SLEEPING WITH ONE EYE OPEN: CHARACTERISING THE WORK SYSTEM, SLEEP-WAKE BEHAVIOUR, SLEEPINESS, FATIGUE AND WORKLOAD OF HELICOPTER EMERGENCY MEDICAL SERVICES (HEMS) PILOTS

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THESIS

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ABSTRACT

Background: Helicopter Emergency Medical Services (HEMS) pilots work around the clock to provide immediate medical support under time constraints to prevent further deterioration of patients' conditions before in-hospital care. This often requires being on call 24 hours a day, which means the crew need to work extended, day and night shifts, during which they cannot predict when a mission will occur. Taken together, these demands may influence crews 'sleep, which in turn may result in increased sleepiness and fatigue while on duty, which, when combined with a high workload, contributes to fatigue that can impact flight safety. Little to no research has been conducted in the South African context on demands and challenges faced by HEMS pilots or on the effects of their working time arrangements. Therefore, this study aimed to characterise the work system of HEMS operation in a South African company, and secondly to explore the effects of different shift types (day and night shifts) on the sleep-wake behaviour, sleepiness, fatigue and workload of a sample of HEMS pilots.

Methodology: The study had two distinct phases. Phase 1 adopted a qualitative descriptive design with the use of semi-structured interviews with the four company experts to gain insight into the work system of HEMS pilots within a South African company. In particular, the focus was on understanding the working time arrangements of pilots. A systems description and deductive thematic analysis were utilised to analyse the data obtained during semi-structured interviews. Phase 2 adopted a prospective observational design to explore the effects that different duty arrangements (day shifts, night shifts and rest/off days) had on pilots' sleep, self-reported sleepiness and fatigue and workload. Participant's sleep was monitored using actigraphy over several days, including workdays and rest days. The Karolinska Sleepiness Scale and Samn-Perelli Fatigue Scale were completed every four hours from the beginning to the end of each shift to assess self-rated sleepiness and fatigue when on duty, respectively. The end-of-duty workload was measured using the NASA-TLX. The company provided mission logs that outlined information on the number of missions, days on which they occurred, and the duration of each mission.

Results: The company provides HEMS services in various parts of the country, with three bases, each having varying shift start times and end-times to accommodate the unique needs of each base. The day and night shifts are 12 hours. The results based on the interviews also highlighted various challenges, one of which was crew shortage.

This led to the repositioning of pilots across various bases, which impacted pilots' rest days and pre-duty rest as they had to commute and travel from across bases. Thirteen (age 40.5 ±10.78 years) pilots participated in phase 2, of which the data of eleven participants were used. Irrespective of shift type, analyses revealed that the crew's main sleep period was at night. There were no significant differences in sleep-wake behaviour of pilots across the shifts and no differences between sleep-wake behaviour during night shifts and rest days. However, pilots obtained short sleep and long Wake after sleep onset (WASO) during workdays and rest days as detailed in the results section. Over consecutive day and night shifts, there were no significant differences in sleep either. Furthermore, sleep was shorter during night shifts when there were missions compared to day shifts that had missions. When naps were considered along with shift sleep; total sleep time over 24 hours was longer. While sleepiness and fatigue ratings were higher at the end of night shifts than during the day shifts, there were no significant differences between day shifts and night shifts. For workload, on day shifts, pilots reported physical demand as the highest contributor to their workload, with night shift pilots reporting that mental demand was the highest contributor.

Discussion and Conclusion: The results revealed that, irrespective of the shift worked (day shifts, night shifts or rest days), pilots obtained short sleep and sometimes poor sleep quality when on duty and off-duty. The short total sleep durations when the crew were on night shift are likely a result of the crew having to sleep at the base during night shifts while on call and having to be ready to respond to an emergency mission. Day shifts may have impacted sleep duration as a result of early shift start times and domestic duties after a shift. Subjective sleepiness and fatigue ratings were higher during the night than during day shifts, likely reflecting the impact of circadian and homeostatic drivers of sleepiness. However, these revealed low to moderate levels of sleepiness and fatigue, which may result from the crew being able to sleep while on call at night. Overall, the results suggest that because pilots mainly slept at night, self-rated sleepiness and fatigue were low, particularly during night shifts, with no differences in sleep-wake behaviour of pilots across the various shifts worked. Furthermore, there were instances where crew napped and this was likely used as a compensatory mechanism for short sleep periods. More research is needed to provide further insight into how the sleep of HEMS pilots within a South African company is characterised under different shifts (day and night shifts).

Keywords: sleep, fatigue, sleepiness, workload, HEMS

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CHAPTER 1: INTRODUCTION

1.1. BACKGROUND TO THE STUDY

The aviation industry is a high safety-critical industry; therefore, the identification, assessment and management of many systemic risk factors, including crew fatigue, is critically important for flight safety (Missoni et al., 2009; Wingelaar-Jagt et al., 2021). Historically and to a large extent currently, crew fatigue is managed through the application of regulations that govern flight duty periods, which outline maximum time on duty and flight time and minimum rest periods to reduce sleep loss associated with duty hours, circadian disruptions and night work (Missoni et al., 2009; Efthymiou et al., 2021).

In South Africa, there has been an interest and debate around making changes to flight and duty period regulations for different parts of the aviation industry since 2016, as outlined thoroughly by Clark (2024). Since then, there have been several industry-research related collaborations to explore the prevalence of fatigue, the contributing factors and the proposed interventions (Blair, 2022; Clark, 2024), with these research projects mainly focusing on fatigue risks in scheduled aviation. While much of this research and interaction has predominantly focused on passenger carrying aviation, more interest has grown in other parts of aviation, such as aerial firefighting, as reported by Zahn (2021) and Tlale (2022) and more recently, other emergency aerial services such as HEMS. This project is part of a long-standing collaboration with different aviation stakeholders in South Africa aimed at gathering scientific information on sleep and fatigue within various parts of aviation operations. Following several interactions with different aviation stakeholders in South Africa, the research team were approached by a South African HEMS company, which was interested in understanding the crew's sleep and fatigue, in relation to their current working time arrangements.

1.2. BACKGROUND TO HEMS SHIFT WORK RESEARCH

Helicopter Emergency Medical Services (HEMS) forms part of the general aviation sector and is an important part of emergency medical services that provide 24-hour medical services to patients, sometimes in remote locations, for day and night shifts under time constraints (Mehmood et al., 2018). To maintain around-the-clock services, the crew often have to work day and night shifts while being on-call. Night shift work is known to impact alertness while on duty, given that it is scheduled at times that oppose circadian and homeostatic signals for sleep (Åkerstedt, 1998; James et al., 2017). It also requires crew to sleep during the day, which is not optimal, often resulting in poor quality and insufficient sleep, which may result in sleep loss, excessive sleepiness and low levels of alertness during subsequent shifts (Dinges & Kribbs, 1991; Ganesan al., 2019; Rosenwasser & Turek, 2015; Flaa et al., 2020; Harris et al., 2010). In addition to working extended hours, having variable workloads, while having to complete consecutive shifts, crew may experience sleep loss due to insufficient recovery and rest before or after a long shift, which contributes to crew experiencing fatigue (Frakes & Kelly, 2004; Flaa et al., 2021; Rogers, 2008; Sadeghniiat-Haghighi & Yazdi, 2015; Caldwell et al., 2019; Nosker, 2020; Nosker et al., 2021; Patterson et al., 2023).

Several studies have reported that fatigue is a challenge in air ambulance operations, with various studies revealing high levels of on-duty sleepiness and fatigue (Gregory et al., 2010; Reid et al., 2020; Frakes & Kelly, 2004; Patterson et al., 2012; Kamine et al., 2022), particularly when shift work is involved. However, other studies found that crew reported functional levels of self-reported sleepiness, alertness levels, and cognitive performance despite the nature of HEMS work due to appropriate fatigue mitigation strategies (Thomas et al., 2006; Amann et al., 2014; Zakarianssen et al., 2019). A consistent theme throughout these studies is that crews experience inadequate sleep (both in terms of quality and quantity). However, the majority of these studies have been conducted outside of the South African context. Given the industrial partners interest in the problem and the lack of literature in South Africa, it is therefore important to first gain an understanding of the work context. This is important to be able to understand the wider demands placed on HEMS crew while trying to answer the second aim, which was to understand how the different work shift types affect HEMS pilots' sleep, alertness and workload within the local South African context. Knowing this will help to inform the development of appropriate management strategies.

Therefore, this study, in collaboration with a HEMS industry partner and based on a negotiated study focus, aimed to provide further understanding of the nature of the work that HEMS pilots in this company perform and the impact of their working time arrangements on sleep, sleepiness, fatigue and workload of pilots. It is therefore important to understand how these different work characteristics affect HEMS pilots in a practical setting, within the local South African context.

1.3. RESEARCH OBJECTIVES

The study objectives are:

- To gain insight and understand the work system and structure of the HEMS operations within the collaborating South African company.
- To compare sleep-wake behaviour, sleepiness, fatigue and workload of pilots working different shifts.

1.4. THESIS STRUCTURE

This thesis begins with a literature review section (Chapter 2), which provides contextual background of HEMS work characteristics that may impact sleep and contribute to sleepiness and fatigue. In addition, it provides a section on fatigue management. Given the dual aims of this study, data were collected in two distinct but overlapping phases, where Chapter 3 captures phase 1 methodology and Results, and Chapter 4 captures the methodology used in phase 2 and reports on the findings. Chapter 5 integrates the findings from the different phases, with the primary focus of interpreting the findings related to the impact of the different shifts on sleep, sleepiness, fatigue and workload. Lastly, Chapter 6 concludes the study and highlights important findings and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1. Overview and types of aviation operations

The aviation industry is a complex system with varying parts often grouped into three main categories: commercial, military, and general aviation. Commercial aviation refers to an aviation sector carrying passengers or cargo for remuneration and compensation, including manufacturers and airlines (Hansen & Oster, 1997; Ohlandt, 2023). Military aviation refers to aircraft used for defence-related purposes, such as armed forces for combat, surveillance, and transport (Hansen & Oster, 1997). General aviation includes all civilian aviation facets that are not attributed to military or commercial aviation airlines (Hansen & Oster, 1997; Ohlandt, 2023). It deals with individual aviators and private ownership of aircraft operations (Shetty & Hansman, 2012; Ohlandt, 2023). General aviation also covers a broad spectrum of aviation activities involving aerial work, such as agriculture, aerial observation, instructional flying, personal flying, aerial firefighting and aeromedical services, to name a few (Hansen & Oster, 1997; Ma et al., 2023). It also covers various types of aircraft, including small private and corporate jets and those utilised for flight training and air ambulance services (De Rosa, 2025).

Each of these parts of the aviation sector encompasses organisational, social, and human aspects, thus forming a dynamic system with controls and constraints to maintain equilibrium, of which safety is an emergent by-product of these control structures (Harris & Stanton, 2010). The aviation industry comprises of various elements such as airports, aircraft, airlines, air traffic management, and air control, all of which interact with aviation rules and regulations (Harris & Stanton, 2010; 2019). To understand complex systems, a systems approach is appropriate as it is a way of understanding systems by taking a holistic perspective (Carayon, 2006). Carayon (2006) argues that it is important to understand the organisational context in which to apply interventions to ensure significant and sustainable impact. This thesis is situated in one part of general aviation, HEMS, which forms part of air ambulance services, of which the following sections will focus on providing contextual HEMS background.

2.2. Overview of Air Ambulance Operations

HEMS forms part of an umbrella of aerial/air ambulance, of which its primary purpose is to provide advanced care to patients and may be available in certain areas and with strict dispatch criteria, allowing for patients to have a higher chance of survival in emergency medical situations (MacFarlance et al., 2005). HEMS is a branch of Emergency Medical Services (EMS), which are an integral part of service provision for unplanned, urgent and life-threatening health-related conditions (Snoks et al., 2019).

One of the first ambulance services was originally in industrial and coal mining regions in the late 1800s. In the 1970s, South Africa recognised the role of paramedics, which allowed them to administer specific scheduled medication within their scope of practice without supervision from a medical officer (MacFarlance et al., 2005). In 1994, regulations in South Africa regarding the ambulance system were passed down whereby all emergency care practitioners had to be affiliated with appropriate registration bodies (MacFarlance et al., 2005). This contributed to EMS being a key pillar of community care (MacFarlance et al., 2005).

2.2.1. Aircrafts used in air ambulance services

Air ambulances provide support with the use of various aircraft, which may depend on the mission requirements. The aircrafts often used in private and public sectors include fixed-wing (jet aircraft) and rotary-wing aircraft (helicopter). (Steenhoff et al., 2022). The fixed-wing aircraft is propeller-driven, and most aircraft have immobile wings. These aircraft are commonly used for long distances because they can cover greater distances without refuelling. They are usually used to transport patients from one hospital to another and have a more extensive interior than rotary-wing aircraft, allowing for more medical equipment and staff on board.

A rotary blade powers the rotary aircraft and is commonly used in short-distance emergencies where transportation needs to be quick. The advantage of this aircraft is that it is able to land close to the scene of the incident, and in difficult geographic areas such as roads and open fields, given that it does not need a runway or landing strip (Steenhoff et al., 2022).

HEMS operations require specially trained and qualified pilots and medical practitioners. The essential crew in a helicopter emergency medical service aircraft consists of the pilot, flight nurse and sometimes three other Ambulance Emergency Technicians, such as paramedics, doctors and other medical staff (Howell & Brannon, 2000). In Helicopter emergency services, pilots often have to complete high-stakes tasks under time constraints and make decisions quickly, even when relevant information may be lacking (MacFarlance et al., 2005).

2.2.2. HEMS work systems and roles

HEMS operations are unpredictable, sometimes uncontrolled, emotionally taxing, dangerous, but rewarding (Bauer & Herbig, 2019; Lawn et al., 2020). HEMS is characterised by high exposure to critical incidents, challenging work conditions, difficult locations, emotionally demanding patient encounters, long working hours, environmental stressors, and fatigue, while managing flight and patient safety (van Herpen et al., 2023). The following section will focus on how the work demands of HEMS, the tasks that the crew handle, the environment, technology and how the system is organised.

The work is also time-sensitive, given that the crew deals with trauma patients and needs, to ensure they attend to the patient, stabilise and transport them to the hospital for further treatment under time pressure (Mehmood et al., 2018). Personnel's response time can range from 15 minutes to 40 minutes after a callout in urban areas and longer in more rural areas (MacFarlance et al., 2005). Pilots may also be in situations where they are faced with having to land in an unfamiliar, remote area with limited infrastructure, including landing on open water and mountains (Meadley et al., 2021). Additionally, HEMS personnel undertake complex tasks including advanced night rescue procedures (Gillott et al., 2023). The above-mentioned operating conditions of HEMS are among the most challenging when compared to most civil aviation operations (Gillott et al., 2023). The crew sometimes work in high-risk, unpredictable and adverse weather conditions with limited information, which, according to Bauer & Herbig (2019), is one of the prominent causes of fatal HEMS accidents. During inclement weather, HEMS aircraft fly at lower altitudes than usual and could face obstacles such as power lines (Bauer & Herbig, 2019).

Furthermore, when in flight, HEMS personnel may be exposed to environmental exposures such as vibrations, thermal, noise and postural stress, which are among the various physical stressors that crew are exposed to, which may contribute to occupational stress (Bauer & Herbig, 2019). Psychosocial factors also make the work conditions stressful, including emotionally demanding patient encounters, working under time pressure, and making quick, important decisions (Bauer & Herbig, 2019). The interaction of the mentioned factors combined may put the crew at a risk of mental health challenges as well (van Herpen et al., 2023).

HEMS personnel work shifts to meet the job demands, which includes extended hours, day and night shifts during the 24hour operation. According to Gillott et al. (2013); Cline (2018), Dery et al. (2007) & Ruskin, (2019), the dynamics of having to transport injured patients in short time notice may lead to a range of emergent challenges unique to the operational context of HEMS. These may emerge due to organisational factors and may contribute to fatigue. These tasks are often completed by a single pilot, which makes fatigue an important safety issue that should be considered (Bauer & Herbig, 2019). Therefore, the review will provide an overview of the concept of fatigue, its causes, and in the context of HEMS based on literature and previous research.

2.3. Overview of fatigue in aviation

Fatigue has been and is still a significant risk factor for aviation safety (Caldwell, 2005; Reis et al., 2013; Olaganathan et al., 2021; Wingelaar-Jagt et al., 2021; Keller et al., 2022). It has been classified as a contributing factor to accidents (Wingelaar-Jagt et al., 2021; Olaganathan et al., 2021). According to International Civil Aviation Association (ICAO) (2016, p.2) it is a "physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload (mental and/or physical activity) that can impair a crew member's alertness and ability to operate an aircraft or perform safety-related duties safely". This definition emphasises that fatigue is multifaceted with symptoms including feeling weary, tired and sleepy due to insufficient sleep and prolonged mental and physical activities (Caldwell et al., 2019).

2.3.1. Types of fatigue

Fatigue can be subdivided into mental and physical fatigue, and further into acute and chronic fatigue, and it is important to distinguish these types (Caldwell et al., 2019). Acute fatigue is short-term and occurs due to extended periods of wakefulness which can be mitigated by adequate sleep (Olaganathan et al., 2021). The first distinction made is between physical and mental fatigue. Physical fatigue is the inability to continue work due to a lack of physical strength from heavy loads (Sagherian et al., 2017). The musculoskeletal system is primarily involved in physical fatigue, causing a decline in functional capacity (Sagherian et al., 2017).

Mental fatigue can be described as the feeling of weariness, exhaustion, tiredness and a decline in vigilance and cognitive functioning (Boksem & Topps, 2008; Sagherian et al., 2017). It is a state that exists between wakefulness and sleep and includes microsleeps or decreased concentration levels, which may be a risk to flight safety (Olaganathan et al., 2021). Mental fatigue may be caused by prolonged periods of cognitively demanding activities and workload and has been found to increase the risk of error, decrease alertness and motivation, increase feelings of tiredness, and decline in performance in a workplace setting (Boksem & Tops, 2008; Van Cutsem et al., 2017). When sufficient recuperative rest is not obtained over long periods, fatigue accumulates, which can make it chronic in nature (Van Cutsem et al., 2017).

Acute fatigue can manifest from mental labour, temporary illness, emotional stress or insufficient recovery (Techera et al., 2016). Chronic fatigue, on the other hand, occurs due to a delay in and incomplete recuperative rest and cumulative sleep inadequacy (Williamson et al., 2011; Olaganathan et al., 2021). Chronic fatigue may be experienced constantly, often not relieved by rest alone (Techera et al., 2016). Most work demands present acute fatigue risks, mostly as a result of poor quality and insufficient sleep or insufficient recovery, which can result from the working times that HEMS crews operate in and can often be relieved by quality rest and sleep. Circadian disruption and sleep loss are some of the main drivers of fatigue (Caldwell et al., 2019; Sadeghniiat-Haghighi & Yazdi, 2015; Åkerstedt & Wright, 2009). In order to understand fatigue and its contributing factors in the context of HEMS in relation to sleep and sleep disruption, a clear understanding of what sleep is, how it is regulated, and its link to fatigue needs to be unpacked.

2.4. General importance of sleep and sleep health

Sleep is defined as "a reversible behavioural state of perceptual disengagement from and unresponsiveness to the environment "(Carskadon & Dement, 2011, p.16). A person's sensitivity to the environment is decreased; however, it is not absent. Immobility of the limbs, sleeping posture, and elevated arousal threshold, which decreases the ability to communicate with one's environment, are the characteristics of sleep (Angelhoff, 2017). Sleep is fundamental for human health and well-being (Barnes, 2012; Loft & Cameron, 2014). It consists of physiological activities necessary for restorative processes for brain functioning as well as homeostatic restoration, thermoregulation, immune control, tissue repair, and memory processing (Hobson, 2005; Walker, 2008; Barnes, 2012). It also plays an important role in memory consolidation and learning, which improves memory performance (Walker, 2008). The optimal duration of sleep for adults is recommended to be 7-9 hours daily (Chaput et al., 2018; Scott et al., 2024). However, it is important to note that there are individual differences whereby people may still feel rested outside of these recommended hours (Walker et al., 2003; Chaput et al., 2018).

Recent arguments emphasise the importance of looking at sleep health as more than just the duration of sleep but rather, it factors in sleep quality which can be attributed by a number of factors, and that sleep health is actually multidimensional in that the characteristics of duration, regularity, quality, efficiency and alignment with circadian rhythms should be considered (DelRosso, 2025). A conceptual model of sleep health (RU-SATED) proposed by Buysee (2014) proposes six dimensions of sleep health: sleep regularity, subjective satisfaction, appropriate timing, adequate duration, high sleep efficiency (SE), and sustained alertness during the day. Sleep regularity is the day-to-day consistency of sleep-timing, which is a strong predictor of health outcomes (Windred et al., 2024). Subjective sleep satisfaction refers to the perceived judgement about an individual's sleep experience at a particular point (Protogerou et al., 2022; Protogerou et al., 2024). Alertness is the ability to maintain attentive wakefulness, and timing refers to the placement of sleep within a 24-hour day (Buysse, 2014). Sleep efficiency refers to the ratio of total sleep time to time in bed, which is 85% or higher and is considered normal for adults (Reed & Sacco, 2016). Sleep duration is the total amount of sleep obtained per 24 hours (Buysse, 2014). Other sleep characteristics used to assess sleep quality are sleep onset (SOL), wake after sleep onset (WASO), and number of awakenings. Sleep onset latency is the time it takes to transition from full wakefulness to sleep, and WASO refers to the total time of wakefulness after sleep onset until final awakening, with a WASO of less than 20 minutes (i.e., ≤10 or 11–20 minutes) considered good quality in adults, and a WASO longer than 41 minutes indicating poor sleep quality (Nelson et al., 2022; Ohayon et al., 2017).

The next section will unpack how sleep-wake behaviour is regulated, which is important to know when exploring the factors in aviation that negatively affect sleep.

2.4.1. Sleep regulation

Sleep is regulated through two main mechanisms that are independent of each other, namely the homeostatic pressure or process referred to as Process S and the circadian process referred to as Process C. The homeostatic process is determined by sleep and waking, while the circadian process is the clock-like mechanism that determines the alternation of periods with high and low sleep propensity (Borbély & Achermann, 1999).

2.4.2. The circadian process

The circadian process (Process C) represents the effects of the body's internal biological clock (Reddy et al., 2023). The process oscillates around a 24-hour rhythm, driven by the suprachiasmatic nuclei (SCN) in the hypothalamus, also referred to as the "master clock" and synchronised to the day-night changes (Borbély, 1982; Stiller & Postolache, 2005). The circadian process plays a pivotal role in regulating sleep timing, meal timing, blood pressure, changes in body temperature, timing and release of hormones such as melatonin, which play a fundamental role in initiating sleep and wakefulness (Gumz, 2023; Smolensky et al., 2017; BaHammam & Pirzada, 2023). Furthermore, it modulates waking behaviour, which includes subjective and physiological sleepiness, behavioural alertness, working memory and vigilant attention (Goel et al., 2013).

The circadian clock is sensitive to changes in the external environment (Reddy et al., 2023). The process of synchronisation is referred to as entrainment, which occurs from through the interaction of the circadian process and exogenous light/dark cycle (Roenneberg & Merrow, 2016). The entrainment occurs through neurotransmitters in the suprachiasmatic nucleus. Neurotransmitters play a role in the sleep-wake cycle by regulating the release of hormones secreted in the pineal gland to initiate sleep and wakefulness (Okechukwu, 2022). The SCN works by initiating the release of certain hormones under dark and light conditions to control sleep and wakefulness (Okechukwu, 2022).

2.4.3. The sleep homeostatic process

The sleep homeostatic process (Process S) acts as a pressure system that regulates the amount of sleep need (Stiller & Postolache, 2005). It acts as an independent system that works in opposition to the circadian clock (Beersma, 1998; Borbély & Achermann, 1999). The upper threshold of process S (refer to figure 1) induces sleep need and continues to increase linearly with sustained wakefulness, leading to a greater accumulation of sleep propensity, and then decreases and reaches a lower threshold during sleep. When adequate dissipation of sleep is reached, wakefulness is initiated, which is referred to as sleep termination (Borbély & Achermann, 1999; Goel et al., 2013; Stiller & Postolache, 2005; Abhilash & Shafer, 2024). This is the preparatory process of anticipating the end of sleep (Born et al.,1999).

2.4.4. The two-process model

The processes (Process C and S) work in parallel with each other to determine the timing of sleep onset and offset, which constitutes as the two-process model in which sleep-wake behaviour is maintained (Borbély, 1982). The interaction between the circadian and sleep homeostatic processes creates a rhythmic sleep-wake cycle entrained within a 24-hour period. The two processes interact with each other, where the need to sleep is at its highest when the difference between process S and process C is at its greatest, which is referred to as the sleep gate, as depicted in Figure 1 (Borbély, 1982). Borbély (1982) proposed that before habitual bedtime, process S is at its peak, as seen in Figure 1, and process C is at low circadian alertness. Wakefulness is initiated when process S is low, and wakefulness is modulated by the circadian drive for arousal (Process C) (Borbély, 1982). Disruptions in either of the processes as a result of factors such as shift work, can result in sleep disturbances, reduced alertness and impaired performance.

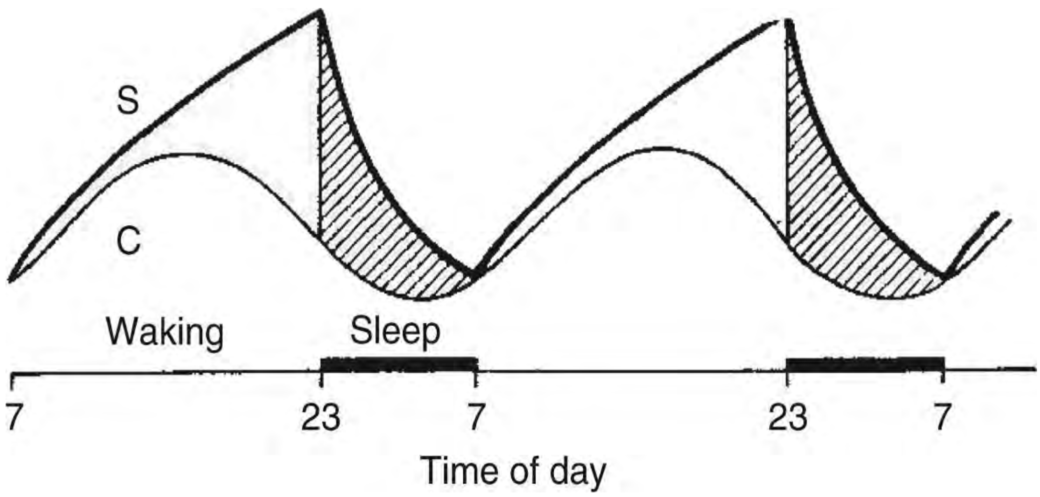

Figure 1:The two-process model for sleep regulation in entrained conditions, where process S represent homeostatic sleep drive and process C represents circadian process (Borbély, 1982).

2.4.5. Linking sleep (loss) and fatigue

Fatigue occurs due to various factors such as time awake, the time of day, workload, health and lifestyle, which will be expanded on later (Caldwell A. et al., 2019). Dawson & McCulloch (2005) argue that sleep plays a fundamental role in fatigue management. The authors state that "mental fatigue associated with a given pattern of work is linked with the timing and duration of sleep and wake, within the break, rather than the duration of the break alone" (Dawson & McCulloch, 2005, p. 366). Furthermore, they state that fatigue is likely the results of insufficient recovery sleep during a recovery break, inadequate break or excessive wakefulness (Dawson & McCulloch, 2005). Within the context of HEMS, several work characteristics such as long work hours, night work, on-call work, consecutive shifts and workload may impair sleep, and consequently, result in increased sleepiness and fatigue risks.

Previous research has reported that fatigue can occur as a result of prolonged wakefulness, being awake during a circadian nadir and inadequate sleep (Macchi et al., 2002; Åkerstedt, 2003; Niu et al., 2011; James et al., 2017; Chang & Peng, 2021). Restorative sleep may be affected by factors such as reduced sleep duration, along with other factors that contribute to sleep health, which may contribute to fatigue and safety risks (Wingelaar-Jagt et al., 2021). Furthermore, Ayas and Özcebe (2025) argue that insufficient and the lack of restorative sleep are key causes of fatigue. This is supported by Williamson et al. (2011, p.499), that fatigue is a "biological drive for recuperative rest", which is influenced by a variety of factors such as time of day, time awake and task-related factors and to reduce the risk of fatigue, adequate sleep quality and quantity is required. If an individual does not obtain restorative rest, it could impair performance capabilities and lead to safety risks (Williamson et al., 2011). As a result of insufficient sleep, due to factors such as prolonged periods of wakefulness and overall poor sleep quality and quantity, drowsiness and decreased levels of alertness may occur. This may result in sleepiness and fatigue, further leading to poor task performance and increased prevalence of work-related injuries, and in aviation and safety-critical contexts like HEMS, this can potentially be detrimental to flight safety (Barnes, 2012).

2.5. Contributing factors of HEMS shift scheduling to fatigue and associated effects on sleep

Factors that generally contribute to disruption in sleep loss and increased risk of fatigue and are associated with include early duty starts, overnight duties, the number of flights in a duty period and the quality of rest obtained pre-duty (Hilditch et al., 2023; Jun-Ya & Rui-Shan, 2023). The combined interaction of irregular work hours, long work hours and consecutive shifts may result in insufficient recovery time, leading to sleep loss and cumulative fatigue (Bourgeois Bougrine et al., 2003; Yuliawati et al., 2015). Although the mentioned factors are of short-haul aviation, there are similarities in the work characteristics with HEMS operations.

The work schedule of HEMS pilots, by the nature of needing to provide 24-hour care, requires the crew to work shifts. Shift work includes work schedules whereby employees change or rotate shifts, which may encompass extended and irregular hours outside standard daytime, including night work and evenings (Guo et al., 2013; Flaa et al., 2020). The term shift work describes someone working outside the normal daytime hours, typically between 7 a.m to 6 p.m. and during a typical working time (early mornings and night work) (Krishnaswamy et al., 2016; Monnaatsie et al., 2021). There is no universally ideal shift pattern, and is comprised of different elements such as shift length, shift rotation, shift breaks, speed of rotation, the number of consecutive shifts, and start and end times (Dall’Ora et al., 2016; Gurubhagavatula et al., 2021). Shift work is necessary and forms an important part of occupations like Helicopter Emergency Medical Services, with varying shifts between countries and organisations whereby shifts can be 12 hours, 24 hours, 48hours and even seven consecutive day shifts and night shifts (Guo et al., 2013; Krishnaswamy et al., 2016; Flaa et al., 2019).

Certain kinds of shift work, such as extended day shifts with early starts or late finishes, and night work, can exacerbate fatigue because of the impact on the ability for pilots to get adequate sleep, which may be associated with sleep loss, fatigue, poorer health and impaired vigilance (Patterson et al., 2024). The following section will highlight some of the key working time characteristics of HEMS pilots, while profiling the impact these have had on pilot sleep, alertness and fatigue, with Table 1 providing a summary of related studies in the air ambulance and HEMS context, further reemphasising the limited research, which has also been included in the relevant parts of the section.

Table 1: Summary table of previous studies that reported sleep characteristics of air ambulance and HEMS personnel

Authors	Shift characteristics	Methods	Key finding on Main on-duty sleep	Key findings on Off-duty sleep
Flaa et al., (2022	7 consecutive 24-hour shifts Start time 06:00am	Sleep diary and actigraphy	3.4 hours of on-duty sleep	off-duty days (6.5 hours) when crew were not on call
Gregory et al., 2010	3 consecutive shifts, 3 off-days, 7 consecutive shifts 3/3/7	Web-based survey	4 hours or more sleep during a typical night shift. 54 % pilots reported 3 to 5 hours of sleep during a typical night shift 51% reported being able to get more than 6hours of sleep during night shifts when they did not fly. 47% reported this amount as less than 3 hours of daytime sleep	
Flaa et al. 2020	7 consecutives 24 h duty shifts (winter and summer seasons)	Actigraphy and Sleep diary	Total sleep time: 5:57- 6:01 hours Bedtime on duty, 24:54 and 24:33 Wake-time: 08:26 and 08:37 WASO: 44 minutes SE: 84.4-85.4 %	Sleep was somewhat affected during the workweek, with delayed sleep period, longer wake after sleep onset, and lower sleep efficiency compared to when off work
Patterson et al. (2019)	12 hour and 24-hour shifts	Actigraphy	During less than 24h shift, sleep duration was 2.6h during night shift. During 24hour shift, sleep duration was 7.3h	Sleep before less than 24h shift = 7.4h before 24hour shift= 7.3h After less than 24h shift= 6.7h After 24h shift= 6.8h
Sallinen et al. (2019)	24 hour and 48hour shifts (including nights)	Questionnaire	6-7 hours of sleep during 24-48hour duty	7-8 hours pre-duty sleep.
Bezuidenhoudt (2014)	12-hour shifts	Questionnaire	42 % of respondents indicated an average sleep debt of 1.25hours per night 4.3 hours of sleep during night shifts only 12.5% of respondents indicated that they could sleep normally during the day,	
Thomas et al. (2006)	3 consecutive 12-hour night shifts	Actigraphy	12hour shift, nurses obtained 4.4 hours when on duty sleep.	12hour period before a shift, nurses obtained 3.2hours of sleep
Raadstaak et al. (2014)	consecutive three day shifts that started at 06:30 a.m. 12 and 13 hours	Questionnaire and actigraphy	Over 3 consecutive shifts: Total sleep time= 5.89 hours SOL= 8.23 minutes Number of awakenings = 8.28	
Samel et al. (2019)	7-day duty and 2day post duty	Actigraphy and subjective Ratings	Sleep duration decreased from 7.8 to 6 hours or less, resulting in a cumulative sleep loss of about 15 hours Bedtime= of 11:30 pm and midnight Wake-up time =5:45 a.m. to 06:00 a.m. Total sleep time= 5.6hours	At home (off-duty) sleep Total sleep time=7.8 hours Wake-up time = 07:38 a.m.

2.5.1. Night shifts

Night shifts work requires personnel to operate during regular sleep hours and is common in aviation settings that require time-sensitive responses, such as aerial firefighting, military, maritime and air ambulance. Night shift work is identified as a significant scheduling risk factor that increases the prevalence of fatigue (Olaganathan et al., 2021; Härmä et al., 2019). A challenge associated with extended duty hours, coupled with night shifts is that crew may be awake for extended periods prior to the next shift, which can increase sleepiness, reduce alertness and increase the risk of fatigue when on duty due to circadian and homeostatic pressure to sleep (Niu et al., 2011; James et al., 2017; Chang & Peng, 2021).

Night shifts also disrupt crews' sleep due to having to operate against the inclination to sleep. Shifts that occur during the night present performance decrements due to operating during the Window of Circadian Low, where alertness is low (Åkerstedt, 2003; James et al., 2017). As a result of having to work at night, the crew are therefore required to sleep during the day, which also presents challenges with the ability to fall asleep and obtaining sufficient and restful sleep/recovery after a shift (Ruggiero & Redeker, 2014; Alshahrani et al., 2017). The challenges around getting adequate sleep during the day mainly arise due to the circadian-driven signals for wakefulness during the day, combined with the exposure to both light and noise (Chang & Peng, 2021). This often leads to night shift workers getting between 2 and 4 hours less sleep during the day, compared to when sleeping at night, which could impact alertness during subsequent shifts (Radstaak et al., 2014).

Several studies have revealed the effects of night work on sleep of air ambulance crew. Patterson et al. (2019) reported that air-medical clinicians who worked between 12-hour shifts and less than 24-hour shifts obtained an average of 2.6 hours of sleep during the scheduled night shift. As a result, the same study revealed that the cognitive performance of air-medical clinicians who worked night shifts was degraded at the end of the shift compared to that of day shift workers (Patterson et al., 2019). Gregory et al. (2010) reported that 47% of air medical pilots reported obtaining less than 3hours of daytime sleep after a night shift, with 25% reporting being able to sleep during the day, despite working a night shift the previous night. The same study also reported that 54% pilots reported being able to get 3 to 5 hours of sleep during a typical night shift. On the contrary, Sallinen et al. (2019) reported that HEMS pilots obtained approximately 6 hours of sleep per 24-hour duty period for overnight duties, due to pilots being able to sleep during these shifts, with 7-8 hours of pre-duty sleep.

Insufficient sleep due to not being able to obtain sufficient quality sleep before, during and/or after night shifts may exacerbate sleepiness when crew are on duty, increasing the risk of fatigue and impacting performance. Radstaak et al. (2014) suggest that night shifts may result from incomplete recovery between shifts and reduced sleep quality and performance decrement. This is reported in several studies. In one study, HEMS pilots reported excessive daytime sleepiness, degradation of alertness as well as the inability to concentrate and another reported an increased level of fatigue in pilots working night shifts (Kamine et al., 2022; Nix et al., 2013).

In the South African context, only one known study on HEMS by Bezuidenhoudt (2014) looked at fatigue in helicopter night operations, including HEMS pilots, maritime pilots and airborne vehicle tracking. The study revealed that 42% of respondents indicated an average sleep debt of 1.25hours per night for the crew that required seven or more hours of sleep per night. On average, 78.2% of respondents obtained 4.3 hours of sleep at night during night shifts (Bezuidenhoudt, 20214). Furthermore, 33.33% of respondents indicated that they perceived fatigue as having an impact on flight safety during night flying activities (Bezuidenhoudt, 20214).

2.5.2. Early shift starts times

HEMS pilots are also required to work day shifts, which normally include an start early, which may be between 4:00 am and 7:00 am (Wickwire et al., 2017). Early shift start times have been documented in previous aviation research to have an impact on sleep and increase sleepiness and fatigue risks (Radstaak et al., 2014; Åkerstedt et al., 2010).

Early shift start times may result in poor and insufficient sleep due to compromised sleep opportunity prior to a flight (Åkerstedt et al., 2021; Roach et al., 2012; Arsintescu et al., 2022). The main reasons for this stem from the need to advance the body's timing system when attempting to wake early (Radstaak et al., 2014). The same study reported that crew that worked consecutive three day shifts that started at 06:30 a.m.

reported obtaining an average of 5.89 hours of sleep, 8.23 minutes of sleep onset latency, and 8.28 number of awakenings when working shift durations ranging between 12 and 13 hours, with an average of 2.83 missions (Radstaak et al., 2014). Another study of HEMS pilots suggested that early wake-up times were the leading cause of reduced sleep duration, with an average bedtime of 11:30 pm and midnight and wake-up times of 5:45 a.m. to 06:00 a.m., which were early compared to when they slept at home during rest days, 07:38 am (Samel et al., 2004). The late bedtime from the just-mentioned study was due to pilots needing time to unwind from duty; however, fatigue when on duty was reported to be low (Samel et al., 2004). If crew members need to commute, they need to wake up early, which may result in short sleep and sleepiness on shift due to being awake for extended hours.

2.5.3. Extended duty hours

HEMS crew work extended hours, which can span over 12 hours, during both day and night shifts. Duty length may also be inclusive of the time spent in the air flying and the time spent during administration and briefing (Wingelaar-Jagt, et al., 2021). Air ambulance crews' long work hours can go up to 14 hours depending on the organisation, which consists of multiple emergencies within a single shift, making the work physically and emotionally demanding (Radstaak et al., 2014; Lawn et al., 2020). These extended shifts may, in turn, result in little prior sleep length before the shift, potentially resulting in sleep loss, sleepiness and increased performance decrements when on duty (Macchi et al., 2002; Åkerstedt, 2003; Caruso, 2014). These work hours and extended hours on duty may not allow for sufficient recuperative rest, which, according to Williamson et al. (2011), is essential for combating fatigue and sleepiness, which pose a risk to operational safety.

According to Rosa & Bonnet (1993), as cited by Gläsener et al. (2023), shift periods that are extended longer than 8 hours lead to decreases in alertness and increased performance lapses as a result of an increase in the need to sleep. Patterson et al. (2019) reported that air-medical clinicians who worked between 12-hours shifts and less than 24-hour shifts obtained an average of 7.4 hours of sleep in a 24 hour period before scheduled shifts and 6.7 hours of sleep after scheduled shifts. Thomas et al. (2006) found that HEMS nurses, obtained 3.2 hours of sleep 12 hour before a shift, and 4.4 hours during the subsequent evening shift (Thomas et al., 2006). Although not specifically focused on pilots, the working time arrangements are similar. However, Frakes & Kelly (2004) found that HEMS pilots were offered the opportunity to obtain on-duty rest for day and night shifts ranging from 10 to 14hours; however, the amount of sleep obtained was not reported.

In several studies, EMS and HEMS crews reported excessive daytime sleepiness, sleep debt before a night shift, poor sleep quality and fatigue during day and night shifts (Kamine et al., 2022; Frakes & Kelly, 2004; Patterson et al., 2012). However, crew in a few other HEMS studies reported normal levels of self-reported sleepiness, alertness levels, and cognitive performance when on duty, despite the nature of HEMS work due to appropriate fatigue mitigation strategies adopted to address fatigue risks which will be expanded on later in the review. (Thomas et al., 2006; Amann et al., 2014; Zakarianssen et al., 2019).

2.5.4. On-call Work

Given the nature of HEMS work, pilots and medical crew often have to be on call. On-call work can be defined as work that is done on an “as-needed basis” and requires employees to be available whenever they are called (Ziebertz et al., 2015; Ziebertz et al., 2017). This type of working arrangement is common in healthcare and emergency services, similar to HEMS, whereby tasks are time-sensitive and, if not performed correctly and accurately, can have significant consequences (Sprajcer et al., 2018). The consequences of on-call work may lead to insufficient recovery and impact the quality of sleep obtained, even when there is no call (Hall et al., 2017). This may be due to heightened anxiety about a call, which is associated with poor sleep due to worrying about potentially missing a call and the anticipation of stressful situations (Vincent et al., 2021).

The unpredictable nature of HEMS operations could negatively affect crews' ability to rest, even when there is an opportunity to relax due to the above-mentioned factors (Bauer & Herbig, 2019; Strauss et al., 2021). Flaa et al. (2020)’s study on pilots working 7 consecutive on-call day shifts reported bedtime measured by actigraphy ranging between 00:54 and 01:13 a.m., wake times between 08:26 a.m. and 08:37 a.m., and total sleep times between 5:57 hours and 6:01 hours. The same study also reported long WASO when on-call (44 minutes) compared to week-offs (ranging between an average of 36 minutes - 41 minutes) even if calls did not occur (Flaa et al., 2020). The findings from the mentioned study suggest that, despite not occurring, the nature of on-call work can impact sleep. A similar study reported significant differences in sleep during on-duty (3.4 hours) and off-duty days (6.5 hours) when the crew were not on call (Fletcher et al., 2022). The same study also reported an average WASO of less than 10 minutes over a 7-day workweek, higher than 90% sleep efficiency as most work occurred during the day, and crew mainly slept at night (Fletcher et al., 2022). Furthermore, Reid et al. (2020) reported 47.9% of HEMS physicians operating day and night shifts indicating that they have sometimes been influenced by fatigue when on-call.

2.5.5. Consecutive duties

HEMS personnel may work long hours, for consecutive day and night shifts. This type of work characteristic, as reported in other studies outside of HEMS, may be associated with changes in sleep patterns which may led to sleep cumulative sleep loss, particularly if disruptive shifts are worked (Gander et al., 1998; Flynn-Evans et al., 2018; Åkerstedt et al., 2021). On the contrary, more consecutive night shifts may cause circadian rhythm adaptation, leading to better ability to sleep during the day (Bjorvatn et al., 2006).

With respect to consecutive day shifts, Flaa et al. (2022) found that pilots working 7-day 24-hour consecutive shifts with the first day starting at 06:00 a.m. and the last day ending at 09:00 p.m., reported average sleep durations that ranged between 6 and 7 hours. One study on police officers with night shifts, similar to those of HEMS, working two, four and seven consecutive night shifts followed by the same number of recovery days revealed no changes in sleep duration and quality with the number of consecutive night shifts (Garde et al., 2020). A HEMS crew study on three consecutive day shifts reported obtaining 4 hours of sleep, with 54% pilots reporting being able to get 3 to 5 hours of sleep during a typical night shift and 51% reporting being able to get more than 6hours of sleep during night shifts when they did not fly due to the ability to sleep during night shifts (Gregory et al., 2010).

Consecutive shifts, either day or night, may impact alertness if there is restricted recovery time between shifts. A study on HEMS pilots working both consecutive day and night shifts stated they should have turned down a flight due to fatigue during consecutive night and day shifts; however, the sleep obtained during this period was not reported (Kamine et al., 2022). In terms of consecutive night shifts, Bezuidenhoudt (2014) found a constant increase in sleepiness over consecutive nights in HEMS pilots. Interestingly, Zakariassen et al. (2019) revealed that 86% of the crew who worked seven consecutive 24-hour HEMS duties reported no fatigue, with 14% reporting having experienced fatigue. This was due to pilots reporting that they obtained sufficient sleep during both on- and off-duty weeks (rest days), with napping being highlighted as an important strategy to prevent sleepiness while on shift. However, when the crew experienced fatigue, 57% of pilots attributed it to sleep loss.

2.5.6. Work Load

The interaction of shift work characteristics reviewed above may lead to poor quality and insufficient sleep. Over and above the working time demands, the workload can contribute to fatigue. Workload refers to the amount of work prescribed to an individual, whether mental or physical (Sadeghniiat-Haghighi & Yazdi, 2015). Aspects of workload that can contribute to fatigue may include but are not limited to: the nature of the amount of work done, the time constraints and factors related to the individual's performance capacity (Wingelaar-Jagt et al., 2021). The workload is considered high when there is a mismatch between the demands of the jobs, i.e., the nature of the amount of work and time constraints and the capabilities of the person doing the job (Fan & Smith, 2021).

A high workload may contribute to the development of fatigue, known as active fatigue, which may reduce performance (Fan & Smith, 2021). High workload may lead to greater subjective fatigue after work (Fan & Smith, 2021). Low workload also leads to reductions in performance and the occurrence of fatigue (Wingelaar-Jagt et al., 2021). This type of fatigue is called passive fatigue, which manifests from insufficient stimulation, cognitive underload and reduced task engagement, which can reveal underlying sleepiness (Saxby et al., 2013; Hu & Lodewijks, 2020). The workload also consists of flight crew trying to meet patients' in-flight medical and nursing needs whilst being exposed to physical stressors such as noise and vibration associated with being aboard an aircraft (Bauer & Herbig, 2019). In HEMS, being called only when an emergency occurs makes the workload variable and unpredictable, and during the missions, pilots continuously interpret information and make decisions, which all require high cognitive effort (Watson et al.,1996; Radstaak et al., 2014).

In short-haul aviation, the work patterns involve multiple take-offs and landings, sometimes in obstructed fields, coupled with multiple segments as a result of numerous emergencies, further contributing to fatigue levels of the crew (Powell & Spencer, 2007). Take-offs and landings are among the most cognitively demanding parts of flying (Çak et al., 2009; Aionesei & Paraschiv, 2024). This may also be the case for HEMS, given the potential of multiple missions in a shift period. However, the calls are unpredictable. The negative effects of shift work can be further affected by the interaction of other factors such as long shifts or extended duty hours, a workload that is either too low or too high, cognitive demands, as well as high emotional demands, which are often expected amongst emergency services (Radstaak et al., 2014).

2.6. Management of sleep disruption and fatigue in aviation

2.6.1. Fatigue Management

Based upon the above sections, it is important for factors contributing to sleep disruptions and fatigue to be managed appropriately in the workplace to reduce fatigue-related risks associated with sleep. Fatigue management is facilitated through a range of operational strategies and countermeasures (Sadeghniiat-Haghighi & Zohreh, 2015; Hulínská & Kraus, 2021; Caldwell et al., 2019; Sprajcer et al., 2022). This can happen at different levels such as the organisational and individual levels. Fatigue management encompasses of methods that operational personnel and aviation service providers use to address the safety implications of fatigue (ICAO, 2016). This section of the review will cover different methods and strategies of fatigue management, from a macro-level to a micro/individual level. It will further briefly cover Fatigue Risk Management Systems as a prospective data-driven approach to managing fatigue.

2.6.2. Regulatory approaches

Flight and duty limitations comprise a set of rules and regulations that service providers should comply with, including flight and duty limits (FDL). These are sets of maximum duty time and flight time as well as minimum break duration within the duty time to prevent excessive build-up of fatigue and allow for enough rest for recovery (Honn et al., 2019). The approach may include minimum rest breaks, minimum day-offs, total weekly/monthly work hours, and consecutive workdays/night shifts (Honn et al., 2019; Efthymiou et al., 2021).

The flight and duty period depend on factors such as the start of the duty and the number of segments (Efthymiou et al., 2021). In South Africa, the South African Civil Aviation Authority (SACAA) outline that an operator may not exceed a maximum flight time of 40 hours during the preceding seven days, 120 hours during the preceding thirty days, 300 hours during the preceding 90 days and 1000 hours during the preceding 365 days (SACAA, 2016, p.6). In terms of rest periods, the regulations state that "each flight duty period, as well as flight watch and home reverse, shall be preceded by a rest period of at least nine consecutive hours including a local night, and following fifty hours of duty, a flight crew member shall have a rest period of not less than twenty-four hours including a local night before he or she commences any further duties" (SACAA, 2016, p.12). These limitations aim to manage fatigue-related risks to ensure aircraft operation safety and differ across regions and countries in civil aviation, however, it does not necessarily take into account general aviation settings like HEMS with unique dynamic structures.

2.6.3. Fatigue risk management systems

Another way of managing fatigue is through data collection to inform fatigue mitigation strategies, such as the use of various sleep and alertness measures, which is being explored in South Africa. In Figure 2, these methods may include obtaining sleep-wake data, using a symptoms checklist, self-report behaviour scales, physiological monitoring and assessing fatigue-related risks and errors. Dawson and McCulloch (2005) highlight that an important component of this process is tracking the sleep-wake behaviour of crew while on duty to assess the impact of the environmental and organisational demands on the quality of sleep, which, if poor, may lead to increased risk of fatigue-related incidents. Although the review is not focused on reviewing FRMS in detail, but more about pointing out that in unpredictable work contexts like HEMS, fatigue likely needs to be managed through a risk-based approach. The methods used in this study can be adopted during FRMS, are discussed in the next section of the review.

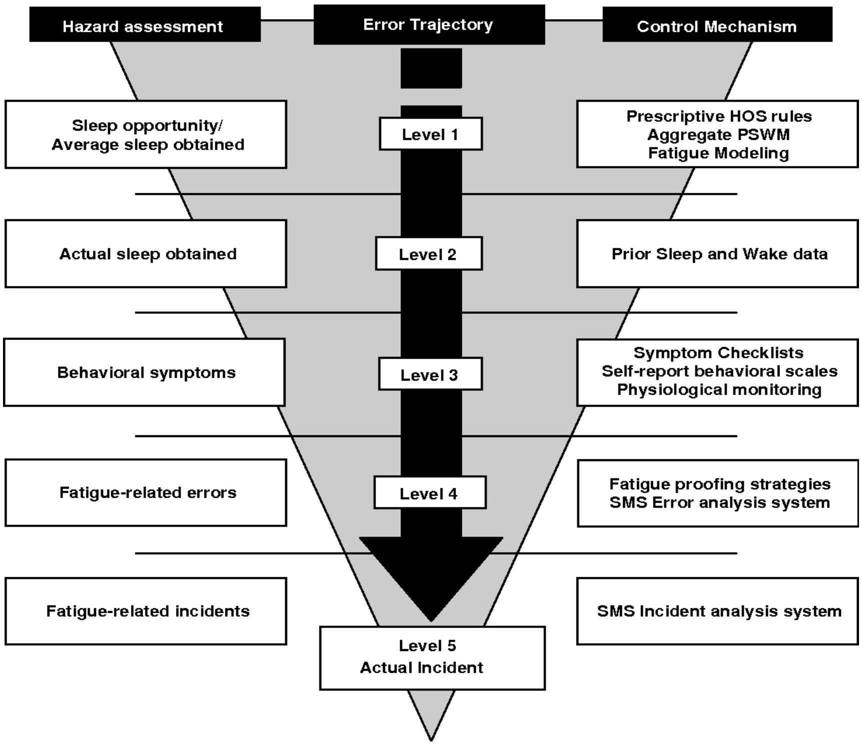

Figure 2: Fatigue-risk trajectory by Dawson and McCulloch when adopting FRMS (2005).

2.6.4. Sleep-wake behaviour measures

As argued by Dawson and McCulloch (2005), data collection on actual obtained sleep and behavioural symptoms is important to understand the impact of work demands on sleep quality. There are various ways and methods of measuring sleep-wake behaviour. These can either be subjective, whereby the individual tracks and describes their sleep-wake behaviour or objective, which is done on their behalf using a tool and/or measures.

2.6.4.1. Polysomnography

Polysomnography (PSG) is considered the “gold standard” for measuring sleep patterns due to its ability to directly measure brain electrophysiology and provide essential elements of the diagnosis of sleep disorders (Marino et al., 2013). It is a technique that objectively monitors and collects multiple physiological patterns during sleep, wakefulness and sleep architecture (McCall & McCall, 2012; Rundo & Downey, 2019; Lehrer et al., 2022). It utilises electrodes to capture physiological changes such as brain activity, respiration, body temperature, blood pressure and limb movement (Kainec et al., 2024). PSG has several limitations due to its practical and logistical factors. It is often administered in a laboratory or clinic setting, is invasive and costly due to its need for equipment, signal processing and the need for expert personnel, making it challenging for long-term use and field studies (McCall & McCall, 2012; Lehrer et al., 2022).

2.6.4.2. Actigraphy

Actigraphy is a method that uses an actigraph wristwatch device to monitor body movement whilst sleeping and can be used continuously (Sadeh, 2015). This is done through an accelerometer, which records movement activity, light exposure and temperature, providing objective sleep and wake timing measures with the combination of sleep logs (Danilenko et al., 2022). Low body movements, low light exposure, alongside other markers such as body temperature changes, are classified as sleeping, and body movements are classified as not sleeping. It has been used in numerous research studies on the safety of civil aviation that focus on pilot fatigue and its effects on performance (Vejvoda et al., 2014; Branislav et al., 2019; Devine et al., 2021; Fletcher et al., 2022).

Actigraphy gives insight into various sleep parameters, namely, bedtime (BT), get-up time (GT), total sleep time (TST), sleep onset latency (SOL), sleep efficiency (SE), wake after sleep onset (WASO), and the number of awakenings (Sadeh, 2015; Fekedulegn et al., 2020). The advantage of using actigraphy is that it is low cost and allows for data to be collected over a long duration, which is useful in FRMS (Krystal & Edinger, 2008). The method is also non-intrusive to the user and does not require complicated installation (Krystal & Edinger, 2008). Studies on air ambulance and HEMS have used actigraphy to obtain data on crews' sleep-wake behaviour (Flaa et al., 2021; Flaa et al., 2022; Fletcher et al., 2022).

2.6.4.3. Sleep diaries

Sleep diaries are a commonly used and valuable method in research and clinical studies. It is a tool used to gather subjective sleep data and can be used to monitor potential sleep disorders (Schmitz et al., 2022). Similar to actigraphy, sleep diaries provide information on sleep parameters and additional measures such as sleep satisfaction (Carney et al., 2012).

The Core Consensus Sleep Diary-M (CSD) developed by Carney et al. (2012), requires the individual to complete the diary an hour after waking up (Maich et al., 2018). The domains of the CSD include sleep quality, duration, disturbances, timing and sleep habits. A limitation of sleep diaries is that sleep duration may be overestimated (Mallinson et al., 2019). However, when used in combination with actigraphy it allows for more accurate scoring of sleep data (Sadeh, 2015). Furthermore, the relevance of using a sleep diary is that it also provides subjective ratings and an overview of individuals sleep, which from the sections above are important and considerable factors for sleep health.

2.6.5. Subjective sleepiness and fatigue measures

There are numerous sleepiness and fatigue scales that have been utilised within the aviation context, including but not limited to the Epworth Sleepiness Scale Questionnaire, the Karolinska Sleepiness Scale, the Standford Sleepiness Scale, the Brief Fatigue Inventory Scale, Chalder Fatigue Scale and Samn-Perelli Fatigue Scale, to name a few (Åkerstedt & Gillberg, 1990; Hoddes et al., 1972; Mendoza et al., 1999; Chalder et al., 1993; Samn & Perelli, 1982). For the purpose of the study, this section will highlight the Karolinska Sleepiness Scale and Samn-Perelli Fatigue Scale.

2.6.5.1. The Karolinska Sleepiness Scale

The Karolinska Sleepiness Scale (KSS) is a self-administered, widely used measure of sleepiness in aviation and shift work studies (Åkerstedt & Gillberg, 1990; Miley et al., 2016). KSS measures subjective sleepiness levels within the last five minutes and can be administered repeatedly as a simple measure of individuals' sleepiness levels, which reflect their psycho-physical state (Shahid et al., 2011; Coombes et al., 2020). It is useful in assessing response changes with environmental factors and circadian rhythm in laboratory and field research (Shahid et al., 2011). It has been shown to positively correlate with polysomnographic measures and alpha and beta EEG activity (Åkerstedt & Gillberg, 1990; Horne & Baulk, 2004; Takahashi et al., 2006). Further, a study by Reyner & Horne (1998) demonstrated a correlation between decreasing or worsening performance with increased levels of KSS ratings and sensitivity to changes in sleepiness. It used a nine-point Likert scale with a cut-off limit of seven, indicating high levels of sleepiness associated with physiological indicators such as longer eyelid closure and slower eye movement (Coombes et al., 2020). The KSS has been utilised in various HEMS studies to assess subjective sleepiness when on duty (Zakariassen et al., 2019; Flaa et al., 2019; Flaa et al., 2022).

2.6.5.2. Samn-Perelli Fatigue scale

The Samn-Perelli Fatigue Scale (SPFS), also known as the Samn-Perelli Crew Status Check, was developed to assess and quantify fatigue levels within aviation operations based on flight crews' work and rest schedules (Samn & Perelli, 1982). The scale was originally utilised to assess fatigue and alertness of pilots before take-off. It is a seven-point scale with ratings from 1 (fully alert) to 7 (completely exhausted, unable to function effectively). The Samn-Perelli Fatigue Scale has been used to assess fatigue of HEMS crew. An example of a study that used SPFS is by Rose et al. (2023) and reported a slight increase in fatigue over a 5-week shift cycle, with the highest SPFS ratings of 3.5 during night shifts, which is suggested to be a result of changes in homeostatic control systems and a reflection of the cumulative workload of working 5 weeks. However, this rating represents low to moderate fatigue risks according to the SPFS scale.

2.6.6. Workload measures

Workload is an important factor, yet it is difficult to quantify objectively, often requiring the use of subjective assessment tools such as the NASA-TLX, Cooper-Harper Rating Scale and the Subjective Workload Assessment Technique (Hart, 1988; Harper & Cooper, 1986; Reid & Nygren, 1988). This review will focus on the NASA-TLX.

2.6.6.1. NASA-TLX

The National Aeronautics and Space Administration Task Load Index (NASA-TLX) is a validated self-assessment measure of workload in Human Factors and Ergonomics (Hart, 1988; Helton et al., 2022). It is a questionnaire that assesses workload on several dimensions and is administered after the execution of a task (Masi et al., 2023). The questionnaire is on the perceived workload in the domains of mental, physical, and temporal demand, performance, effort, and frustration (Hart, 1988). The NASA-TLX items are presented on a 21-point scale (0-20), which is then multiplied by 5 to create scores ranging from 0-100 (Helton et al., 2022). It consists of two sections, the first being where individuals rate their workload on a numeric scale, and the second being a comparison between the dimensions whereby a selection of the type of demand they perceive contributed most to workload is made (Alaimo et al., 2020). Bezzerra & Ribeiro (2012) assessed helicopter emergency pilot's workload using the NASA-TLX, revealing that time pressure contributed to increased mental demand in an emergency in flight due to the need to make rapid decisions and actions. The same study also reported that pilots found emergency procedures for approach and landing under various flight system failure tasks contributed to mental and physical demand. Bezuidenhoudt (2014) used the NASA-TLX for HEMS pilots and revealed that performance and effort were the highest contributors to workload during day shifts, whereas mental demand and performance were the highest contributors to workload during night shifts. The combined use of objective and subjective methods, such as sleep diaries, actigraphy, alertness scales and workload measures is important to offer a comprehensive integrated approach in the understanding of the effects of shift work.

2.6.7. Fatigue management strategies and countermeasures

According to Sadeghniiat-Haghighi & Yazdi (2015), there are numerous fatigue countermeasures and strategies, with no single comprehensive countermeasure to eliminate fatigue (Caldwell et al., 2012). Difference countermeasures that crew can use on a micro-level to improve their sleep hygiene include but are not limited to sleep timing and regulation and napping, caffeine and exercise (De Pasquale et al., 2024). It is acknowledged that there are a number of fatigue countermeasures, however the following section will review the commonly used countermeasures which have been reported in several HEMS studies (Gregory et al., 2010; Zakariassen et al., 2019; Akter et al., 2021; Fletcher et al., 2022).

2.6.7.1. Education on sleep hygiene and minimising sleep loss

As a result of coping with irregular flight schedules and circadian disruption, flight crew typically have challenges with maintaining proper sleep hygiene (Wingelaar-Jagt et al., 2021; van Drongelen et al., 2014). Sleep hygiene refers to the modifiable behaviours and environmental adjustments that can be used to improve sleep quality and quantity (De Pasquale et al., 2024; McAlpine et al., 2024). Poor sleep hygiene, which may be driven by shift work, may lead to restricted sleep, which can compromise vigilance and performance in subsequent duty periods, and individuals usually do not fully recover after one single night of sleep (Van Dongen et al., 2003; Belenky et al., 2003; Caldwell et al., 2019). Therefore, in addition to obtaining data on crew's sleep, alertness and workload, training crew members and promoting sleep quality and quantity and obtaining optimal rest time before a shift are important in ensuring optimal performance levels when on duty (Sadeghniiat-Haghighi & Yazdi, 2015). Education and training on sleep hygiene can reduce self-reported fatigue and lead to improvements in sleep quality and performance (Wingelaar-Jagt et al., 2021).

2.6.7.2. Napping

Napping is regularly used as a fatigue countermeasure and is often taken prior to overnight, in flight and following night duty (Gregory et al., 2010; Bendak & Rashid, 2020; Wingelaar-Jagt et al., 2021). Naps are considered short periods of sleep that occur outside a longer main nocturnal sleep period (Leong et al., 2022; Lou et al., 2024). Napping helps with cognitive performance by decreasing sleepiness and enhancing alertness, while reducing sleep debt (Brooks & Lack, 2006; Hartzler, 2014; Roach et al., 2011; Bendak & Rashid, 2020). Napping as a fatigue countermeasure has been found to be effective for shift workers (Sadeghniiat-Haghighi & Yazdi, 2015). When naps are taken during long periods of continuous wakefulness, they are effective in improving alertness levels and decreasing fatigue upon wakening (Oriyama & Kobayashi, 2014; Loato & Lack, 2010; Sadeghniiat-Haghighi & Zohreh, 2015).

In addition, naps that range between 90 minutes and 120 minutes, making up a single sleep cycle, are also effective in improving alertness (Sadeghniiat-Haghighi & Zohreh, 2015). Daytime naps that are taken before and after a shift, including night shifts, can also decrease fatigue and increase performance due to a decrease in homeostatic sleep pressure following the naps (Wingelaar-Jagt et al., 2021; Garbarino et al., 2004; Brooks & Lack, 2006; Caldwell et al., 2009; Ruggiero & Redeker, 2014; Martin-Gill et al., 2018). Military and commercial aviation commonly use daytime and night-time naps as a fatigue countermeasure, particularly preceding night work (Gregory et al., 2010; Zakariassen et al., 2019; Wingelaar-Jagt et al., 2021). A study on helicopter and fixed wing EMS and search and rescue personnel revealed that crew used napping during the afternoon to complement shorter sleep periods, and during off days (Fletcher et al., 2022). The same study reported on duty sleep duration of 3.4 hours on average, and 5.9 hours with a total 24-hour sleep time (Fletcher et al., 2022). Another study on HEMS pilots found that napping was a prevalent strategy for managing sleepiness and fatigue (Zakariassen et al., 2019). These studies highlight the value of napping, especially when short sleep is obtained.

2.6.7.3. Caffeine

Caffeine is a common non-prescription method to enhance mental or cognitive functions and fight sleepiness as a result of inadequate sleep (Snel & Lorist, 2011; Caldwell et al., 2019). It stimulates the central nervous system by blocking adenosine receptors, and its effects can be noticeable within 15–20min and can last 4-6hours (Caldwell et al., 2009; Daubner et al., 2021; Wingelaar-Jagt et al., 2021). It can improve vigilance on tasks as long as 8 hours after administration (Klopping et al., 2005; Wingelaar-Jagt et al., 2021). Flaa et al. (2022) revealed that 28% of one group HEMS pilots working a 7-day work period, followed by 14 days off work consumed 3-4 cups of caffeine, and 40% consumed 5-6 cups. Another group of the same study had 50% of HEMS pilots working a 7-day work week, followed by a 7-day rest week consumed 3-4 cups of caffeine intake, with 18.2% consuming 5-6 cups, with reported overall low levels of sleepiness during the work week. Another study revealed that military search and rescue helicopter personnel consumed an average of 2.9 cups of caffeine per day when off duty, however the study did not find an association between caffeine use and the prevalence of daytime sleepiness (Akter et al., 2021). These reviewed studies highlight the common use of caffeine in air ambulance pilots.

Summary and Rationale for this study

While there has been some research into understanding sleep, alertness, performance and fatigue of air ambulance personnel highlighting that the nature of HEMS and work characteristics are associated with poor sleep, sleepiness, impaired alertness and fatigue risks factors, very little is known within South African HEMS, with one known study by Bezuidenhoudt (2014). In collaboration with a South African HEMS company, this research aimed at characterising the work system of a South African HEMS company, and characterised sleep-wake behaviour, sleepiness, fatigue and workload of HEMS pilots under different working times (day shifts, night, and rest days). This is important as it has not yet been fully researched and understood within the South African context, with increasing industry interest.

CHAPTER 3: PHASE 1 METHODOLOGY AND RESULTS

Phase 1: Methodology

3.1. Research design and study context

This phase of the study adopted a descriptive qualitative research design that aimed to characterise the work systems and working time arrangements of a Helicopter Emergency Medical Services (HEMS) company in South Africa using semi-structured interviews with industry experts from the company. The experts were from a company that provides helicopter emergency medical services in South Africa.

3.2. Data Collection Methods

Prior to understanding the working time arrangements and their effects, a wider understanding of the HEMS operations and systems was necessary. This was achieved through semi-structured interviews with relevant stakeholders from whom the research could obtain contextual information. Semi-structured interviews allow for flexibility in responses and allow for follow-up questions (McIntosh & Morse, 2015). Combined with a walk-through/observation, they are beneficial in gaining more insight into the helicopter emergency medical services system of the company, focusing more on the working time arrangements and the various HEMS bases of the company. The interview questions were developed to answer the aim of the first phase of the study. Refer to Table 2 for the interview questions and reasons for inclusion.

Table 2: Questions included in the semi-structured interview schedule.

Proposed Questions	Reason for inclusion
1. Could you please tell me about yourself, who you are, your role in the company, and number of years of experience in the company and industry?	These questions were to contextualise the work system and gain insight into the purpose of the company and the role and challenges associated with the work, in particularly on the pilot's side.
2. Can you provide an overview of the purpose of helicopter emergency medical services and the pilots' role in this type of operation?	
3. Apart from flying, what other tasks do pilots do when on duty?	
4. In your experience, what are some of the challenges that helicopter emergency medical services pilots face?	
5. To maintain around-the-clock emergency medical services, what are the shift arrangements, and can you explain why shifts are designed that way? (Prompt: Is it influenced by factors such as regulations?)	These questions were asked to further have a deeper understanding on how HEMS pilots' shifts are designed and how missions work.
6. What are the differences in shift arrangements across bases, and why is this the case?	
7. When pilots fly to attend to a medical emergency, typically, how many missions occur in a single shift, how long does each mission take, and why?	
8. Based on the shift arrangements, what effects does it have on pilots sleep and fatigue levels? (Prompt: What do pilots say about their sleep?)	
9. Do pilots sleep at home when on duty, or does the company provide sleeping locations? (Prompt: Do pilots sleep at the base or at home during workdays, and what about rest days?)	These questions focused on pilots' sleep quality when on duty
10. When there are no missions, are pilots allowed the opportunity to sleep?	
11. What interventions or strategies does the company use to enhance sleep quality and manage fatigue?	
12. Is there any other important information not mentioned in this interview that you would like to add?	

3.3. Study Participants and Sampling Strategy

The participants were industry experts from the company consisting of pilots and executive members that were recruited through purposive sampling. Recruitment continued until the researcher believed adequate information had been obtained, and how many experts were available to participate. The participants were recruited in person by visiting the headquarters of the company.

3.4. Ethical Clearance

Prior to the commencement of data collection in the company, ethical clearance was granted by the Rhodes University Human Ethics Committee (RU-HEC, Approval number: 2023-7495-8266). Following ethical clearance, the company granted the gatekeeper permission. The gatekeeper permission letter (Appendix B) was accompanied by a copy of the interview schedule for Phase 1 (Appendix G), a list of instruments intended to be utilised in Phase 2, as well as how the instruments were to be used (Appendix H to L).

3.5. Data collection procedure

The interviews were conducted in person at the participants' workplace and were recorded. Before the recording, participants were informed of the purpose of the interviews, and the consent process was followed. Participants were asked to thoroughly read and sign the informed consent form (Appendix E). Upon consent, the recording took place using the semi-structured interview schedule as a guide. Additional notes were taken during the interview using pen and paper. Probes as outlined in the interview schedule, and follow-up questions were asked for clarity and for information that the researcher found important and relevant in gaining insight into the system.

3.6. Data analysis

The recorded interviews were transcribed using a transcription tool, the Turboscribe website (https://turboscribe.ai/), which were checked after the report was generated. Information from the interviews was used to provide a description of the system. As depicted in Table 3, questions related to the company’s purpose and structure, shift arrangements and designs, and emergency calls and missions were descriptively summarised and presented to give context. Questions pertaining to the effects of shift designs on pilot's sleep, fatigue and coping mechanisms were analysed inductively using thematic analysis. Questions related to the challenges that helicopter emergency medical services pilots face were deductively analysed, also using thematic analysis using the Work Systems Model (discussed below). Thematic analysis allows for identifying essential and important themes and patterns from the data (Braun & Clarke, 2006). The method is widely used as it provides flexibility and interpretation when analysing the data (Castleberry & Nolen, 2018). The researcher followed the steps and stages outlined in the thematic analysis by Braun & Clarke (2006).

Table 3: Types of analysis applied to interview questions

Questions related to	**Type of analysis**
Questions related to: the company's purpose, structure and pilot tasks (Q2, 3). Sleeping opportunities and locations (Q 9, 10) Shift arrangements and design across bases (Q5, 6) Emergency calls and mission duration (Q7)	Descriptive
Effects of shift design on pilots' sleep and fatigue levels and coping mechanisms and strategies (Q8, 11)	Inductive thematic analysis
Challenges that helicopter emergency medical services pilots face (Q4)	Deductive thematic analysis

Familiarisation with the data

The first step of thematic analysis that the researcher followed was to familiarise themselves with the data. This was done through immersion with the data set (Braun & Clarke, 2006). The process involved "repeatedly reading" and actively going through the data to search for patterns and meanings (Braun & Clarke, 2006). The interview recordings were listened to and transcribed from audio to text. Once the transcription reports were generated, each individual interview recording was listened to multiple times in conjunction with the transcription report, and edits were made to ensure the transcription was done accurately and retained its original nature (Braun & Clarke, 2006). The descriptively analysed data was analysed by the extraction of key information and collating it.

Generating initial codes

The next step of thematic analysis that the researcher undertook was to generate initial codes in the data after familiarisation (Braun & Clarke, 2006). This process, as outlined by Braun & Clarke (2006), involved identifying what appeared to be interesting to the researcher and allowed for the data to be organised and assessed in a meaningful way. The researcher coded the data according to what they believed was relevant and answered the research question using the semi-structured interview questions to guide the process. From this, the researcher derived themes that were relevant to the research questions.

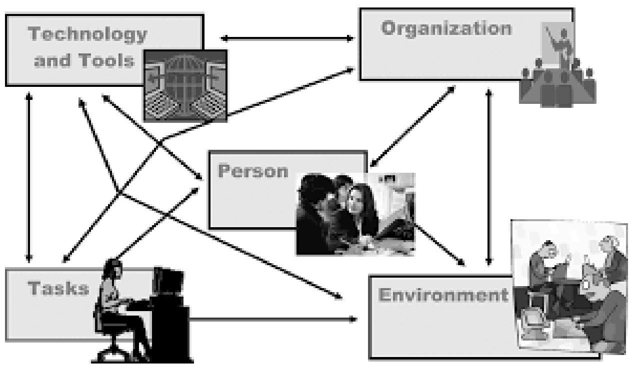

Figure 3: Work Systems model developed by Smith and Carayon-Sainfort (1989).

Searching, reviewing and defining themes

The next step of the analysis was to search, review and define the themes derived from the codes identified in the previous step (Braun & Clarke, 2006). This was done by identifying the relationship of different codes and how they could be combined to form overarching themes in the data set (Braun & Clarke, 2006). The themes were then revised and refined to form a coherent pattern (Braun & Clarke, 2006). The researcher derived themes that were relevant to the research questions. This process took place deductively for system challenges, which means that theme development was theory-driven (Braun & Clarke, 2006). The theoretical model the research used for the deductive part of the analysis was the work systems model (refer to Figure 3), which was appropriate for providing a holistic understanding of the tasks within a physical environment using various tools and technologies governed by organisational conditions, as well as the interactions of these components (Smith & Carayon-Sainfort ,1989). The data on effects of shift design on pilots' sleep, fatigue levels and coping mechanisms and strategies were analysed inductively, which means the themes emerged from the data in alignment with the research aims.

Producing the report and data representation

The last step of thematic analysis that the researcher undertook upon formulating and reviewing themes was to produce the report and represent it in a concise, coherent and logical way in relation to the research question (Bruan & Clarke, 2006). This was done by providing an overview and purpose of the company more broadly and then focusing more on the HEMS sections, the missions, challenges associated with the operation, the effects of shift arrangements on sleep and fatigue, and potential strategies adopted to manage fatigue.

Phase 1: Results

3.7. Experts characteristics

Industry experts were selected from a South African aviation company based on their aviation experience and position in the company. Four experts agreed to be interviewed: three pilots and one executive member without flying experience. The interviews were conducted face-to-face; three were recorded, and one expert requested that the interview not be recorded for personal reasons; therefore, pen and paper notes were taken. Each interview took ±25-40 minutes.

Participant One (P1) was the HEMS operations executive member. The second expert (P2) worked as a night HEMS captain. Participant 3 (P3) was a senior night pilot. The fourth expert participant (P4) was one of the HEMS operations executive members. The pilot experts (P2, P3 and P4) had an average flying years' experience of 29.4 years (±11.73).

3.8. Systems description

The purpose of the interviews, as outlined in the methodology chapter, was to provide contextual background into the study in order to gain insight into Helicopter Emergency Medical Services (HEMS) in South Africa, in particular, the working time arrangements, and to provide contextual background into the company with which the research was being done and how they operated. The first section of the results provides a systems description of the company, and the work characteristics and role of the pilot within this HEMS company as obtained from the interviews. The next section of phase 1 of the results provides overall categories, themes and subthemes that emerged from the data to present important factors of the system.

3.8.1. Services provided by the company

The umbrella company comprises of numerous companies grouped into the flight school and the charter side. The flight school is comprised of experienced instructors (P4, 2024; personal communication). The charter side is *“heavily reliant”* on the mining industry and provides services such as transporting gold, platinum, diamonds, passengers, vehicle tracking and security flights (P4, 2024; personal communication).

In addition to this, the company provides Helicopter Emergency Medical Services (HEMS) to mines, medical aid schemes and the Department of Health (P4, 2024; personal communication). All of these require a highly trained and experienced crew (P4, 2024; personal communication).

3.8.2. The HEMS bases and locations

The company has three HEMS bases across the country in the provinces of Gauteng, Limpopo, and the Northern Cape of South Africa, as depicted in Figure 4. Each base has a base manager responsible for making decisions for their respective bases, taking charge of all flight aviation responsibilities, managing the pilots, working with the clinical team and reporting to the Chief pilot (P1, 2024; personal communication). There are no flight schools or additional charter operations at the out bases in Limpopo and Northern Cape provinces; therefore, the primary operations in these bases were HEMS services (P1, 2024; personal communication). As a result of this, the shift rosters are more stable at the out bases (in Northern Cape and Limpopo), with the crew working predominantly one type of shift in a week. This is different for the Gauteng base, where the crew can work different kinds of jobs: HEMS, car tracking, and charter, which means they are rostered differently depending on the work they are doing over day shifts and night shifts to support the multiple services provided. This will be expanded upon below.

Figure 4: South African map showing the provinces where the company HEMS bases are situated and their cities. Adopted from Loots et al. (2018).

3.9. The purpose of the company

The Helicopter Emergency Service is a 24-hour service that focuses on providing a solution for time-critical emergency conditions through medical aid schemes. These emergency conditions are of such a nature that advanced alternative resources, such as helicopters, are utilised to transport or transfer patients to an appropriate specialised facility that provides emergency and trauma care that is not nearby. These emergencies typically occur in remote locations with limited infrastructure and healthcare, "*so it is typical where there is impairment of skills and infrastructure in the outlying areas*" (P1, 2024; personal communication). *"This is different from the international context; in the South African context, it really works well where you are 150 kilometres outside. That is where we get most of our patients"* (P1, 2024; personal communication).

To fulfil this role, the processes involved in call activation are facilitated by the flight desk coordinators, who directly receive the calls, dispatch the crew, and further track and monitor the flights when on a mission (P1, 2024; personal communication). The crew consists of the pilots who operates the aircraft by transporting the paramedics to the medical scene or hospital, and the paramedics who administer medical care. Upon completion of each mission, the paramedics fill out a patient report form (PRF), and pilots complete flight hours and do post-flight checks. Together, HEMS provides support to the larger EMS sector in South Africa and achieves better patient outcomes (P1, 2024; personal communication). (Refer to Figure 5).

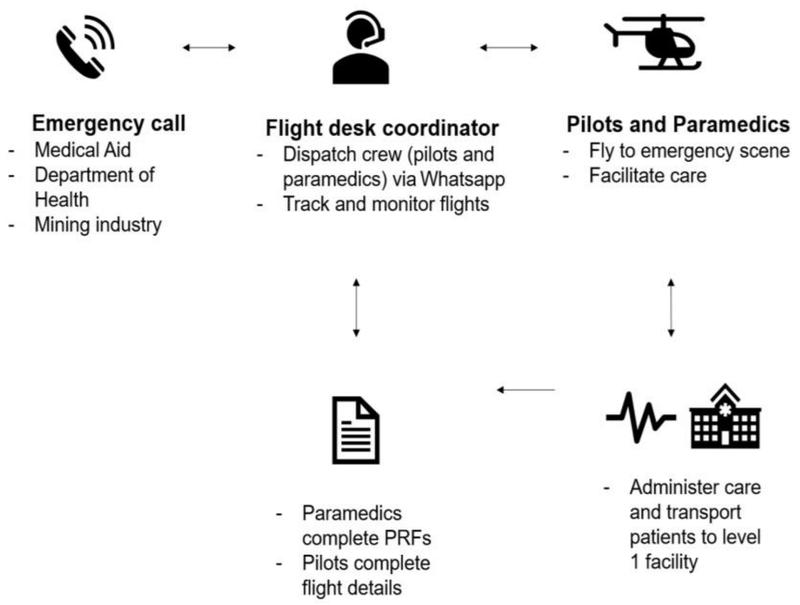

Figure 5: Processes and procedures involved in HEMS delivery.

3.10. Work characteristics and roles of the pilots

The pilots are seen as *“the drivers”* as their primary role is to safely transport persons (patients and paramedics) from emergency sites and hospitals to medical care centres (P2, 2024; personal communication). The primary role of a pilot is to operate the aircraft. The pilots are responsible for the safety of about four to five individuals: the patients, two paramedics, and possibly a co-pilot. The pilots are expected to make flight operational decisions in alignment with the medical crew's clinical decisions and ultimately deliver patients and paramedics back to safety, which is the core of the execution of the pilots’ tasks (P1, 2024; personal communication).

Additionally, pilots undertake administrative work linked to the execution of the flight, pre-flight and post-flight. Pre-flight planning includes ensuring the helicopter has fuel, weather checks, fulfilling their duties in the context of safety regulations and being on standby ready for a call. Post-flight work entails ensuring there are no safety problems with the aircraft and that it is ready for the next flight, preparing medical equipment with the paramedics, and recording flying hours (P1 and P4, 2024; personal communication). After each mission, on the paramedic's side, they must complete a comprehensive electronic online patient report, which can take up to 45 minutes to an hour. If there is another call, the crew will complete the document at home, given the time constraints to respond to an emergency (P1 and P4, 2024; personal communication).

When the crew are on standby and not flying, various tasks are offered to them, which are optional. These tasks include internal training, which consists of recurrent training (refresher courses), conversion training (training courses on new equipment and skills), and assisting at the flight school, which is entirely separate from the HEMS operation.

3.11. Sleeping locations and facilities provided to the crew

The company provides sleeping facilities to the crew at various bases. At Base1, pilots working day shifts mainly sleep at home and commute to work. Pilots working night shifts sleep at the base, where sleeping facilities are provided at the hangar (P4, personal communication; 2024). The rooms are insulated from noise and individually air-conditioned (P4, personal communication; 2024). The rooms are designed to make the crew as comfortable as possible to create a comfortable sleeping area. There is a fully equipped communal area with amenities such as a lounge area with a television and a kitchenette with a coffee machine, which has been described as an important part of creating a comfortable space for the crew (P1 and P4, 2024; personal communication).

Base 2 has sleeping locations at the hangar that are well equipped, with washrooms, a kitchen and a lounge to make it comfortable for the crew. At base 3, "*It is more a family environment*; the crew all live together in a farmhouse with a kitchen, dining room and en-suite bathrooms (P4, 2024; personal communication).

3.12. Emergencies calls and mission duration

3.12.1. Types of emergency calls

There are two main types of emergency calls: primary calls and inter-hospital transfers (IHTs), with which the crew deals (P1, 2024; personal communication). Primary calls are of the nature where the crew fly directly to the accident scene to assess, stabilise and transport patients to a medical facility, which can take 20 minutes to an hour, depending on the severity and complication of the patient's condition, the location and the distance and time flown to the emergency scene. The response time for primary calls is a minimum of eight minutes, from mission activation to the time the crew departs from the base. IHTs are when a patient is transported from one hospital to a more advanced healthcare facility, often due to the local hospital being unable to deal with the case due to complications and limited access to relevant equipment. Many of the company's missions are with babies and mothers as primary calls or IHTs (P4, 2024; personal communication).

Outside of the two main types of emergency calls, the company also provides HEMS to mining companies, and it has a 24-hour standby operation and provides HEMS services to the Department of Health in Limpopo (P2 and P4, 2024; personal communication). The company has a contract with the Department of Health (DOH) in the Limpopo province, whereby when there is an emergency and a patient is admitted into a local clinical that may not have the necessary equipment, the hospital can request a helicopter to be dispatched to transport the patient to another hospital through the DOH system (P1, 2024; personal communication).

3.12.2. Duration of emergency calls/missions

The flight and mission times depend on each unique emergency and the provinces in which they occur. The Northern Cape province usually has longer flight times due to the large province size and lack of infrastructure compared to Gauteng, a significantly smaller province, as depicted in Figure 1. Based on the perspective of the different stakeholders following the interviews, the mission durations at the Limpopo base may be a result of an ill-equipped hospital, which may take paramedics longer to stabilise the patients before they are transported to the hospital, which can result in a mission time of up to five to six hours (P4, 2024; personal communication).

However, in a single shift, the crew may be on standby with no missions at all; however, on a busy day, the number of missions may be up to three to four, which is often the maximum number of missions that can be done as a result of the time taken to transport the patient, for the hospital handover, and refuelling for the next potential mission. In a busy month, there could be 90 to 140 missions across the bases, with the base in Limpopo being the busiest in terms of activation due to this part of the business's contract with the DOH (P4, personal communication, 2024).

3.13. The design of the shift arrangements

The company's shifts are designed differently across the different bases using a centralised roster system. The duration of the shifts, shift start, and end times are also arranged differently between shift types as well as bases.

3.13.1. The roster system

As previously mentioned, the company has three HEMS bases, the crew of which are rostered on a monthly basis. Shifts are usually 12 hours, with three to four working days (day, night or standby) and two to three rest/off days. The rostering depends on the flight time and duty period regulations, and the number of available crew members at different bases. The Gauteng base roster is more '*fluid'* due to having to sustain multiple services offered outside of HEMS (P3, 2024; personal communication). The out bases in Limpopo and Northern Cape have a more stable roster due to only offering HEMS services; therefore, crew work predominantly one type of shift in a week (predominantly day shifts or predominantly night shifts with rest days interspersed). For HEMS operations, the roster runs on a 06:00 to 18:00 and 18:00 to 06:00 rotation.

3.13.2. Working time arrangements across bases

Each base is *'decentralised'*, which means they have slightly different shift start and end times, despite the roster shift start and end time, to accommodate the bases' unique characteristics (P1, personal communication, 2024). The base managers work with their crew on the shift start and end times according to what works best for them at their respective bases, within safety parameters and shift scheduling (P1, personal communication; 2024). The Gauteng base schedules their work shifts from 05:30 to 17:30 for day shifts and 17:30 to 05:30 for night shifts to ensure that the crew on day shifts arrive at the base before the morning traffic and before evening traffic for night shifts. Gauteng and Northern Cape additionally provide 24-hour standby HEMS services to mines in the event of a mine-related incident.

At the Limpopo base, shift start and end times are 07:00 to 18:00 for day shifts and 18:00 to 07:00 for night shifts, which is an hour longer than the other bases. The reason for a later start time for day shifts is to accommodate commute time, as the secondary paramedics in Limpopo base are provided by the Department of Health (DOH) and need to travel to the base, as the province is larger.

At the out bases, as they are smaller and only provide HEMS services, if there is a mission activated closer to the end of the current shift and the start of the next shift, the crew can decide to end the shift earlier and start the next. This means that the pilot going into the next shift will take the mission, so the previous pilot will not work for extended periods as the mission duration is unknown. An example of this is provided by one of the experts stating:

> "*If there is a call coming in at 17:00 and the next rotation only starts at 18:00 because they are a tight-knit unit, they would say, listen, I am going to take this; otherwise, you are going to be working till 21:00; because it is a functioning team."*

In the Northern Cape, the shift arrangements are 06:00 to 18:00 for day shifts and 18:00 to 06:00 for night shifts, as the crew lives in the same house at the base. As previously mentioned, the Northern Cape bases also provide a 24-hour standby service to one of the mines (P1 and P4, 2024; personal communication).

3.14. Challenges associated with HEMS operations

The following section will provide results of thematically analysed data of tables for each category which will be provided throughout the section in their respective appropriate parts. Table 4 provides a summary of deductively analysed data on challenges associated with the nature of HEM themes and subthemes, of which the results will be unpacked.

The experts pointed out several challenges associated with the nature of HEMS, particularly in South Africa. These challenges emerged following deductive thematic analysis using the work systems model as outlined in the methodology section (refer to Table 4).

Table 4: Outline of deductively analysed data of challenges associated with HEMS operations

Category	Theme	Sub-theme
Challenges associated with HEMS operations	Person and task-related challenges	Nature of cases
	Environment-related challenges	Weather conditions Power outages and load-shedding
	Technology-related challenges	Night vision goggles
	Organisational challenges	Crew shortage Working times Access to refuelling stations

3.14.1. Person and task-related challenges

Given the nature of the work, the crew are faced with the cost of dealing with ***"real stuff",*** especially in a primary call where the stakes are high (P1, 2024; personal communication). The ***nature of the cases*** that crew typically interact with, more especially in Polokwane, is of a maternal nature where "*there is a mom that's giving birth to a kiddie, and there are complications either with the mom or the kiddie, and the hospital can't deal with it*" (P1, 2024; personal communication). In terms of the pilot's role, they are required to be highly experienced and possess specialised training, of which retraining, as mentioned by the P4 (2024; personal communication), "*is very difficult to do*" given the work characteristics and demands. Furthermore, ***access to refuelling stations*** in certain areas is a challenge mentioned by one of the experts. This is a challenge in situations when crew need to prioritise their primary task to transport patients to and from areas without refuelling routes. In such cases, the mission is turned down. However, there are refuel stations on most of the routes taken (P2, 2024; personal communication).

3.14.2. Environmental related challenges

Weather conditions are an environmental factor that experts highlighted as a challenge to flight safety. If the weather conditions are not favourable for flying, the crew may not be able to pick up the patient from the scene or hospital and would need to make a "*plan B on where to get the patient*" (P2, 2024; personal communication). A factor that also affects flying is ***power outages and load-shedding***, which refers to controlled electrical supply interruption to reduce load the electricity power system and is a unique challenge within the South African context. During these conditions, pilots must fly at low light levels, making it difficult to see, especially when flying and landing in remote environments and difficult terrains.

3.14.3. Technology related challenges

To address the challenge of having to fly at night during power cuts and "load-shedding", pilots use Night Visions Goggles (NVGs), which are technological device that assists pilots' vision during low light conditions when operating the rotor-wing aircraft which is *"an expensive machine"* (P2, and P4, 2024; personal communication).

3.14.4. Organisational challenges

Each base ideally has a minimum of five crew members. However, the company is currently experiencing a ***crew shortage***, which results in supplementing (getting crew) from other bases weekly (P3, 2024; personal communication). The shortage affects the amount of crew available to roster into multiple services, *"but we hope to stabilise it quickly and help out from Gauteng if someone is on leave, ill or there was a drastic change; but we push quite hard to have the bases fully autonomous"* (P4 and P3, 2024; personal communication). The Senior night pilot made the following statement about the effects of the shortage and its effects on the crew.

"If you've got a large roster where you've got 40 pilots, you have to roster them into a system and several different systems. You've got vehicle tracking, charter, and all that; you roster just the guys available for five days and put them on call for six days, but that does not make provision for the potential fatigue. It fits into your flight and duty, but it does not make provision for fatigue".

An organisational and operational challenge that HEMS faced was the design of the working time. The crew work long hours, spanning up to 12-hour shifts for consecutive days. This has been highlighted to present a number of challenges with regard to sleep and rest, which will be expanded upon below under the shift system design.

3.15. The effects of shift arrangements and repositioning on pilots' sleep and fatigue

The following two sections, as outlined in Table 5, provide inductively analysed data on the effects of shift arrangements on pilot's sleep, and strategies and interventions that the company has adopted to manage fatigue (under the heading: strategies and interventions adopted to manage fatigue). It also provided emergent themes from each category which will be expanded upon further.

Table 5: Categories and themes that emerged from data related to effects of shifts arrangements on sleep and adopted fatigue management strategies

Category	**Theme**	**Sub-theme**
The effects of shift arrangements on pilots' sleep and fatigue	Effects of consecutive day shifts on sleep	
	Effects of consecutive night shifts on sleep	Polyphasic sleep No work-life balance
	Effects repositioning of crew on rest/off days	
Strategies and interventions adopted to manage fatigue	Fatigue response and management policies	
	Reporting systems	
	Roster design	
	Strategies while on shift	

3.15.1. Effects of consecutive day shifts on sleep

The experts expressed that the shift arrangements can "*profoundly affect sleep and fatigue*" when working consecutive shifts, especially given that the operation is around the clock and the crew works long hours (P4, 2024; personal communication, P3, 2024; personal communication). Each type of shift presents challenges with obtaining sleep, as highlighted by some experts below. One of the experts stated the following challenges faced with day shifts:

"*Due to the hours, sometimes three or four-day shifts in a row tire you out more the night shift would because you leave home at four o'clock in the morning to get to* *work, leave six o'clock, half past six in the evening, you get home, you want to spend time with family, eat, get in bed at 10/11 o'clock at night. So, how much do you sleep? So, after three or four days, you have lost a night's sleep."*

3.15.2. Effects of consecutive night shifts on sleep

For night shifts, the crew sometimes take naps during the daytime after the shift if they have a night flight (P3, 2024; personal communication). The following statement by the experts highlights the effects of night shifts and that crew sleep ***polyphasic***, however short:

"*You might get home and sleep for two hours and start the rest of the day, have a nap in the afternoon, and then you are back on action, and if you get another night like that, by night three, you are absolutely completely knackered".*

However, some pilots prefer night shifts, which would be regarded as *"graveyard shifts"* because of factors such as family pressures; for example, crew with small children take night shifts to be able to spend the day at home with family (P4, 2024; personal communication). It was highlighted that the crew and their families also adapt to the *"rhythm"* of being a shift worker. However, it may not be conducive to *a "good family life; it's a challenge"* (P4, 2024; personal communication). In addition to ***work-life balance***, one of the experts highlighted that even the people working in other areas of HEMS are *"24 hours engaged"* with the operation (P4, 2024; personal communication).

3.15.3. Effects of repositioning of crew on rest/off days

In relation to crew shortage, as previously discussed, one of the experts highlighted its effect on rest/off days when outsourcing and crew repositioning are used. When the crew are repositioned to another base, they are required to travel, which takes place during rest/off days, which *"becomes your travel days, so it's not even an off day, they don't have travel days" (*P3, 2024; personal communication). Furthermore, this may impact the amount of rest time, which is a minimum of nine hours, that the crew need before being on duty (P3, 2024; personal communication). The amount of pre-duty rest time that the crew obtain depends on the travel time and distance between one base and the other. When the crew are outsourced from Gauteng to Limpopo, the road commute time is two hours, *“so you leave early morning, you rest before you go on a night shift”* (P3, 2024; personal communication). The Northern Cape base commute time from the Gauteng base is a six-hour drive, *"what they normally do is they, the co-pilots, are sent in the morning, arrive at two o'clock in the afternoon then you are on the night shift"* (P3, 2024; personal communication). The commanders, however, fly to the various bases "*so they don’t have to travel that six hour*” (P3, 2024; personal communication).

3.16. Strategies and interventions adopted to manage fatigue

3.16.1. Fatigue response and management policies

There are no formal policies on fatigue response systems other than to comply with aviation regulations (P1, 2024; personal communication). However, when the crew are on night shifts, they can sleep at night when there is no mission/s. One of the experts mentioned that the crew may discuss it amongst themselves, and when it does resurface, the managers will intervene in several ways depending on the severity of the case (P4, 2024; personal communication). The Chief Executive Officer provided an example of one way they have intervened:

"We have stood the service down for them to just get in some rest, but it happened once or twice just to get some rest."

3.16.2. Reporting systems

Additionally, due to the organisational culture, one of the experts mentioned that the crew can report to the base managers if they feel tired or if there are issues to the, who, if necessary, will report the matter to the chief pilot who is familiar with risk management given their previous experience in commercial aviation (P4 and P1, 2024; personal communication). Furthermore, the company has an in-house mentor, life coach, and aviation psychologist that the crew have access to, especially when the crew have been exposed to difficult missions (P4. 2024; personal communication).

3.16.3. Roster design

The roster has also been identified as a way to ensure there is a balance, fairness and accuracy in shifts amongst crew *"in the prospects of a weekend off or a leave (day off) that doesn't get altered. However, that doesn't always happen"* (P4, 2024; personal communication).

3.16.4. Strategies while on shift

As a protective safety mechanism to mitigate the effects of fatigue on safety, there is a cockpit procedure with a single pilot for day shifts and a co-pilot during night shifts. This is to allow for more than one pilot in the cockpit to allow for "*another pair of eyes"* (P3, 2024; personal communication). Additionally, based on the walkabout and interviews, the company provided multiple coffee stations, which are an important countermeasure used by the crew. *" It is a huge deal breaker if the coffee isn't good, strangely enough"*. (P4, 2024; personal communication). With respect to sleep, pilots are offered the opportunity to sleep when on duty, as sleeping locations, as previously mentioned, are provided at the base.

CHAPTER 4: PHASE 2 METHODOLOGY AND RESULTS

Phase 2: Methodology

4.1. Research Design

Phase 2 was a prospective observational study that explored the effects of different duty arrangements (day shifts, night shifts, and rest days) of HEMS operations on pilots' sleep, self-reported sleepiness and fatigue and workload.

4.2. Study Context and Setting

The participants were pilots from a company that provides helicopter emergency medical services in South Africa across different provinces. Each duty cycle consisted of individual shifts that were 12 hours long, with the crew working for approximately five days on duty and two to three days off duty across the different bases, which will be discussed more in the results section.

4.3. Data Collection Methods

Participants' sleep was monitored on workdays and rest days. Additionally, sleepiness, fatigue and workload levels were rated when on duty using the Karolinska Sleepiness Scale and Samn-Perelli Fatigue Scale, as depicted in Figure 6.

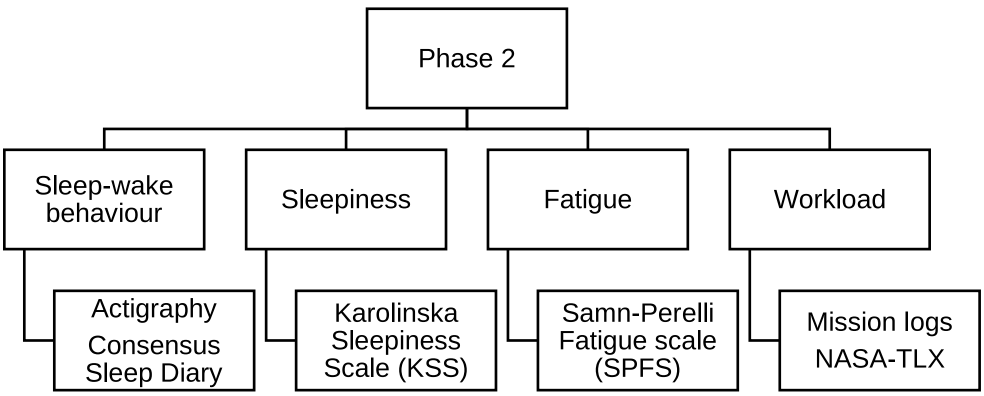

Figure 6: Adopted methods in phase 2 of monitoring pilots' sleep, sleepiness, fatigue and workload

4.3.1. Basic Demographic Information

Basic demographic information, specifically on sex, age, job role, and sleeping location when on duty (if they sleep at home, base or both). These questions were included in similar studies by Zakariassen et al. (2019), Flaa et al. (2019), Flaa et al. (2020) and Flaa et al. (2022).

4.3.2. Sleep tracking using actigraphy

The Condor Instrument ActTrust 2 actigraph wristwatch tracked participants' sleep-wake behaviour. This is a convenient, non-invasive, objective method of tracking sleep timing (onset and offset), duration and efficiency. The devices collected sleep and wake cycles by capturing body movement through an accelerometer, light exposure and temperature using a temperature sensor to determine sleep/rest and wake cycles. The devices allowed for objectively measuring sleep and wake time.

The watch was programmed at a desired interval of 60 seconds, the default setting, and configured at PIM/TAT/ZCM as desired mode and at 60s epochs. Each watch was cleared and configured for each participant. Participants were asked to wear watches continuously for seven days on their non-dominant hand, including work and rest/off days. Additionally, they were asked to press the event marker when they attempted to sleep with the lights off (defined as bedtime) and when they woke up and did not return to sleep (defined as wake time). Other sleep parameters such as time in bed (TIB), total sleep time (TST), sleep onset latency (SOL), wake-after sleep onset (WASO), sleep efficiency (SE) and the number of awakenings were also derived from the actigraph watch.

4.3.3. Consensus Sleep Diary-Morning

Sleep diaries are a commonly used method in research and clinical studies. Like actigraphy, sleep diaries allow researchers to capture information on nightly SOL, TST, time in bed (TIB) and sleep satisfaction (Carney et al., 2012). The Consensus Sleep Diary-Morning (M) was utilised as it provided a comprehensive overview of sleep and other sleep-related questions such as the number of naps, caffeine and drinks containing alcohol. (Appendix I for the full Consensus Sleep diary). The diary asks questions relating to sleep quality, duration, disturbances, timing and sleep habits. Sleep diary variables were combined with actigraphy to control the quality of actigraphy and obtain more accurate data (Sadeh, 2015; Fletcher et al., 2020). The sleep diary was completed online on Google Forms every day in the morning for the duration of data collection, within an hour of getting out of bed as prescribed in the diary (Carney et al., 2012). This is inclusive for pilots who worked night shifts because the main sleep period for all pilots, irrespective of the shifts they were working, was at night.

4.3.4. Karolinska Sleepiness Scale

The Karolinska Sleepiness Scale (KSS), as depicted in Appendix J, was the selected scale to measure subjective sleepiness while the crew are on duty, at the start, twice during the shift and at the end. It is a nine-point scale that measures subjective levels of sleepiness at a particular point during the day, with a score of 1 being "very alert" and a score of 9 being "very sleepy, great effort to stay awake, fighting sleep" (Åkerstedt & Gillberg, 1990; Shahid et al., 2010). A score of seven or higher indicates excessive sleepiness. This measure has been commonly used in the aviation industry and several studies on air ambulance services' sleep and sleepiness (Amann et al., 2014; Zakariassen et al., 2019; Flaa et al., 2019). The participants were asked to rate their sleepiness when on duty, every four hours, from the start to the end of the shift.

4.3.5. Samn-Perelli Fatigue Scale

Ratings on each personnel's fatigue levels were obtained using the Sam-Perelli Fatigue Scale when the crew were on duty at the start of the shift, twice during the shift and at the end, which measures an individual's perceived level of fatigue. Similar to the KSS, it used a Likert-type scale, which consists of seven items, one being "fully alert, wide awake" and seven being "completely exhausted and unable to function effectively" (Samn & Perelli, 1982). It measures fatigue level at that moment (Smith et al., 2018). It was originally designed to measure aircrew fatigue based on work and rest profiles (Samn & Perelli, 1982). The participants were asked to rate their fatigue when on duty, every four hours, from the start to the end of each shift.

4.3.6. Mission Logs

An overview of the number of missions and their duration was obtained from the mission logs that the company provided. The total time spent on missions was recorded as the time from the activation of a call to when the crew returned to the base after the completion of the mission (Flaa et al., 2019; Flaa et al., 2022). The mission logs at the time of data collection for each base were provided by the company, outlining the date and time of activation, the departure from the base, arrival at the base and the flight time.

4.3.7. Workload measure (NASA-TLX)

In addition to mission logs, a workload measure was used to provide an overview of the perceived workload. The NASA Task Load Index (NASA-TLX) is a widely used multidimensional scale that assesses perceived workload (Hart, 1988; Tubbs-Cooley et al., 2018). It comprises six subscales: mental demand (related to the mental activity required by the exercise/task), physical demand (related to the level of physical effort employed to perform the task), temporal demand (related to the duration, intensity and pace at which the exercise occurred), own performance (related to the successes achieved during the task and satisfaction level gained with the results), effort (related to the work necessary to fulfil the task) and frustration (related to the feelings experienced during the task and the ratio between commitment and benefit achieved (Hart & Stareland, 1988). Each participant completed the NASA-TLX at the end of each shift worked using the NASA-TLX application on their personal devices.

4.4. Study Participants and Sampling Strategy

The participants in Phase 2 were HEMS pilots from three different air bases: Gauteng, Limpopo, and Northern Cape. This phase of the study adopted convenience sampling, whereby the sample size depended on the pilots' availability and interest in participating. The participants were recruited through the base managers, whereby the researcher sent a briefing video entailing details of the study and information letters, which were distributed to the pilots. Interested pilots were contacted for a more detailed briefing, over video conferencing platforms, on the data collection process, what they would be required to do should they participate and the consent process.

4.5. Data Collection Procedure and Timeline

4.5.1. The Pilot Study

A pilot study was conducted before the primary data collection to assess the feasibility of the methodology in the real context of HEMS and get feedback to improve the methodology and study procedure. The seven-day pilot study was done on two HEMS pilots working night shifts, three flight desk coordinators, two working day shifts, and one working night shift. Feedback from the pilot study was addressed, and the study protocol was refined to provide more clarity on the sleep diary questions, more specifically on the days caffeinated and alcohol drinks were consumed, and the timelines of the data collection period for each base. Based upon discussions with the company experts, it was decided that the data collection period would be extended to approximately a month per base instead of two weeks, with seven days of data collection for each participant to increase participant number and ensure enough data for analysis.

4.5.2. Data Procedure and Timeline

Phase 2 of data collection was on a focus group of pilots working day and night shifts. Data on workdays/days on duty and rest days/days off duty were collected. As depicted in Figure 7, participants' sleep-wake patterns were monitored for both workdays and rest days using actigraphy and the Consensus sleep diary. The actigraphy watches were sent to participants via courier. The Consensus sleep diary was completed via Google Forms daily upon awakening during both workdays and rest days. Actigraphy watches were also worn for both workdays and rest days, and participants pressed the event markers on the watches upon awakening and falling asleep. Daily reminders were sent to each participant on WhatsApp, with links to the various measures.

Additionally, during each 12-hour shift, self-reported sleepiness and fatigue and end-of-duty workload were measured only during workdays. Sleepiness and fatigue levels were rated at four-hour intervals for each 12-hour duty period from the start, midway through the shift (the second- and third-time intervals), and at the end of the shift on Google forms accessed on their personal devices. Participants did not provide ratings during the time when they were activated due to operational demands or when they were asleep.

At the end of each duty period, personal device NASA-TLX applications were used to assess participants' end-of-duty workload for Android and IOS devices. Participants rated their workload using the NASA-TLX application on their personal devices, and reports were sent at the end of each shift in either PDF, Excel, or screenshot format. Each participant was sent a daily WhatsApp reminder to complete the sleep diaries, scales and Nasa-TLX.

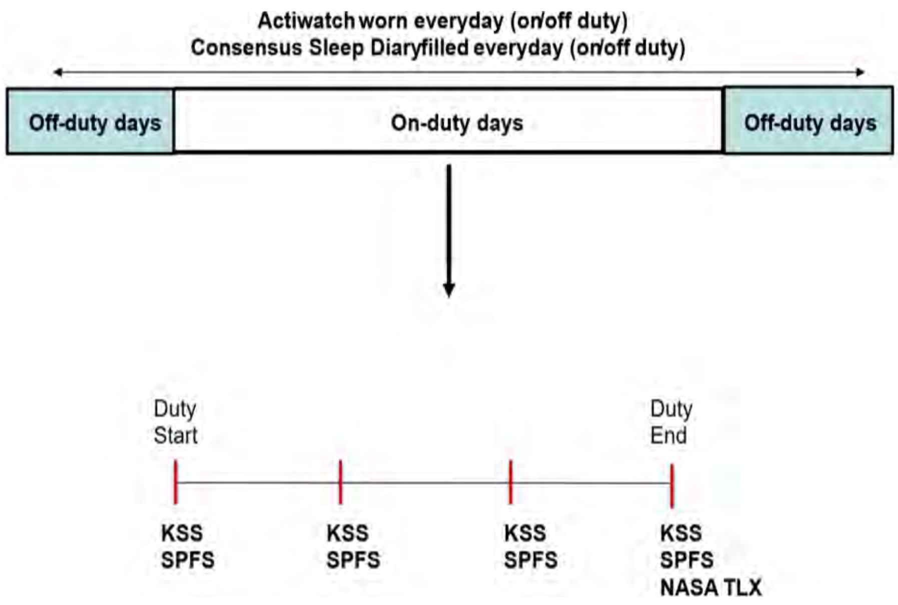

Figure 7: Timeline of how data was collected at different on-duty and off-duty points.

4.6. Data Analysis

4.6.1. Descriptive Statistics

Participant demographic characteristics and categorical variables were presented as mean (standard deviation) and percentages. Shift start and end times were also analysed similarly, using means, standard deviation, and percentages to present the data.

4.6.1.1. Sleep-wake behaviour analysis

After each round of data collection from the bases, data from the watches were downloaded, reduced, and scored before being analysed using descriptive statistics.

Participant sleep characteristics (all sleep metrics) from the actigraphy watches were scored using the ActStudio 2.1.2.8 RC8 Win software. The dates of the first day initial and last day participants wore the watch were inputted into the software to correspond with the period when participants wore the watch, and light/dark phases were adjusted according to the country and city where participants were during the time when they wore the devices as per the user manual of the devices (Condor Instrument Actlumus- User Manual, 2023). Sleep was scored using the "expert mode " as it allowed manual scoring using the event markets and sleep diaries (Condor Instrument Actlumus- User Manual, 2023). The sleep diary data were not input into the software but used as a guide to ensure accuracy in the scoring; however, sleep quality and quantity, caffeinated drinks and alcoholic drinks from the sleep diaries were used in the overall analysis. Caffeinated drinks and alcoholic drinks were analysed descriptively to provide an overview of consumption.

To score the data, body movement, and light indicators from the software algorithm provided information as indicators of when participants got into bed and when they woke up. In addition, the researcher manually scored the data with the use of the event markers provided by the participants on when they intended to go to sleep, and when they got out of bed, alongside sleep diaries. This is in line with the scoring method proposed by Chow et al. (2016), given that the actigraphy algorithm may yield imprecise rest intervals. In instances where event markers were not provided, the researcher used bedtimes and get-up times from the sleep diaries, provided they corresponded with changes in light and activity counts on the actogram.

The outputs received from scoring the data were participants' sleep patterns, in particular, bedtime (BT), get-up time (GUT), time in bed (TIB), total sleep time (TST), sleep onset latency (SOL), wake-after sleep onset (WASO), sleep efficiency (SE) and the number of awakenings (AWK). Nap data was scored on the actigraphy software using event markers that participants provided when naps were taken. Sleep diaries were used as a guide on which days naps were taken and the duration of the naps. In cases where participants reported having taken a nap in the sleep diary, but it was not visible in the ActStudio software, the nap was not scored and excluded from the overall nap data report. The nap data alone was used to obtain total sleep time in 24 hours. The data tables from the software displaying each participant’s daily sleep-wake patterns over the recorder period for each individual were exported into a CSV file and separated into shift types, which were converted from time format to decimals in preparation for analysis to be run in the statistical software.

4.6.1.2. Sleep regularity

Sleep regularity was determined using the standard deviation of each participant's bedtime, wake-up time and total sleep time for day shifts and night shifts over the data collection period. There is no gold standard for calculating sleep regularity, with various studies using sleep regularity index (SRI) or standard deviations to determine sleep regularity (Fischer et al., 2021; Windred et al., 2023; Teece et al., 2024; Nauha et al., 2024; Zitser et al., 2024; Halson et al., 2022). For the purpose of providing an overview of sleep regularity, this study used standard deviations. This is a commonly used method to quantify variability in sleep and circadian research (Fischer et al., 2021). Standard deviation displayed the amount of variance, with a lower number indicating more regular patterns and a higher number indicating higher irregularity (Fischer et al., 2021). Each participant's standard deviation for BT, GUT and TST was calculated and put into shift types according to the shifts in which they worked. There is no cut-off for what constitutes regular or irregular sleep patterns. To determine regularity, this study used SD <60 minutes as more regular, and SD >60 minutes was defined as less regular. Nauha et al. (2024) also used standard deviations to determine regularity for bedtime, wake-up time and total sleep time by using quartiles 1 -4, with quartile one being more regular and quartile 4 being less irregular. Quartiles 3 -4 for bedtime were standard deviations more than 00:58:51, > 01:12:22 for wake-up time and more than 01:16:13 for total sleep time. Zitser et al. (2024) defined irregular sleep as an SD of > 1 hour in sleep duration and onset, which, as cited in their study, was reported by Huang et al. (2020), who demonstrated that an SD of more than 1 hour of sleep duration increased the risk of cardiovascular disease.

4.6.1.3. Karolinska Sleepiness Scale and Samn-Perelli Fatigue Scale analysis

The Karolinska Sleepiness scale and Samn-Perelli fatigue scale followed the same analysis procedure. The data was categorised into ratings at the start of the shift, midway through the shift and at the end of the shift. The start of the shift ratings was scored as ± 2 hours from the start of the shift.

For the second and third ratings (mid-shift ratings), some participants provided both ratings; however, due to operational demands or because participants were asleep, some participants were only able to provide one of these KSS and SPFS ratings, usually the earlier one. In most cases, participants did not provide a rating at the third time point. This meant that only one was used. In cases where two ratings were provided midway through the shift, the average of the two ratings was calculated to ensure consistency in the analysis of the data. Midway through, the shift was classified as between 09:00 and 15:00 for day shifts and 21:00 and 03:00 for night shifts. The end-of-duty ratings were classified between ± 2 hours from the end of the shift. The ratings were then separated into shift-type categories: day shifts and night shifts. Consecutive day and night shifts, as well as individual ratings of KSS and SPFS ratings, were analysed descriptively due to limited participants and missing data that resulted in the inability to conduct inferential statistics due to operational demands where the crew were either sleeping or flying.

4.6.1.4. NASA-Task Load Index analysis

The data from the NASA-TLX reports were transferred into Excel and analysed using standard descriptive statistics for each workload dimension for the different shift arrangements.

4.6.1.5. Mission logs analysis

During data collection, each base's mission logs were acquired, sorted and separated into day shifts, night shifts and rest days. Each shift had categories of time of activation, departure from base, arrival at base, flight time and mission duration. Furthermore, mission logs were used to determine participants who were on missions and their sleep patterns.

4.7. Inferential Statistics

While more details about the participant characteristics is provided at the start of the results, it is relevant to mention the final participant numbers, the associated data obtained from them and the decisions regarding the analysis. In total, 13 participants started phase 2. While participants were asked to wear the watch for 7 days, the level of compliance varied. One participant wore the device for two nights, which was insufficient to be meaningfully scored. Thus, their data were excluded. This participant was a standby pilot. One other participant was also a standby pilot, who completed 5 days of the study. Given that there was only one standby pilot, this data was not included in the main analysis, but is available in Appendix M.

Inferential statistics were conducted using the Statistica software model TIBCO Statistica Software Inc. (2020). All data were first tested for normality using the Shapiro-Wilks test. All data for bedtime, get up time, time in bed, total sleep time, number of awakenings, sleep quality and self-rated restfulness were normally distributed, as was the data for the Karolinska Sleepiness scale, Samn-Perrelli fatigue scale and NASA TLX. The data for sleep onset latency, sleep efficiency and wake after sleep onset were not normally distributed and therefore subject to analysis using nonparametric tests as summarised in Table 6. Nap data and mission log data were analysed descriptively.

Given that the number of shifts that participants worked and wore the watch varied, initial analyses looked to compare the average sleep- wake behaviour characteristics across all night shifts compared to day shifts to determine whether sleep differed between these two shifts. For this, a general Linear (GLM) model, specifically a one-factorial analysis of variance, was applied. For non-normal sleep data (SOL, SE, WASO), a Mann-Whitney U Test was applied to explore differences between all day shifts and all-night shifts. This data was expressed using the median and interquartile range (25 – 75%). A separate comparison of sleep-wake behaviour between rest days (for night shift workers only) and night shifts was achieved using a dependent t-test for normally distributed data and a Wilcoxon Matched Pairs test for data that was not normally distributed. No statistical comparisons were made between rest days and workdays for participants that had day shifts, as there were too few participants to make a meaningful comparison and as all-day shift pilot’s rest days data were obtained.

Following this, we ran a larger model to compare sleep-wake behaviour between day and night shifts over consecutive shifts (it was determined that for all day shift pilots and night shift pilots, participants worked at least three consecutive shifts each while wearing the watches). Therefore, to determine whether there were any differences in the sleep-wake behaviour, a two-factorial repeated measures ANOVA was applied to all normally distributed data. For sleepiness (KSS) and fatigue (SPFS) ratings, a two-factorial ANOVA was also applied to compare differences in average ratings between day and night shifts across the three measurement points (start, midpoint and end). For non-normal data, we ran individual Mann-Whitney U tests to compare differences between day and night shift pilots' SOL, SE and WASO for each of the three consecutive shifts. To compare whether these responses changed over the three shifts, a Friedman ANOVA and Kendall's concordance were applied separately for day shifts and night shifts.

For workload, a one-factorial analysis was conducted to determine differences between shifts for each construct. For all statistics, significance was set at $p>0.05$. (Refer to Table 6 for a summary of the analysis).

Table 6: Summative Table of inferential statistics

	Normally distributed		**Not normally distributed**	
	Variables	Statistical test	Variables	Statistical test
Average sleep data comparison between day and night shift pilots	Bedtime, Get-up time, Time in bed, Total Sleep Time, Number of awakenings, Sleep Quality, Restfulness	One-factorial analysis of variance	Sleep onset latency, Wake-after-sleep onset, Sleep efficiency	Mann-Whitney U Test
Rest days and work shifts (night shifts only)	Bedtime, Get-up time, Time in bed, Total Sleep Time, Number of Awakenings, Sleep Quality, Restfulness	Dependent t-test	Sleep onset latency, Wake-after-sleep onset, Sleep efficiency	Wilcoxon Matched Pairs test
Consecutive shifts (day vs night shifts)	Bedtime, Get-up time, Time in bed, Total Sleep Time	Two-factorial repeated ANOVA	Sleep onset latency, Wake-after-sleep onset, Sleep efficiency	Mann-Whitney U Test Multiple dependent samples using Friedman ANOVA and Kendall's concordance
KSS data	All variables	Two factorial analyses of variance		
SP data	All variables	Two factorial analyses of variance		
NASA-TLX data	All variables	One factorial analysis of variance		

Phase 2: Results

4.8. Participant Characteristics

A total of 13 HEMS pilots participated in phase 2 of the study; however, 11 pilots' data was used due to insufficient data from two pilots that worked standby shifts (refer to Appendix M for averaged standby descriptive data). Overall, three female pilots and ten male pilots with a mean age of 40,5 years ±10,78 (exclusive of one male pilot who did not share this information) participated in the study. The crew worked across the three different bases. Four pilots worked shifts in Base 1 in the Gauteng Province, with one pilot working predominantly day shifts and three pilots working night shifts. Base 2, located in the Limpopo province, had four pilots; two worked predominantly day shifts, and two worked night shifts. Lastly, there were three pilots from Base 3 in the Northern Cape province, working nights with no data obtained for day shifts at Base 3. Pilots in this study had their main sleep time during the night, irrespective of the type of shift they worked.

Table 7: Summary of descriptive statistics of participant characteristics represented by total number (n), age by mean, standard deviation, and percentage in brackets

Variables	Mean ± SD (%)
Age	40,5 ±10,78
Sex	
Female	3 (27.27%)
Male	8 (72.72%)
Main sleep period	
Nighttime	11 (100%)
Daytime	0
Main sleeping location while on shift	
Base	7 (63.63%)
Home	4 (36.36%)
Pilots per Base	
Base 1	4 (36.36%)
Base 2	4 (36.36%)
Base 3	3 (27.27%)
Number of shifts monitored	
Day shits	14 (20.89%)
Night shifts	41 (61.19%)
Rest days	12 (17.91%)

4.9. Shift arrangements across bases

On average, a single shift was 12 hours for both day and night, but this differed across bases. Base 2, situated in the Limpopo province, had night shifts 1 hour longer than Base 1 in Gauteng and Base 3 in the Northern Cape because of the shift start and end times as depicted in Table 8. Day shifts at Base 2 had a later start time, an hour later than the day shifts at Base 3. The day shifts ended at the same time for Base2 and Base3, as depicted in Table 8.

Table 8: Summary of shift start and end times across the different bases.

	Base 1		Base 2		Base 3	
	Day shift	**Night shift**	**Day shift**	**Night shift**	**Day shifts**	**Night shift**
Start	05:30	17:30	07:00	18:00	06:00	18:00
End	17:30	05:30	18:00	07:00	18:00	06:00

4.10. Sleep-wake behaviour

4.10.1. Comparison of average sleep-wake behaviour by shift type

Table 9 provides an overview of sleep parameters across day shifts, night shifts and rest days, irrespective of base. Analyses revealed that there were no significant differences for average bedtime (F (1, 9)=4.579, p=0.0610), get-up time (F (1, 9)= 1.1325, p=0.3149), time in bed (F(1, 9)= 0.4766, p=0.4766), total sleep time (F(1, 9)= 0.3386, p=0.5749), sleep onset latency (U= 7), p=0.3583), sleep efficiency (U=9, p= 0.6098), wake after sleep onset (U= 12), p= 1.0) and number of awakenings (F (1, 9)= 0.2628, p= 0.6205), sleep quality (F(1, 9)=0.2628, p=0.6205), and restfulness (F(1, 9)=1.1237, p=0.3167), between day shifts and night shifts. (Appendix N1).

Additionally, a separate comparison of sleep-wake behaviour between rest days and work shifts (for night shift pilots only) was conducted to determine whether differences existed. Overall, there were no significant differences in any sleep parameters between rest days and night shifts (Refer to Appendix N2 for full statistics tables). A comparison of rest days and day shifts could not be conducted due to limited data; however, bedtime was later during rest days, and total sleep time was shorter on rest days compared to day shifts, as depicted in Table 9.

Table 9: Descriptive statistics of sleep patterns across shifts

Sleep parameters	Day shifts (n=14)	Night shifts (n=41)	Day shifts rest days (n=2)	Night shift rest days (n=10)
Shift Start time (hrs: min)	06:30 (0:51)	17:48 (0:15)		
Shift end time (hrs: min)	18:00 (0:17)	06:00 (0:37)		
Bedtime (hrs: min)	21:30 (0:46)	22:52 (0:59)	22:45 (00:39)	22:24 (00:55)
Getup time (hrs: min)	05:26 (0:44)	06:07 (01:00)	05:00 (01:23)	06:11 (01:00)
Time in Bed (hrs: min)	7:56 (0:25)	7:16 (1:28)	6:15 (0:43)	7:47 (0:23)
Total Sleep Time (hrs: min)	6:51 (0:27)	6:20 (1:27)	5:44 (0:31)	6:54 (0:28)
Sleep onset latency (min:sec)	05:44 (03:19-11:24)	06:34 (04.31-13:19)	03:00 (03:00-03:00)	07:00 (03:00-08:30)
Sleep efficiency (%)	92.68 (75.57- 92.81)	89.30 (81.13-91.82)	91.99 (90.39-93.60)	91.21 (87.57-91.89)
WASO (hrs: min)	00:29 (00:27-01:50)	00:36 (00:28-00:58)	00:23 (00:18-00:29)	00:46 (00:23-01:12)
Number of awakenings	16.5 (9.53)	14.76 (6.92)	10 (0)	16.64 (8.21)
Self-rated sleep quality	3.88 (0.68)	3.63 (0.76)	4.5 (0.70)	4.5 (0.57)
Self-rated restfulness	4.20 (0.69)	3.53 (0.99)	4.5 (0.70)	4.5 (0.57)

*n=number of shifts/ * Mean(sd)/ *Mdn(IQR 25%-75%) for not normally distributed data*

Figure 8, shows an example of fragmented sleep highlighted by high and numerous body movements during a sleep period of a pilot working night shifts, which is reflected the high variability in WASO.

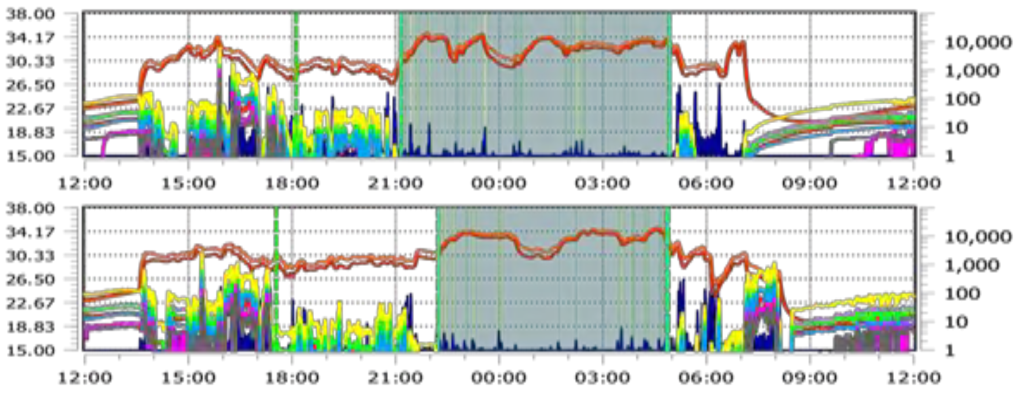

Figure 8: Actogram of fragmented sleep periods of one pilot

4.10.2. Comparison of sleep wake behaviour over consecutive day and night shifts

To compare whether sleep-wake behaviour changed over three consecutive day shifts and night shifts, a two-factorial repeated measures ANOVA revealed no statistically significant differences between the shift types, days and there was no interaction effect between consecutive days and shifts for BT, GUT, TIB, TST and number of awakenings, sleep quality and self-rated restfulness. However, there was a significant effect for the number of awakenings (F (2, 18) = 4.2756, p= 0.030247) over days, with postdoc analyses revealing that the number of awakenings were significantly fewer on shift three, relative to shift 2. Non-parametric analyses revealed no significant differences between shift type for SOL, SE and WASO and no significant differences across the three-day shifts or three-night shifts (refer to N3 for statistics Tables for all sleep parameters, and Appendix M2 for descriptive statistics for consecutive day shifts and consecutive night shifts).

Table 10 provides an overview of the average number of caffeine and alcoholic drinks consumed. On average, participants who worked night shifts consumed more caffeinated drinks compared to day shifts, with the last caffeine drink being towards the start of the night shift. However, rest days had the highest number of caffeinated drinks and alcoholic drinks.

Table 10: Overview of average number of caffeinated and alcoholic drinks consumed.

Variables	Number of drinks Mean ± SD	Time of last serving (hours: min)
Daily caffeinated drinks		
Day shifts (n=14)	2.64 (1.08)	11:37 (02:51)
Night shifts (n=36)	2.86 (2.02)	17:47 (03:02)
Rest days (n=10)	2.90 (1.73)	15:58 (03:03)
Daily alcoholic drinks		
Day shifts (n-14)	0.00 (0.00)	
Night shifts (n=38)	0.28 (1.14)	17:30 (03:32)
Rest days (n=14)	0.73 (1.27)	20:40 (01:36)

**n=number of responses*

4.10.3. Total Sleep Time in a 24-hour period

Tables 11 and 12 provide descriptively analysed data to show differences between the sleep duration when the crew took daytime naps and without daytime naps. Only the crew who indicated having taken naps before or after a shift, had their data was used for analysis. The data was analysed by first calculating the total sleep time for the days when naps were taken (exclusive of the daytime naps) and, secondly, calculating the total sleep time of the same days, including the naps. The results represent data from nine-night shifts and one rest day. While this could not be analysed statistically, it was evident that napping increased the total sleep time achieved in a 24-hour period, particularly when the main sleep periods were short following a night shift. Given the bedtimes of naps ranging from the morning after shift the end of a shift and evening, before the commencement of the next shift, it is evident that naps were taken either shortly after night shifts or before the next one.

Table 11: Comparison of Total Sleep Time with daytime napping and without daytime napping.

Participant (number of shifts napped)	Shift type	Main sleep without naps (hrs: min)	Sleep over 24hours (hr:min)
Participant A (3)	Night	04:18 (02:38)	05:39 (02:49)
Participant B (3)	Night	08:26 (00:23)	09:17 (2:12)
Participant C (2)	Night	06:47 (00:13)	08:10 (00:16)
Participant D (1)	Night	07:18 (0:0)	07:34 (0:00)
Participant E (1)	Rest	08:41 (0:00)	09:57 (0:00)
Total		07:11 (01:50)	08:07 (01:39)

Table 12: Ranges for earliest and latest nap bedtimes and get-up times, and average nap duration.

	Bedtime (earliest – latest)	**Get-up time** (earliest – latest)	**Nap duration** Mean (sd)
Night shifts	07:24 – 17:32	11:02 -18:00	01:11 (00:17)
Rest days	17:09	18:37	01:16

4.10.4. Overview of mission duration and flight time

At the time of data collection, a total of 13 missions occurred at Base 1. Eight of the missions were during day shifts, and five were during night shifts. There was a total of 24 missions at Base 2: 17-day shifts and seven-night shifts. Base 3 had two-night missions. On average, the flight time for day shift missions, across all bases, was 1h 35minutes (± 41minutes), with an average mission duration of 3h 41minutes (± 1h 19minutes). The average flight time for night shift missions, across all bases, was 2h 17 minutes (±46 minutes) with an average total mission duration of 4h 2 minutes (± 1h 8 minutes).

4.10.5. Sleep during day and night shifts with and without missions

Table 13 provides an overview of descriptive statistics of sleep during shifts when there were missions and when there were no missions. The results are for participants whose sleep was able to be linked to mission days (not all participants were able to be linked to missions, as the mission logs did not include the pilots that were on each mission).

There were no noticeable differences in sleep parameters during day shifts with missions and without missions. During night shifts, however, bedtime was later when there were missions, compared to when there were no missions, with get-up times being approximately the same time. As a result, the total sleep time when pilots had missions was shorter than on nights when there were no missions. Wake after sleep onset and a number of awakenings during the night when there were no missions were higher compared to nights when there were missions.

Table 13: Sleep during shifts with missions and without missions (day shifts and night shifts)

	Day shifts		**Night shifts**	
	Day shifts without missions (n=6)	Day shifts with missions (n=7)	Night shifts without missions (n=20)	Night shifts with missions (n=3)
Bedtime (hrs: min)	21:22 (00:48)	20:56 (00:33)	22:52 (01:18)	02:31(01:05)
Getup time (hrs: min)	05:01(00:41)	05:04 (00:38)	06:07 (01:50)	05:52 (01:08)
Time in Bed (hrs: min)	07:38 (01:14)	08:07 (00:58)	07:17 (01:51)	03:21 (02:10)
Total Sleep Time (hrs: min)	06:43 (01:03)	06:38 (00:31)	06:00 (01:29)	02:52 (02:13)
Sleep onset latency (min:sec)	00:15 (00:07-00:12)	08:00 (06:00-18:00)	00:27 (00:14-00:52)	09:00 (05:00-10:00)
Sleep efficiency (%)	91.51 (81.97-93.60)	82.42 (76.87-93.32)	85.2 (75.50-91.71)	81.20 (70.59-92.88)
Wake after sleep onset (hrs: min)	00:36 (00:21-01:08)	01:14 (00:21-01:42)	00:34 (00:21-01:17)	00:17 (00:14-00:21)
Number of awakenings	18.17 (7.98)	21.6 (10.85)	17.75 (10.16)	6 (1.73)

*number of missions: day shift missions= 10; night shift missions= 3

4.10.6. Sleep regularity of participants across different shift arrangements.

Table 14 provides descriptive statistics on participants' sleep regularity. Sleep regularity of participants working different shifts was calculated using standard deviation for each participant's bedtime, getup time and total sleep time when on duty during different shifts.

For bedtime, the crew working night shifts had a more regular bedtime, followed by day shifts. Getup time was more regular on day shifts, with all-day shift pilots falling into this category, followed by night shifts. Day shift pilots had a more regular total sleep time, followed by night shift pilots experiencing the most irregular total sleep time.

Table 14: Sleep regularity and irregularity of participants across different shifts represented as the average standard deviation in time, number of participants and percentage of participants that worked the specified shifts in brackets.

	More Regular (< 60 minutes)		**Less regular (> 60 minutes)**	
	Night shifts	Day shifts	Night shifts	Day shifts
Bedtime (hrs: min)	00:31 6 (75%)	00:39 2 (66.66%)	01:33 2 (25%)	01:32 1 (33.33%)
Getup time (hrs: min)	00:28 6 (75%)	00:39 3 (100%)	01:30 (3) 37.5%	0:00 0 (0%)
Total Sleep Time (hrs: min)	00:38 4 (50%)	00:38 (2) 66.66%	01:30 4 (50%)	01:55 1 (33.33%)

*Day shift pilots= 3; night shift pilots = 8

4.11. On-duty self-rated sleepiness and subjective fatigue

4.11.1. Karolinska Sleepiness Scale ratings

As depicted in Figure 9, there was no statistically significant difference in sleepiness ratings between the shift types ($F(1, 7) = 2.5264$, $p = 0.1560$). Additionally, there were no significant differences in the average change of ratings over time ($F(2,14) = 1.8564$, $p = 0.1927$), nor a significant interaction effect between the time of day and shift types ($F(2,14) = 2.6589$, $p = 0.1049$). The night shift's mid-shift sleepiness ratings have the highest variance as the crew provided ratings at different times between 21:30 and 03:00.

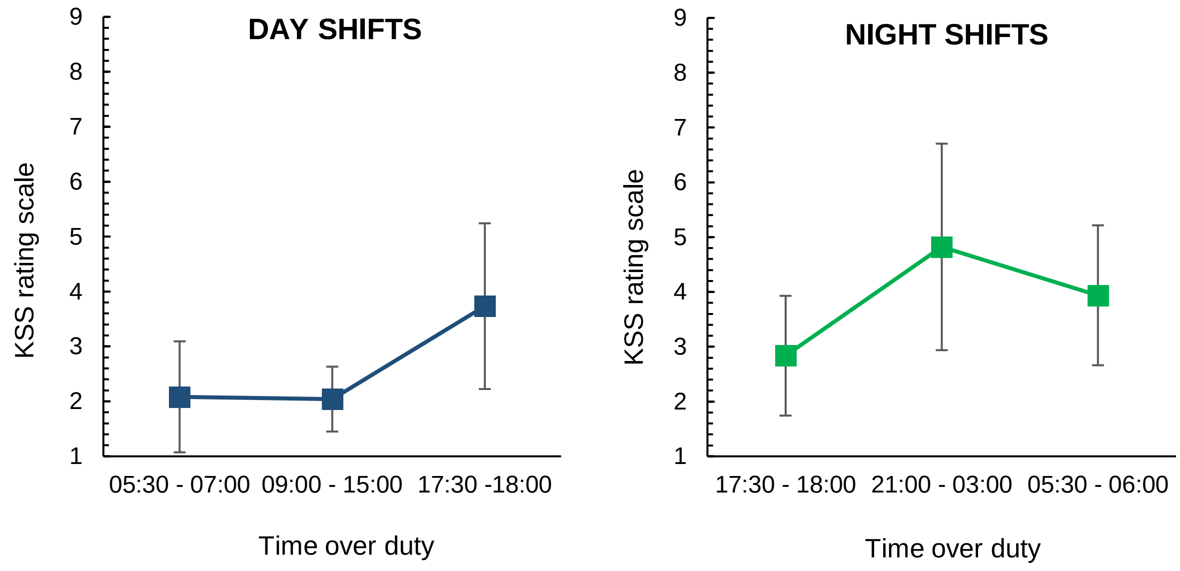

Figure 9: Karolinska Sleepiness Scale (KSS) ratings for day shifts (left panel) and night shifts (right panel).

4.11.2. Individual participant sleepiness ratings

In Figure 10, participants' individual ratings across a day shift (left) and night shift (right) are depicted. Although individual data is not normally used, are included to provide a further overview depiction of each pilot’s ratings across all measurement points in the shift. Similar to the previous Figures, day shift pilots’ individual ratings (P1, P2, and P3) sleepiness ratings gradually increased over the shift, with the highest ratings occurring at the end of the day shifts. A similar trend can be observed with night shift individual ratings with a peak at ratings 2 (between 21:30 and 22:00), but a decrease towards the end of the shift. There were participants with ratings that continued to increase (P8, P10). Rating 3 was not frequently completed by participants as a result of being on a mission or because they were sleeping.

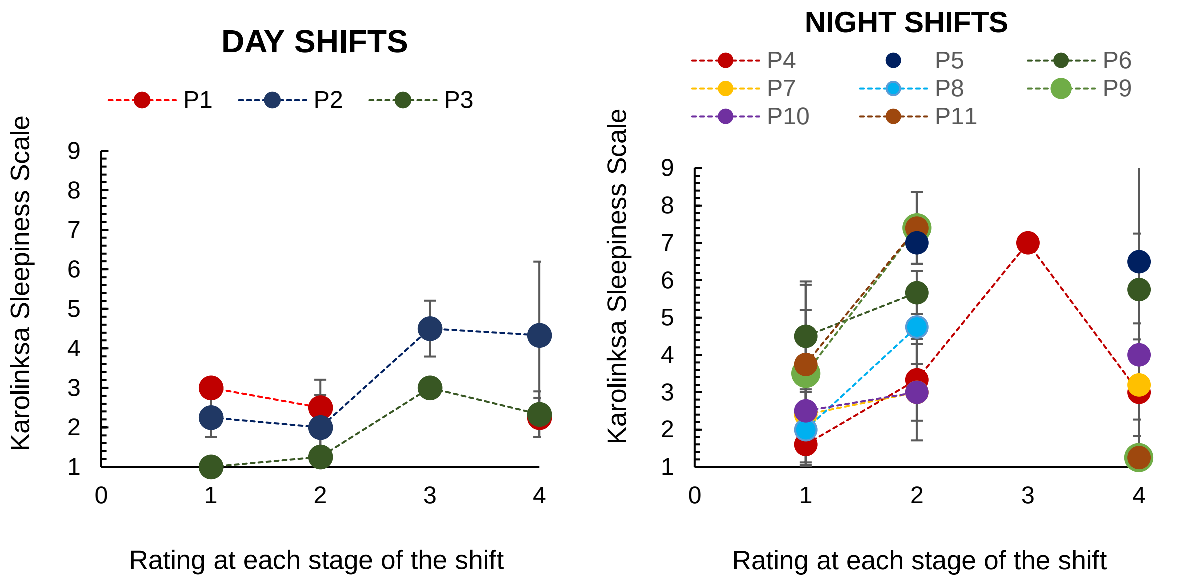

Figure 10: Individual participant KSS ratings for day shifts (left panel) and for night shifts (right panel).

4.11.3. Karolinska Sleepiness Scale (KSS) ratings for consecutive day and night shifts.

For consecutive day and night shifts, as depicted in Figure 11, inferential statistics were not performed due to a missing data set as a result of operational demands. Based on the descriptive statistics, on day shifts, sleepiness ratings, day shift three had the lowest ratings were lower. For mid-shift ratings, day shift two had the highest sleepiness rating compared to day shifts one and three. End-of-shift sleepiness was the highest during the day shift two and lowest during day shift three.

During night shifts, sleepiness levels peaked mid-shift, with night one having the highest sleepiness rating at the start of the shift and night two having the lowest sleepiness rating. For mid-shift ratings night shift two and three having the highest mid-shift sleepiness ratings, with a high variance during night 1, suggesting that some crew that worked the first night shift experienced high levels of sleepiness, still within moderate levels (less than 7). However, there was a high variance that surpassed the threshold (over 7) during the first night shift. End-of-shift sleepiness during night shift one was the highest rating with a high variance, followed by night two and night three.

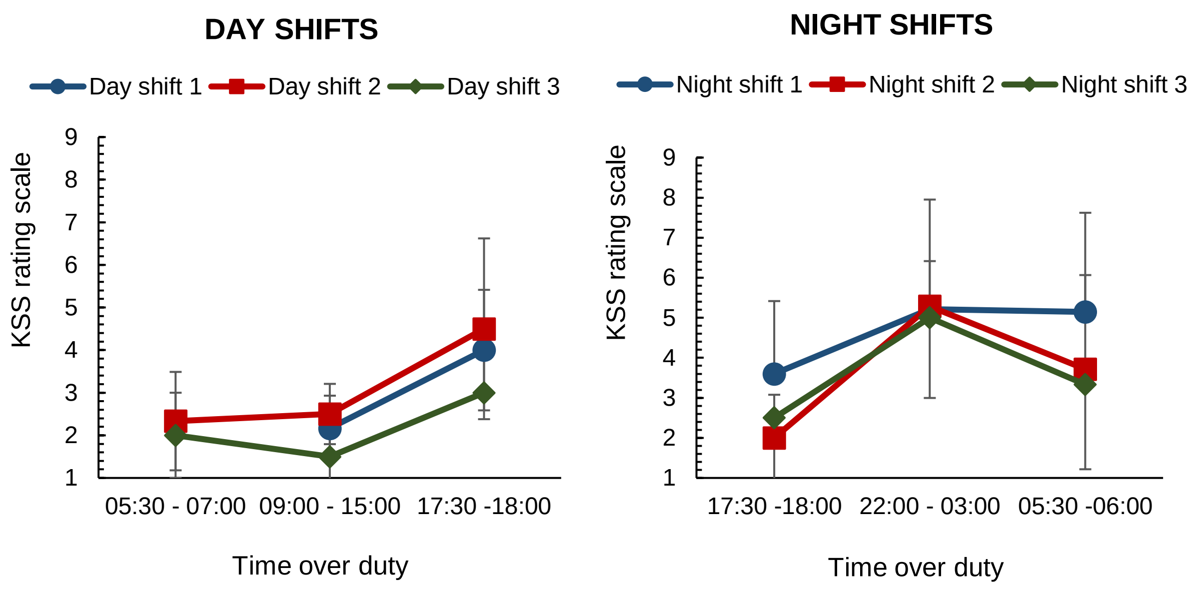

Figure 11: Karolinska Sleepiness Scale ratings for consecutive 3 day shifts (left panel) and consecutive 3 night shifts (right panel)

4.11.4. Samn-Perelli Fatigue Scale ratings

In Figure 12 below, there were no significant differences in the average fatigue ratings between shift types ($F(1, 6) = 5.5987$, $p = 0.0558$). Additionally, there were no significant differences in the change of average ratings over time ($F(2, 12) = 1.3771$, $p = 0.2894$), nor a significant interaction effect between the time of day and shift types ($F(2, 12) = 2.1884$, $p = 0.1548$). The end of day shifts and night shifts had a higher variance compared to the start and midway of the shift.

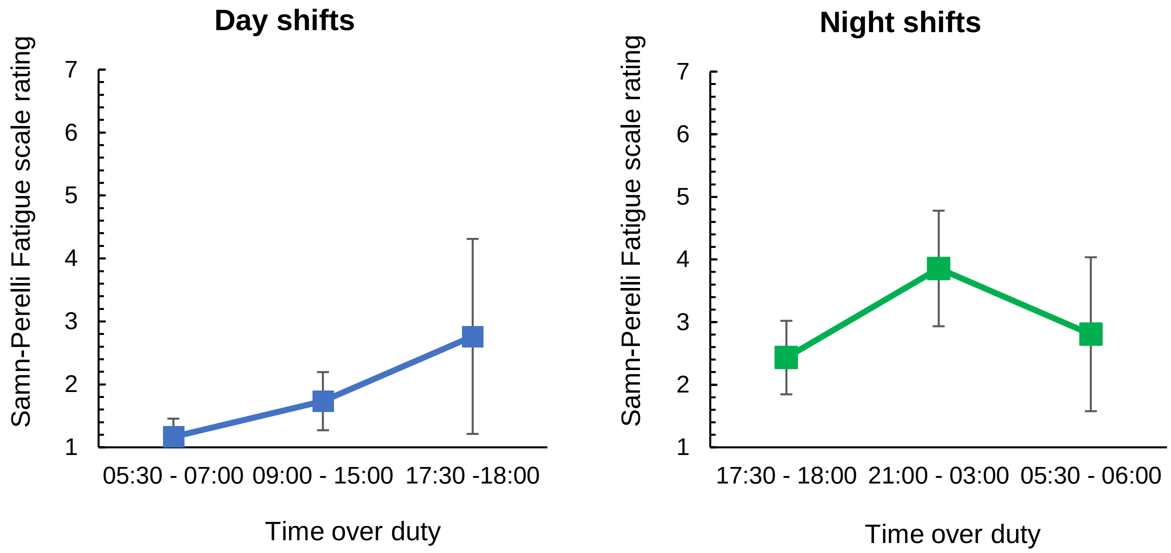

Figure 12:Samn-Perelli Fatigue Scale ratings for day shifts (left panel) and night shifts (right panel).

4.11.5. Individual participant fatigue ratings

In Figure 13, participants' individual ratings across a day shift (left) and night shift (right) are depicted. Similar to the previous figure, day shift pilots' individual fatigue ratings (P1, P2, and P3) gradually increased across the shift. A similar trend was observed with night shift individual ratings with a peak at ratings 2, and a decrease towards the end of the shift (rating 4). P8's rating however continued to increase till the end of the shift. Similar to the KSS, Rating 3 was not frequently completed by participants as a result of being on a mission or because they were sleeping.

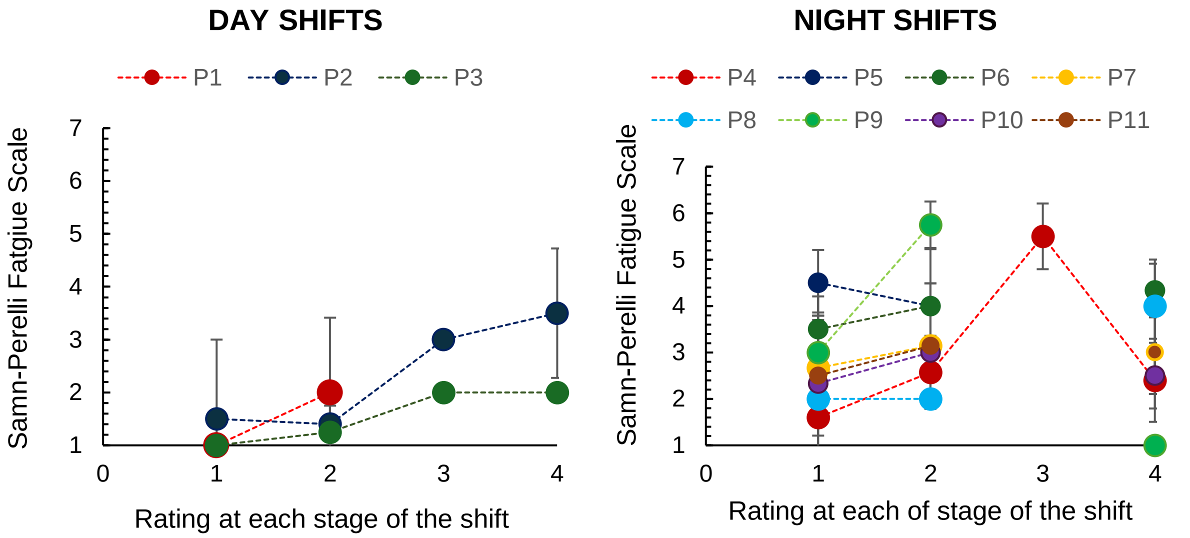

Figure 13: Individual participant SPFS ratings for day shifts (left panel) and for night shifts (right panel).

4.11.6. Samn-Perelli fatigue scale ratings for consecutive day and night shifts.

Similar to the KSS consecutive ratings, inferential statistics on the consecutive day and night shift Samn-Perelli fatigue ratings were not conducted due to some missing data. Furthermore, there was no variance in some of the data points as a result of participants rating the same level of fatigue for that specific duty point. Based on the descriptive statistics, as depicted in Figure 14, fatigue levels increased on day shifts from the start to the end of the shift, with day shift 2 having the highest ratings. For consecutive night shifts, night 1 had the highest fatigue rating at the start of the shift, with overall fatigue ratings peaking for all shifts mid-shift for all three nights, with night 3 having the highest rating. End-of-shift ratings decreased for all shifts. However, overall fatigue levels were low for both consecutive day and night shifts.

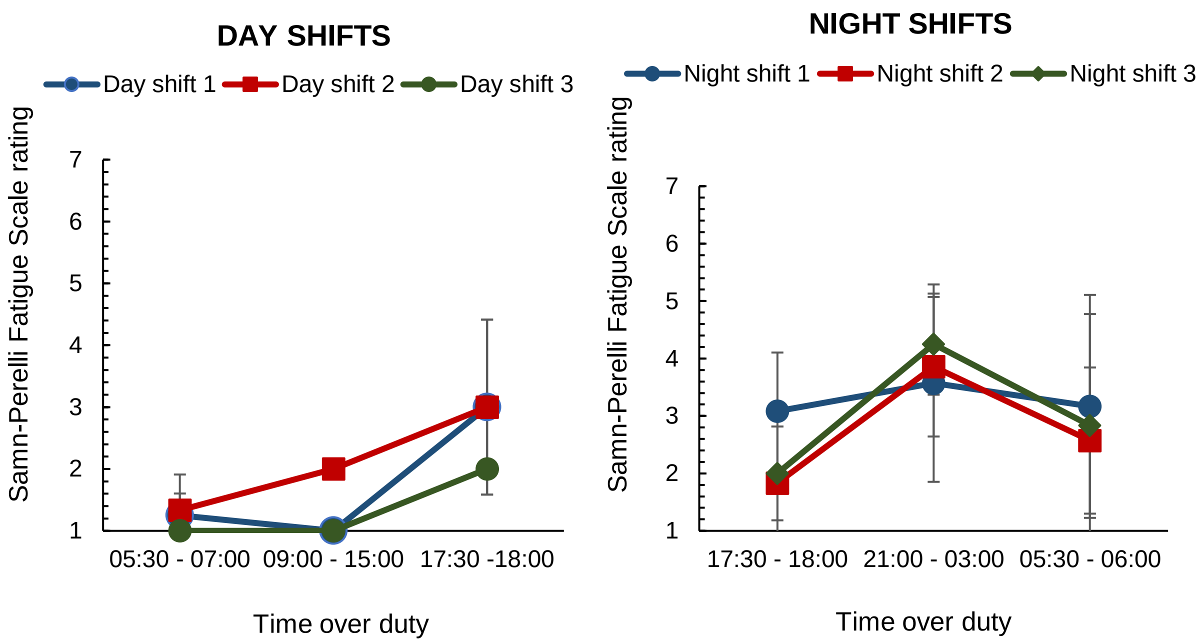

Figure 14: Samn-Perelli Fatigue Scale ratings for consecutive 3 day shifts (left panel) and consecutive 3 night shifts (right panel).

4.12. Workload measure (NASA-TLX)

4.12.1. NASA-TLX ratings

There were no significant differences in mental demand (F (1, 8) = 0.0023, p= 0.9627) and physical demand (F (1, 8) = 0.020, p= 0.8907) between day shifts and night shifts, despite mental demand being the highest contributor of workload on night shifts and physical demand being the highest contributor of workload on day shifts as observed in Figure 15. Similarly, there was no statistically significant difference between shifts for effort (F (1, 8) =0.0677, p= 0.8013) despite being the lowest contributor of end-of-duty workload on night shifts and frustration (F (1, 8) = 0.18024, p= 0.6823) on day shifts. Refer to Appendix N5 for statistics on other NASA-TLX dimensions.

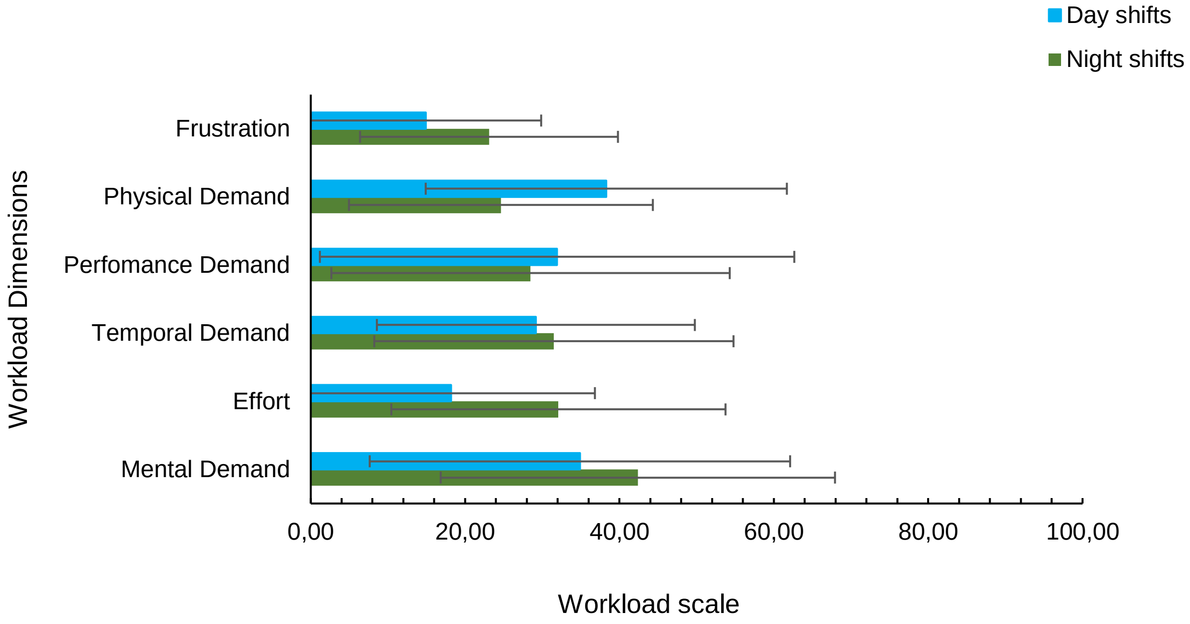

Figure 15: NASA-TLX ratings for day and night shifts.

*day shifts n= 13; night shifts n=38

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CHAPTER 5: DISCUSSION

5.1. Summary of key findings

The first aim of the study was to gain an understanding of the HEMS operations in a South African company by contextualising the work system, with a particular focus on the working time arrangements. The interviews with executives revealed that the shift arrangements were typically three to four consecutive duty days (day or night shifts) with two to three rest days. Each duty day was approximately 12 hours per shift, with differences across bases to accommodate the demands of each base.

The results also revealed that HEMS operations in this company face various unique challenges. Organisationally, these included a shortage of skilled HEMS pilots and more specific environmental challenges to the South African context, such as load shedding. The skill shortage has an impact on the rostering system, which may affect the number of shifts the crew are allocated and the repositioning of pilots between bases. Additionally, pilots have to deal with the demands of work and potential fatigue risks, for which no formal policies are in place; however, the organisation promotes a reporting culture, allowing the crew to report if they feel tired and for appropriate steps to be taken. Furthermore, the interviews revealed that the company tries to ensure a balanced roster, where having a co-pilot included in missions during night shifts is a protective safety mechanism used to mitigate the effects of on-duty sleepiness and fatigue. The company also provides sleep locations to promote on-duty sleep, especially during night shifts.

At the Gauteng base, day shifts started earlier than at other bases for pilots to factor in road traffic, as day shift pilots mainly slept at home. The Limpopo base day shifts started later to allow secondary paramedics, provided by the Department of Health, to commute to the base, making the day shifts 11 hours and night shifts 13 hours in length. However, as highlighted from the interviews, this arrangement works for this particular base. The Northern Cape province base had 12-hour shifts and provided an additional 24-hour standby HEMS service to the mining industry, meaning that some pilots were on duty for 24 hours. However, this shift arrangement was not accounted for during data analysis.

A second aim of this study was to explore the effects that different shift arrangements have on HEMS pilots' sleep, subjective sleepiness, self-reported fatigue and workload. The findings revealed that sleep, across all shift types, was generally shorter than recommended, with main sleep happening at night. Additionally, no differences were found in the sleep characteristics of HEMS pilots working night and day shifts. Furthermore, no differences were found between sleep on night shifts and rest days. Despite pilots obtaining less than the recommended sleep duration, bedtime and wake-up times were fairly regular. Along with shorter sleep durations, wake after sleep onset (WASO) was, on average, higher than recommended during both work and rest days. The crew that slept at the base were provided with comfortable sleep locations provided by the company, which included insulated single rooms with air-conditioning, bathrooms and a living area, suggesting that these facilities may be used to compensate for the effects of duty scheduling and contribute to the crew feeling well-rested. To compensate for shorter sleep, some crew napped during the daytime, particularly following night shifts when they had missions. This often resulted in a longer sleep duration compared to when there were no naps; however, this study did not test this statistically.

Generally, the findings revealed low levels of self-reported on-duty sleepiness and fatigue across the different shifts, with no significant differences between different shifts. While inferential statistics revealed no significant differences, generally sleepiness was higher during the night shift than during the day shift. For night shifts, sleepiness and fatigue peaked mid-shift and decreased towards the end of the shift. These findings suggest that because pilots mainly slept at night, even during night shifts, it resulted in generally low levels of self-reported sleepiness and fatigue than previous research that has focused on the effects of being awake at night. The NASA-TLX workload assessment revealed that physical demand contributes the most to workload during day shifts and mental demand contributes the most during night shifts; however, there were no significant differences.

The discussion section will report the main findings of the study, focusing on the effects of different shift arrangements on sleep, sleepiness and fatigue, and workload, with the use of the data from the interviews for further interpretation. The section will be followed by the study limitations, the research, and practical recommendations.

5.2. Discussion on key findings

5.2.1. Unpredictable work patterns with unique systemic challenges

In this present study, it was found that sleeping spaces provided to the crew allowed for the opportunity to sleep when on duty, when there was no mission. When there were missions, the mission durations differed between day and night shifts, with longer flight times and mission durations during night shifts. This could be explained by the fact that flying at night could be more challenging, combined with the possibility of landing and taking off under challenging terrains in remote locations. Some of these missions may have also occurred in provinces or areas lacking infrastructure and with ill-equipped hospitals, resulting in paramedics taking longer to stabilise the patients and make the necessary transfers, as highlighted in the interviews. The mission durations may also be coupled with the contextual challenge of power cuts. However, a definite conclusion cannot be made.

With respect to working time, there are some similarities and differences in these shift arrangements to compare with previous studies done in HEMS companies in other countries. In this present study, shifts each shift is 12hours long, with at least three consecutive shifts and two to three rest days. In the study by Radstaak et al. (2014), the shift arrangements of Dutch HEMS pilots were 40 hours over three consecutive days, with almost 13 hours each shift, with three or four rest days. A study was conducted on HEMS medical crew fatigue risks based in England, who worked a 3-in-3 off-forward rotating rota, which means the crew worked three consecutive days followed by three rest days (Rose & Lyon, 2023).

In the Norwegian Air Ambulance, a study on crews with shifts arranged in a 7-day period, 14 days off, 9 days on, and 21 days off (Zakariassen et al., 2019). The duty week started at 10:00 am on a Monday morning and ended at 10:00h the following Monday, with the crew working 24 hours during each duty, with a limitation of 14 hours of active work during a 24-hour period, with a maximum flight time of 7 hours in 24 hours. In this current study, crew are not on-call 24 hours, but rather, the shifts were split into day and night shifts, and were, on average 12-hours in duration. A prominent difference between the Zakarianssen et al. (2019) study and this current study is that the other studies had fatigue mitigating strategies and adopted an FRMS, with specific flight and duty limitations and informed crew scheduling and rostering. Essentially, there are some differences in terms of how the shifts and working times of HEMS are designed and structured across studies and countries, with others having 24-hour standby shifts for consecutive days, as opposed to 12-hour day shifts and night shifts, as is the case in this present study.

5.2.2. Shorter, fragmented but regular sleep-wake behaviour across shifts

A key finding of this study was that all sleep characteristics did not differ across the different day and night shifts, despite different working times. However, the total sleep time for day shifts, night shifts, and rest days was lower than the recommended 7-9 hours for adults, with longer than 20 minutes of WASO suggesting that there were sleep disruptions (Chaput et al., 2018; Hirata et al., 2020). Sleep efficiency, however, was above 85%, suggesting that although the crew obtained fewer hours of sleep on average, most of the time spent in bed was spent sleeping (Hirata et al., 2020). Furthermore, despite short sleep durations during all shifts (including rest days), overall pilots reported fair sleep quality and being well-rested, with rest days' sleep quality and restfulness ratings being higher, but not significantly so. These findings reflect that pilot may be used to sleeping in these contexts and combined with a short sleep onset latency, it appears that crew can fall asleep quickly, which likely reflects the comfortable nature of the accommodation provided at the bases.

Furthermore, the majority of night shift and day shift pilots had a fairly regular (defined as the day-to-day consistency of sleep-timing) bedtime and get-up time, which may be due to set shift times. Pilots working day shifts had more regular total sleep times compared to night shift pilots, where 50% of night shift pilots had less regular total sleep time which could be due to night shift pilots having to sleep on duty and being disturbed by the prospect of a mission or an actual call to respond to one. This can be explained by the fact that being on call (during the night shift) may have impacted the opportunities to sleep. This is discussed in the following paragraphs.

Regarding total sleep time, the results suggest that despite working day or night shifts, the crew still obtained a similar amount of sleep, ranging from over six hours to less than seven hours. The findings on total sleep time for nights are longer compared with Flaa et al. (2020) and Sallinen et al. (2019). The ability of pilots in this study to sleep may be a result of crew being afforded the opportunity to sleep when on duty; therefore, their main sleep period is at night, which aligns with the natural circadian signals to sleep during this time (Goel et al., 2013; Okechukwu, 2022). Additionally, the sleep locations provided by the company at the different bases had insulated separate bedrooms to ensure comfort and the ability to sleep.

In this study, the majority of night shift pilots were positioned at the base and were able to sleep consistently with bedtimes and get-up times (if there were no missions), given that crew could sleep when on duty without having the distractions of being at home. A similar study found consistent sleep timing, which could also be explained by relief from domestic obligations and duties while at work (Flaa et al., 2022). These results may reflect the implication of sleeping away from home where crew may have fewer competing demands on time, while also sleeping in favourable environmental conditions (Jay et al., 2015).

Secondly, with crew working consecutive shifts away from home at the same site, it affords them the chance to become familiar with sleeping in a work location. This may likely be the case for pilots in this study. The interviews also highlighted the adaptability of the crew being shift workers and the demands that come with it. For night shifts, the interviews also highlight that some pilots prefer working night shifts in order to sleep while on duty and be able to spend time with family during the day. This is a critical step towards trying to ensure work-life balance for shift workers.

Apart from the timing of sleep periods, the shortened sleep durations across different shifts may be explained by the fact that sleep was fragmented, as evidenced by long WASO and a high number of awakenings, which were likely due to the nature of HEMS work. More specifically, this refers to the effects of being on-call, particularly during the night shifts. On-call work is unpredictable and requires rapid response when there is a call; however, when there is no call, the quality of crew’s sleep can be impacted due to heightened anxiety about a call, predicting a call and worrying about missing the potential call, as has been reported in previous research in this area (Hall et al., 2017; Vincent et al., 2021). The anxiety created from this likely contributed, in part, to long WASO and fragmented sleep. Sleep fragmentation is characterised by repeated episodes of short sleep interruptions, which may lead to reduced sleep quality, increased objective sleepiness, inability to concentrate during wake periods and fatigue (Bonnet & Arand et al., 2003; Benkirane et al., 2024), however, this present study did not measure this phenomenon.

Another possible contributing factors to the shortened sleep, particularly during the day shifts, were the shift starts and end times, which were arranged differently across the various bases to accommodate each operation/ provincial demand. These shifts' start and end times may have contributed to the pilot's bed and wake times during day shifts and night shifts. The overall get-up time for all bases, for crew working day shifts, was earlier than night shifts and rest days, although not significantly so. Day shift pilots' get-up times may be a result of pilots who had to commute to the base and wake up earlier to do so, taking into consideration factors such as traffic and domestic demands, as mentioned in the interviews. Some night shift pilots were stationed at the base, and had later shift start times; therefore, they did not have to wake up as early and may not have had other competing demands in the evening.

This is consistent with Radstaak et al. (2014) findings, where crews with 12 and 13-hour shifts that started at 06:30 a.m. reported short average sleep duration. Samel et al. (2004) also reported similar results on crew get-up times due to early shift starts. These may further contribute to insufficient sleep opportunities prior to the next shift, more especially with consecutive shifts (Åkerstedt et al., 2021; Roach et al., 2012; Arsintescu et al., 2022). These may further contribute to insufficient sleep opportunities prior to the next shift (Åkerstedt et al., 2021; Roach et al., 2012; Arsintescu et al., 2022).

5.2.3. Consistently short sleep on work and rest days

There were no statistically significant differences in sleep during rest and on-duty days for the night shift workers. Furthermore, total sleep time during rest days was not within the sleep duration recommendation range, despite not being on duty. Although sleep duration was short, sleep efficiency was high, which is consistent with Fletcher et al. (2022), who reported high sleep efficiency during a workweek. These findings may reflect a product of irregular sleeping patterns. Some of the crew lived at the base and may stay at the base during these rest days, which may result in still being settled into the work routine even on rest days. According to Ferguson et al. (2012), small adaptations in circadian rhythm during night work could result in a longer time needed to resume normal sleeping patterns (at night) after a series of night shifts, which is reflective of circadian disruption. This study, however, this current study did not go as far as comparing a series of day and night shifts with a series of rest days after day shifts and rest days after night shifts.

The findings may also suggest that sleep on rest days could also have been insufficient because some of these rest periods were used for repositioning through travel, as revealed during the interviews with executives. This may have resulted in the crew not having sufficient days to recover from consecutive shifts. However, this was not monitored in this study but is certainly an observation that may warrant future research. Furthermore, other contributing factors, which were not the focus of this study but may be useful to consider, such as domestic responsibilities during rest days, may have affected sleep opportunities during rest days/off-duty days.

5.2.4. Sleep-wake behaviour during missions across day shifts and night shifts

While only descriptively analysed, the results revealed no noticeable difference in sleep parameters between day shifts with and without missions. This was likely the result of most missions not going beyond shift end times, and therefore, these did not influence the opportunity for the crew to sleep at night. In contrast, there were noticeable differences in sleep parameters for night shifts with missions compared to those without. The average bedtime was later and more variable during nights with missions. Despite sleeping later, the crew also had to wake up at the same time, mainly because the night shift had ended. This resulted in a shorter average total sleep time, being less than 3 hours on average. Furthermore, the crew slept approximately six hours when there was not a night mission. These findings are consistent with the study of Gregory et al. (2010), where more than half of the pilots reported getting 6 hours or more of sleep during night shifts when they did not fly. These findings suggest that missions greatly impact sleep during night shifts, resulting in shorter sleep periods, and to cope with this, pilots take daytime naps after a night with missions (discussed below).

While not explored in this study, the crew were required, whether awake or asleep, to be in the air within eight minutes of receiving a call. As such, sleep inertia may have impacted alertness at the start and during a flight, particularly if the crew had been sleeping for several hours prior to the call (Kovac et al., 2020). Sleep inertia is the transitory period between sleep and alert wakefulness, which is associated with subjective feelings of disorientation, reduced alertness, and objective reductions in cognitive performance compared to when awake (Tassi & Muzet, 2000). This was not explored in the current study but may be an important phenomenon that future studies should understand better.

5.2.5. The importance of napping following or before night shift missions

So far, the discussion has focused on interpreting the findings around sleep-wake behaviour without the consideration of napping. There were several occasions where pilots reported sleeping in a polyphasic manner. During these occasions, the crew took naps, often after night shifts, more especially on days when missions occurred. When looking at the total sleep time with and without napping, the results reveal when naps were taken, total sleep duration was higher compared (8h07 ± 1h39) in 24 hours, compared to when no napping occurred (7h11 ± 1h50). The difference was approximately an hour, which is further supported in the interviews that highlight that the crew may take naps of over an hour after working night shifts; however, based on the sleep data, this was only common after nights of missions when short sleep durations were obtained. These findings are consistent with those of Fletcher et al. (2022) who reported that on fixed-wing air ambulance personnel sleep length on duty was shorter compared to off-duty, with napping being used to supplement shorter sleep durations. The benefit of polyphasic sleep is that it allows for multiple sleep episodes in a 24-hour period, inclusive of anchored sleep and shorter sleep episodes (Weaver et al., 2021). This suggests that napping was an effective fatigue strategy, especially after nights of sleep periods.

Based on the interviews, day shift pilots may not necessarily take daytime naps due to engaging in secondary tasks outside of HEMS flying that the company offers, as well as attending training sessions and, for some pilots, facilitating various training programs, whilst night shift pilots are not provided with additional tasks. A similar study of HEMS pilots also suggested that administrative duties, phone calls and environmental factors prevented one group of pilots from napping more than another group (Zakariassen et al., 2019).

5.2.6. Consecutive shifts do not result in changes in sleep-wake behaviour

The effects of consecutive day shifts reflected in experts' interviews highlighted that consecutive day shifts in a row "*tire you more*" than a night shift due to early morning starts, family responsibilities, and demands after the shift. They further highlighted that after three or four-day shifts, because of this routine, pilots may experience concerning levels of sleep loss.

To explore the veracity of this concern, we compared sleep-wake behaviour over the course of different shifts and found that there were no differences in sleep-wake characteristics, but as with previous comparisons, the total sleep time was shorter than recommended. This may lead to cumulative sleep loss or sleep debt, which can cumulatively impact alertness and performance across shifts (Guzzetti & Banks, 2022). While the study did not test the effects of this on objective alertness or performance, self-reported sleepiness and fatigue (measured through the KSS and SPFS) were measured, which also did not reveal the effects of the cumulative sleep loss. While likely multifaceted, this may have resulted from the impact of cumulative sleep loss and how this has previously been found to interfere with the ability for sleep deprived individuals to self-rate their level of impairment due to the brain's adaptations to sleep restrictions (Belenky et al., 2003; Van Dongen et al., 2003). More research is needed in this area.

5.2.7. Low on-duty sleepiness and fatigue

Overall, this present study found no significant differences in self-reported sleepiness and fatigue during day and night shifts, with no evidence of excessive on-duty sleepiness and fatigue. This may be due to the pilots having their main sleep period at night, irrespective of the shift type.

Self-reported sleepiness and fatigue during day shifts increased from the start to the end of the shifts; however, they stayed within ranges that are not considered risky. The increase over the day shift period may somewhat resemble the effects of oscillation of normal circadian rhythms, combined with an increase in sleep pressure with extended wakefulness. This observation is consistent with HEMS-specific research, such as the study by Flaa et al. (2020), where HEMS pilots reported low levels of sleepiness at shift start and increased towards the end. Early shift start times, combined with extended duties, may be a contributor to pilots' increase in sleepiness and fatigue, particularly at the end of the day shifts. This is supported by Åkerstedt (2003), who states that early times of rising (between 04:00 and 05:00h) are strongly associated with increased sleepiness during the rest of the day. Despite the increase in sleepiness and fatigue during day shifts, the ratings were, on average, relatively low. Similar findings have been reported in a previous HEMS study where pilots reported relatively low levels of KSS scores (Zakariassen et al., 2019). The present study findings suggest that pilots were able to obtain sufficient rest when on duty, as a result of being able to sleep at night. Furthermore, during day shifts, low levels of sleepiness may have been maintained by pilots undertaking several administrative tasks, assisting at the flight school and attending training sessions when on standby, as highlighted in the interviews.

With respect to the night shifts, sleepiness and fatigue ratings were on average, below concerning levels, but peaked midway through the shift and decreased towards the end. The increase in sleepiness and fatigue mid-shift times is consistent with Bezuidenhoudt's (2014) findings on the HEMS crew that reported a constant increase in sleepiness, with the highest levels at 01:00 am, and revealed that pilots indicated that even though they were able to safely complete a flight, fatigue limited their performance. Nix et al. (2019) also found higher ratings of fatigue scores by HEMS pilots who worked night shifts. However, in this present study, fatigue scores were low as a result of the crew being able to sleep at night and as a result, decreased sleep pressure (Borbély & Achermann, 1999; Goel et al., 2013; Abhilash & Shafer, 2024). However, as revealed in the individual presentations of sleepiness and fatigue across the night shifts (Figures 10 and 13) some crew did report high levels of sleepiness (over a rating of 7) and fatigue (over a rating of 5), which emphasise the importance of managing fatigue through a risk-based approach in cases where individual pilots may be struggling with fatigue.

Another factor that may have contributed to low levels of sleepiness and fatigue in this study may have been caffeine consumption. During day shifts, the crew consumed an average of 2.64 cups, whilst night shift pilots consumed an average of 2.86 cups. Pilots in this current study consumed fewer caffeinated drinks compared to a similar study (Flaa et al., 2022). Having access to decent coffee, as revealed from the interviews, was an important affordance provided by the company and may be another explanation for the low levels of sleepiness on shift. This is given that it is used to enhance cognitive functioning and increase alertness and vigilance and is effective in alleviating fatigue and drowsiness by blocking adenosine receptors (Daubner et al., 2021; Wingelaar-Jagt et al., 2021; Evens et al., 2024).

When looking at consecutive shifts on sleep and fatigue, day shift 3 had the lowest overall sleepiness and fatigue ratings, with day shift 3 having the highest ratings (sleepiness and fatigue). For consecutive night shifts, night 2 had the lowest overall sleepiness and fatigue ratings at the beginning of the shift, and night 3 had the highest ratings midshaft rating. However, overall sleepiness and fatigue ratings during consecutive shifts were low, with night shifts having slightly higher ratings. This, again, may be due to the fact that pilots could sleep at night, which means the sleep pressure was effectively reduced. The findings are similar to Flaa et al. (2019), where the highest sleepiness scores were reported on the first workday.

Overall, the results suggest that for night shift pilots, crew adapted to being able to anchor their sleep at night even when on duty (Wickwire et al., 2017; Reddy et al., 2023), with sleep being shorter perhaps due to crew needing to respond to a potential mission, with sleep being short during day shifts due to crew having early start times and possible domestic obligations. This is also evident in low sleepiness and fatigue ratings, despite consecutive shifts.

5.2.8. Differential workload components across shifts

There were no significant differences in workload dimensions assessed by the NASA-TLX for day and night shifts. Mental workload was the highest contributor to workload during night shifts, which may be attributed to the crew having to be awake during periods of the circadian low window, especially during night flights when there are missions. These findings are consistent with Bezuidenhoudt's (2014) study, where the mental demand of the NASA-TLX was reported to have a higher contribution to workload during night shifts. Additionally, given that the crew rated workload at the end of each duty period, the workload for day and night shifts may have been influenced by whether or not pilots had a mission and the number of missions in that shift. There were more reported missions during day shifts than night shifts, which may have contributed to day shift pilots experiencing more physical demands that is associated with operating the aircraft. Furthermore, on a night when pilots have missions, they are required to take off and land in the dark, and with the potential of factors such as power outages and load-shedding. As outlined in the interviews, loadshedding is a unique challenge. Within the South African HEMS context which may have resulted in high mental workload (Çak et al., 2009; Aionesei & Paraschiv, 2024).

5.2.9. Significance of organisational culture in fatigue management

The interviews revealed that the company does not have formal fatigue management policies in place other than complying with aviation regulations. Despite not having formal fatigue management policies, the company adopted several mechanisms to limit and manage fatigue risks. The company has an organisational culture that encourages the crew to report fatigue, and appropriate measures and steps will be taken. The influence of organisational culture is recognised as being instrumental in ensuring safety, and awareness of determinants of fatigue may aid in the development of effective fatigue mitigation strategies (Rainbird et al., 2010). Houston et al. (2012) highlight that high reporting rates may be an indication of an organisational culture that is committed to mitigating and reducing safety risks, including those associated with fatigue. Overall, pilots obtained short sleep when on duty; however, the main sleep is at night, as the company afforded them the opportunity to sleep, which reduced on-duty sleepiness and fatigue.

5.3. Limitations of the study

There were several limitations of the study that should be noted. This study had a limited sample size due to the company experiencing a crew shortage and, therefore, not having enough permanent pilots allocated to each base. While every effort was made to ensure compliance in wearing the actiwatch for the full seven days, the compliance varied across participants, which impacted the overall sample size. Furthermore, the study cohort was from one company in South Africa. Therefore, the findings are not generalisable across the broader HEMS sectors of South Africa.

Given the contextual and operational demands, when the crew had missions or they needed to sleep, they were not able to complete the sleepiness and fatigue scales at all points during their shifts, and in some cases, the NASA-TLX. This led to missing data as the majority of the crew could not complete the KSS and SPF four times per shift; rather, they completed it three times or whenever they were able to. With the NASA-TLX, there were days when participants did not provide a report, which could have been due to operational demands and duties. This had an impact on the analysis and insights into understanding the experience of the pilots during the most challenging part of the night shift (circadian nadir). The study was not able to differentiate between rest days and travelling during repositioning to characterise if sufficient rest was obtained before the commencement of a night shift and did not consider other activities during rest/off days and how these may have contributed to short sleep. Furthermore, the impact that different bases may have had was not considered in the analyses. With respect to missions, sleep inertia was not monitored during shifts when there were missions for each pilot.

5.4. Future research recommendations

As a result of the sample size, future research should have a larger sample size by collaborating with numerous HEMS companies in South Africa for the findings to be generalised. Interviews with pilots may be conducted to gain the perspective of their sleep experience when on and off duty, and fatigue risks.

Future studies should explore the effects of sleep inertia in response to missions and the impact it has on pilot alertness and flight performance. In addition to this, future research should explore assessing sleepiness, fatigue and workload before and after missions to determine the effects of missions on alertness and workload.

Based on the findings that highlighted repositioning during rest/off-days, future studies should explore further and monitor the effects that repositioning has on rest and sleep opportunities. In addition, future studies should make a comparison of sleep pre-duty, on-duty and post-duty, and if the number of rest days is sufficient to recover from consecutive shifts. This suggestion stems from the results revealing that there were no significant differences between on-duty days and rest days. It is recommended that future research should follow pilots during both day and night shift rotations so that you can make a comparison within individuals and not just between individuals.

For workload measurement, future studies, in addition to the NASA-TLX and mission logs, should consider exploring factors associated with the shift that contribute to workload through questionnaires, surveys, or interviews. This study also suggests that future research should explore post-mission workload. Future research could explore the additional use of objective methods of alertness and fatigue when on duty to supplement subjective measures. These methods will also facilitate a more holistic perspective of the impact of the different working times on pilot alertness and performance capabilities. Lastly, future studies, given the overall short and fragmented sleep of pilots, should explore the effects these working time arrangements have on HEMS personnel’s stress, mental health and wellbeing.

5.5. Practical recommendations

As highlighted from the interviews, when crews are repositioned to work at one of the outbases, they are required to travel, often a six-hour drive, to the next base and need at least a 9-hour rest time before starting a night shift. This commute/travel takes place during the pilot's rest days, which reduces the amount of rest opportunity. Travel days should be factored into the roster for repositioned pilots, as the roster is set for one month. This way, pilots will not need to travel during their rest days and increase sleep/ rest opportunities. However, the study did not know whether pilots were repositing to different bases, from the data.

Based on the researcher's knowledge and interviews with the company and industry experts, the company does not have formal fatigue management strategies and policies in place. However, despite this, there are still fatigue mitigating and safety mechanisms that the company adopts. To supplement this, the company could have more formal fatigue management strategies that entail collecting data on crews sleep and alertness and further providing pilots with their own sleep data. Sleep health and hygiene educational programs could form part of the fatigue management policies to educate the crew about the effects that their working time arrangements may have on their sleep and the impact of fatigue and further equip the crew with the necessary coping strategies. Napping can be one of the strategies that can be promoted for crew to take before and after shifts, which from the study shown to be an effective supplementary strategy to increase total sleep obtained following night shifts with missions.

CHAPTER 6: CONCLUSION

This current study aimed to provide insight into the work system of HEMS and further the work arrangements of pilots in a South African company. It further explored the sleep of HEMS pilots under different shift arrangements, as well as on-duty sleepiness, fatigue, and workload. The study also highlighted the impact of mission days on pilots' sleep on day and night shifts.

Taken together, the results show that irrespective of the type of shift worked, pilots slept predominantly at night. It also revealed no differences in sleep patterns of pilots working different shifts. However, across the shifts, crew obtained insufficient and often fragmented sleep, evidenced by the long WASO and high number of awakenings. Various factors may have impacted the pilot's sleep. Early shift start times and long work hours are suggested to have factored into pilots obtaining poor sleep during day shifts. Additionally, on-call work and sleeping at the base may impact pilots' sleep, with consecutive night shifts potentially resulting in short sleep; however, no significant differences were found with consecutive night shifts. The effects of which need to be understood in future studies. It also found that during night shifts when there are missions, sleep was shorter; however, napping after the shift was used as a compensatory mechanism, which resulted in pilots getting close to the recommended sleep durations, just in a polyphasic manner. Furthermore, the company offered pilots well-equipped sleep areas at the various bases, which may have contributed to pilots' ability to sleep during night shifts, which led to perceived good sleep quality and restfulness.

Sleepiness and self-rated fatigue were relatively low during both day and night shifts. With night shifts, the low sleepiness was likely the result of the fact that the crew could sleep at night, which supported circadian signals for sleep at night, while reducing homeostatic pressure. Furthermore, this study revealed that although on average sleepiness and fatigue were lower, some individual responses revealed high levels of sleepiness and fatigue, emphasising the need to monitor and support individuals in on-call settings like HEMS.

Given the limited research in the field of HEMS sleep and fatigue within the South African context, this study offers a unique insight into how HEMS pilots manage the effects of being on call at different times of the day, achieved largely by anchoring their sleep at night, irrespective of the shifts they work. Further research is necessary to understand the implications of this strategy and how it might fit into a wider fatigue risk management program in the current company and in other similar settings.

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APPENDICES:

APPENDIX A: Ethical clearance letter

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Rhodes University Human Research Ethics Committee
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NHREC Registration number: RC-241114-045
https://www.ru.ac.za/researchgateway/ethics/

27 March 2024

Nthati TLALE

Email: g19t2675@campus.ru.ac.za g19t2675@campus.ru.ac.za

Review Reference: 2023-7495-8266

Dear Nthati TLALE

Title: Characterising the effects of different shift arrangements on sleep-wake behaviour, self-reported sleepiness, subjective fatigue and perceived workload of Helicopter Emergency Medical Services pilots

Researcher: Nthati TLALE

Supervisor(s): Dr Jonathan Davy

This letter confirms that the above research proposal has been reviewed and **APPROVED** by the Rhodes University Human Research Ethics Committee (RU-HREC). Your

Approval number is: 2023-7495-8266

Approval has been granted for 1 year. An annual progress report will be required in order to renew approval for an additional period. You will receive an email notifying you when the annual report is due.

Please ensure that the ethical standards committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the ethics committee on the completion of the research. The purpose of this report is to indicate whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloguing number allocated.

Sincerely,

Janet Hayward

Dr Janet Hayward

Chair: Rhodes University Human Research Ethics Committee, RU-HREC

cc: Ethics Coordinator

APPENDIX B: Gatekeeper permission letter

[redacted]

26 March 2024

Dr Jonathan Davy
Senior Lecturer
Department of Human Kinetics and Ergonomics
Rhodes University
Makhanda
By email

Dear Dr Davy,

MASTERS CANDIDATE: Ms NTHATI TLALE

Study: Characterising the work system, sleep-wake behaviour, self-reported sleepiness, subjective fatigue and perceived workload of Helicopter Emergency Medical Services (HEMS) pilots under different shift arrangements.

Principle researcher: Dr Jonathan Davy
Co-researcher: Nthati Tlale

This letter confirms that [redacted] is a willing participant in the study mentioned above, which will be conducted by the principal researcher and co-researcher discussed above.

Please do not hesitate to contact me with any questions.

Sincerely,

[redacted]
Executive Chairman

[redacted]

APPENDIX C: Phase1 Information letter

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LETTER OF INFORMATION TO PARTICIPANTS

Phase 1

Dear Sir/Madam

My name is Nthati Tlale, a Master's by thesis candidate in the Human Kinetics and Ergonomics department at Rhodes University, supervised by Dr Jonathan Davy.

Thank you for showing interest and willingness to take part in this study provisionally titled: Characterising the effects of different shift arrangements on Helicopter Emergency Medical Services (HEMS) pilot's sleep-wake behaviour, subjective sleepiness, self-reported sleepiness and perceived workload.

This letter provides you with the purpose and understanding of the project, possible expectations required from you, and the risks and benefits should you participate. Please read through the letter carefully and the consent form that follows. If you are interested in participating, a consent form will be signed at your workplace and emailed back to the research team.

Background and Aim of the Study

Over the years, fatigue has been and continues to be considered a significant risk factor in the aviation industry. Extensive research has been conducted on fatigue in commercial aviation, with little on non-scheduled aviation with unique work characteristics such as Helicopter Emergency Medical Services (HEMS). To support medical services, crew are required to work around the clock, for long hours, with the unpredictability of when a mission will occur for both day and night shifts. These working time characteristics, combined with work demands, are associated with extended wakefulness, sleep loss, circadian disruption, decreased sleep quality and quantity and increased fatigue levels. This can result in performance decrements and compromise the quality of patient care and the safety of patients and crew. This study aims to investigate the effects of different shifts on sleep, sleepiness, fatigue and the workload experienced by HEMS pilots. This study is two-phased. Phase 1 is a descriptive qualitative study design that will characterise the work system of helicopter emergency medical services and the shift arrangements to contextualise the operation of helicopter emergency medical services, particularly in a South African context. The purpose is to provide a brief background of the context in which the study will take place.

Testing procedure

The thesis will adopt a human factors lens to understand helicopter emergency medical services work system in a South African air ambulance company. We aim to achieve this through semi-structured interviews and discussions with the relevant company stakeholders as industry experts. Experts' opinions will be of great value to the thesis as they have more knowledge in the field of aviation, particularly helicopter emergency medical services.

Should you wish to participate, basic demographic information will be obtained, specifically age, sex, years of experience in the industry and position. A set of open-ended questions will be prepared before the interview to facilitate a discussion between the researcher and industry expert.

The interviews will be conducted online via Zoom or a similar platform, with a video recording. For in-person interviews, interviews will occur at the base where the participant is based, and a voice recording will be made. Participants will be made aware of the recordings before the start of the interview, and consent will be requested. The purpose of the recordings is for the researcher to be able to go back to interview discussions. Each interview will not take more than an hour.

Anonymity and Withdrawal

All data and personal information obtained from the study will be coded and disassociated from all the names of the participants. Information leading to the identification of each individual will not be released and will remain anonymous. The research student and supervisor will be the only people who will know of this information, solely for data sorting purposes. The raw data will be stored with a passcode on the principal investigator's laptop and can only be accessed by the research team upon request, provided the reason for access is valid. The data will be stored securely for 5 years per the Rhodes University Ethical Standards Committee (RUESC) requirements. The name of the company will also remain anonymous throughout the thesis.

You have the right to withdraw from the study at any point of data collection. If you remain to participate in the study, you will be reminded that you are permitted to withdraw from the study if you wish to, for whatever reason you may have.

Risks and Benefits

There is minimal to no risk in participating in the study. Some participants may feel uncomforTable answering one-on-one questions; however, the questions are not designed to make anyone uncomforTable and are focused on only contextualising the work system.

The results will contribute to the body of knowledge of sleep and fatigue in aviation settings and, more specifically, how the shifts in helicopter emergency medical services impact pilot sleep, which may further help formulate and implement fatigue and sleep management strategies.

Should you have any questions or uncertainty, please feel free to contact me at any point.

Thank you for showing interest in the study. Your participation is highly appreciated.

Yours Sincerely

Nthati Tlale

Research Student

g19t2675@campus.ru.ac.za

nthatitlale16@gmail.com

0744563393

Dr Jonathan P Davy

Supervisor

jonathan.davy@ru.ac.za

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APPENDIX D: Phase 2 Information letter

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LETTER OF INFORMATION TO PARTICIPANTS

Phase 2

Dear Sir/Madam

My name is Nthati Tlale, a Master's by thesis candidate in the Human Kinetics and Ergonomics department at Rhodes University, supervised by Dr Jonathan Davy.

Thank you for showing interest and willingness to take part in this study provisionally titled: Characterising the effects of different shift arrangements on Helicopter Emergency Medical Services (HEMS) pilot's sleep-wake behaviour, subjective sleepiness, self-reported sleepiness and perceived workload.

This letter provides you with the purpose and understanding of the project, possible expectations required from you, and the risks and benefits should you participate. Please read through the letter carefully and the consent form that follows. If you are interested in participating, a consent form will be signed at your workplace and emailed back to the research team.

Background and Aim of the Study

Over the years, fatigue has been and continues to be considered a significant risk factor in the aviation industry. Extensive research has been conducted on fatigue in commercial aviation, with little on non-scheduled aviation with unique work characteristics such as Helicopter Emergency Medical Services (HEMS). To support medical services, crew are required to work around the clock, for long hours, with the unpredictability of when a mission will occur for both day and night shifts. These working time characteristics, combined with work demands, are associated with extended wakefulness, sleep loss, circadian disruption, decreased sleep quality and quantity and increased fatigue levels. This can result in performance decrements and compromise the quality of patient care and the safety of patients and crew. This study aims to investigate the effects of different shifts on sleep, sleepiness, fatigue and the workload experienced by HEMS pilots. This study is two-phased. This letter provides information of Phase 2, which is an observational prospective comparative study design. The objective in this phase is to track the sleep behaviour and alertness of HEMS pilots under different shift arrangements.

Testing procedure

Should you wish to participate, basic demographic information will be obtained, specifically age, sex, years of experience in the industry, position and current sleeping location (if you sleep at home or at the base). You will be asked to wear an actigraphy (ActTrust Condor Instrument) wristwatch for 2 weeks, including workdays and off days. Actigraphy is a small, non-invasive, lightweight wristwatch that tracks temperature, light exposure and wrist movement worn on the non-dominant hand to track sleep-wake behaviour. It is important to note that these wristwatches do not pick up on other personal information, such as sound. The watches are to be worn 24/7 and only taken off when immersing yourself in water or performing intense physical activity. To accompany the watches, a Consensus Sleep diary would need to be completed every day when you wake up (in the morning for day shifts and in the afternoon for night shifts).

You will be required to complete two scales every four hours when on duty, from the start to the end of the duty. One scale is a sleepiness scale called the Karolinska Sleepiness Scale, a seven-point likert scale where you will be required to rate your sleepiness level within the past 5 minutes by selecting the point that best describes how you feel. The second scale is a fatigue scale called the Samn-Perelli fatigue, which is a nine-point likert scale and will be completed the same way as the Karolinka Sleepiness scale, whereby you will be asked to assess your fatigue level. At the end of each duty day, you will be required to fill out a perceived workload measure, the NASA-TLX.

The sleepiness scale, fatigue scale and NASA-TLX are completed for two weeks only on workdays and not on days offs; however, the actigraphy watches and sleep diaries will be completed on both workdays and non-work days for 2 weeks.

The sleepiness and fatigue scales will be completed online through Google forms. The NASA-TLX will be completed through a mobile app that will be loaded on each participant's personal device.

Anonymity and Withdrawal

All data and personal information obtained from the study will be coded and disassociated from all the names of the participants. Information leading to the identification of each individual will not be released and will remain anonymous. The research student and supervisor will be the only people who will know of this information, solely for data sorting purposes. The raw data will be stored with a passcode on the principal investigator's laptop and can only be accessed by the research team upon request, provided the reason for access is valid. The data will be stored securely for 5 years per the Rhodes University Ethical Standards Committee (RUESC) requirements. The name of the company will also remain anonymous throughout the thesis.

You have the right to withdraw from the study at any point of data collection. If you remain to participate in the study, you will be reminded that you are permitted to withdraw from the study if you wish to, for whatever reason you may have.

Risks and Benefits

There are minimal risks associated with participating in this study. However, participants with sensitive skin may experience pressure sores from wearing the actigraphy watches, as they will be required to be worn 24/7 for two weeks of data collection. If this is the case for any participant, it is advised that the watches should be taken off for a few minutes to reduce the risks of such an occurrence.

The results will contribute to the body of knowledge of sleep and fatigue in aviation settings and, more specifically, how the shifts in helicopter emergency medical services impact pilot sleep, which may further help formulate and implement fatigue and sleep management strategies.

Should you have any questions or uncertainty, please feel free to contact me at any point.

Thank you for showing interest in the study. Your participation is highly appreciated.

Yours Sincerely

Nthati Tlale	Dr Jonathan P Davy
Research Student	Supervisor
g19t2675@campus.ru.ac.za	jonathan.davy@ru.ac.za
nthatitlale16@gmail.com	
0744563393	0722260430

APPENDIX E: Phase 1 Informed consent declaration letter

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PARTICIPANT INFORMED CONSENT DECLARATION

Phase 1

(To be signed by research participant/s)

Project Title: Characterising the effects of different types of shift work arrangements on the sleep-wake behaviour, self-reported sleepiness, subjective fatigue and perceived workload of Helicopter Emergency Medical Service(HEMS) pilots.

Nthati Tlale the researcher, and Dr Jonathan Davy the supervisor from the Department of Human Kinetics and Ergonomics, Rhodes University, has requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to firstly provide an overview of the work system of Helicopter Emergency Medical Services (HEMS) operations and secondly to track pilots sleep-wake behaviour, sleepiness, fatigue and workload ratings to assess how different shift arrangements.

2. Rhodes University has given ethical clearance to this research project ***(Ethics Approval Number 2023-7495-8266)*** and I have seen/may request to see the clearance certificate by contacting the Ethics Coordinator (ethics committee@ru.ac.za)

3. By participating in this research project I will be contributing towards providing an understanding on how the working time arrangements of Helicopter Emergency Medical Services may affect crews sleep and alertness, particularly within the South African context.

4. I will participate in the project by answering interview questions for one session that will be focused on characterising the work system of helicopter emergency medical services.

5. My participation is entirely voluntary, and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.

6. I will not be compensated for participating in the research, but my out-of-pocket expenses will be reimbursed.

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7. The following risks are associated with my participation: There is minimal to no risk in participating in the study. Some participants may feel uncomforTable in answering one on one questions; however, the questions are not designed to make anyone uncomforTable and are focused on only contextualising the work system.

8. The Researcher intends to publish the research results in the form of a Master's Thesis and academic publications. However, confidentiality and anonymity of records will be maintained, and my name and identity will not be revealed to anyone who has not been involved in the conducting of the research, ***unless I indicate to the contrary/recognise that as a public Figure my identity will inevitably be/become known, in which case I agree to accept the loss of anonymity.***

9. In terms of the Protection of Personal Information Act (No. 4 of 2013) it remains my right to request the Researcher to provide me with a detailed explanation of exactly how confidentiality and anonymity of the data I provide will be achieved. I may also request to know exactly how my personal information will be stored securely, for how long it will be stored.

10. If any data collected from me for this research project is to be used by the Researcher for any further study, I am to be informed in writing and my written consent requested again. I need not give consent for the new research if it is incompatible with the initial purpose of the present study (POPIA, s15(3)). Equally, I can simply reject the request. In such cases, a formal request needs to be made to me by the researcher via the Ethics Coordinator (ethics-committee@ru.ac.za).

11. In terms of the POPI Act, I possess the right to receive feedback about this research. This will take the form of a written report that will be sent to the company.

12. Any further questions that I might have regarding the nature of the research and/or my participation in it will be answered by Nthati Tlale (g19t2675@campus.ru.ac.za)

13. By signing this informed consent declaration, I am not waiving any legal claims, rights, or remedies. A copy of this informed consent declaration will be given to me, and the original will be kept on record by the Researcher.

14. I ***agree/disagree*** (delete inapplicable) to the Researcher's use of voice recording of my comments and opinions during interviews, the purpose of which is to ensure the accurate recording of my views/responses. Furthermore, I have the right to request a copy of the interview transcriptions to confirm that my opinions are accurately recorded

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I, ………………………………………………………………………….., have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I wished to ask, and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurised in any way and I voluntarily agree to participate in the above mentioned project.

………………………………… ……………………….. …………………………
Participants signature Witness Date

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APPENDIX F: Phase 2 Informed consent declaration letter

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PARTICIPANT INFORMED CONSENT DECLARATION

Phase 2

(To be signed by research participant/s)

Project Title: Characterising the effects of different types of shift work arrangements on the sleep-wake behaviour, self-reported sleepiness, subjective fatigue and perceived workload of Helicopter Emergency Medical Service(HEMS) pilots.

Nthati Tlale the researcher, and Dr Jonathan Davy the supervisor from the Department of Human Kinetics and Ergonomics, Rhodes University, has requested my permission to participate in the above-mentioned research project.

The nature and the purpose of the research project and of this informed consent declaration have been explained to me in a language that I understand.

I am aware that:

1. The purpose of the research project is to firstly provide an overview of the work system of Helicopter Emergency Medical Services (HEMS) operations and secondly to track pilots sleep-wake behaviour, sleepiness, fatigue and workload ratings to assess how different shift arrangements.

2. Rhodes University has given ethical clearance to this research project ***(Ethics Approval Number 2023-7495-8266)*** and I have seen/may request to see the clearance certificate by contacting the Ethics Coordinator (ethics committee@ru.ac.za)

3. By participating in this research project I will be contributing towards providing an understanding on how the working time arrangements of Helicopter Emergency Medical Services may affect crews sleep and alertness, particularly within the South African context.

4. I will participate in the project by wearing actigraphy wristwatches and completing sleep diaries for 7 days for both workdays and non-work days, as well as completing a sleepiness scale and fatigue scale every four hours for each duty day. Aperceived workload scale will be completed at the end of each duty to obtain a workload indicator.

5. My participation is entirely voluntary, and should I at any stage wish to withdraw from participating further, I may do so without any negative consequences.

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6. I will not be compensated for participating in the research, but my out-of-pocket expenses will be reimbursed.

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7. The following risks are associated with my participation: There is a low risk in participating in the study; however, participants with sensitive skin may experience pressure sores from wearing the actigraphy watches, and if this is the case, participants are advised to remove the watches for a few minutes. There is a low to no risk that participation in the study will compromise employment in the company as anonymity and confidentiality will be maintained in the thesis and feedback report. Therefore, the company managers will not be aware of who participated in the study.

8. The Researcher intends to publish the research results in the form of a Master's Thesis and academic publications. However, confidentiality and anonymity of records will be maintained, and my name and identity will not be revealed to anyone who has not been involved in the conducting of the research, ***unless I indicate to the contrary/recognise that as a public Figure my identity will inevitably be/become known, in which case I agree to accept the loss of anonymity.***

9. In terms of the Protection of Personal Information Act (No. 4 of 2013) it remains my right to request the Researcher to provide me with a detailed explanation of exactly how confidentiality and anonymity of the data I provide will be achieved. I may also request to know exactly how my personal information will be stored securely, for how long it will be stored.

10. If any data collected from me for this research project is to be used by the Researcher for any further study, I am to be informed in writing and my written consent requested again. I need not give consent for the new research if it is incompatible with the initial purpose of the present study (POPIA, s15(3)). Equally, I can simply reject the request. In such cases, a formal request needs to be made to me by the researcher via the Ethics Coordinator (ethics-committee@ru.ac.za).

11. In terms of the POPI Act, I possess the right to receive feedback about this research. This will take the form of a written report.

12. Any further questions that I might have regarding the nature of the research and/or my

participation in it will be answered by Nthati Tlale (g19t2675@campus.ru.ac.za)

13. By signing this informed consent declaration, I am not waiving any legal claims, rights, or remedies. A copy of this informed consent declaration will be given to me, and the

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original will be kept on record by the Researcher.

I, ……………………………………………………………………….., have read the above information / confirm that the above information has been explained to me in a language that I understand and I am aware of this document's contents. I have asked all questions that I

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wished to ask, and these have been answered to my satisfaction. I fully understand what is expected of me during the research.

I have not been pressurised in any way and I voluntarily agree to participate in the above mentioned project.

………………………………… ……………………… …………………………
Participants signature Witness Date

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APPENDIX G: Semi-structured interview schedule

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Proposed semi-structured interview questions to characterise the work system of Helicopter Emergency Medical Services

Dear Sir/Madam

My name is Nthati Tlale, the researcher of this study, and I am a Masters by thesis candidate in the Human Kinetics and Ergonomics department at Rhodes University. My supervisor is Dr. Jonathan Davy.

Thank you for showing interest and willingness to take part in this study.

This interview aims to gain more insight into the helicopter emergency medical service's work system and the required working time arrangements, specifically within a South African company. This information will be used to provide background in which the study will be taking place, as in phase 2 of the study, whereby pilots' sleep-wake behaviour, sleepiness, fatigue, and workload will be collected to investigate the effects that different duty arrangements have on sleep and alertness of helicopter emergency medical services pilots.

As outlined in the participant consent form and information letter provided to you, which you are requested to read through thoroughly before the commencement of this interview, there is minimal to no risk in participating in the study. Should you feel uncomforTable answering some of the questions, please remember that the questions are not designed to make you uncomforTable but are aimed at on only contextualising the work system. If a question is unclear, do not hesitate to ask me to clarify it. You are reminded that participation in this study is entirely voluntary, and you have the right not to answer any of the questions and to choose to withdraw from this interview for whatever reason you may have. The interview will be recorded not for any other reason but so I can use it for analysis purposes. It should not take more than an hour of your time.

Should you have any concerns or questions, please feel free to ask me. Do you consent to taking part in this recorded interview? If so, please also read and complete the accompanying consent form.

Proposed Questions

1. Could you please tell me about yourself, who you are, your role in the company, and number of experience in the company and industry?
2. Can you provide an overview of the purpose of helicopter emergency medical services and the pilots' role in this type of operation?
3. Apart from flying, what other tasks do pilots do when on duty?
4. In your opinion, what are some of the challenges that helicopter emergency medical services pilots face?
5. To maintain around-the-clock emergency medical services, what are the shift arrangements, and can you explain why shifts are designed that way? (Prompt: Is it influenced by factors such as regulations?)
6. What are the differences in shift arrangements across bases, and why is this the case?
7. When pilots fly to attend to a medical emergency, typically, how many missions occur in a single shift, how long does each mission take, and why?
8. Based on the shift arrangements, what effects does it have on pilots sleep and fatigue levels? (Prompt: What do pilots say about their sleep?)
9. Do pilots sleep at home when on duty, or does the company provide sleeping locations? (Prompt: Do pilots sleep at the base or at home during workdays, and what about rest days?)
10. When there are no missions, are pilots allowed the opportunity to sleep?
11. What interventions or strategies does the company use to enhance sleep quality and manage fatigue?

12. Is there any other important information not mentioned in this interview that you would like to add?

We have reached the end of the interview. Thank you for showing interest and taking time out of your day. Your participation is highly appreciated.

Should you have any questions or uncertainty even after the interview, please feel free to contact me or my supervisor at any point.

Nthati Tlale

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Dr Jonathan Davy

Supervisor

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Appendix H: Demographic information sheet

Participant code	Watch number	Name	Surname	Age	Sex M/F	Role	Main sleep location (base or home)	email	phone number

APPENDIX I: Consensus sleep diary (M)

Sleep Diary Instructions (CSD)

General Instructions

What is a Sleep Diary? A sleep diary is designed to gather information about your daily sleep pattern.

How often and when do I fill out the sleep diary? It is necessary for you to complete your sleep diary every day. If possible, the sleep diary should be completed within one hour of getting out of bed in the morning.

What should I do if I miss a day? If you forget to fill in the diary or are unable to finish it, leave the diary blank for that day.

What if something unusual affects my sleep or how I feel in the daytime? If your sleep or daytime functioning is affected by some unusual event (such as an illness, or an emergency) you may make brief notes on your diary.

What do the words "bed" and "day" mean on the diary? This diary can be used for people who are awake or asleep at unusual times. In the sleep diary, the word "day" is the time when you choose or are required to be awake. The term "bed" means the place where you usually sleep.

Will answering these questions about my sleep keep me awake? This is not usually a problem. You should not worry about giving exact times, and you should not watch the clock. Just give your best estimate.

Sleep Diary Item Instructions

Use the guide below to clarify what is being asked for each item of the Sleep Diary.

Date.: Write the date of the morning you are filling out the diary.

1. What time did you get into bed? Write the time that you got into bed. This may not be the time you began "trying" to fall asleep.

2. What time did you try to go to sleep? Record the time that you began "trying" to fall asleep.

3. How long did it take you to fall asleep? Beginning at the time you wrote in question 2, how long did it take you to fall asleep.

4. How many times did you wake up, not counting your final awakening? How many times did you wake up between the time you first fell asleep and your final awakening?

5. In total, how long did these awakenings last? What was the total time you were awake between the time you first fell asleep and your final awakening. For example, if you woke 3 times for 20 minutes, 35 minutes, and 15 minutes, add them all up (20+35+15= 70 min or 1 hr and 10 min).

6a. What time was your final awakening? Record the last time you woke up in the morning.

6b. After your final awakening, how long did you spend in bed trying to sleep? After the last time you woke-up (Item #6a), how many minutes did you spend in bed trying to sleep? For example, if you woke up at 8 am but continued to try and sleep until 9 am, record 1 hour.

6c. Did you wake up earlier than you planned? If you woke up or were awakened earlier than you planned, check yes. If you woke up at your planned time, check no.

6d. If yes, how much earlier? If you answered "yes" to question 6c, write the number of minutes you woke up earlier than you had planned on waking up. For example, if you woke up 15 minutes before

the alarm went off, record 15 minutes here.

7. What time did you get out of bed for the day? What time did you get out of bed with no further attempt at sleeping? This may be different from your final awakening time (e.g. you may have woken up at 6:35 a.m. but did not get out of bed to start your day until 7:20 a.m.)

8. In total, how long did you sleep? This should just be your best estimate, based on when you went to bed and woke up, how long it took you to fall asleep, and how long you were awake. You do not need to calculate this by adding and subtracting; just give your best estimate.

9. How would you rate the quality of your sleep? "Sleep Quality" is your sense of whether your sleep was good or poor. (1=very poor, 2=poor, 3= fair, 4=good, 5= very good).

10. How restful or refreshed did you feel when you woke up for the day? This refers to how you felt after you were done sleeping for the night, during the first few minutes that you were awake. (1=Not al all rested, 2= slightly rested, 3=somewhat rested, 4=Well-rested, 5= Very well-rested)

11a. How many times did you nap or doze? A nap is a time you decided to sleep during the day, whether in bed or not in bed. "Dozing" is a time you may have nodded off for a few minutes, without meaning to, such as while watching TV. Count all the times you napped or dozed at any time from when you first got out of bed in the morning until you got into bed again at night.

11b. In total, how long did you nap or doze? Estimate the total amount of time you spent napping or dozing, in hours and minutes. For instance, if you napped twice, once for 30 minutes and once for 60 minutes, and dozed for 10 minutes, you would answer "1 hour 40 minutes." If you did not nap or doze, write "N/A" (not applicable).

12a. How many drinks containing alcohol did you have? Enter the number of alcoholic drinks you had where 1 drink is defined as one 12 oz beer (can), 5 oz wine, or 1.5 oz liquor (one shot). *12b. What time was your last drink?* If you had an alcoholic drink yesterday, enter the time of day in hours and minutes of your last drink. If you did not have a drink, write "N/A" (not applicable).

13a. How many caffeinated drinks (coffee, tea, soda, energy drinks) did you have? Enter the number of caffeinated drinks (coffee, tea, soda, energy drinks) you had where for coffee and tea, one drink = 6-8 oz; while for caffeinated soda one drink = 12 oz.

13b. What time was your last caffeinated drink? If you had a caffeinated drink, enter the time of day in hours and minutes of your last drink. If you did not have a caffeinated drink, write "N/A" (not applicable).

14. Did you take any over-the-counter or prescription medication(s) to help you sleep? If so, list medication(s), dose, and time taken: List the medication name, how much and when you took EACH different medication you took tonight to help you sleep. Include medication available over the counter, prescription medications, and herbals (example: "Sleepwell 50 mg 11 pm"). If every night is the same, write "same" after the first day

15. Comments: If you have anything that you would like to say that is relevant to your sleep feel free to write it here.

Definitions of sleep parameters

Bedtime: the time one got in bed to prepare for sleep.

Get-up time: the final awakening after a sleep period

Sleep onset latency: the time it takes to transition from full wakefulness to sleep

Time in Bed: the duration spent in bed and is derived by subtracting the time the subject went to bed (in bedtime) from the time the subject arose (get up time).

Total Sleep Time: the total amount of time spent sleeping.

Sleep efficiency: the ratio of total sleep time to time in bed sleeping.

Wake after sleep onset: the total time of wakefulness after sleep onset until final awakening

Number of awakenings: the number of times woken up during between sleep onset and sleep onset

Self-rates restfulness: how you felt after you were done sleeping for the night, during the first few minutes that you were awake

Self-rated sleep quality: perceived experience of the quality of sleep obtained

APPENDIX J: Karolinska Sleepiness Scale

KAROLINSKA SLEEPINESS SCALE

Please, indicate your sleepiness during the five minutes before this rating through circling the appropriate description.

Participant code: ________ **Base:**___________ **Date:**__________

1=extremely alert

2=very alert

3=alert

4=rather alert

5=neither alert nor 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

APPENDIX K: Samn-Perelli Fatigue Scale

Samn-Perelli Fatigue Scale

Please, indicate how you are feeling at this current moment by rating through circling the appropriate description.

Participant code: ________ Base: __________ Date:_____________

1=fully alert, wide awake

2=very alert, responsive, but not a peak

3=okay, somewhat fresh

4=a little tired, less than fresh

5=moderately tired, let down

6=extremely tired, very difficult to concentrate

7=completely exhausted, unable to function effectively

APPENDIX L: NASA-TLX

NASA-TLX RATING SCALE DEFINITION

(Taken from Hart and Staveland, 1988)

RATING SCALE DEFINITIONS		
Title	**Endpoints**	**Descriptions**
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
PERFORMANCE	*Good/Poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

Mental Demand How mentally demanding was the task?

Very Low - Very High (0-100)

Physical Demand How physically demanding was the task?

Very Low - Very High (0-100)

Temporal Demand How hurried or rushed was the pace of the task?

Very Low - Very High (0-100)

Performance How successful were you in accomplishing what you were asked to do?

Perfect -Failure (0-100)

Effort How hard did you have to work to accomplish your level of performance?

Very Low - Very High (0-100)

Frustration How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low - Very High (0-100)

APPENDIX M: Basic Descriptive Statistics

Descriptive statistics table for number of days of monitoring for phase 2.

	Number of days monitored workdays	Number of days monitored during rest days
Participant 1	6	1
Participant 2	6	2
Participant 3	7	1
Participant 4	4	1
Participant 5	5	0
Participant 6	6	1
Participant 7	5	1
Participant 8	3	1
Participant 9	5	0
Participant 10	4	1
Participant 11	4	3

Descriptive statistics table for average sleep parameters of standby shifts (worked by 1 standby pilots)

Sleep parameters	**Standby (n=7)**
Shift Start time (hrs: min)	06:00 (0)
Shift end time (hrs: min)	06:00 (0)
Bedtime (hrs: min)	23:51 (00:59)
Getup time (hrs: min)	06:32 (00:42)
Time in Bed (hrs: min)	6:40 (0:17)
Total Sleep Time (hrs: min)	6:00 (0:24)
Sleep onset latency (min:sec)	07:09 (04.40-09:40)
Sleep efficiency (%)	89.85 (88.04-91.67)
WASO (hrs: min)	00:28 (00:19-00:37)
Number of awakenings	10.7 (10.7-10.7)
Self-rated sleep quality	3 (1.41)
Self-rated restfulness	3 (1.41)

Descriptive statistics table for consecutive three day shifts

	Day 1	Day 2	Day 3
Bedtime (hrs: min)	20:52 (00:30)	21:42 (01:31)	20:44 (01:21)
Getup time (hrs: min)	05:44 (00:48)	05:27 (01:15)	04:55 (00:52)
Time in Bed (hrs: min)	08:52 (01:08)	07:45 (01:02)	07:13 (01:40)
Total Sleep Time (hrs: min)	07:32 (01:32)	06:48 (00:19)	05:52 (00:46)
Sleep onset latency (min:sec)	03:00 (03:00 -10:00)	03:00 (03:00 -18:00)	04:00 (03:00 -20:00)
Sleep efficiency (%)	91.21 (69.13 – 94.65)	92.82 (76.87 – 96.60)	90.62 (67.45 -91.54)
Wake after sleep onset (hrs: min)	00:49 (00:21 – 02:34)	00:26 (00:11- 01:42)	00:32 (00:23 -02:36)
Number of awakenings	20.3 (10.21)	19.00 (12.76)	14.67 (13.32)

Descriptive statistics for consecutive three night shifts

	Night 1 (1 mission)	Night 2 (1 mission)	Night 3 (1 mission)
Bedtime (hrs: min)	23:07 (02:01)	22:51 (01:21)	00:00 (02:12)
Getup time (hrs: min)	05:20 (02:09)	06:13 (00:58)	06:14 (01:04)
Time in Bed (hrs: min)	06:20 (02:58)	07:22 (01:20)	06:14 (03:00)
Total Sleep Time (hrs: min)	05:31 (02:46)	06:24 (01:13)	05:40 (02:52)
Sleep onset latency (min:sec)	06:00 (05:00 – 08:00)	06:00 (03:30- 12:30)	05:00 (03:30 -07:00)
Sleep efficiency (%)	87.89 (81.87 -89.67)	88 (83.12 -92.34)	93.39 (78.61 -93.89)
Wake after sleep onset (hrs: min)	00:38 (00:23 -00:54)	00:39 (00:18 - 01:11)	00:20 (00:14 -00:26)
Number of awakenings	13.50 (7.78)	17.13 (8.79)	9.25 (5.55)

APPENDIX N: Inferential Statistics

APPENDIX N1: Main Sleep data

One-way anova for bedtime

Effect	Univariate Tests of Significance for BT Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.9446				
	SS	Degr. of Freedom	MS	F	p
Intercept	4295.203	1	4295.203	4813.883	0.000000
Shift	4.085	1	4.085	4.579	0.061043
Error	8.030	9	0.892		

One-way anova for get-up time

Effect	Univariate Tests of Significance for GUT Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.9507				
	SS	Degr. of Freedom	MS	F	p
Intercept	291.7105	1	291.7105	322.7541	0.000000
Group	1.0236	1	1.0236	1.1325	0.314959
Error	8.1343	9	0.9038		

One-way anova for time in bed

Effect	Univariate Tests of Significance for TIB (MAINSLEEPDATAJUNE17 (1)) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1.3093				
	SS	Degr. of Freedom	MS	F	p
Intercept	505.3341	1	505.3341	294.7954	0.000000
Group	0.9454	1	0.9454	0.5515	0.476641
Error	15.4277	9	1.7142		

One-way anova for total sleep time

Effect	Univariate Tests of Significance for TST (MAINSLEEPDATAJUNE17 (1)) Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1.3106				
	SS	Degr. of Freedom	MS	F	p
Intercept	380.3740	1	380.3740	221.4332	0.000000
Group	0.5816	1	0.5816	0.3386	0.574947
Error	15.4600	9	1.7178		

Mann-Whitney U Test for sleep efficiency

	Mann-Whitney U Test (w/ continuity correction) (MAINSLEEPDATAJUNE17 (1)) By variable Group Marked tests are significant at p <.05000

variable	Rank Sum D	Rank Sum N	U	Z	p-value	Z adjusted	p-value	Valid N D	Valid N N	2*1sided exact p
SE	21.00000	45.00000	9.000000	0.510310	0.609834	0.510310	0.609834	3	8	0.630303

Mann-Whitney U Test for onset latency

	Mann-Whitney U Test (w/ continuity correction) (MAINSLEEPDATAJUNE17 (1)) By variable Group Marked tests are significant at p <.05000									
variable	Rank Sum D	Rank Sum N	U	Z	p-value	Z adjusted	p-value	Valid N D	Valid N N	2*1sided exact p
OL	13.00000	53.00000	7.000000	-0.918559	0.358327	-0.918559	0.358327	3	8	0.375758

Mann-Whitney U Test for WASO

	Mann-Whitney U Test (w/ continuity correction) (MAINSLEEPDATAJUNE17 (1)) By variable Group Marked tests are significant at p <.05000									
variable	Rank Sum D	Rank Sum N	U	Z	p-value	Z adjusted	p-value	Valid N D	Valid N N	2*1sided exact p
WASO	18.00000	48.00000	12.00000	0.00	1.000000	0.00	1.000000	3	8	1.000000

One-way anova for Number of Awakenings

	Univariate Tests of Significance for AWK Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 7.5752				
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	2135.257	1	2135.257	37.21061	0.000179
Group	6.765	1	6.765	0.11790	0.739209
Error	516.447	9	57.383		

One-way Anova for sleep quality

	Univariate Tests of Significance for SQ Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.7415				
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	123.3970	1	123.3970	224.4389	0.000000
Group	0.1445	1	0.1445	0.2628	0.620545
Error	4.9482	9	0.5498		

One-way Anova for restfulness

	Univariate Tests of Significance for RF Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.9360				
Effect	SS	Degr. of Freedom	MS	F	p
Intercept	130.3117	1	130.3117	148.7432	0.000001
Group	0.9845	1	0.9845	1.1237	0.316738
Error	7.8848	9	0.8761		

APPENDIX N2: Comparison of Rest days with Night shifts

Dependent t test comparison for average BT during night shifts vs rest periods

Variable	T-test for Dependent Samples (Sleep wake data) Marked differences are significant at p < .05000									
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
WN_BT	23.00748	0.977966								
RN_BT	22.40710	0.921015	7	0.600376	1.043752	1.521862	6	0.178867	-0.364933	1.565685

Dependent t test comparison for average GUT during night shifts vs rest periods

Variable	T-test for Dependent Samples (Sleep wake data) Marked differences are significant at p < .05000									
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
WN_GUT	6.029955	1.044228								
RN_GUT	6.195198	1.008901	7	-0.165244	1.328260	-0.329148	6	0.753230	-1.39368	1.063192

Dependent t test comparison for average TIB during night shifts vs rest periods

Variable	T-test for Dependent Samples (Sleep wake data) Marked differences are significant at p < .05000									
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
WN_TIB	7.051259	1.421609								
RN_TIB	7.788095	0.392843	7	-0.736837	1.256516	-1.55150	6	0.171765	-1.89892	0.425247

Dependent t test comparison for average TST during night shifts vs rest periods

Variable	T-test for Dependent Samples (Sleep wake data) Marked differences are significant at p < .05000									
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
WN_TTS	6.073770	1.350820								
RN_TTS	6.907143	0.482265	7	-0.833373	1.241657	-1.77577	6	0.126113	-1.98171	0.314968

Wilcoxon Matched pairs test comparing WASO for night shifts vs rest periods

Pair of Variables	Wilcoxon Matched Pairs Test Marked tests are significant at p <.05000			
	Valid N	T	Z	p-value
WN_WASO & RN_WASO	7	12.00000	0.338062	0.735317

Wilcoxon Matched pairs test comparing SOL for night shifts vs rest periods

Pair of Variables	Wilcoxon Matched Pairs Test Marked tests are significant at p <.05000			
	Valid N	T	Z	p-value
WN_SOL & RN_SOL	7	4.000000	1.690309	0.090970

Wilcoxon Matched pairs test comparing SE for night shifts vs rest periods

Pair of Variables	Wilcoxon Matched Pairs Test Marked tests are significant at p <.05000			
	Valid N	T	Z	p-value
WN_SE & RN_SE	7	10.00000	0.676123	0.498963

Dependent t test comparison for average AWK during night shifts vs rest periods

Variable	T-test for Dependent Samples Marked differences are significant at p < .05000									
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
WN_AWK	15.01293	7.431898								
RN_AWK	16.64286	8.209315	7	-1.62993	7.715021	-0.558961	6	0.596418	-8.76514	5.505272

Dependent t test comparison for average SQ during night shifts vs rest periods

Variable	T-test for Dependent Samples (Copy of MAINSLEEPDATAJUNE18) Marked differences are significant at p < .05000									
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
WN_SQ	3.658333	0.487150								
RN_SQ	4.500000	0.577350	4	-0.841667	1.001989	-1.67999	3	0.191551	-2.43605	0.752721

Dependent t test comparison for average RF during night shifts vs rest periods

Variable	T-test for Dependent Samples (Copy of MAINSLEEPDATAJUNE18) Marked differences are significant at p < .05000									
	Mean	Std.Dv.	N	Diff.	Std.Dv. Diff.	t	df	p	Confidence -95.000%	Confidence +95.000%
WN_RF	3.508333	0.875754								
RN_RF	4.500000	0.577350	4	-0.991667	0.745542	-2.66026	3	0.076322	-2.17799	0.194658

APPENDIX N3: Consecutive shifts (day and night shifts)

Two factorial repeated measures ANOVA for comparison of bedtime between shift types (Night vs Day) over three consecutive shifts

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 2.3284				
	SS	Degr. of Freedom	MS	F	p
Intercept	13092.37	1	13092.37	2414.898	0.000000
Shift	24.38	1	24.38	4.497	0.062976
Error	48.79	9	5.42		
DAYS	2.94	2	1.47	0.738	0.492209
DAYS* Shift	2.07	2	1.04	0.519	0.603698
Error	35.90	18	1.99		

Two factorial repeated measures ANOVA for comparison of get up time between shift types (Night vs Day) over three consecutive shifts

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1.9878				
	SS	Degr. of Freedom	MS	F	p
Intercept	847.7428	1	847.7428	214.5441	0.000000
Shift	1.5500	1	1.5500	0.3923	0.546660
Error	35.5623	9	3.9514		
DAYS	0.3930	2	0.1965	0.1995	0.820899
DAYS* Shift	2.7633	2	1.3816	1.4031	0.271460
Error	17.7242	18	0.9847		

Two factorial repeated measures ANOVA for comparison of time in bed between shift types (Night vs Day) over three consecutive shifts

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 3.4629				
	SS	Degr. of Freedom	MS	F	p
Intercept	1414.407	1	1414.407	117.9498	0.000002
Shift	12.829	1	12.829	1.0698	0.327973
Error	107.924	9	11.992		
DAYS	2.905	2	1.453	0.6486	0.534576
DAYS* Shift	5.099	2	2.550	1.1385	0.342315
Error	40.311	18	2.239		

Two factorial repeated measures ANOVA for comparison of total sleep time between shift types (Night vs Day) over three consecutive shifts

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 3.3147				
	SS	Degr. of Freedom	MS	F	p
Intercept	1054.370	1	1054.370	95.96529	0.000004
Shift	6.032	1	6.032	0.54899	0.477618
Error	98.883	9	10.987		
DAYS	2.612	2	1.306	0.78946	0.469197
DAYS*Shift	3.652	2	1.826	1.10386	0.353019
Error	29.772	18	1.654		

Two factorial repeated measures ANOVA for comparison of number of awakenings between shift types (Night vs Day) over three consecutive shifts

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 13.6746				
	SS	Degr. of Freedom	MS	F	p
Intercept	6409.102	1	6409.102	34.27412	0.000242
Shift	145.102	1	145.102	0.77597	0.401289
Error	1682.958	9	186.995		
DAYS	183.735	2	91.867	4.27567	0.030247
DAYS*Shift	28.462	2	14.231	0.66234	0.527768
Error	386.750	18	21.486		

Two factorial repeated measures ANOVA for sleep quality between shift types (Night vs Day) over three consecutive shifts

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1.1311				
	SS	Degr. of Freedom	MS	F	p
Intercept	375.0316	1	375.0316	293.1489	0.000000
Shift	2.7891	1	2.7891	2.1802	0.173910
Error	11.5139	9	1.2793		
DAYS	0.0177	2	0.0088	0.0244	0.975955
DAYS*Shift	0.6237	2	0.3119	0.8600	0.439851
Error	6.5278	18	0.3627		

Two factorial repeated measures ANOVA for restfulness between shift types (Night vs Day) over three consecutive shifts.

Effect	Repeated Measures Analysis of Variance Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1.6202				
	SS	Degr. of Freedom	MS	F	p
Intercept	380.5568	1	380.5568	144.9740	0.000001
Shift	7.1023	1	7.1023	2.7056	0.134405
Error	23.6250	9	2.6250		
DAYS	0.0909	2	0.0455	0.0744	0.928603
DAYS* Shift	0.0909	2	0.0455	0.0744	0.928603
Error	11.0000	18	0.6111		

SOL, WASO and SE not normal = MU test for each variable, for each shift

SOL, DAY 1

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D1_OL	14.00000	52.00000	8.000000	-0.714435	0.474959	-0.729512	0.465689	3	8	0.496970

DAY 2

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D2_OL	15.00000	51.00000	9.000000	-0.510310	0.609834	-0.523567	0.600580	3	8	0.630303

DAY 3

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D3_OL	17.50000	48.50000	11.50000	0.00	1.000000	0.00	1.000000	3	8	0.921212

SE, DAY 1

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D1_SE	21.00000	45.00000	9.000000	0.510310	0.609834	0.510310	0.609834	3	8	0.630303

DAY 2

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D2_SE	21.00000	45.00000	9.000000	0.510310	0.609834	0.510310	0.609834	3	8	0.630303

DAY 3

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D3_SE	12.00000	54.00000	6.000000	-1.12268	0.261573	-1.12268	0.261573	3	8	0.278788

WASO, DAY 1

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D1_WASO	21.00000	45.00000	9.000000	0.510310	0.609834	0.510310	0.609834	3	8	0.630303

DAY 2

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D2_WASO	17.00000	49.00000	11.00000	-0.102062	0.918707	-0.102295	0.918523	3	8	0.921212

DAY 3

variable	Mann-Whitney U Test (w/ continuity correction) By variable Shift Marked tests are significant at p <.05000									
	Rank Sum Group 1	Rank Sum Group 2	U	Z	p-value	Z adjusted	p-value	Valid N Group 1	Valid N Group 2	2*1sided exact p
D3_WASO	26.00000	40.00000	4.000000	1.530931	0.125787	1.530931	0.125787	3	8	0.133333

SOL COMPARISON OVER CONSECUTIVE DAY SHIFTS

Variable	Friedman ANOVA and Kendall Coeff. of Concordance ANOVA Chi Sqr. (N = 3, df = 2) = 3.714286 p = .15612 Coeff. of Concordance = .61905 Aver. rank r = .42857			
	Average Rank	Sum of Ranks	Mean	Std.Dev.
D1_OL	1.500000	4.500000	5.333333	4.041452
D2_OL	1.833333	5.500000	8.000000	8.660254

D3_OL	2.666667	8.000000	9.000000	9.539392

SE COMPARISON OVER CONSECUTIVE DAY SHIFTS

Variable	Friedman ANOVA and Kendall Coeff. of Concordance ANOVA Chi Sqr. (N = 3, df = 2) = 4.666667 p = .09697 Coeff. of Concordance = .77778 Aver. rank r = .66667			
	Average Rank	Sum of Ranks	Mean	Std.Dev.
D1_SE	2.333333	7.000000	84.99667	13.84817
D2_SE	2.666667	8.000000	88.76333	10.47190
D3_SE	1.000000	3.000000	83.20333	13.65054

WASO COMPARISON OVER CONSECUTIVE DAY SHIFTS

Variable	Friedman ANOVA and Kendall Coeff. of Concordance ANOVA Chi Sqr. (N = 3, df = 2) = 2.666667 p = .26360 Coeff. of Concordance = .44444 Aver. rank r = .16667			
	Average Rank	Sum of Ranks	Mean	Std.Dev.
D1_WASO	2.000000	6.000000	74.66667	70.11657
D2_WASO	1.333333	4.000000	46.33333	48.78866
D3_WASO	2.666667	8.000000	70.33333	74.32586

SOL COMPARISON OVER CONSECUTIVE NIGHT SHIFTS

Variable	Friedman ANOVA and Kendall Coeff. of Concordance ANOVA Chi Sqr. (N = 8, df = 2) = 1.448276 p = .48474 Coeff. of Concordance = .09052 Aver. rank r = -.0394			
	Average Rank	Sum of Ranks	Mean	Std.Dev.
D1_OL	2.250000	18.00000	7.62500	5.28982
D2_OL	2.062500	16.50000	11.50000	14.13203
D3_OL	1.687500	13.50000	5.37500	2.13391

SE COMPARISON OVER CONSECUTIVE NIGHT SHIFTS

Variable	Friedman ANOVA and Kendall Coeff. of Concordance ANOVA Chi Sqr. (N = 8, df = 2) = 5.250000 p = .07244 Coeff. of Concordance = .32812 Aver. rank r = .23214			
	Average Rank	Sum of Ranks	Mean	Std.Dev.
D1_SE	1.500000	12.00000	83.57625	13.59152
D2_SE	1.875000	15.00000	87.00000	6.38218
D3_SE	2.625000	21.00000	87.57750	10.93952

WASO COMPARISON OVER CONSECUTIVE NIGHT SHIFTS

Variable	Friedman ANOVA and Kendall Coeff. of Concordance ANOVA Chi Sqr. (N = 8, df = 2) = 4.750000 p = .09302 Coeff. of Concordance = .29687 Aver. rank r = .19643			
	Average Rank	Sum of Ranks	Mean	Std.Dev.
D1_WASO	2.375000	19.00000	39.37500	23.56715
D2_WASO	2.250000	18.00000	45.00000	29.21350
D3_WASO	1.375000	11.00000	24.87500	22.31871

APPENDIX N4: Karolinksa Sleepiness Scale (KSS) and Samn-Perelli Fatigue Scale

Two-factorial analysis for KSS

Effect	Repeated Measures Analysis of Variance KSS Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 1.6736				
	SS	Degr. of Freedom	MS	F	p
Intercept	*168.6689*	*1*	*168.6689*	*60.22191*	*0.000111*
Shift types	7.0760	1	7.0760	2.52644	0.155977
Error	19.6055	7	2.8008		
TIME	5.8845	2	2.9423	1.85642	0.192698
TIME*Shift types	8.4283	2	4.2142	2.65894	0.104998
Error	22.1887	14	1.5849		

Two-factorial analysis for Samn-Perelli Fatigue Scale

Effect	Repeated Measures Analysis of Variance SPFS Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 0.9889				
	SS	Degr. of Freedom	MS	F	p
Intercept	*105.6031*	*1*	*105.6031*	*107.9853*	*0.000047*
Shift types	5.4752	1	5.4752	5.5987	0.055813
Error	5.8676	6	0.9779		
TIME	2.6683	2	1.3341	1.3771	0.289474
TIME* Shift types	4.2405	2	2.1202	2.1884	0.154775
Error	11.6261	12	0.9688		

Appendix N5: NASA-TLX

One-way anova mental demand

Effect	Univariate Tests of Significance for Mental Demand Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 26.4893				
	SS	Degr. of Freedom	MS	F	p
Intercept	14775.63	1	14775.63	21.05734	0.001781
Shift type	1.63	1	1.63	0.00232	0.962743
Error	5613.48	8	701.69		

One-way anova physical demand

Effect	Univariate Tests of Significance for Physical Demand Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 21.2871				
	SS	Degr. of Freedom	MS	F	p
Intercept	4677.475	1	4677.475	10.32236	0.012371
Shift type	9.120	1	9.120	0.02013	0.890695
Error	3625.121	8	453.140		

One-way anova temporal demand

Effect	Univariate Tests of Significance for Temporal Demand Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 22.4525				
	SS	Degr. of Freedom	MS	F	p
Intercept	9443.498	1	9443.498	18.73284	0.002518
Shift type	34.482	1	34.482	0.06840	0.800287
Error	4032.916	8	504.114		

One-way anova performance demand

Effect	Univariate Tests of Significance for Perfomance Demand Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 27.0744				
	SS	Degr. of Freedom	MS	F	p
Intercept	*10105.17*	*1*	*10105.17*	*13.78559*	*0.005932*
Shift type	323.38	1	323.38	0.44116	0.525241
Error	5864.19	8	733.02		

One-way anova effort

Effect	Univariate Tests of Significance for Effort Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 22.1012				
	SS	Degr. of Freedom	MS	F	p
Intercept	*9751.567*	*1*	*9751.567*	*19.96382*	*0.002089*
Shift type	33.050	1	33.050	0.06766	0.801343
Error	3907.696	8	488.462		

One-way anova frustration

Effect	Univariate Tests of Significance for Frustration Sigma-restricted parameterization Effective hypothesis decomposition; Std. Error of Estimate: 16.6333				
	SS	Degr. of Freedom	MS	F	p
Intercept	*3584.978*	*1*	*3584.978*	*12.95769*	*0.006986*
Shift type	49.867	1	49.867	0.18024	0.682352
Error	2213.344	8	276.668		