Chapter 01

GENERAL INTRODUCTION
The feeling of sleepiness when you are not in bed, and can’t get there, is the meanest feeling in the world.

Edgar Watson Howe (1853-1937)  
Country Town Sayings, 1911
Sleep and fatigue-related performance impairments are widely recognized workplace hazards, which have the potential to adversely affect health, safety, productivity, and sustainable employability of offshore workers.¹⁻³ Fatigue risk management is an important risk mitigation strategy for managing sleep and fatigue-related risks associated with offshore shift work rosters. However, the specific courses, prevalences and predictors of sleep and fatigue problems during offshore shift rotations are not yet well understood. The aim of this thesis is to provide a better understanding of the courses, prevalences and potential predictors of sleep and fatigue problems during full 2-weeks-on/2-weeks-off (2on/2off) offshore day-shift rotations, including pre-, offshore, and post-offshore work periods. The new knowledge may help to improve existing fatigue risk management programs (FRMPs) and fatigue risk management systems (FRMS).

EPIDEMIOLOGY OF SLEEP AND FATIGUE

The prevalence of sleep and fatigue-related problems, especially in western societies, is on the rise.⁴ In Europe, an average of 18% of the working population reports restless sleep.⁵ Over the past decades increases among (diagnosed) sleep and fatigue problems and disorders,⁶ the amount of (prescribed) sleeping medications,⁷ and the number of reported fatigue at work and off work have been observed.⁸⁻¹⁰ Moreover, the proportion of short sleepers (< 6h a day) doubled from 15% to 30% over the last four decades.⁴ As a society, we have even been said to be chronically sleep deprived and that we are dealing with an unmet public health problem.¹¹⁻¹³ The above findings may be linked to broad societal changes such as globalization, electronic innovations and the emergence of 24-h operations. Pressing societal demands for 24-7 operations limit sleep opportunity and shift work arrangements become indispensable.¹⁴ In addition, several studies have shown that sleep is more and more of limited importance to individuals and is often sacrificed for work or pleasure.⁶ In particular, individuals spent more time at work, commuting, watching television and using the internet/social media. In 1995, David F. Dinges already raised his concerns that: ‘Sleep is ignored at our (own) peril’ (p.12), and that as a result the chances of fatigue-related accidents might increase.¹⁵ Occasional lack of sleep does not pose significant problems, as a minimum level of behavioural functioning can usually be maintained without immediate negative consequences.⁶ Sustained lack of sleep from an accumulation of short sleep episodes or acute lack of sleep due to a very short sleep episode, however, has been shown to negatively affect health, performance and personal as well as operational safety.¹⁶ One of the major consequences of lack of or poor sleep is fatigue. Fatigue, sometimes also referred to as sleepiness, drowsiness or lack of alertness, is a complex phenomenon affecting cognitive decision-making, attention spans and reaction times.¹⁷ In the past, both poor sleep and elevated fatigue levels have been linked to health and safety concerns.¹⁸⁻²¹ In the US, it is estimated that fatigued workers in workplaces are costing employers more than $18 billion a year.²² In particular, it has been shown that fatigue-related productivity losses are costing employers close to $2000 per employee per year.²³ Furthermore, a recent study among five OECD countries (America, Japan, Germany, Canada
and the United Kingdom) found that each year an average of about 3.7 million working hours are lost due to insufficient sleep.24

THE CONSTRUCT OF SLEEP
Sleep has been defined as an active behaviour, a reversible, repeating state of unconsciousness that can only be resisted for a limited amount of time. Sleep is one of our basic human physiological/survival needs (alongside oxygen, water, food and shelter) without we cannot function.25 Furthermore, sleep serves several vital bodily functions, ranging from the control of our metabolism, to memory consolidation and the replenishment of cognitive functions.26 Although the exact function(s) of sleep are still being debated, one of the most agreed upon function of sleep is its restorative/recuperative value.27 During sleep, our brain ‘resets’, meaning that experiences accumulated during the day are processed and neuronal connections are strengthened. In general, sleep is comprised of complex, active and highly organized physiological processes which, when disordered or deficient, result in ill-health or death.6 In addition, close interactions exist between the sleep-wake regulation, core temperature, blood pressure as well as immune and hormonal rhythms leading to optimizations of the internal temporal order. Sleep/wake regulation is controlled by the two-process model ‘the homeostatic and circadian sleep drive’. The two-process model describes the interplay of two processes: a wake promoting and a sleep promoting drive.28 (Figure 1) The homeostatic system involves neural systems in the brain stem and basal forebrain, which control sleep/wake regulation and which are influenced by prior sleep debt. This sleep debt can stem from acute (daily) and chronic (accumulated) sleep loss. Thus, over the course of the day, a reduction in sleep time must result in an increase in hours of wake. The acute sleep/wake drive describes fatigue experienced due to daily sleep loss, whereas the chronic sleep/wake drive refers to fatigue because of accumulating sleep loss over several days.29 The circadian pacemaker, located in the suprachiasmatic nucleus (SCN) of the hypothalamus, generates circadian 24-h rhythms of core bodily functions and controls brain alerting signals based on light exposure. The SCN initiates signals to other parts of the brain that control the release of sleep/wake regulating hormones such as cortisol and melatonin. Thus, together with the homeostatic sleep/wake drive, the circadian drive helps to regulate sleep/wake behaviour.

The two sleep/wake regulating hormones, cortisol and melatonin, follow opposing diurnal rhythms. Cortisol concentrations rise in the morning whereas melatonin concentrations increase at night.31 (Figure 2) Cortisol secretion occurs in the adrenal glands and is controlled by the hypothalamic-pituitary-adrenal (HPA) axis. The peak in cortisol concentration is reached at around 9am after which it gradually declines until reaching the nadir at around midnight. Cortisol has two primary functions: (1) cortisol stimulates glucogenesis (the breakdown of protein and fat to provide metabolites that can be converted to glucose in the liver) and (2) cortisol activates anti-stress and anti-inflammatory pathways.32 Sleep is initiated
Figure 1. The two-process model. Sleep-wake regulation: homeostatic and circadian processes. Adopted from Dijk DJ, et al. (1999).30

Figure 2. The normal synchronous relationships between sleep and daytime activity and varying levels of cortisol, melatonin and body temperature.31

when HPA axis activity is at its lowest. When asleep, the release of cortisol is suppressed. However, when sleep is interrupted and sleep is reduced, less cortisol suppression takes places (HPA axis activation) resulting in high cortisol concentrations. HPA axis hyperactivity has been associated with fragmented and shortened sleep as well as decreased slow-wave sleep.33 Melatonin is produced by the pineal gland and released to the blood stream and cerebrospinal fluid. Melatonin is a sleep-promoting hormone, which is sensitive to the light/dark cycle and its release occurs at night-time (once daytime inhibitory signals from the SCN are reduced). In general, the role of melatonin is two-fold: (1) initiating and maintaining
sleep and (2) activating the circadian timing of other 24-h body rhythms. The synergistic relationship between circadian and homeostatic sleep/wake drives thus determines the individuals’ levels of alertness and fatigue as well as performance and rest-activity patterns during a day.

**THE CONSTRUCT OF FATIGUE**

Fatigue is a complex phenomenon, which has a multitude of antecedents, causes and consequences. Some of the antecedents and causes include lack of/poor sleep, circadian misalignment, time awake and prolonged cognitive stimulation such as time-on-task and monotonous work tasks. As instantiated by the two-process model of sleep regulation, circadian and homeostatic processes interact with situational factors in the workplace (e.g. working hours, workload, napping policies). Furthermore, they also interact with situational factors outside the workplace, such as stress at home, light exposure and lifestyle. In addition, medical conditions, such as e.g. obstructive sleep apnoea, may negatively interfere with the quantity and quality of sleep potentially increasing fatigue levels. Fatigue has been shown to affect individual well-being and performance as well as personal and operational safety through lapses in attention and errors. Fatigue has been linked to cancer risk, cardiovascular and mental health, as well as mood changes such as irritability and problems with memory consolidation. In particular, fatigue has been found to be related to future sickness absence. In the current scientific literature and in industrial settings, the terms fatigue, sleepiness, drowsiness/somnolence, tiredness and lack of alertness are used interchangeably. However, they are distinct phenomena and conceptual differences exist. Fatigue has been described as an overwhelming sense of tiredness/lack of energy associated with impaired task performance resulting from physical or psychological strain. Sleepiness has been associated with the neurobiological need to sleep, sometimes also referred to sleep propensity, resulting from physiological wake and sleep drives. The more direct state of drowsiness/somnolence is the transitional state between wakefulness and sleep in which symptoms of sleepiness can be experienced. 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. For the remainder of the introduction, the term ‘fatigue’ will be used to refer to both fatigue and sleepiness constructs. In the past years, increased attention has been given to fatigue hazards in occupational environments. Existing health and safety manuals are now including fatigue risk management plans to try to mitigate fatigue-risk.

**Fatigue Risk Management**

Fatigue risk management is a shared responsibility between employers and employees. Employers have legal responsibilities to manage fatigue in the workplace by e.g. providing staff with a work schedule that does not require excessive wakefulness and by providing opportunities to obtain sufficient sleep. Employees have the legal obligation and responsibility
to manage their personal activities and ‘non-work related’ fatigue. Employees are responsible for using their allocated time away from work to obtain sufficient sleep to report to work alert and to maintain that alertness until they are in a safe environment. If a sufficient level of alertness cannot be guaranteed, the employee has an obligation to notify his/her employer that they are not alert, and therefore not fit for work. Fatigue risk management plans (FRMPs) manage the risk of fatigue stemming from work to maintain and improve workers health and safety as well as company reputation and economic means. Fatigue risk management systems (FRMS) are bio-mathematical modelling techniques that predict fatigue risk at work. It has been suggested for FRMPs to incorporate bio-mathematical modelling (i.e. FRMS) to better predict and manage fatigue risk at work. In recent years there has been a shift from traditional prescriptive fatigue risk management approaches (e.g. regulating the hours of service) to alternative approaches, which increase operational flexibility and focus on outcomes.\textsuperscript{43} For example, logistic companies have used pupil dilation and lane deviation behaviours as a marker of fatigue in professional drivers. Sleep and fatigue risk science is still a developing field and more knowledge on the underlying mechanisms, antecedents and consequences of sleep and fatigue parameters during shift work is needed to further advance existing FRMS and to ultimately better manage and or mitigate fatigue risk at work.

**THE OFFSHORE SHIFT WORK ENVIRONMENT**

One of the most common occupational sleep and fatigue risk areas are shift work environments. Shift work, i.e. work that takes place outside the traditional Monday thru Friday 09:00h – 17:00h working day, poses increased fatigue risk due to potential lack of sleep, poor sleep quality and circadian misalignment.\textsuperscript{14,35,44} Working extended (> 8 hours/day), successive (> 5 days) or rotating (alternating morning-, evening-, night-) shifts can predispose workers to experience sleep problems and elevated fatigue levels.\textsuperscript{35,38,44-47} Moreover, the interaction between disturbed biological systems and psychosocial factors due to shift work, has been linked to several other adverse health effects including cardiac, mental, metabolic ill-health and cancer.\textsuperscript{38} The offshore oil and gas industry environment is a unique shift work environment, combining hazards from shift work and industrial and marine environments. These hazards, such as extended work hours, noisy sleep environments and platform motion have the potential to contribute towards sleep and fatigue problems offshore. In general, offshore workers work on remote platforms located on average between 30 minutes to 4 hours away from the shore, and are reached by helicopter or boat. Depending on the country of employment, work conditions such as shift work (e.g. day-, night-, or swing-shifts) and shift durations as well as unique physical and environmental characteristics of a platform can differ. Offshore shift rotations vary in duration usually ranging between 2-4 weeks offshore followed by 2-4 weeks of leave periods. Offshore work hours predominantly consist of 12-h shifts, deployed as either day-, night- or swing-shifts.
In the Dutch Continental Shelf, most offshore workers work 12-h day-shifts for a consecutive two-week period followed by two-weeks of leave (2on/2off). Although both day and night-shift operations exist, most offshore installations nowadays limit the amount of night-shift operations and only assign a limited number of on-call workers. A unique feature of offshore work is that offshore workers sleep and work on the offshore oil and gas platforms. Depending on the location of living quarters, sleep quantity and quality might be impacted by increased noise exposure stemming from the installation. Distinctions need to be made between permanent and temporary living quarters. Permanent living quarters are strategically placed on the platforms to lessen the impact of noise stemming from the installation. Temporary living quarters are placed on the offshore installations later-on to accommodate more offshore workers on demand, and therefore are exposed to more noise. Most offshore workers share one 8-12m² cabin equipped with a private bathroom, two beds, two tv’s, two closets, two chairs and a table during offshore periods. These offshore workers therefore face possible privacy issues and ergonomic discomforts such as incompatible mattresses, pillows and duvets that might not be an ideal fit for individual body types (e.g. someone’s height, weight). The offshore sleep environment is thus another potential contributing factor to sleeping problems and fatigue experiences. Aside from the work and environmental challenges, being physically separated from family, friends and social activities poses additional demands in the lives of offshore workers as they cannot engage in normal social activities, e.g. weekly sport practice/tournaments; attending birthdays. Previous research among shift workers showed that shift workers perceive the negative social consequences associated with shift work as more important than those related to their health.

The offshore oil and gas industry represents a high-risk occupational sector in which fatigue, as a result of poor quality or lack of sleep, is one of the most hazardous health and safety concerns. Some of the most renown industry fatalities linked to human errors and fatigue are the Piper Alpha explosion off the coast of Aberdeen in 1988 and the Deep Water Macondo Well explosion in the Gulf of Mexico in 2010. In the past few years, cost-cutting and other economic pressures have revived the discussion around offshore shift durations. Prolonged offshore shifts (more than two weeks) have financial and safety benefits as air travel and commuting times are reduced and less staff is required. Health and safety aspects associated with extended offshore shifts, however, are often neglected or ranked as a lower concern in this discussion. Negative impacts of extended offshore shifts on offshore workers health, safety and performance levels are likely to put a higher economic burden on employers and societies and thus offset initial cost savings.

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1 The UK offshore sector changed their operating rosters to three-weeks-on/three-weeks-off a year after the study was completed.
PHD THESIS GOAL, SPECIFIC AIMS AND OUTLINE

The overall goal of the thesis is to better understand sleep and fatigue parameters during offshore shift rotations. The specific aims are 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 are investigated. The research questions are as follows:

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

**Research question 2**: 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)? (chapter 3)

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

**Research question 4**: 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? (chapter 5)

**Research question 5**: 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? (chapter 6)

Knowledge on the specific influences of offshore shift rotations on sleep and fatigue parameters, including for example extended working hours (12-h shifts) and successive days-on-shift (14-day rotations) will contribute to the knowledge of fatigue risks offshore. Ultimately, the findings may contribute towards advancing existing offshore FRMPs and FRMS.

In the following chapters, various aspects of sleep and fatigue parameters during full 2on/2off offshore shift cycles are investigated. (Figure 3)

**Chapter 2** investigates the needs of offshore workers for a healthy ageing and sustainable employability program offshore and presents the prevalence and relevance of sleep and fatigue problems among offshore workers. In **Chapter 3**, the courses of subjective, self-reported (sleep diary), and objective sleep quality (actigraphy) and sleepiness parameters are investigated. Pre-offshore (1 week), offshore (2 weeks) and post-offshore (1 week) work periods are compared. In **Chapter 4**, daily fatigue scores and changes in circadian rhythm markers over the course of two-week offshore day-shift period are examined. Both courses of subjective (sleep diary) and objective (PVT-B) fatigue estimates are investigated as well as
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**Chapter 2**
- Identification of sleep and fatigue problems offshore

**Chapter 3**
- Investigation of subjective and objective sleep quality and sleepiness parameters across full-offshore day-shift rotation periods

**Chapter 4 & 5**
- Investigation of subjective and objective fatigue parameters, circadian rhythms and the accumulation of sleep loss during offshore work periods

**Chapter 6**
- Investigation of demographic, lifestyle and health predictors of sleepiness during offshore work periods

**Figure 3.** PhD thesis overview.
potential circadian shifts. Dim-light melatonin onset times and evening cortisol concentrations are used to investigate potential circadian variation. **Chapter 5** investigates the accumulation of fatigue over a two-week offshore day-shift period. In particular, the effects of time of day and days-on-shift as well as acute and chronic sleep loss on the rate of fatigue accumulation are examined. In **Chapter 6**, the individual courses of sleepiness and the daily prevalences of severe sleepiness in offshore day-shift workers, working two-week offshore day-shift rotations, are investigated. In addition, potential demographic, lifestyle and health-related predictors of individual courses of sleepiness and daily prevalences of severe sleepiness in two-week offshore day-shift rotation periods are examined. **Chapter 7**, the general discussion, summarizes and discusses the main findings of the thesis. In addition, the methodological strengths and limitations and the implications of the study findings for policy, practice and scientific research are presented.

**DATA SOURCES & MEASURES**

This thesis is based on two field research studies. The first study (chapter 2) concerns a needs assessment to explore the needs and preferences of supervisors and offshore workers for the development of a healthy ageing at work (HA@W) and sustainable employment program. Nineteen semi-structured interviews among offshore supervisors were conducted to identify the management views on the needs and contents of a HA@W offshore program. Then, six focus groups regarding the needs of a HA@W offshore program were performed, including 49 offshore workers. Next, the findings were used to develop a HA@W questionnaire. In total, 260 offshore workers completed the questionnaire.

The following study (chapters 3 – 6) concerns an intensive longitudinal cohort study with repeated measures among 42 offshore workers on four gas production platforms in the Dutch Central North Sea. The offshore workers were followed for 28-consecutive days (one whole 2on/2off offshore shift cycle) with frequent daily subjective and objective measurements. (Figure 4) Data collection started one week before the offshore work period (offshore workers’ second week of leave) and finished one week after the offshore work period was completed (offshore workers’ first week of leave). Subjective, self-reported, measurements included a baseline and 1-month follow-up questionnaire and bi-daily sleep diaries. Objective measurements included: continuous actigraphy recordings, bi-daily PVT-B reaction time tasks (when offshore), saliva sampling on three offshore days and voluntarily sleep environment measurements (noise, temperature and humidity levels).
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Figure 4. Study design, timeframe and measures.
REFERENCES


[41] Dawson D, Darwent D, Roach GD. How should a bio-mathematical model be used within a fatigue risk management system to determine whether or not a working time arrangement is safe? *Accid Anal Prev*. 2017;99:469-73.


