existing scientific studies.\textsuperscript{10,33} Moreover, a wealth of individual data points was collected in this intensive longitudinal repeated measures study, resulting in more reliable indications of sleep and fatigue parameters of offshore workers compared to previous offshore investigations. For the more exploratory investigations (chapters 3 – 5), the sample size was sufficient, however, when investigating potential predictors of the individual courses and prevalences of fatigue during offshore shifts, a larger sample size would have been preferred, to bare more robust findings. The limited sample size, i.e. the limited number of outcome events per predicting variable, likely explains the inconsistent findings of potential fatigue predictors in chapter 6. It has been suggested to use 5 to 20 events per predicting variable but the choice should be study dependent and in general the more events per predicting variable, the better.\textsuperscript{34} Thus,
larger sample sizes with more outcome events per predicting variable are needed to identify robust fatigue predictors.

Conducting this study among a representative sample of real-life offshore day-shift workers was an important prerequisite for the validity of the findings in this thesis as mainly descriptive analyses of sleep and fatigue parameters were performed. To improve the overall representativeness of the offshore study sample, careful attention was paid to the sampling procedure. This careful approach may have reduced the chance of potential sample and self-selection bias that would have resulted in an over- or underestimation of results. In general, important factors that might influence the validity of the data are the sample characteristics of offshore workers. In both the mixed method intervention mapping study (chapter 2) and the longitudinal repeated measures follow-up study (chapters 3 – 6), study participation was voluntarily. Consequently, potential self-selection/non-response bias needs to be considered. In the offshore sector, workers are required to engage in stringent medical examinations every 2 – 3 years. Therefore, offshore workers are, on average, considered to be a healthy workforce. From previous research we know that health conscious individuals are more likely to participate in research studies. Yet, in this thesis, some offshore workers also reported suffering from sleep and fatigue-related problems, contributing to the overall representativeness of the sample. Furthermore, other sample characteristics were similar to previously investigated offshore workers, such as the distributions of age, BMI and gender.

For example, the presented findings are based on male offshore workers only, as no female offshore workers volunteered to participate in the study. Although it is unknown how many female offshore workers were present during the conduction of the study (due to data access restrictions and privacy issues), it is known that the number of females working in the offshore industry is very limited. Previous research showed that on average, less than 10% of females work more than 100 days on offshore platforms. Thus, the lack of female offshore workers in our studies is not likely to have negatively influenced the generalizability of our findings and the representativeness of the offshore sample.

**Study design**

A combination of study designs was applied in this thesis, contributing to a better understanding of sleep and fatigue offshore and the reliability and validity of results. In detail, a mixed method approach using qualitative and quantitative data (chapter 2), and an intensive longitudinal repeated measures design using a variety of objective and subjective, self-reported measures were used (chapters 3 – 6). The intensive longitudinal repeated measures design allowed for a rigorous investigation of sleep and fatigue parameters during and across full 2on/2off offshore day-shift rotation periods (including pre, offshore, and post-offshore work periods) increasing the reliability of the data. Moreover valuable in-depth information on the individual perceptions of sleep and fatigue experiences and general sleep and fatigue trends was collected, contributing to the existing scientific literature. Vast interindividual
differences in the perceptions and experiences of sleep and fatigue parameters exist, making sleep and fatigue a highly personalized experience, which should not be aggregated on a group level. Yet, to date, most social and medical publications make inferences about individuals based on aggregated group scores and a lack of evidence-based recommendations for individual shift workers to prevent sleep and fatigue-related problems exists. Recent emphases by researchers have been on improving the group-to-individual generalizability, i.e. the overestimation of the accuracy of aggregated statistical estimates to individual outcomes, and on adopting a more person-centred scientific approach for sleep and fatigue investigations. By investigating both aggregated group and individual levels of sleep and fatigue parameters (chapters 2 & 6) we supported a more person-centred scientific approach and contributed towards increasing the group-to-individual generalizability.

The rigorous investigation of longitudinal and repeated sleep and fatigue parameters during and across full 2on/2off offshore day-shift rotation periods also allowed the investigation of the dynamics and temporal relationships of sleep and fatigue processes over time. Many times, biopsychosocial constructs, like sleep and fatigue, do not follow ergodic processes, i.e. sleep and fatigue processes are erratic and behave inconsistently over time. Moreover, most constructs not only change over time, but also affect each other continuously. As momentary assessments of these constructs thus may fail to capture these nuances, rigorous longitudinal daily sampling was performed. It is important to note, that when using repeated measures, there is a risk of potential learning/order effects. However, as comprehensive measurements were conducted and the PVT-B has been reported to only have minor learning effects, this limitation is not likely to apply to the presented data.

It is important to mention that general offshore logistics impacted sound data collection. For example, cancelled and/or delayed flights as well as hectic handover periods impeded e.g. PVT-B sampling, on the first offshore day. Therefore, several PVT-B data points on the first offshore day were missing. Subsequently, potential sleep and fatigue-related problems on commuting days might have been missed, potentially affecting the reliability of the results. Previous offshore studies have shown that the first offshore day is one of the most fatigue prone days and thus our results might have underestimated this effect. Furthermore, due to the simultaneous conduction of the study and the geographical dispersion of platforms, it was not possible for the principal investigator to be physically present on each platform during data collection. Hence, extensive efforts were invested in the planning, set-up and conduction of the offshore study, to instruct dedicated offshore personnel to supervise, arrange and collect the data. Continuous communication was sought with the dedicated offshore personnel to ensure good data quality and adherence to study guidelines.
**Study measurements**
In this paragraph, the methodological considerations regarding the various study devices and study measures will be elaborated.

**Study devices**
Innovative research appliances (i.e. iPad PVT-B app, electronic sleep diaries) were used to measure both sleep and fatigue parameters as well as the ambient sleep environment. All devices had to be intrinsically safe, i.e. no ignition hazards due to potential releases of electrical and/or thermal energy, which is an important prerequisite for any device used offshore. The reliability and validity of all included research appliances was confirmed in previous studies.\(^4\)\(^3\)-\(^4\)\(^5\) However, to date, no universally accepted objective fatigue tests exist, as from an etiological and pathophysiological point of view, the underlying concepts of fatigue are too complex. Thus, objective fatigue tests rely on measuring fatigue proxies, such as sleep onset latency and reaction times. The most commonly used objective fatigue test is the Multiple Sleep Latency Test (MSLT), which assesses how readily somebody falls asleep in a conducive laboratory environment by means of evaluating multiple sleep latency periods across the day.\(^4\)\(^6\) As the MSLT is expensive, time-consuming and requires a lot of resources, e.g. EEG, EOG and PSG measures, the MSLT is not deemed suitable for field studies. The PVT-B has been shown to be an inexpensive alternative to the MSLT, as it accurately assesses objective fatigue proxies, i.e. increases in reaction times and other performance deteriorations, in work settings and field studies.\(^4\)\(^4\) In addition, by using the 3-min PVT-B version, rather than the 10-min PVT version, we were able to restrict the time investment of offshore workers and were able to conduct bi-daily PVT-B tests instead of daily PVT tests, increasing our data set size. Nevertheless, it has been argued that the shorter the PVT tests are, the less sensitive they become to measuring fatigue.\(^4\)\(^7\)

Another potential bias that could have negatively influenced the validity of our findings was the sub-optimal PVT-B testing environment. Ideally, the PVT-B test is conducted in a quiet room with limited distractions and only the participant present. However, given the limited space offshore, the general offshore work/living conditions might have adversely influenced some of the study measures as unwanted group dynamics emerged. On one offshore platform, it was reported that the PVT-B task turned into a spectated competition (chapter 4). This competition was good for test compliance and social morale offshore; however, we cannot exclude that the competitive environment might have led to information bias. As offshore workers were being watched, their motivation to succeed in the task might have increased. Consequently, better and/or faster reaction time tests might have been obtained, leading to either stable or decreasing reaction time rates, potentially biasing the acquired data and negatively influencing the validity of the results. Though, as the competition was only reported on one offshore platform, with only a limited number of offshore workers affected,
and the average daily reaction times being similar to the other offshore platforms, the risk of information bias, i.e. biased PVT-B scores, is probably low.

**Study measures**

Following recommended practices, a combination of both, subjective, self-reported, and objective, actigraph, sleep and fatigue measures was used to investigate courses and potential causes of fatigue offshore.\(^{48}\) Adopting this approach, increased the validity and overall quality of the collected data (e.g. due to cross-referencing) and helped us to better understand and differentiate between fatigue perceptions and fatigue performance impairments, during and across offshore day-shift rotation periods.\(^{13,48,49}\) In general, strong correlations between subjective, self-reported, sleep diary data and objective actigraphy data were found. Although, initially, not being a specific aim of the thesis, the identification of differences between subjective and objective fatigue reports will likely aid future FRMPs to better predict, manage and mitigate fatigue risk offshore.

It is important to note that sleep diaries might have been influenced by recall bias and social desirability, leading to potential information bias. Depending on the question and the time the question is completed, offshore workers answers might be influenced by memory effects (e.g. the time-lag between waking up and filling out the sleep diary). Recall bias in this thesis, mainly pertains to the baseline questionnaire in which offshore workers were asked to report e.g. their sleep quality in the past month. In addition, given that this was a study initiated by the offshore workers employer and executed at the workplace, social desirability might have impacted the offshore workers statements. It is possible, that offshore workers did not fully admit their real fatigue levels, thinking that it might negatively affect them at work (e.g. if their supervisors saw how tired they were and subsequently negatively influencing their performance rating). Additionally, the existing ‘macho-culture’ offshore might have prevented offshore workers from confessing their true fatigue levels or general ailments. Subsequently, presented results on sleep and fatigue-related problems might be underestimated/underreported, negatively affecting the validity of the data. To minimize social desirability and/or information bias, elaborate briefing sessions on study design and anonymization procedures were held among offshore workers. Lastly, the saliva sampling might have been slightly compromised due to sub-optimal environmental conditions, e.g. too much artificial light exposure. Natural melatonin synthesis is supressed by artificial light.\(^{50}\)

Thus, if too much artificial light was present during the saliva sampling, melatonin scores could have been negatively impacted and potential circadian shifts might have been underestimated. Although individual saliva sampling records were checked, and dedicated offshore personnel was instructed to perform the saliva sampling in dark environments, no verification of appropriate saliva sampling conditions could be performed. Thus, we cannot exclude that the validity of the circadian data may have been compromised.
**IMPLICATIONS**

The findings of this thesis add new and unique knowledge to the existing sleep and fatigue literature among offshore workers. In the following section, implications for future research as well as for policy and practice will be discussed.

**Implications for future research**

*Replication of presented thesis findings*

More intensive longitudinal, repeated measures studies should be conducted among larger numbers of offshore workers to confirm the presented findings. In particular, the following four topics should be further investigated: 1) sleep and fatigue parameters across the full offshore shift rotation cycle, 2) potential fatigue risk prone periods, 3) differential findings between, and predictive power of, subjective and objective fatigue measures and 4) potential fatigue predictors.

First, more longitudinal studies on the full offshore shift rotation cycle are warranted as particularly research on pre-offshore work period is lacking. For instance, indications for pre-offshore work preparation strategies were found (e.g. inefficient sleep banking practices, chapter 3), yet further observational studies are needed to confirm these findings. Second, more longitudinal research on the identified potential fatigue risk prone periods (e.g. end-of-shift-effect, third-quarter phenomenon and spill-over-effects) should be conducted to confirm the existence of potential fatigue risk prone periods. Confirmed fatigue risk prone periods could subsequently be incorporated in fatigue risk management systems (FRMS) to improve fatigue management. This research should be executed among varying lengths of offshore shift rotation periods to see whether the potential fatigue risk prone periods change with varying shift durations. In addition, the underlying mechanisms, consequences and interindividual differences regarding potential fatigue risk prone periods should be investigated to further advance and customize FRMS and fatigue risk management plans (FRMPs). For example, future bio-mathematical models could consider incorporating the interaction between time of day and days-on-shift as well as evening fatigue (KSS) scores to predict fatigue development offshore (chapter 5). Yet, additional longitudinal field research is necessary to confirm fatigue risk prone periods and individual fatigue predictors. Third, longitudinal research on the differential findings between subjective and objective fatigue is needed to examine the predictive power of both subjective and objective occupational fatigue measures on e.g. performance impairments. Knowing which occupational fatigue measure better predicts e.g. performance impairments, is necessary for the identification and recommendation of fatigue screening, prevention and proofing tools. Lastly, more longitudinal research on the investigated potential fatigue predictors in larger samples sizes is needed to further elaborate on inconsistent findings (chapter 6) and to eventually suggest reliable and valid fatigue predictors to be used in bio-mathematical algorithms to predict fatigue.
Improving research designs, analyses and devices

Novel research designs and statistical techniques such as time-series analyses or dynamic multilevel modelling should be deployed to investigate temporal order effects of accumulating sleep and fatigue-related problems offshore. Also, additional daily, preferably hourly, fatigue measures should be conducted to better plot the courses of both subjective and objective fatigue estimates during the day and over days-on-shift. These improved study designs are likely to aid the advancement of current bio-mathematical algorithms used in FRMS, as the incorporation of fatigue risk prone periods in FRMS-algorithms may increase the sensitivity and specificity of fatigue predictions. Furthermore, multiple daily fatigue measures, or continuous (real-time) monitoring using innovative fatigue tracking devices such as pupil dilation, would aid the investigation of diurnal and circadian changes over time. It is however necessary to test the feasibility, reliability and validity of these aforementioned real-time fatigue monitoring tools, as empirical research for these devices is currently lacking and real-time monitoring devices have to be certified and proven to be (intrinsically) safe in order to be used offshore. In addition, randomized controlled trials should be conducted to investigate the effectiveness of preparatory fatigue prevention practices (e.g. sleep banking strategies) on sleep and fatigue parameters whilst offshore, and on subsequent coping strategies for handling offshore work periods.

Furthermore, this thesis lays the foundation for the continuation of the Intervention Mapping approach initiated in Chapter 2. Intervention Mapping is an integrated knowledge translation approach, which increases the relevance, applicability and impact of research through defining feasible and relevant study objectives and implications. A general lack of sleep and fatigue field research studies has been recognized, as most knowledge stems from simulated-laboratory environments, hampering the generalizability of findings to real-life scenarios. The presented results in chapters 3 – 6 provide in-depth information to feed into Intervention Mapping step 3 (IM 3, selection of theory-based intervention methods) to be used to finish the IM approach. Future research can build upon these findings to select and test intervention methods, and develop and evaluate future HA@W programs offshore (IM step 4-6).

Challenges and new research avenues

The decision which variables to investigate in this thesis was made based on published scientific evidence and available research devices. In hindsight, we would have preferred to collect additional data on e.g. the duration, nature (i.e. shift type), and level of stress during previous offshore shift rotations to account for these potential influential factors and improve the validity of findings. Moreover, only limited data on work characteristics during the investigated offshore shift period was collected. Previous studies have shown that work has the potential to adversely affect sleep and fatigue parameters. Thus, possibly explaining and predicting sleep and fatigue courses offshore. Analysing how the amount and content of work each day impacted sleep and fatigue parameters offshore would have been preferred.
Additionally, potential gender and shift type (night-/swing-shifts) differences in sleep and fatigue parameters offshore should be investigated to understand the specific antecedents, causes and consequences of sleep and fatigue-related problems in these populations.

In general, longitudinal field research on the consequences and implications of sleep and fatigue-related problems (e.g. acute and chronic sleep loss) among offshore workers is needed to better understand the impact of e.g. sleep loss on health, safety and performance measures. In particular, retrospective studies and prospective longitudinal studies are needed that investigate, monitor and relate sleep loss to e.g. safety incident rates, sickness absences, and/or accomplished production targets. Knowing the distribution of near misses, incidents and accidents over the courses of offshore shift rotations is essential, to eventually link offshore sleep and fatigue-related problems to offshore safety statistics. This research is especially relevant for the ongoing discussion on optimal shift length durations. Being able to predict how fatigued offshore workers become during the course of an offshore shift rotation is essential when discussing the maximum/optimal lengths of offshore shift rotations. To date, there is a particular lack of prospective longitudinal studies focusing on the health and safety risks associated with extended (offshore) shift durations. More research on the health and economic consequences of varying offshore shift lengths is needed to inform the debate on extended offshore shift rotations. In particular, cost-benefit analyses, should be conducted to weigh the potential accumulating fatigue risks, due to extended offshore shift rotations, with the additional travel/commuting risks (i.e. road and helicopter accidents) in shorter offshore shift rotations to decide whether or not it is safe to extend offshore shift rotations beyond two-weeks.

Implications for policy and practice
Awareness of the accumulation of sleep and fatigue-related problems during and across offshore shift rotations should be raised by influential industry stakeholders. This awareness might help offshore workers to manage, reduce and/or eliminate dip-experiences (e.g. end-of-shift-effect and the third-quarter phenomenon) and cope with acute and chronic sleep loss and increasing post-shift fatigue levels. Various communication streams, such as: toolbox talks, weekly team meetings, site safety inductions or mandatory learning modules could be used to educate offshore workers and their managers. In addition, it might be beneficial to educate offshore workers on sleep hygiene practices, i.e. behavioural and environmental practices to promote a healthy sleep, to improve sleep quality and quantity and decrease fatigue accordingly. Employers need to warrant good sleep environments by meeting basic ergonomic requirements of sleeping accommodations (e.g. controlling for noise, temperature/humidity and light levels) and endorsing single-cabin use if possible. It is important that both employers and employees are aware of the sleep and fatigue risks and mitigation procedures, and that both parties take actions to improve current work and sleep conditions accordingly.
Based on the presented thesis findings on accumulating sleep and fatigue-related problems over two-week offshore day-shift rotations, it may be hypothesized that extending offshore shift rotations beyond two-weeks might increase sleep and fatigue-related problems. As of today, offshore work rosters should be adjusted to accommodate the findings and limit the offshore work period to two-weeks, until the health and safety implications of extended offshore shift rotation periods have been further investigated. In addition, as high prevalences of fatigue have been identified among offshore workers, increased attention should be paid to general fatigue risk management practices and specifically the use of fatigue mitigation and proofing procedures. However, it is important to mention that most fatigue prevention tools and fatigue mitigation/proofing strategies e.g. real-time fatigue monitoring tools, have not been empirically tested, and thus the feasibility, durability and (cost-) effectiveness of these initiatives have yet to be established. Thus, it is important that more joint research projects between industry and academia are conducted, to test new fatigue monitoring/proofing strategies in the workplace. Precautionary actions might already be implemented by organizations, such as the monitoring and consideration of potential fatigue risk prone periods. By making small adjustments to work rosters (e.g. avoiding the conduction of HSSE critical tasks during the end-of-shift) and introducing intermittent fatigue checks (e.g. pre- and post-offshore tour fatigue checks, daily fit-for-duty tests, and/or pre-HSSE critical tasks tests) safer work environments or safer commutes will be facilitated. These fatigue/fit-for-duty checks could make use of e.g. PVT-B tasks, KSS questions, or the Prior-Sleep-Wake Calculator. The identified fatigue screening tools are easily implemented, quick and inexpensive fatigue risk management options to manage occupational fatigue and commuting risks offshore. The question however remains, which fatigue risk management procedures will be followed if an offshore worker is fatigued? To our knowledge, no industry guidelines exist discussing and/or evaluating potential follow-up implications for fatigued employees. Offshore FRMPs need to consider these potential follow-up implications before introducing any fatigue screening tools to manage expectations, create a culture of trust and leverage potential adverse economic (e.g. staffing and production) and social outcomes (e.g. prejudice and discrimination). As a final point, the findings on accumulating sleep and fatigue problems and potential fatigue risk prone periods might be relevant for other parties outside the offshore oil and gas industry, because it might inform them about the organization and extension of shift work periods and may raise awareness on sleep and fatigue trends at work.

CONCLUSION
This thesis presents new insights and knowledge on offshore sleep and fatigue parameters and potential fatigue predictors, during and across full 2on/2off offshore day-shift rotation periods. The intensive longitudinal repeated measures study design and the use of advanced statistical analyses, allowed a rigorous investigation of the subjective, self-reported, and objective sleep and fatigue parameters among offshore day-shift workers, despite the limited sample size. The investigation of the courses and prevalences of sleep and fatigue parameters
offshore revealed accumulating sleep and fatigue-related problems and potential fatigue risk prone periods as the two main findings. In general, more field research is needed to confirm our thesis findings and to better understand the antecedents, causes and consequences of sleep and fatigue-related problems offshore. Once our study findings are confirmed, the thesis findings can be incorporated in existing FRMS and FRMPs to better predict, manage and mitigate fatigue risk offshore to ultimately improve the health, safety and sustainable employability of offshore workers.
REFERENCES


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