The impact of on-call work on anxiety, sleep, and cognitive performance in a laboratory environment

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Dissertation submitted in fulfilment of the requirements for the degree of
Doctor of Philosophy

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24th November 2018

Abstract

Given the current production and service requirements for many organisations, 24/7 operations have become increasingly commonplace. This has resulted in a greater use of non-standard working arrangements, including shift work, and increasingly, on-call work. Despite being operationally essential for many industries, there has been limited research on the human impact of on-call work. There is evidence to suggest that workers experience increased anxiety surrounding their on-call periods, which has been linked with poorer sleep outcomes. It is well known that poor sleep can result in significant cognitive and work performance decrements. As such, it is vital to understand any changes to anxiety and subsequent sleep, as decrements may have far reaching implications for worker and organisational health and safety. This is particularly pertinent as on-call work is often performed in response to emergency situations or in workplaces with high levels of safety risk (i.e., emergency services, healthcare, power network services).

Despite the potentially severe consequences of impaired cognitive performance when on-call, no research has determined which components of on-call work may lead to increased worker anxiety and poorer sleep. Additionally, little previous research has investigated the effects of on-call periods decoupled from the sleep restriction that accompanies the calls and call-outs themselves. As such, this thesis investigates how certain components of on-call work affect anxiety, sleep, and cognitive performance in a laboratory context, without the confounding effect of shortened or interrupted sleep periods. This thesis consists of three studies, each designed to address one component of on-call work thought to cause anxiety. Seventy-two healthy, male participants were recruited to participate in a four-night laboratory study in the Appleton Institute's time-isolated sleep laboratory (n = 24 per study). The same methodology was employed in each study, aside from the on-call conditions they comprised. The four nights of each study were; an adaptation night, a control night (not on-call), and two counterbalanced on-call nights designed to address specific on-call components.

These components were;

Study 1: The likelihood of receiving a call (on-call conditions = *definitely* and *maybe;* Chapter 3),

Study 2: How stressful the tasks to be performed on-call are (on-call conditions = *high stress* and *low stress;* Chapter 4), and

Study 3: The perceived chance of missing the alarm (on-call conditions = *high chance* and *low chance;* Chapter 5).

Participants were given instructions regarding their on-call status prior to bed each night. Outcome measures included pre-bed state anxiety, sleep (as measured by both polysomnography and quantitative electroencephalographic assessment), and next day cognitive performance. The effect of trait anxiety on state anxiety, sleep, and cognitive performance was measured across all three studies. The relationship between trait anxiety and each of these outcome variables was examined in the context of each on-call component, to determine if higher levels of trait anxiety result in poorer tolerance of on-call work (Chapter 6).

Results indicated that conditions with uncertainty around the on-call alarm resulted in poorer sleep and cognitive performance. These differences were seen when participants were instructed that they *may* be called (Chapter 3), and when there was a *high chance* of missing the alarm (Chapter 5). Further, next day cognitive performance improved when participants performed a high stress task on-call, compared with a low stress task, potentially as a result of increased physiological and psychological arousal (Chapter 4). However, the magnitude of these changes was limited. When the effect of trait anxiety was examined in the context of these three studies, it appeared that individuals with lower trait anxiety were no more tolerant of on-call working arrangements than those with higher trait anxiety (Chapter 6).

From this thesis we can conclude that there are some components of on-call work that affect anxiety, sleep, and cognitive performance outcomes more than others. Specifically, the uncertainty around calls seems to produce the most noticeable decrements, though these decrements were not large in magnitude. The findings of this thesis suggest potentially simple, cost-effective strategies for minimising the uncertainty surrounding on-call periods (e.g., a backup call system, or the identification and management of call likelihood). Additionally, findings suggest that there may be some protective effects of performing high stress tasks on cognitive performance on-call. However, it is important to note that this protective effect was apparent under laboratory conditions with just one high stress on-call night, and must be interpreted with caution. These findings are presented with a view to making on-call periods safer and more productive for workers and organisations.

Acknowledgements

First and foremost, I'd like to thank my supervisors – Sally Ferguson, Sarah Jay and Grace Vincent. What a team! I certainly wouldn't have been able to get through this process without your tireless efforts. Sally, your knowledge, and calm and constructive help has been invaluable. SJ, you really struck a balance at helping me see the big picture of my thesis while helping me get through the day to day. And Grace, thank you so much for listening to me when I was getting fed up, for going over my writing with a fine toothed comb, and being so generally supportive. I really couldn't have imagined a better group of women to go through this process with. Working with this team has truly shown me the value in having a supportive network of researchers on a project, and really, what other supervisory team would end every meeting with a group high five?

I'd like to thank Andrew Vakulin, whose assistance with the analysis of my sleep data was invaluable, and Leon Lack, who was so helpful in putting my research into a broader, real world context. I would also like to thank Xuan Zhou for his statistical knowledge and support, and James Leslie, for his help in developing software for the project.

To the research assistants and students on the project – particularly Sally Perrin, Helen Preece and Katya Kovac – thank you so much for being such an amazing team. It was a mammoth effort in the lab, and I really appreciate all the work you put in and the support you gave me.

My sincere thanks also goes to the other PhD students who were such a strong support throughout this whole process. Firstly, Tess Benveniste – without you I wouldn't have been able to see the light at the end of the tunnel, and now that it's done, I believe you owe me a whisky sour! Yasya King and Hannah Brajkovich, you have both also been so supportive, even if sometimes it was way more fun to chat with you in our office rather than finish the thing! Also to Monique Stewart, thanks so much for all your help, snacks, tea, and chats.

To my fiancée Jess – thank you for reading my drafts, making me coffees, and giving me your unwavering support and confidence. Also to my mum, Angela and my dad, Kevin, thank you for your support, and for not asking me too frequently how far off finishing I was!

Financial support

I gratefully acknowledge the funding received from Australian Research Council through the Discovery Projects scheme (DP150104497) which has supported this research.

This research higher degree candidature was supported by a Scholarship from the Australian Government's Research Training Program / Research Training Scheme. I gratefully acknowledge the financial support provided by the Australian Government.

Declaration of Authorship and Originality

I, the undersigned author, declare that all of the research and discussion presented in this thesis is original work performed by the author. No content of this thesis has been submitted or considered either in whole or in part, at any tertiary institute or university for a degree or any other category of award. I also declare that any material presented in this thesis performed by another person or institute has been referenced and listed in the reference section.

Copyright statement

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(Original signature of Candidate) Date

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List of Abbreviations

Abbreviation	Definition
AD	Adaptation night
ANOVA	Analysis of variance
ANS	Autonomic nervous system
BMI	Body mass index
CON	Control
DASS	Depression Anxiety Stress Scale
ECG	Electrocardiogram
EDF	European Data Format
EEG	Electroencephalogram
EMG	Electromyogram
EOG	Electro-oculogram
ESS	Epworth Sleepiness Scale
FFT	Fast Fourier transformations
h	Hour
HPA axis	Hypothalamic-pituitary-adrenal axis
MEQ	Morningness Eveningness Questionnaire
min	Minutes
ms	Milliseconds
MSLT	Multiple Sleep Latency Test
N1	Stage 1 sleep
N2	Stage 2 sleep
N3	Stage 3 sleep

NREM or non-REM	Non-rapid eye movement
OC1	On-call night one
OC2	On-call night two
PSG	Polysomnography
PSQI	Pittsburgh Sleep Quality Index
PTSD	Post-Traumatic Stress Disorder
PVT	Psychomotor vigilance task
qEEG	Quantitative electroencephalogram
REM	Rapid eye movement
RRT	Reciprocal reaction time
RT	Reaction time
SCN	Suprachiasmatic nuclei
SPSS	Statistical Package for the Social Sciences
STAI	State Trait Anxiety Inventory
SWS	Slow wave sleep
TSD	Total sleep deprivation
TST	Total sleep time
WASO	Wake after sleep onset

Publications arising from thesis

Published

1. **Sprajcer, M.**, Jay, S.M., Vincent, G.E., Vakulin, A., Lack, L., Ferguson, S.A. (2018) Uncertain call likelihood negatively affects sleep and next-day cognitive performance while on-call in a laboratory environment. *Chronobiology International*, 35(6), 838-848.
   doi: 10.1080/07420528.2018.1466788.

2. **Sprajcer, M.**, Jay, S.M., Vincent, G.E., Vakulin, A., Lack, L., Ferguson, S.A. (2018). The effects of anticipating a high stress task on sleep and performance during simulated on-call work. *Journal of Sleep Research*, e12691.
   doi: 10.1111/jsr.12691

3. **Sprajcer, M.**, Jay, S.M., Vincent, G.E., Vakulin, A., Lack, L., Ferguson, S.A. (2018). How the chance of missing the alarm during an on-call shift affects pre-bed anxiety, sleep and next day cognitive performance. *Biological Psychology*, 137, 133-139.
   doi: 10.1016/j.biopsycho.2018.07.008

Under review

1. **Sprajcer, M.**, Jay, S.M., Vincent, G.E., Zhou, X., Vakulin, A., Lack, L., Ferguson, S.A. Are individuals with low trait anxiety better suited to on-call work: a laboratory study on anxiety, sleep, and cognitive performance. Under review at Ergonomics.

Note to Readers

This thesis is made up of an introduction, a literature review, four experimental chapters, and a general discussion. Chapters 3, 4, and 5 have been published in relevant journals, with citations presented at the beginning of each of these chapters. Chapter 6 is currently under review for publication. Each publication has been formatted into a style that is consistent with the rest of the thesis. With the exception of minor edits, the content provided in each of the study chapters is consistent with published content. Publications as they are in journals are presented as appendices. Additionally, the papers that make up Chapters 3, 4, and 5 were developed concurrently, and as such are limited in their reference to one another.

Chapter 1. Introduction

1.1 Background

Flexible and non-standard working arrangements have been used increasingly in recent decades in response to economic growth, production demands, and other environmental and societal changes (Costa, 2014; Parent-Thirion et al., 2012). Traditionally, shift work has been used to accommodate 24/7 operations. However, on-call working arrangements are increasingly being utilised instead of, or in conjunction with shift work to ensure operational needs are met (Ziebertz et al., 2015). More than 25% of Australian (Australian Bureau of Statistics, 2016) and 21% of European (Parent-Thirion et al., 2012) employed populations are currently engaged in roles that include an on-call component. In the United States, it was estimated that in 2015, on-call work was performed by 17% of the workforce, a 15% increase from the 2005 rate (Golden, 2015; United States Department of Labour, 2005).

On-call periods typically require employees to be contactable and available to work if required, and is often utilised during periods of time when workloads are unpredictable (Nicol & Botterill, 2004). As such, on-call work often occurs outside of standard work hours (Ziebertz et al., 2017). For example, electricity supply workers may have standard, rostered shifts during the day, but may be on-call overnight to manage emergency outages if required. On-call work is used in a variety of industries, including healthcare, engineering, information technology, aviation, and emergency services (Ferguson et al., 2016; Hall et al., 2016; McCrate, 2018; Nicol & Botterill, 2004). For organisations, the major benefit of on-call work is flexibility and the constant coverage of workplace needs, without the cost associated with rostering staff onto on-site shifts (McCrate, 2018; Nicol & Botterill, 2004; Ziebertz et al., 2015). Furthermore, a recent investigation into the use of on-call work identified a range of other potential benefits for employers (Burri et al., 2018). These include managing volatility in demand or volume of work, the availability of permanent staff, covering employee leave periods (i.e., sick or annual leave), lower labour law protection risk, advantages with recruitment (i.e., longer trial periods and/or temporary recruitment of on-call staff), and lower perceived costs (Burri et al., 2018).

On-call periods can be on-site (proximal), where the employee remains in the workplace until called, or off-site (distal). Distal on-call periods permit employees to be at home, but require them to remain contactable, and to potentially return to their workplace or deploy to an incident with minimal time delays (Paterson et al., 2016; Ziebertz et al., 2015). To meet these requirements, on-call workers are expected to manage their on-call time away from the workplace with the awareness that their personal life may be interrupted. This has been shown to be a significant source of stress and disruption (Bamberg et al., 2012; Lindfors et al., 2006; Nicol & Botterill, 2004; Reid, 2010). Once called, work requirements can differ greatly between roles and industries. For some industries, such as rail, on-call work may require the employee to be available to be contacted by phone, but would not require them to return to their workplace (Cebola, 2014). Conversely, the healthcare industry favours on-site on-call working arrangements (Lim et al., 2017; Rose et al., 2008). For example, doctors may be on-call for up to 24 h at a time and must remain at the hospital for the duration of that period (Lim et al., 2017; Rose et al., 2008). In contrast, for many information technology, emergency response or engineering organisations, on-call periods are off-site, but require workplace attendance when called (Ziebertz et al., 2017).

The frequency with which on-call work is utilised varies both between and within industries. For example, some industries only use on-call to manage rare or unexpected workplace requirements, whereas others include scheduled on-call periods (e.g., roadside assistance vehicle operators who are on-call to attend breakdowns for a specific duration of time). There are also significant differences in on-call management, particularly regarding the proportion of time spent on-call, how on-call periods are interspersed with designated work periods, and how on-call is distributed across a workforce/team. For example, some rail operators require employees to be on-call immediately following a regular work shift, but classify this on-call time as “rest”, as long as no calls are received (Cebola, 2014). Conversely, other rail organisations have seven consecutive 24-h on-call periods, followed by several weeks of rostered work with no on-call periods (Cebola, 2014). Additionally, on-call work is also performed by volunteers (e.g., volunteer firefighters in rural communities), who may be called at any time on top of their regular work schedules (Jay et al., 2018; Paterson et al., 2016).

Despite the practical and/or financial benefits, much is unknown about the effects of on-call work on employees. Research has suggested that there may be variety of negative outcomes for workers, including changes to anxiety (Nicol & Botterill, 2004; Ziebertz et al., 2015), sleep (Ferguson et al., 2016), and cognitive performance (Grantcharov et al., 2001; Wali, 2011). These human impacts of on-call work are the focus of this thesis.

1.2 Research problem

This thesis addresses the main effects of on-call work on anxiety, sleep, and cognitive performance. Though the causal relationship between these factors is outside of the scope of this thesis, one proposed potential relationship between on-call, anxiety, sleep, and cognitive performance is shown in Figure 1.

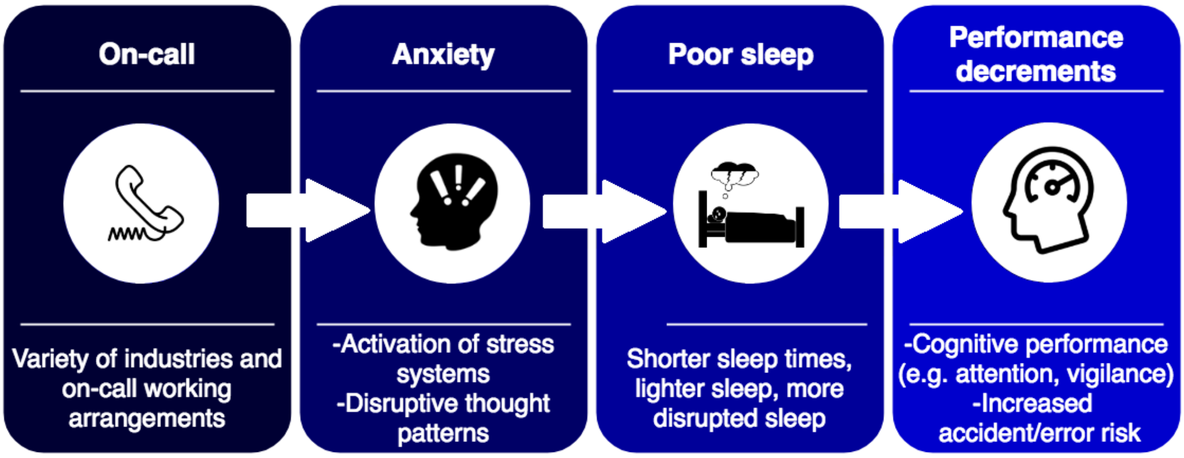

Figure 1. Proposed relationship between on-call work and individual outcomes

1.2.1 Anxiety

Though on-call periods are generally planned, there is inherent unpredictability with regard to if and when calls will occur. As a result, apprehension and anxiety have been consistently reported in association with on-call periods (Bamberg et al., 2012; Nicol & Botterill, 2004; Paterson et al., 2016). Workers report feeling unable to relax during on-call periods (Cebola, 2014), and that they experience anxiety about receiving calls to distressing events (e.g., emergency services workers attending motor vehicle accidents) (Paterson et al., 2016). Further, anxiety may result from the inability to disconnect from the workplace (i.e., the awareness that they may be called at any time) (Nicol & Botterill, 2004; Ziebertz et al., 2015). Subjective reports have also indicated that the perception that on-call workers may miss their alarm or call may lead to increased anxiety (Bamberg et al., 2012; Paterson et al., 2016).

Though anxiety has been shown by both subjective (Bamberg et al., 2012; Paterson et al., 2016) and objective (e.g., salivary cortisol, heart rate) (Dishman et al., 2000; Gonzalez-Cabrera et al., 2018; Hellhammer et al., 2009) measures on-call, it is unclear which components of on-call work lead to this outcome. There are three components of on-call work that have been identified as potential causes of anxiety for workers (Barnes, 2000; Ferguson et al., 2016; Jay et al., 2016; Paterson et al., 2016; Wuyts et al., 2012). These components will be examined in detail in this thesis, and are addressed by the laboratory studies detailed in Chapters 3, 4, and 5. They are;

a) the likelihood that the worker will receive a call during the on-call period (e.g., whether they will they be required to attend an incident or to their workplace);

b) the task they will be required to perform upon waking (i.e., whether this task is stressful or not), and;

c) how likely the individual perceives it to be that they will miss their alarm (i.e., whether they will sleep through their call).

1.2.2 Sleep

In addition to increased anxiety, on-call work has been linked with poorer or shortened sleep (Ferguson et al., 2016). As on-call work often occurs during the night, workers may be woken by a call, or may even be called before they fall asleep. This disruption may result in sleep restriction (shortened sleep) or deprivation (a total lack of sleep) (Ferguson et al., 2016). The impact of receiving calls during the night on sleep is relatively straightforward to identify and quantify, and has been investigated to some degree in the relevant literature (Åkerstedt et al., 1990; Arora et al., 2008; Imbernon et al., 1993; Jay et al., 2008; Nida et al., 2016; Ziebertz et al., 2017). However, little research has been performed on on-call sleep when no calls are received (Torsvall & Åkerstedt, 1988; van de Ven et al., 2015; Wuyts et al., 2012). The limited literature in the area indicates that on-call periods without calls can also result in poorer or shortened sleep (Torsvall & Åkerstedt, 1988; van de Ven et al., 2015). It has been suggested that these sleep decrements are the result of the increased anxiety that workers reportedly experience when on-call (Torsvall & Åkerstedt, 1988; Van Gelder & Kao, 2006). However, to date there has been no systematic investigation of this relationship specifically in the on-call context. The link between anxiety and sleep is well known, with increased anxiety being associated with poor or shortened sleep periods (Amaral et al., 2018; Gould et al., 2017; Kim & Dimsdale, 2007; Wallace et al., 2017). Consequently, the components of on-call work that are likely to affect anxiety may also affect sleep. As such, this thesis also examines how the previously mentioned components of on-call work affect sleep outcomes.

1.2.3 Cognitive performance

It is important to understand how on-call work affects anxiety and sleep, because of the potential negative effects of poor or shortened sleep (During & Kawai, 2017; Krause et al., 2017; Lowe et al., 2017). These effects can include adverse mental (Freeman et al., 2017) and physical health outcomes (DePietro et al., 2017; Glaser & Styne, 2017; Pigarev & Pigareva, 2017), in addition to cognitive performance decrements, such as decreased reaction time and vigilance (During & Kawai, 2017; Krause et al., 2017; Lowe et al., 2017). Further, sleep restriction is linked with increased rates of absenteeism (Tomaka, 2015), poorer safety and productivity in the workplace (Barger et al., 2009; Uehli et al., 2014), an increase in the likelihood of errors, and higher accident risk (Lockley et al., 2007; Scott et al., 2006). Poorer workplace safety is often linked with poor sleep through decrements to cognitive performance, including reaction time, vigilance and attention, processing speed, executive functioning and memory (Lowe et al., 2017). As such, this thesis will also examine how components of on-call work affect next day cognitive performance.

1.2.4 Individual differences

Individual differences may play a role in how being on-call affects anxiety, sleep and cognitive performance. It has been suggested that individuals with higher trait anxiety (i.e., how anxious a person is generally) may be less tolerant of non-standard working time arrangements (Saksvik et al., 2011; Tamagawa et al., 2007). This may result from differences in physiological and psychological reactivity to stressors (Ebner & Singewald, 2017). Typically, the ability to tolerate a working time arrangement is measured by individual outcomes, such as sleep quality, alertness, health, and stress (Saksvik et al., 2011). The relationship between trait anxiety and tolerance to non-standard working time arrangements has largely been explored in traditional shift work environments (Saksvik et al., 2011), with far less research in the on-call space. Subjective reports have suggested that higher trait anxiety and the tendency to worry resulted in increased levels of irritation on-call (Bamberg et al., 2012), in addition to increased fatigue and mental stress (Reid, 2010). However, to date there has been no research specifically addressing the relationship between trait anxiety and on-call anxiety, sleep, and cognitive performance, and which components of on-call work may affect these relationships.

1.3 Thesis objectives

Despite its' prevalence, there has been little research into the human impacts of on-call work. In addition, current understanding of the implications of on-call work for individuals is limited, particularly regarding anxiety, sleep, and cognitive performance. Furthermore, to date, no research has investigated how individual differences may affect these outcomes in the on-call context. As such, this thesis aims to determine how components of on-call work (the likelihood of receiving a call, task stress, and the chance of missing the alarm) affect these outcomes, with a view to providing information to individuals and organisations about how best to manage on-call work. Therefore, the aims of this thesis are:

1) To examine how the uncertainty surrounding an on-call period (i.e., whether the individual will receive a call or not) affects anxiety, sleep, and cognitive performance.
2) To investigate how task stress (i.e., how stressful on-call tasks are) affects anxiety, sleep, and cognitive performance.
3) To understand how the perceived chance of missing the alarm during an on-call period affects anxiety, sleep, and cognitive performance.
4) To determine how individual differences in trait anxiety affect state anxiety, sleep, and cognitive performance outcomes on-call.

To isolate the effects of on-call work generally from the effects of receiving calls during sleep, this thesis focuses on on-call periods with no calls.

1.4 Significance of research

As we do not currently have a full understanding of how certain aspects of on-call work contribute to increased anxiety, in addition to sleep and cognitive performance decrements, it is difficult to develop and implement practical management strategies to keep employees safe and the workplace productive (Dawson & McCulloch, 2005; Lerman et al., 2012). Indeed, regulations in some countries assume that on-call periods with no calls are just as restful as time off (Unison Bargaining Support, 2013), and do not account for any potential adverse impacts on workers. This is despite evidence that this is not the case (Pilcher & Coplen, 2000; Torsvall & Åkerstedt, 1988). Specifically, it has been found that on-call periods with no calls result in poorer sleep outcomes than time off, for example in ships' engineers (Torsvall & Åkerstedt, 1988) and in rail workers (Pilcher & Coplen, 2000). As the areas of employment that tend to include on-call work are generally considered high risk (e.g., emergency services, medicine, and aviation), the impact of poor or shortened sleep on cognitive and work performance may result in catastrophic consequences to persons and/or property. Indeed, on-call work has been linked with heightened injury risk, even when controlling for work environment and occupation type, potentially as a result of "reduced cognitive function and concentration" (Baek et al., 2018, p. 9). If on-call periods are not effectively managed, there may be significant negative outcomes for the safety and performance of these employees. Investigating the outcomes of being on-call through systematic, laboratory-based research will add to the evidence base underpinning future workplace management strategies.

Chapter 2. Literature Review

2.1 Introduction

This chapter presents a review of the relevant literature. It comprises sections on anxiety, sleep and cognitive performance, followed by a review of the current understanding of the on-call components that this thesis addresses. These components include the likelihood of being called, how stressful the task to be performed upon waking is, and the chance of missing the alarm.

2.2 Anxiety

On-call periods are often characterised by reports of increased anxiety (Bamberg et al., 2012; Gonzalez-Cabrera et al., 2018; Nicol & Botterill, 2004; Ziebertz et al., 2015). These reports are commonly associated with stressors that are unique to on-call work, such as the requirement to perform high-stress tasks, and worry about receiving or potentially missing calls (Bamberg et al., 2012; Cebola, 2014; Kecklund et al., 1997; Paterson et al., 2016). This section comprises a review of the literature linking on-call work with anxiety, in addition to how individual differences in anxiety affect pre-bed anxiety, sleep and next day cognitive performance on-call.

Broadly, two kinds of anxiety are discussed in this section – state and trait anxiety. State anxiety refers to how anxious an individual feels *at a given time*, which may be caused by a specific stressor or circumstance (Endler & Kocovski, 2001; Spielberger, 2013). Trait anxiety is an individual's *inherent*, or *baseline* level of anxiety (Endler & Kocovski, 2001). Generally, it is thought that there are individual differences in trait anxiety which lead to "a generalised and enduring predisposition to react to many situations in a consistent manner" (Endler & Kocovski, 2001, p. 233). Anxiety has developed to maintain human safety and wellbeing in response to dangerous situations throughout human evolution (Lang et al., 2000). While anxiety can be an adaptive response, heightened anxiety over long periods can result in poor physical and psychological outcomes (Sylvers et al., 2011).

Though anxiety has been described as "an ambiguous construct" (Endler & Kocovski, 2001, p. 232), it is generally defined as an emotional state characterised by worry, fear and agitation, which is often accompanied by physiological arousal (Barlow, 2002; Endler & Kocovski, 2001). This arousal may include perspiration, shortness of breath, tingling in the extremities, increased heart rate, changes to heart rate variability, and problems with sleep (e.g., difficulty initiating or maintaining sleep) (Asher et al., 2017; Barlow, 2002; Uhde et al., 2009). Though high levels of anxiety are typically associated with clinically diagnosed anxiety disorders (Endler & Kocovski, 2001), it is normal to experience some degree of anxiety, particularly under stressful or challenging circumstances (Crawford & Henry, 2003). Higher levels of trait anxiety can impact how individuals respond to stressful situations (Souza et al., 2015). Specifically, individuals with higher trait anxiety may be less physiologically reactive to stressful situations, due to their typical physiological arousal level being higher than in others, potentially producing a 'ceiling effect' (i.e. as they already have a higher level of physiological arousal at all times, there is limited scope for increases based on external events/stressors) (Souza et al., 2015). Further, higher trait anxiety individuals may struggle to cope psychologically when these situations arise (Spielberger, 2013).

Though stress and anxiety are often used interchangeably within the relevant literature, it is important to note that these constructs are different (Smith et al., 2007). Stress is generally described as "a challenge to a person's capacity to adapt to inner and outer demands, which may be physiologically arousing, emotionally taxing, and cognitively and behaviourally activating" (Burton et al., 2015, p. 859). Anxiety, though eliciting similar outcomes, is a psychological state, heightened levels of which can be clinically diagnosable disorders (Burton et al., 2015). Higher than baseline state anxiety has been linked with on-call periods (Bamberg et al., 2012; Chambers & Belcher, 1994; Gonzalez-Cabrera et al., 2018; Nicol & Botterill, 2004; Ziebertz et al., 2015), in addition to poor sleep outcomes (Peltz et al., 2017; Rosa et al., 1983; Uhde et al., 2009), and as such may play a role in the ability of individuals to manage on-call working arrangements.

2.2.1 On-call and anxiety

Increased anxiety has been demonstrated in on-call workers in a variety of populations and industries, including healthcare (Chambers & Belcher, 1994; Gonzalez-Cabrera et al., 2018; Heponiemi et al., 2015), emergency services (Paterson et al., 2016), rail workers (Cebola et al., 2013), university students (Bloom & Dean, 1997), and general population samples (Ziebertz et al., 2015). There are a number of elements of on-call periods that may elicit heightened anxiety. Firstly, the general uncertainty surrounding whether or not a call will be received has been reported to increase anxiety (Cebola, 2014; Jay et al., 2018; Paterson et al., 2016). Whether a call occurred or not, on-call rail workers have reported anticipation and general anxiety being "always in the background" during their on-call periods (Cebola, 2014, p. 129). This anxiety was described as occurring because the workers are constantly expecting a call, and as such are unable to "relax, because you're always expecting a phone call to come in" (Cebola, 2014, p. 130). Indeed, even workers who remain at their workplace while on-call, such as firefighters, report that their environment is "tense", and as such may not be conducive to relaxation even between calls (Chung et al., 2016; Sawhney et al., 2017).

The tasks undertaken when on-call are likely to be safety or time-critical by nature (e.g., a firefighter attending to a house fire or motor vehicle accident when called (Guidotti, 1992)), which may also result in heightened anxiety (Paterson et al., 2016). Additionally, on-call workers have reported anxiety relating to the belief that they may miss their alarm when it sounds during an on-call period (Paterson et al., 2016). Most of these reports of anxiety have come from subjective interviews with on-call workers (Cebola, 2014; Jay et al., 2018; Paterson et al., 2016). While this data is valuable, it is somewhat limited in terms of applicability to the broader on-call population, as it is largely based on small numbers of on-call workers from specific work groups (Talja, 1999). Additionally, this research has not typically involved the use of validated scales measuring state or trait anxiety (Cebola, 2014; Jay et al., 2018; Paterson et al., 2016). One controlled study on live fire drills did find a trend towards heightened state anxiety, as measured by the State Trait Anxiety Inventory (STAI) (Spielberger, 1983) following work tasks (Smith et al., 2001). However, this finding was not statistically significant, possibly reflecting a small sample size and lack of statistical power. As such, there is a need for additional research using validated scales to determine and quantify the effects of being on-call on anxiety. The impacts of specific on-call components; the likelihood of a call, task stress, and the chance of missing the alarm, are discussed further in section 2.5.

Factors tangential to on-call shifts themselves may also result in heightened anxiety (Bamberg et al., 2012; Cebola, 2014; Imbernon et al., 1993; Lindfors et al., 2006; Ziebertz et al., 2015). For example, the potential negative effects of on-call work on interpersonal relationships and health outcomes may be associated with anxiety (Bamberg et al., 2012; Nicol & Botterill, 2004). The integration of work and personal lives has been identified as a significant stressor for on-call workers and their families (Bamberg et al., 2012; Lindfors et al., 2006; Morris & Blanton, 1994). On-call rail workers indicated that, given the choice, they would prefer not to have on-call as part of their regular work scheduling, largely as a result of the interruptions to their family life (Cebola, 2014). These stressors extend to partners of on-call workers, which may further exacerbate anxiety (Dyrbye et al., 2014; Emmett et al., 2013). For example, if the on-call worker's partner is frustrated with the interruptions to family life or overnight sleep periods, this may negatively impact their personal relationship (Emmett et al., 2013). Additionally, as on-call workers who participate in distal shifts are required to be constantly available to be contacted and/or to start work, this can be limiting in terms of what activities they are able to participate in (e.g., sport or social commitments), how far from their workplace they are able to be, and any childcare/household duties that may be required (Emmett et al., 2013; Imbernon et al., 1993; Jay et al., 2018; Ziebertz et al., 2015). However, while there is significant anecdotal and qualitative evidence of anxiety occurring on-call because of personal and social factors (Emmett et al., 2013; Jay et al., 2018), there has been limited quantitative research into this relationship. Further, much of the research into the effects of on-call work on anxiety include a wide variety of variables (e.g. family responsibilities, interpersonal relationships, social commitments), which makes it difficult to identify which elements of on-call work may be having these detrimental outcomes.

Another factor that may result in heightened anxiety for on-call workers is the impact on recovery time (Nicol & Botterill, 2004; Ziebertz et al., 2015). For time off from work to be restorative, there must be some capacity to disengage from the workplace (Moreno-Jiménez et al., 2009; Sonnentag, 2001, 2012). By nature, this does not occur during on-call periods (Bamberg et al., 2012; Ziebertz et al., 2015). A lack of disengagement from the workplace is often associated with higher levels of anxiety (Nicol & Botterill, 2004), as the individual must be in a constant state of readiness to respond to a call, should it occur (Paterson et al., 2016). Additionally, a large proportion of on-call work inherently occurs overnight, or outside of regular working hours (Bamberg et al., 2012). This is generally because on-call operates on as-needed basis to provide coverage in case of an emergency, or in situations where regular work shifts would be unnecessary (Bamberg et al., 2012; Nicol & Botterill, 2004). As such, on-call workers are often at home attempting to rest or sleep when they are called (Bamberg et al., 2012). As a result, on-call workers may feel as though their sleep is negatively impacted by the expectation of a call and the anxiety surrounding this expectation (Åkerstedt et al., 2012; Kecklund et al., 1997). For example, in airline cabin crews, early start times, and the knowledge that they will be woken before they have had sufficient sleep, are associated with higher levels of apprehension (Åkerstedt et al., 2012; Kecklund et al., 1997).

In addition to the psychological aspects of anxiety that are associated with on-call work, physiological stress responses, commonly seen as markers of anxiety (Boudarene et al., 2002; Gorman & Sloan, 2000; Vreeburg et al., 2010) have been reported (Dishman et al., 2000; Gonzalez-Cabrera et al., 2018; Hellhammer et al., 2009). These include changes to heart rate or the stress hormone, cortisol (Dishman et al., 2000; Gonzalez-Cabrera et al., 2018; Hellhammer et al., 2009). These physiological stress responses are typically seen as a marker of anxiety. For example, higher average heart rates can be a marker of anxiety, and have been observed in individuals when on-call compared with not being on-call (Tendulkar et al., 2005; Torsvall & Åkerstedt, 1988). Higher arterial pressure, decreased parasympathetic modulation and increased sympathovagal balance have also been shown overnight in a laboratory environment, where participants know they will be required to perform a stressful task upon waking (Hall et al., 2004). As such, the heightened heart rates shown while on-call by Tendulkar et al. (2005) and Torsvall and Âkerstedt (1988) may indicate a stress response to on-call work, which can be a marker of anxiety (Boudarene et al., 2002; Gorman & Sloan, 2000; Vreeburg et al., 2010). Similarly, extended work availability (the ability to be contacted via phone or internet) has been shown to result in increases in cortisol levels, which is linked with the inability to recover appropriately (Dettmers et al., 2016). However, findings regarding physiological outcomes of on-call are mixed, with some research showing no significant physiological consequences of on-call shifts (Cebola, 2014; Harbeck et al., 2015). For example, no differences in cortisol were seen between on-call and not on-call in rail workers (Cebola, 2014). Additionally, in a prospective cohort study of physicians, no differences in physiological stress outcomes (cortisol, epinephrine and norepinephrine) were seen between the beginning of a shift, and after a 24-h on-call shift (Harbeck et al., 2015). However, the presence of physiological changes (e.g., heart rate) in response to on-call work across a variety of other studies (Tendulkar et al., 2005; Torsvall & Åkerstedt, 1988) does suggest that there is a link between these outcomes and on-call work to some degree. Therefore, the physiological assessment of on-call periods appears to supports the notion that on-call is linked with heightened anxiety, though this has not been investigated directly in the relevant physiological research (i.e., none of the relevant literature has directly linked these physiological outcomes with heightened subjective anxiety).

Another facet of on-call work that appears to be linked with heightened anxiety is the type of work that must be performed during on-call periods. As on-call workers are often contacted in the context of an emergency or are immediately required to work for other reasons (Aronsson et al., 2002), it follows that work tasks are often high-risk, have safety implications, are complex, and/or require significant cognitive attention (Hall et al., 2016; Heponiemi et al., 2015; Lindfors et al., 2006; Nicol & Botterill, 2004). The possibility that the individual may be required to perform at such a high level immediately upon waking may result in increased apprehension and anxiety (Paterson et al., 2016). For example, self-reports from Finnish physicians indicated that on-call work was associated with increased "time pressure, patient-related stress, stress related to team work, and stress related to patient information systems when compared with physicians who did not work on-call" (Heponiemi et al., 2015, p. 616). The sample size for this study was a third of the total physician population in the country (7000, out of a total of 21 000 physicians), and as such is highly representative of the experience of this kind of on-call worker (Heponiemi et al., 2015). This suggests that it is likely that work type is particularly relevant regarding anxiety in on-call workers.

Many on-call workers are also rostered on for extended periods, which appears to be linked with heightened anxiety and negative affect (Bamberg et al., 2012). This is pertinent for on-call workers, whose work hours can be particularly long compared with other roster types (Cebola, 2014; Cooke et al., 2012; Ozkarahan, 1994). For example, hospital residents can work on-call shifts in excess of 36 h (Ozkarahan, 1994), while some rail organisations require employees to be on-call in addition to their regular work hours (Cebola, 2014). In a sample of 704 general practitioners, questionnaires revealed that working more than one on-call night per week was a predictor of anxiety (Chambers & Belcher, 1994). Within this sample, 31.1% of respondents reported "excessive anxiety" (Chambers & Belcher, 1994). In a separate study of Finnish physicians, it was found that working in excess of forty on-call hours per month was associated with poorer psychological outcomes (Heponiemi et al., 2008). While this study did not measure anxiety, high levels of personal distress (which may be similar to anxiety) were found to result from this amount of on-call work (Heponiemi et al., 2008). Therefore, it appears that work hours may result in heightened anxiety in on-call workers, though as with much of the research that has been performed in this area, there are a number of confounding variables within each study (e.g., organisational differences, health status, or level of experience with on-call work). As such, it remains unclear to what degree each element of on-call periods may result in anxiety.

Another feature of on-call work that may result in heightened anxiety is the way recovery is managed. Many workplaces consider time on-call when no calls are received to be "time off" (European Commission, 2011). However, as being on-call with no received calls may result in heightened anxiety (Reid, 2010), on-call workers may not obtain adequate recovery during this time. This inability to recover may also be linked with heightened anxiety, perpetuating the issue (Reid, 2010). Additionally, a perceived lack of control over working time, and a potential lack of satisfaction with the financial compensation associated with on-call work, may be linked with feelings of anxiety (Ziebertz et al., 2015).

Despite the finding that on-call work is associated with heightened anxiety, there is some indication that individuals may experience some degree of acclimatisation to this working arrangement over time (Cebola, 2014). Subjective reports indicate that after working on-call for extended periods of time (i.e., months or years of on-call work), some individuals may be able to adapt, and not experience the same level of anxiety during on-call periods as they did originally (Arora et al., 2008; Cebola, 2014). In reference to the anxiety felt while on-call, one rail worker who was interviewed stated that "years ago I was always on edge because you didn't know when you were going to get a call – now you don't but at the end of on-call you still go ahhhh (relief sound)" (Cebola, 2014, p. 132). Similarly, Arora et al. (2008) found that medical students working on-call obtained less sleep at the beginning of the academic year, when they were not yet acclimatised to on-call periods. This finding may result from higher levels of anxiety at the beginning of the year, though this was not measured in this investigation (Arora et al., 2008). However, as these results are seen just over one year of on-call work, it is unclear how these sleep outcomes would change over longer periods of time, as there has been no research specifically investigating this. Furthermore, it is possible that there are individual differences in the ability to manage on-call work, which play a role in adaptation (Bamberg et al., 2012; Heponiemi et al., 2015; Reid, 2010).

Despite some level of possible adaptation to on-call work, the body of research presents support for the relationship between this working arrangement and anxiety from a wide variety of industries (Bamberg et al., 2012; Dishman et al., 2000; Gonzalez-Cabrera et al., 2018; Hellhammer et al., 2009; Nicol & Botterill, 2004; Paterson et al., 2016). Further, even if the level of anxiety experienced on-call is mitigated by experience, it is still important to understand this relationship, and determine which components of on-call work result in heightened anxiety for new on-call workers or those that have not adapted to the demands of this working arrangement.

2.2.2 Individual differences

On-call worker outcomes may also be influenced by individual differences, particularly with regards to anxiety and stressful situations. Though stress and anxiety are different, anxiety is often a response to stressful situations, and is linked with the stress response (Burton et al., 2015). It has been well established that there is variation in individual levels of trait anxiety (Eysenck, 2000). Further, there is evidence to suggest that these individual differences may explain why some individuals are better equipped to cope with stressful situations (Ebner & Singewald, 2017). Some of this research suggests that an individual's ability to manage stress is largely physiological (Admon et al., 2009; Porges, 1992), while other research indicates that this ability to cope is linked with environmental and experiential factors, such as stress exposure in early life (Ebner & Singewald, 2017; Hellhammer & Wade, 1993; McEwen & Morrison, 2013; Pena et al., 2017). Vulnerability to stress may be linked with genetic factors, in addition to impairment in stress-neurocircuit function (the way the brain manages stress) (Ebner & Singewald, 2017). Functional stress responses are managed by hormone output through the hypothalamic-pituitary-adrenal (HPA) axis and the autonomic nervous system (ANS), and occur in order to adapt to stressful environments and maintain homeostasis (Ebner & Singewald, 2017; Schneiderman et al., 2005). However, there are individual differences in the functionality of this system and, as such, some individuals may be more or less responsive to stressors (Doom & Gunnar, 2013; Ebner & Singewald, 2017; Schneiderman et al., 2005).

Higher trait anxiety has been linked with a poorer ability to cope with stress (Ebner & Singewald, 2017), and increased physiological responses to stress in rodent models (Landgraf et al., 2007). Additionally, individuals who are high in trait anxiety are also thought to have attentional and interpretive processing biases, in addition to being more likely to perceive a stimulus as being a threat (Walsh et al., 2009). Therefore, higher trait anxiety may be associated with increased vulnerability to stressful situations (e.g., increased stress responses and likelihood of developing a stress-related mental or physical health disorder) (Ebner & Singewald, 2017), potentially including on-call work, which has been described as a stressor in much of the literature (Bamberg et al., 2012; Eslick & Raj, 2002; Lim et al., 2017; Lindfors et al., 2006).

A variety of individual differences have been investigated in the context of non-standard working hours in the previous literature (Saksvik et al., 2011), though research is limited in the on-call context (Bamberg et al., 2012; Heponiemi et al., 2015; Reid, 2010). The main body of research into working arrangements and individual differences has been performed in the context of shift work tolerance. Shift work tolerance generally refers to “the ability to adapt to shift work without adverse consequences”, and is measured by outcomes including sleep, sleepiness, fatigue, social functioning, physical health and mental health (Saksvik-Lehouillier et al., 2015, p. 69). Individual differences may explain why some individuals find it easy to tolerate shift work, whereas others struggle significantly (Saksvik-Lehouillier et al., 2015).

There is evidence suggesting that poorer shift work tolerance is associated with higher levels of trait anxiety (Saksvik et al., 2011; Tamagawa et al., 2007). For example, Tamagawa et al. (2007) found based on subjective questionnaires that in a sample of police officers (n = 89), individuals with high trait anxiety experienced more difficulties managing shift work than those with low trait anxiety. This included increased subjective sleep difficulties and fatigue across a variety of schedules, including night work and rotating shifts (Tamagawa et al., 2007). However, as this study utilised self-report measures, we cannot be confident in the directionality of the relationship – it may be that the ability to tolerate varied shift work schedules has a bidirectional relationship with anxiety, rather than being causally related. This is supported by a study on graphic plant workers (n = 24), who completed a questionnaire including items relating to manifest (trait) anxiety, in addition to other subjective and objective measures of sleep and health (Costa et al., 1989). In this study, lower levels of self-reported trait anxiety were associated with better tolerance to shift work, though similarly, due to the fact that data came from the completion of just one questionnaire, causality cannot be inferred.

There is research to suggest that trait anxiety may result in poorer shift work tolerance because of the negative relationship between trait anxiety and sleep outcomes (i.e., higher trait anxiety is associated with poorer sleep) (Chambers & Kim, 1993; Fuller et al., 1997; Gray, 2017; Nakajima et al., 2014). For example, a recent study of over 1300 college students found a significant relationship between heightened trait anxiety and poor sleep outcomes (Gray, 2017). This may suggest that individuals with higher trait anxiety have poorer sleep, which may then decrease their ability to manage the difficulties associated with shift work (Gray, 2017). However, much of the research into shift work tolerance has been performed using subjective measures of sleep (Harma, 1993; Saksvik et al., 2011). As such, these findings may not be as robust as had objective measures (e.g., polysomnographic (PSG) or actigraphic recordings) of sleep been used. Further, as these studies address shift work rather than on-call work, their applicability in the on-call space is limited, and additional research on the relationship between trait anxiety and the ability to cope with on-call work is required. A full overview of the relationship between anxiety and sleep is presented in section 2.3.5.

There has also been research into individual differences in trait anxiety and the ability to manage non-work stress (Hengartner et al., 2017; Spielberger, 2013; Stokes & Kite, 2017). Again, while not being directly reflective of the on-call context, these stressors may be analogous with on-call stress. This research has suggested that higher levels of trait anxiety may result in individuals being more reactive to stressful situations (Hengartner et al., 2017; Spielberger, 2013; Stokes & Kite, 2017). Indeed, in a recent book discussing performance in aviation, Stokes and Kite (2017) stated that “the trait anxious person is more likely to perceive a given situation as threatening, and to react to this apparent threat with higher levels of state anxiety" (p.25). Research in children and adolescents has suggested that those with higher levels of trait anxiety are more likely to have a greater physiological and/or psychological response to stressors (Barlow, 2002; Cole et al., 1996; Weems et al., 2007). For example, a study was performed on the anxiety experienced by children and adolescents (n = 52) affected by Hurricane Katrina (Weems et al., 2007). Higher trait anxiety was associated with heightened post-traumatic stress symptoms and increased risk of generalised anxiety disorder symptoms (Weems et al., 2007). Similar findings have been seen in adult populations (Albus et al., 1988; Stokes & Kite, 2017; Zahn et al., 1991). Indeed, research has shown that adults with anxiety disorders have a higher level of trait arousal, which is linked with greater physiological (heart rate) responses to stressors (Albus et al., 1988; Stokes & Kite, 2017; Zahn et al., 1991). These physiological responses lasted for longer periods in individuals with trait anxiety (Albus et al., 1988; Stokes & Kite, 2017; Zahn et al., 1991). In the on-call context this may suggest that higher trait anxiety would result in longer, more significant physiological stress responses either when calls are received or in response to the stress related to waiting for calls. However, it is important to note that physiological heart rate and psychological disorders are not necessarily reflective of tolerance to stress (Acharya et al., 2006; Beck et al., 2005), particularly in the on-call context.

Despite the evidence suggesting that individuals with higher trait anxiety may be less tolerant of non-standard working arrangements or other stressful situations, there has been very limited research performed regarding on-call work. In an investigation of the effects of on-call work on wellbeing in information technology workers, Bamberg et al. (2012) found that individuals with higher levels of anxiety and the tendency to worry were more negatively affected by being on-call, particularly in relation to levels of irritation, operationalised as a "psychological state between exhaustion or fatigue and mental illness" (p.306). Additionally, during on-call periods where no calls occur, research into fire officers and physiotherapists demonstrated that individuals with higher trait anxiety had greater fatigue and mental stress than lower trait anxiety individuals (Reid, 2010). These irritation, fatigue and stress outcomes indicate that it is possible that higher trait anxiety individuals find it more difficult to cope with on-call work, though further investigation is required.

As anxiety is reported to be one of the main negative psychological consequences of on-call work (Bloom & Dean, 1997; Cebola, 2014; Chambers & Belcher, 1994; Gonzalez-Cabrera et al., 2018; Heponiemi et al., 2015; Paterson et al., 2016; Ziebertz et al., 2015), it is important to understand the relationship between trait anxiety and the ability to manage this working arrangement. This is important not only for the mental health and wellbeing of workers, but to also understand whether there are subsequent effects on sleep and next day cognitive performance.

2.3 Sleep

There have been extensive reports from on-call workers that their sleep is either disrupted, shortened, or of poor quality during on-call periods (Billings & Focht, 2016; Cebola, 2014; Geer et al., 1996; Iversen et al., 2002; Paterson et al., 2016; Torsvall & Åkerstedt, 1988). As such, it is important to understand the relationship between on-call work and sleep, and the potential role of anxiety in this relationship (i.e., does being on-call lead to heightened anxiety, which then leads to poorer sleep?). This section includes a review of the functions and physiology of sleep, the links between sleep and anxiety, followed by a review of the current understanding of the on-call – sleep relationship.

Sleep is a reversible physiological and behavioural state that is necessary for the restoration and maintenance of physiological and psychological functioning (Carskadon & Dement, 2011). Sleep is characterised by sensory disengagement from the environment, altered brain function, and a lack of physical movement (Cirelli & Tononi, 2008). Carskadon and Dement (2011) describe the state as generally including “postural recumbence, behavioural quiescence, closed eyes, and all the other indicators one commonly associates with sleeping” (p.16).

Habitual sleep need varies between individuals, though it is typically suggested that between 7 and 9 h of sleep per night is ideal for optimal functioning (Badr et al., 2015; Hirshkowitz et al., 2015; Sleep Health Foundation, 2015).

2.3.1 Functions of sleep

The exact function of sleep is still largely unknown, but current understanding indicates that sleep is primarily a restorative measure that the body requires for recovery (Assefa et al., 2015; During & Kawai, 2017). Recovery comprises physiological restoration (During & Kawai, 2017), including from physical and exercise performance (Fullagar et al., 2015), in addition to many cognitive functions, such as performance and mood (Dinges et al., 1997). When inadequate sleep (i.e., less sleep than the individual requires for optimum functioning, or poor quality sleep) is obtained, these outcomes can be negatively affected (Krause et al., 2017; Lim & Dinges, 2010; Lowe et al., 2017). Further, inadequate sleep is associated with feelings of sleepiness and has negative repercussions for work performance and adaptability to the environment (Dinges et al., 1997; During & Kawai, 2017). The effects of sleep restriction on cognitive performance are discussed in depth in section 2.4.

2.3.1.1 Physiological functions

There are numerous physiological processes that can be affected by sleep, including metabolic and immune functions (During & Kawai, 2017), hormonal systems (Assefa et al., 2015), weight regulation (Assefa et al., 2015; Kim et al., 2015; Spaeth et al., 2013), energy conservation (Assefa et al., 2015), and physical exercise performance (Van Helder & Radomski, 1989). Adequate sleep is linked with positive health outcomes, such as reduced hypertension, improved glucose metabolism and lower rates of coronary heart disease (Buysse, 2014; During & Kawai, 2017). Additionally, rapid eye movement sleep (REM) has been linked with brain development in infants and children (Peirano & Algarín, 2007).

One of the main physiological systems that is linked with sleep is hormone production. This includes testosterone and prolactin (Assefa et al., 2015), in addition to growth hormone, pulses of which occur largely during the early phases of slow wave sleep (SWS) (Assefa et al., 2015; Holl et al., 1991; Kim et al., 2015). Melatonin is linked with sleep, with heightened production preceding sleep (Cain et al., 2010; Gooley et al., 2011). Similarly, cortisol, the stress hormone, has a circadian rhythm, which may be disturbed by sleep restriction or shift work (Scheer et al., 2009; Wehr et al., 2001). In a normally entrained individual, cortisol peaks in the early morning (Dorn et al., 2007; Scheer & Buijs, 1999). However, if the individual is engaged in shift work, this rhythm may be disturbed (Scheer et al., 2009; Wehr et al., 2001).

There are also long term health consequences that can result from chronically restricted sleep (i.e., shortened sleep periods over the long term) (During & Kawai, 2017). Consequences can include cardiovascular disease, high blood pressure, gastrointestinal issues, migraines and lung disorders (Åkerstedt, 2006; During & Kawai, 2017; Haack & Mullington, 2005; Kripke et al., 2002; Spiegel, 2008). Chronic sleep restriction is also associated with an overall increased risk of mortality (Assefa et al., 2015).

2.3.1.2 Psychological functions

Some of the main functions of sleep are thought to relate to the restoration and support of brain activity (Benington & Heller, 1995; De Vivo et al., 2017; Rattenborg et al., 2017). This includes the “recovery, maintenance and plasticity of nerve cells and neuronal networks”, which assist the brain with alertness, cognitive processing and consolidation, and behavioural control (Rattenborg et al., 2017, p. 2). Further, research suggests that sleep is important for the functioning of the central nervous system (De Vivo et al., 2017; Scharf et al., 2008). This includes the maintenance and recovery of these systems (Scharf et al., 2008), in addition to regulating neuronal connections (De Vivo et al., 2017).

Not only is good sleep associated with improved brain functioning, it is also linked with mental health outcomes (Reid et al., 2006; Stein et al., 2008). Sleep restriction or deprivation has been linked with a higher risk of developing clinically diagnosed disorders such as major depression (Roberts & Duong, 2014). Additionally, sleep deprivation and restriction are associated with poorer mood, increased anxiety, anger, confusion, irritability, fatigue (Babson et al., 2010; Baum et al., 2014; Dinges et al., 1997), and an inability to effectively regulate emotions (Olia et al., 2017; Palmer & Alfano, 2017).

Learning and memory are also aided by sleep (Maquet, 2001). Sleep appears to be particularly linked with memory consolidation, as opposed to encoding and retrieval of memories (Diekelmann & Born, 2010). Memory consolidation refers to integrating memories that have been encoded during wake with long term memories that already exist (Diekelmann & Born, 2010). It appears that this kind of consolidation is largely incompatible with the waking state, and is linked with benefits for both declarative and procedural memories, and as such is a major function of sleep (Diekelmann & Born, 2010). Additionally, sleep deprivation negatively impacts learning particularly when the task involves novel behavioural strategies (Maquet, 2001). Further, sleeping after learning a new task has been shown to promote learning-dependent synapse formation (Yang et al., 2014).

Poor sleep can also result in significant cognitive performance impairment, which can have wide reaching effects on personal and professional safety and risk (Krause et al., 2017; Lowe et al., 2017). These changes to performance that occur when adequate sleep is not obtained are discussed in detail in section 2.4.

2.3.2 Sleep regulation

Sleep/wake regulation is generally conceptualised using the two process model (Borbély, 1982). This model includes circadian and homeostatic components, known as Process C and Process S, respectively (Borbély, 1982; Borbély et al., 2016). This two process model was conceived of over thirty years ago, and remains the most commonly used conceptualisation of sleep regulation (Borbély & Achermann, 1999, Figure 2; Borbély et al., 2016). These processes interact to control the sleep/wake cycle in humans (Borbély, 1982), and are described in detail in this section.

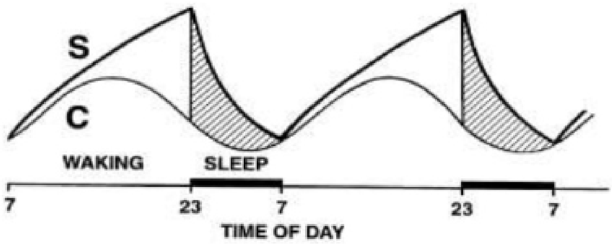

Figure 2. Processes underlying sleep regulation (Process C and Process S) (Borbély & Achermann, 1999)

2.3.2.1 Circadian regulation (Process C)

Circadian rhythms are biological processes controlled by both endogenous and exogenous elements that fluctuate in a predictable way over each 24 h period (Carskadon & Dement, 2011; Harrington, 2001). Each 24-h period comprises cyclical patterns in a variety of behavioural and physiological processes, including sleep, alertness, core body temperature, cognitive performance, gastrointestinal functioning, hormone production, respiratory rate and cell division (Borbély & Achermann, 1999, Figure 2; Harrington, 2001). Each of these functions have peaks and troughs that occur at approximately the same time during each 24-h period (Carskadon & Dement, 2011; Harrington, 2001).

The endogenous component of circadian rhythms is regulated by an internal "master body clock" located in the supra-chiasmatic nuclei (SCN), in the anterior hypothalamus, above the optic chiasm (Colwell et al., 2015; Rivkees, 2007). The SCN is made up of neuron clusters that have peaks in electrical potential during the biological day (Toh, 2008). The role of the SCN in determining sleep/wake timing has been demonstrated in rodent models, where the creation of lesions in this area of the brain resulted in arrhythmic behaviour (Weaver, 1998). Further, the role of an internal clock in sleep/wake regulation has also been shown in human studies that have involved the removal of all external time cues (Mills et al., 1974; Zulley, 1980). These time-isolated studies have consistently shown that without external stimuli, the endogenous circadian rhythm has a period length slightly longer than 24 h in most humans (Czeisler et al., 1980; Mills et al., 1974).

There is some variability, however, in the period length of the circadian rhythm (Czeisler et al., 1999; Sack et al., 2000). As such, exogenous cues are used in conjunction with the endogenous system to keep circadian rhythms entrained to the 24-h day, in order to synchronise with the environment (Toh, 2008; Vitaterna et al., 2001). Exogenous cues are known as zeitgebers, from the German term for "time giver". The primary zeitgeber is light, which is key in maintaining circadian rhythms (Quante et al., 2018). The SCN is entrained by exposure to light through melanopsin-containing retinal ganglion cells, which are photoreceptors that project to the SCN (Hattar et al., 2002; Vosko et al., 2010). This light exposure also results in changes to the production of melatonin in the pineal gland, the hormone associated with sleep, which can also entrain the circadian system (Vosko et al., 2010). While light is the primary zietgeber, meal timing, physical activity and social interaction can also impact the sleep/wake cycle (Duffy et al., 1996). These zeitgebers, in combination with circadian rhythms, result in normally entrained individuals sleeping during the night and being most alert during the day.

2.3.2.2 Homeostatic regulation (Process S)

The sleep/wake cycle is also driven by homeostatic regulation (Process S), which refers to the amount and timing of prior sleep, and how this affects sleep propensity (Borbély et al., 2016; Goel et al., 2013). Broadly, this means that the homeostatic need for sleep increases with time awake, and decreases during sleep (Borbély & Achermann, 1999, Figure 2). The sleep need controlled by Process S is generally entrained to a diurnal profile by Process C (Borbély et al., 2016). This means that while time awake does result in increased sleepiness, peaks and troughs from circadian timing are still apparent (Van Dongen & Belenky, 2009, Figure 3).

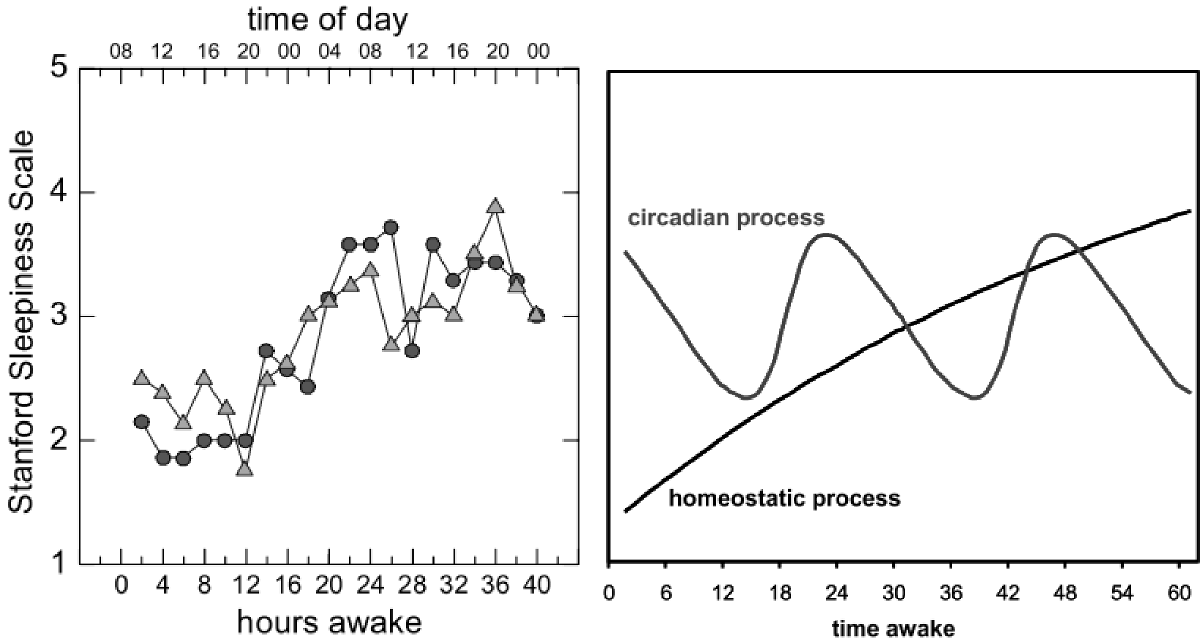

Figure 3. Effect of circadian and homeostatic processes on sleepiness (Van Dongen & Belenky, 2009).

Homeostatic regulation of sleep has been demonstrated by studies investigating total sleep deprivation (TSD) (Borbély, 1982; Carskadon & Dement, 1979, 1987; Franzen et al., 2008). TSD studies have shown that with increased time awake, particularly above 16-18 h, sleep propensity increases, and the ability to stay awake voluntarily is compromised (Borbély, 1982). This increased sleep propensity has been shown by Multiple Sleep Latency Tests (MSLTs), where individuals are given a number of sleep opportunities over a time period, and the time it takes them to fall asleep each time is measured (Carskadon & Dement, 1987). MSLTs have demonstrated that as time awake increases, sleep latency decreases, indicating greater sleep propensity (Carskadon & Dement, 1979, 1987; Franzen et al., 2008).

Another marker of sleep homeostasis is slow wave electroencephalographic (EEG) sleep in non-REM (non-rapid eye movement) sleep (Borbély & Achermann, 1999). After a night without sleep, it has been shown that not only is sleep latency shortened, but SWS is reached twice as fast as after a full night of sleep (Dinges, 1986). Additionally, following periods of sleep restriction (i.e. shortened sleep periods), subsequent sleep periods have a greater proportion of SWS (Borbély & Achermann, 1999). Specifically, a laboratory study showed that when sleep was restricted to 4 h, the following night of sleep consisted of 20% more SWS during non-REM periods (Brunner et al., 1993). The amount of SWS is dependent on the length of the prior sleep period, for example, greater proportions of SWS when prior sleep is shorter (Åkerstedt & Gillberg, 1986).

2.3.3 Sleep stages

Sleep can be divided into four different stages that occur in a cyclical pattern throughout each sleep period (Borbély et al., 1981). In order to determine the proportion and timing of sleep stages, brain activity is typically measured via EEG, in combination with electro-myographic (EMG) and electro-oculographic (EOG) output (PSG) (Iber, 2007). These recordings give an indication of the amplitude and frequency of the electrical activity that is occurring within the brain. Sleep outcomes that are commonly measured include sleep onset latency (the length of time it takes the individual to fall asleep), wake after sleep onset (WASO; the number of minutes spent awake during the sleep period after falling asleep), sleep efficiency (what proportion of the time in bed was spent asleep) and which stage of sleep the individual is in (Iber, 2007). The duration and composition of each sleep stage can be a marker of sleep quality, and there are specific guidelines and criteria regarding the identification of sleep stages and events (Iber, 2007). The makeup of a sleep period, in terms of sleep stages, is typically referred to as sleep architecture.

According to standard guidelines, sleep stages are generally scored in 30-s epochs (Iber, 2007). Brain activity and physical differences such as muscle tone or eye movements are used to categorise each 30-s period as a specific stage of sleep. Brain activity (i.e., frequency and amplitude bands) is classified according to type (e.g., alpha, delta) and proportion (i.e., what percentage of that 30-s epoch comprised delta brain activity) (Armitage, 1995).

Sleep stages are classified in the following ways (Iber, 2007);

N1: slow rolling eye movements, >50% low voltage mixed frequency waves (predominantly 4-7 Hz)

N2: K-complexes, sleep spindles

N3: low frequency waves (0.5-3 Hz) in at least 20% of the epoch (SWS)

REM: rapid eye movements, low amplitude mixed frequency waves, reduced EMG activity (muscle atonia)

Normal sleep, based on research conducted on healthy, young, well rested adults (Hirshkowitz et al., 2015), occurs at night and is cyclical, with sleep cycles lasting approximately 90 min (Carskadon & Dement, 2011). These cycles begin with light sleep (N1) then progress through to deeper sleep (N2 then N3), before becoming lighter again, and ending with a short period of REM sleep (Keenan & Hirshkowitz, 2011; Koo & Kim, 2013, Figure 4). Cycles that occur later during the sleep period typically include a smaller proportion of SWS (N3), and a greater proportion of REM, as a result of Process S (Carskadon & Dement, 2011).

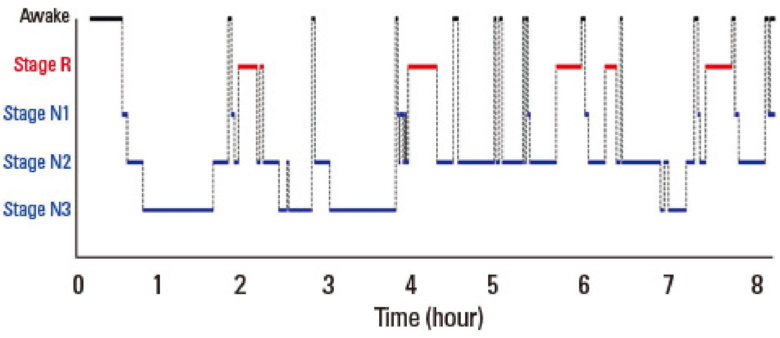

Figure 4. An example of sleep stages across the night (Koo & Kim, 2013)

Stage R = REM sleep

The main types of brain activity that are used to identify sleep stages are;

Beta: generally experienced during wake, these are high frequency, low amplitude waves.

Alpha: associated with relaxation and a large proportion of both wake and light sleep stages, slower than beta with higher amplitude.

Theta: slower and with higher amplitude than alpha, generally seen during sleep.

Delta: slow, high amplitude, associated with deep sleep (N3).

NREM sleep refers to the non-REM stages of sleep - N1, N2, and N3 (non- rapid eye movement). N1 sleep is the lightest, and the stage that generally occurs first upon falling asleep. Individuals are generally very easily aroused from this stage, and may have some awareness of their surroundings. This initial N1 period typically lasts approximately 1-7 minutes, and is associated with slow eye movements and reduced muscle tone (Carskadon & Dement, 2011). Scoring criteria state that within a 30-s epoch of N1 sleep, less than 50% of this period must consist of alpha brain activity (more than 50% alpha being associated with wakefulness) (Keenan & Hirshkowitz, 2011). N1 then transitions to N2, which is slightly deeper sleep (less easily aroused from, with less awareness of surroundings). N2 is defined by a higher proportion of theta brain activity, and less than 20% of slow wave activity (delta) (Keenan & Hirshkowitz, 2011). N2 is also associated with sleep spindles and K complexes (Keenan & Hirshkowitz, 2011). N2 is followed by N3, which is characterised by a higher proportion of slow wave activity (delta) (Keenan & Hirshkowitz, 2011). N3 sleep has been shown to be restorative compared with other sleep stages, particularly neurophysiologic restoration, including plasticity and memory consolidation (Ooms et al., 2017).

REM sleep is often referred to as “dreaming” sleep, where the brain is active, but the body experiences diminished muscle tone (Carskadon & Dement, 2011). REM is also characterised by episodic rapid eye movements, as the name suggests (Carskadon & Dement, 2011). The electrical activity occurring in the brain during REM is similar to wake, with high frequency waves shown in PSG recordings (e.g., alpha waves), though brain activity is variable (Acharya et al., 2005). There is also a circadian component to REM sleep regulation (Carskadon & Dement, 2011). In a normally entrained individual, REM propensity is greatest at the nadir of core body temperature, generally in the early hours of the morning (Carskadon & Dement, 2011; Czeisier et al., 1980; Zulley, 1980). As such, if sleep is initiated during this period, a higher proportion of REM is likely (Carskadon & Dement, 2011).

Sleep architecture is particularly important to understand in the context of assessing the impact of external factors on sleep, as the proportion of different stages within a sleep period can be indicative of alterations to sleep quality, and as such may relate to differences in subsequent performance. For example, sleep periods which include higher proportions of SWS have been found to result in improved cognitive performance (Ferrara et al., 2000; Marshall et al., 2006). Additionally, increased proportions of REM have been associated with improved memory (Siegel, 2001).

2.3.4 Quantitative EEG analysis

Quantitative EEG (qEEG) analyses, also known as power spectral analyses, can be performed on PSG recordings to investigate the frequency composition of each sleep stage (Vakulin et al., 2016). The term frequency composition refers to the frequencies of brain activity (e.g. alpha, beta, delta) that make up each sleep stage (Walczak & Chokroverty, 1994). While PSG is used to understand sleep architecture in terms of the number of minutes spent in each sleep stage, in addition to total sleep time, sleep latency, and other macro measurements of sleep, qEEG analysis instead assesses more nuanced changes in sleep (Achermann, 2009; Campbell, 2009). Assessing frequency compositions during a given sleep period can provide a more detailed understanding of how light or deep the sleep is, and can be indicative of changes that are imperceptible when utilising standard PSG (Achermann, 2009). Further, PSG is assessed via visual inspection by a trained technician, which may result in interrater reliability concerns (Levendowski et al., 2009). While PSG is accepted as the gold standard for data collection in the sleep field, qEEG analyses allows a more detailed and mathematical look at this output, beyond what can be detected via visual inspection of PSG output (Achermann, 2009; Walczak & Chokroverty, 1994). Achermann (2009) states that because of the rhythmicity of brain waves (e.g., alpha activity occurring between 8 and 12 Hz), it is important to deconstruct the signal into associated frequencies. Essentially, because the frequencies within each sleep stage and frequency band are variable, additional information can be gleaned from looking at the specific values of each frequency (Campbell, 2009; Vakulin et al., 2016).

In order to determine the frequency values, the PSG output is scored according to standard criteria, and then processed. Fast Fourier transformations are performed on this output, which result in values representing the power density spectrum, i.e. specific values are determined for each frequency band (Campbell, 2009). This type of analysis deconstructs the waveforms seen in PSG into a sum of sine waves. These sine waves occur at different frequencies, amplitudes and phases, and are determined by the Fourier transformation (a mathematical operation) (Walczak & Chokroverty, 1994). This transformation produces coefficients for the amplitude and frequency of each sine wave, which are then squared and summed to produce a measures of the power at that specific frequency (Walczak & Chokroverty, 1994). The power spectrum that is produced by a value at each frequency can be used to determine the relative amounts of each frequency (Walczak & Chokroverty, 1994). Generally, these values are calculated for non-overlapping 5-s periods of sleep, and used to create averages for each 30-s period, allowing for the removal of “noisy” periods of data (Vakulin et al., 2016). For example, if two out of six 5-s periods are designated “noisy”, the average for that 30-s epoch will be made up of an average of the remaining four 5-s periods (Vakulin et al., 2016). This is particularly important as Fourier analyses cannot differentiate PSG artefact from steady recording (Walczak & Chokroverty, 1994).

Differences in frequency composition are understood to be indicative of within-sleep arousal (Campbell, 2009). A greater proportion of high frequency activity, for example beta, can be indicative of lighter sleep, with higher levels of arousal (Campbell, 2009; Tarokh et al., 2015). Conversely, more delta activity within a sleep stage can suggest a deeper sleep. For example, an increase in delta can often be seen after sleep deprivation, as a restorative response (Campbell, 2009). This restorative response is also typically indicative of Process S, with additional homeostatic sleep pressure resulting in higher levels of low frequency activity (Borbély & Achermann, 1999).

QEEG analyses provide a definitive numerical value for the proportion of each sleep stage that is made up of brain activity at certain frequencies. The frequency bands that are generally assessed in qEEG analyses are;

Delta: 0.5-4.5 Hz

Theta: 4.5-8.0 Hz

Alpha: 8.0-12.0 Hz

Sigma: 12.0-15.0 Hz

Beta: 15.0-32.0 Hz

These frequency bands are reflective of electrical activity occurring in the brain. Every manually scored sleep stage includes a certain proportion of each frequency (i.e., even SWS has some high frequency activity, and light sleep has some low frequency activity) (Vakulin et al., 2016). However, these proportions can change significantly between and within each sleep stage (Campbell, 2009; Vakulin et al., 2016). This frequency makeup of sleep stages can therefore be identified and used to assess sleep quality (Brunner et al., 1993; Tarokh et al., 2015).

2.3.4.1 EEG slowing ratios

Not only can the absolute values for each frequency band and composition be identified, but EEG slowing ratios can also be calculated (Vakulin et al., 2016). This ratio between high and low frequency activity can reveal if brain activity is slowing in a given sleep period (Vakulin et al., 2016). Ratio analyses are performed comparing delta with alpha activity (delta/alpha). Increases in this ratio indicate a larger proportion of slow, high amplitude brain activity, otherwise known as EEG slowing.

Ratio analyses are also performed with the inclusion of other frequency bands to further investigate EEG slowing. This ratio can be calculated by the following equation:

((delta + theta) / (alpha + sigma + beta)) = EEG slowing ratio

These ratios can provide additional insight into the complex nature of brain activity during sleep (Achermann, 2009). Rather than identifying the absolute amount of each frequency activity, ratio analyses instead are used to determine the proportion of each frequency (Brunner et al., 1993; Vakulin et al., 2016). As such, this can provide insight into the degree of EEG slowing that is occurring. High rates of EEG slowing, for example, may be suggestive of particularly deep or restful sleep, or, in combination with the absolute frequency values, may be able to give us a more comprehensive picture of frequency composition (Campbell, 2009). For example, if a high delta value is seen within N3 of a certain sleep period, but there is no indication of EEG slowing (i.e., a low ratio value), this may suggest that there is also a higher proportion of high frequency activity. Conversely, this finding may suggest that the individual has a higher rate of low frequency activity generally. As such, EEG slowing analyses are useful in a more detailed understanding of changes to sleep, particularly in terms of sleep quality and type of brain activity.

2.3.5 Sleep and anxiety

On-call periods have been associated with shortened or poor quality sleep under different conditions (Ferguson et al., 2016; Vincent et al., 2018) and in a variety of industries, including marine engineering (Torsvall & Åkerstedt, 1988), aviation (Kecklund et al., 1997), medicine (Morhardt et al., 2017; Richardson et al., 2007), paramedicine (Takeyama et al., 2009) and residential support (Dorrian et al., 2017). Increased anxiety, resulting from being on-call, is a potential cause of these findings (Nicol & Botterill, 2004). It is well established in the relevant literature that anxiety is associated with negative sleep outcomes, as can be seen in the systematic review by Kim and Dimsdale (2007), with links well-established in general community samples (Emre et al., 2016; Ramsawh et al., 2009; Spoormaker & van den Bout, 2005), older adults (Gould et al., 2017; Potvin et al., 2014), university students (Amaral et al., 2018; Gray, 2017; Wallace et al., 2017) and in children and adolescents (Alfano et al., 2010; Fletcher et al., 2018). The relationship between anxiety and sleep is thought to be bi-directional (Jack et al., 2016; Kalmbach et al.), with poor or shortened sleep resulting in higher anxiety (Kalmbach et al.; Sagaspe et al., 2006), and individuals who experience anxiety subsequently having poorer sleep (Amaral et al., 2018; Shanahan et al., 2014). A number of other factors associated with anxiety have also been associated with poor sleep outcomes, including daily hassles, rumination, hyperarousal and work pressures (Åkerstedt et al., 2012; de Lange et al., 2009; Rugulies et al., 2012; Winzeler et al., 2014). Anxiety has also been found to affect sleep when individuals are anticipating a specific upcoming stressor (Lund et al., 2010). For example, a cross-sectional online survey which included measures of sleep quality (Pittsburgh Sleep Quality Index (PSQI)) (Buysse et al., 1989) and stress was given to 1,125 American college students to investigate the effects of upcoming examinations (Lund et al., 2010). Results from this study indicated that students experienced significantly poorer sleep during periods of academic stress (examination periods) (Lund et al., 2010). In this study, 24% of the variance in sleep outcomes was caused by increased tension and stress during this period, which are known to cause anxiety (McEwen et al., 2012). Though this study utilised a self-report measure of sleep rather than a quantitative measure, the PSQI is validated as a measure of sleep quality (Buysse et al., 1989). As such, these results suggest that anxiety associated with anticipating an upcoming stressor can result in significantly poorer sleep. This is particularly relevant to on-call work, as calls are reported to be significant stressors, which on-call workers anticipate during on-call periods (Bamberg et al., 2012).

Sleep decrements resulting from anxiety have also been demonstrated in research employing PSG and other objective measures of sleep (Fuller et al., 1997; Galbiati et al., 2018). In a matched comparison of individuals with (n = 27) and without insomnia (n = 20), it was found that objectively measured sleep decrements (increased wake after sleep onset, and diminished total sleep time and sleep efficiency) were linked with increased levels of worry and rumination, which are associated with anxiety (Galbiati et al., 2018). Further, in laboratory conditions, 15 adult participants with heightened generalised anxiety (as measured by the STAI (Spielberger, 1983) and the Penn State Worry Questionnaire (Meyer et al., 1990)) were found to have longer sleep onset latency, a smaller proportion of SWS, increased stage one sleep and lower REM density than a control group of adults without heightened anxiety (Fuller et al., 1997). However, while these studies all employed objective measures of sleep quality, study populations included individuals with clinical symptoms or diagnoses, which may limit their generalisability. However, a review paper found similar outcomes (i.e., poor sleep) where physical or psychological stress, which may be associated with anxiety, have been induced (Kim & Dimsdale, 2007).

The effects of induced stress on sleep can include shortened total sleep times, poorer sleep efficiency, reduced or altered REM, increased awakenings, and less SWS (Kim & Dimsdale, 2007). These changes were seen under a variety of conditions, including in participants who were shown an aversive film (Baekeland et al., 1968) or had been treated poorly prior to sleep (Cohen, 1975). Further, performing a stressful task prior to sleep or knowing that a stressful task will be performed upon waking has also been associated with poor sleep, including increased arousals and reduced SWS (Hall et al., 2004; Kecklund & Åkerstedt, 2004;

Söderström et al., 2004). The relationship between anxiety and sleep has also been explored in the context of life events (Kim & Dimsdale, 2007). For example, a study on 61 individuals experiencing marital separation found that this stressful life event was associated with changes to sleep, including less delta sleep, increased REM and shorter REM latency (Cartwright & Wood, 1991). In response to such life events, intrusive thoughts and avoidance, which can be associated with anxiety (Borkovec et al., 2004; Purdon & Clark, 1993), are linked with a longer sleep onset latency and lower delta sleep ratio values (Hall et al., 1997). Similarly, traumatic events that result in anxiety, or even the development of post-traumatic stress disorder (PTSD), have been linked with sleep disruption (Charuvastra & Cloitre, 2009; Kim & Dimsdale, 2007; Lavie, 2001). While this relationship has not been directly investigated in the on-call literature, there are extensive reports of poor sleep on-call (Ferguson et al., 2016). As on-call work is often perceived as a stressor (Bamberg et al., 2012; Torsvall & Åkerstedt, 1988), sleep may be negatively impacted by heightened feelings of anxiety or apprehension experienced prior to bed while on-call.

2.3.6 On-call and sleep

On-call working arrangements are often associated with negative sleep outcomes (Ferguson et al., 2016). Poor or shortened sleep has been seen on-call in a variety of industries, including emergency services (Billings & Focht, 2016; Paterson et al., 2016), healthcare (Geer et al., 1996; Iversen et al., 2002), and rail (Cebola, 2014). The following section is an overview of the literature that addresses the impact of on-call work on sleep and is divided into real world on-call scenarios where calls are and are not received. This distinction has been made to differentiate between specific instances of sleep disruption (calls) and the impact of anxiety or apprehension. Additionally, a review of literature investigating the effect of on-call work on sleep in simulated/laboratory environments is presented.

2.3.6.1 *On-call sleep when calls are received*

Receiving calls during on-call periods, which often occur overnight (Bamberg et al., 2012), is logically a cause of poor or disrupted sleep. A recent review showed that sleep is disturbed by calls during on-call periods and, as such, fewer hours of sleep are obtained (Ferguson et al., 2016). Indeed, much of the current research into on-call work involves on-call periods where calls were received, and investigate the effects on sleep (Imbernon et al., 1993; Morhardt et al., 2017; Torsvall & Åkerstedt, 1988). For example, medical residents were found to have 1.5 hours less sleep on-call compared with nights not on-call as a result of disruptions during the on-call period (Morhardt et al., 2017). Similarly, gas and electricity workers were found to have 6.8 h of sleep on average while on-call, compared with 7.4 h when they were not on-call (Imbernon et al., 1993). Further, in ships' engineers, on on-call nights with 2.0 ± 1.0 alarms per night, EEG, EOG and ECG (electrocardiographic) recordings indicated that total sleep time (including both non-REM and REM) was shorter compared with when they were not on-call (Torsvall & Åkerstedt, 1988). In addition to shortened sleep, on-call work can result in changes to the frequency composition of brain activity during sleep (Torsvall & Åkerstedt, 1988). Specifically, sleep during on-call nights has been shown by qEEG analysis of PSG measures to have less delta and theta powered activity than nights not on-call, which is associated with lighter, less restorative sleep (Torsvall & Åkerstedt, 1988). These studies have included objective measures of sleep in real world on-call workers, and as such present compelling evidence to suggest that on-call periods where calls are received result in poorer sleep for workers. However, given that these studies were performed in different populations under a variety of on-call conditions, and the fact that so few studies have been performed using objective measures, we cannot be certain which components of these on-call periods, aside from actual calls, were causally related to these sleep outcomes.

Subjective reports also suggest that on-call work leads to poor or shortened sleep as a result of receiving calls. Poor sleep has been reported by rural general practitioners (Iversen et al., 2002), who have stated that "doing one call at three in the morning [is] as bad as being up all night because you can’t get back to sleep again” (p.141). Similarly, using the PSQI, it was shown that 73% of firefighters who operated on-call reported poor sleep during on-call periods (Billings & Focht, 2016). Additionally, interviews conducted with rail workers established that fatigue was a major consequence of on-call work, and when presented with subjective questionnaires, workers reported that on-call work was perceived as being a leading cause of sleep disturbance (Cebola, 2014). Shortened hours of sleep, as self-reported in sleep diaries, have also been found in residential support on-call workers (Dorrian et al., 2017) and in medical staff (Geer et al., 1996). Self-reported sleepiness (Rose et al., 2008) and fatigue (Park & Baek, 2017) have been reported as being higher than normal following on-call periods, even after a night of recovery sleep (Dru et al., 2007; Rose et al., 2008). Indeed, residential support workers have reported severely restricted sleep during “sleepover” work shifts, where they remain in the home of individuals in their care, reporting just 2-3 h of sleep on a “bad” night (Dorrian et al., 2017). Interview data has also revealed that emergency services workers experience shortened sleep during on-call periods where calls are received (Jay et al., 2018; Paterson et al., 2016). This finding was supported by subjective measures in an experimental field study conducted by Ziebertz et al. (2017), where participants reported longer sleep latencies, more awakenings, and more wake after sleep onset when they were in an on-call condition. However, these self-reported decrements were not aligned with actigraphic recordings, which showed no differences between the on-call and control conditions (Ziebertz et al., 2017). Therefore, it appears that perception of the effects of on-call on sleep may differ from physiological sleep outcomes. However, as the research performed under on-call conditions utilising objective measures of sleep (i.e., PSG or actigraphy) is limited, further research is required.

Interestingly, one study also indicated that shortened sleep occurs in on-call rail workers who are only required to engage via phone, rather than attending the workplace (Cebola, 2014). Participants indicated that they often found it difficult to fall back asleep, with the author suggesting this may be due to either rumination or as a result of the adrenaline and cognitive load associated with the call (Cebola, 2014). However, in this study, the degree to which sleep is affected appears to depend on the nature and length of the phone call (Cebola, 2014).

2.3.6.2 On-call sleep when no calls are received

Research has indicated that sleep may also be negatively affected by on-call periods even when no calls are received (Torsvall & Åkerstedt, 1988; van de Ven et al., 2015). In a study of 38 doctors, Jay (2008) observed significantly shorter total sleep time (by 39 minutes per night) when on-call compared with not being on-call, as measured by a combination of activity monitors and sleep/duty diaries, regardless of whether calls were received during the on-call periods. Van Gelder et al. (2006) found similar results in actigraphic recordings of ophthalmology residents, with poorer sleep during on-call periods, irrespective of whether calls were actually received. Further, Torsvall & Akerstedt (1988) found that on-call engineers had shorter total sleep times, as well as reduced SWS and REM sleep – changes which were observed prior to any calls occurring. In this study, self-rated sleep quality was also poorer, and self-rated sleepiness was higher after nights on-call (Torsvall & Åkerstedt, 1988).

Similarly to Torsvall and Âkerstedt (1988), van de Ven (2015) found in a study of 280 technical gas distribution workers that self-reported sleep was negatively impacted during on-call periods where no calls occurred. This study also found that participants reported requiring more recovery after on-call periods when compared with not on-call, regardless of whether calls were received (van de Ven et al., 2015). These data were also supported by Pilcher and Coplen (2000) who assessed 14-day activity logs of 198 train engineers, and found that participants reported difficulties in falling asleep and maintaining sleep while on-call. However, as these were retrospective self-reported activity logs, rather than objective measures of sleep, more research may be required to support these findings. Subjective reports from rail workers have also suggested similar outcomes - that the stress associated with on-call work leads to poorer quality sleep, or sleep that is disturbed by the individual hearing “imagined” calls (Cebola, 2014). One on-call rail employee in this study stated that he was “knackered by the end of an on-call week even if [he doesn't] get any calls" (p.131) (Cebola, 2014). Cebola (2014) also found that working on-call resulted in significant self-reported fatigue following on-call periods, which supports the notion that on-call periods are associated with poorer sleep. This may indicate that individuals experience sleep disruption or disturbance even if they are not contacted for a call during this period. However, there is very limited available research into on-call periods where no calls are received. This appears to be because most on-call occupations that have been included in studies have had high call frequencies (e.g., ships' engineers, rail workers, emergency services), and indeed, have likely been chosen for research because of this fact. Additionally, much of the literature in this area uses self-reported sleep data (Cebola, 2014; Pilcher & Coplen, 2000; van de Ven et al., 2015). This is particularly limiting given that subjective measures of sleep are not necessarily reflective of objective sleep outcomes (Bastien et al., 2003; Lauderdale et al., 2008). Therefore, additional research using objective sleep measures (e.g., PSG) are necessary to determine the impact of on-call periods with no calls on sleep.

2.3.6.3 Sleep in simulated on-call conditions

Changes to sleep have also been seen in on-call simulations. In a recent study, Ziebertz et al. (2017) recruited students to participate in on-call field simulations, where they slept in their own home but were on-call on one of two nights (on-call vs control). Self-reports indicated that participants had significantly more sleep problems on-call, including shortened total sleep time and longer sleep onset latency (Ziebertz et al., 2017). However, this study also employed actigraphy, which did not reveal any objective changes to sleep. This may suggest that while participants perceived having sleep difficulties or disturbances under on-call conditions, their physiological sleep was not affected. This presents an interesting challenge for organisations undertaking a risk management approach to sleep and fatigue, as organisational reporting is often based on subjective assessments of both sleep quality and fitness for duty (Dawson & McCulloch, 2005). However, some significant objective changes to on-call sleep have been seen under controlled laboratory conditions. Wuyts et al. (2012) performed a study in a time-isolated sleep laboratory and found that objectively measured sleep outcomes were poorer on-call compared with control. PSG showed more wake after sleep onset, in addition to longer sleep onset latency and poorer sleep efficiency on-call compared with control. This may suggest that under certain on-call conditions, in a laboratory compared with at home, for example, different degrees of sleep disturbances are experienced. Additionally, the perception of sleep disturbance may differ from actual on-call sleep. Conversely, in a study with a similar design to the one conducted by Wuyts et al. (2012), Jay et al. (2016) found no significant effects of on-call conditions on sleep in a laboratory environment. However, there were slight differences in methodology between these two studies, including the specific on-call instructions that were given and the way in which participants were woken. As a result, it appears that specific components of on-call periods (i.e., the on-call conditions) may be linked with sleep outcomes. This thesis will attempt to understand which specific components of on-call work affect these changes. These components are discussed in section 2.5, and are the likelihood of being called, how stressful the task to be performed upon waking is, and the perceived chance of missing the alarm.

2.4 Cognitive performance

It is well established that poor or shortened sleep is likely to lead to performance decrements in a number of cognitive domains (Alhola & Polo-Kantola, 2007; Krause et al., 2017; Lowe et al., 2017). Further, variations in cognitive performance can be seen as a result of time of day and circadian phase (Van Dongen & Dinges, 2000). For example, performance tends to be worse in the early hours of the morning, with a secondary, smaller dip in the mid-afternoon (Lack & Lushington, 1996; Van Dongen & Dinges, 2000). Hours of sleep and time spent awake can also alter cognitive performance (Killgore, 2010; Lowe et al., 2017). As such, a great deal of research has been conducted on the effects of prior wake, sleep duration, and sleep quality on cognitive performance (Lowe et al., 2017). Poor or shortened sleep can also negatively impact work performance (Krause et al., 2017; Lowe et al., 2017), which can have practical implications for safety and productivity within workplaces. As a result of this body of research, it is clear that any decrements to sleep seen on-call are likely to have a negative impact on next day cognitive performance. As such, this section presents a review of the literature regarding the effects of sleep restriction on cognitive performance, and also how these effects have been seen under on-call conditions.

2.4.1 Sleep restriction and cognitive performance

Cognitive domains impacted by poor or shortened sleep can include reaction time, constructive thinking, processing speed, vigilance, auditory and visuo-spatial attention, and reasoning abilities, among others (Krause et al., 2017; Lowe et al., 2017). Negative effects of sleep restriction have also been found in emotional functioning, with blunted positive emotional responses (Olia et al., 2017) and poorer emotional regulation (Palmer & Alfano, 2017). While most types of cognitive function are affected by sleep restriction, it appears that tasks requiring attention and vigilance are affected most severely (Lim & Dinges, 2010; Lowe et al., 2017). A meta-analysis performed by Lim and Dinges (2010) determined that there were several potential ways that sleep restriction may impact cognitive performance. The first is known as the controlled attention hypothesis, which posits that tasks that require higher levels of attention are more likely to be affected by sleep deprivation or restriction (Pilcher et al., 2007). This is supported by extensive literature indicating that sustained attention and vigilance are particularly affected by sleep loss, both in adults (Belenky et al., 2003; Dinges et al., 1997; Van Dongen et al., 2003) and in adolescents (de Bruin et al., 2017). Lim and Dinges (2010) also review literature indicating that there may be a neuropsychological explanation for the effects of sleep on cognition, with sleep restriction affecting the prefrontal cortex, resulting in changes to cognitive performance (Harrison et al., 2000; Jones & Harrison, 2001). The third explanation for the relationship between sleep restriction and poorer cognitive performance considers vigilance as the main cognitive component affected. This hypothesis suggests that poorer vigilance results in deficits to other, more complex cognitive domains (Krause et al., 2017; Lim & Dinges, 2010; Lowe et al., 2017). The relationship between sleep and cognitive performance has been thoroughly investigated in both laboratory and real world environments, with different degrees of sleep restriction (sleep duration) and with a variety of outcome measures (Alhola & Polo-Kantola, 2007; During & Kawai, 2017). Total sleep deprivation has also been extensively researched (Harrison & Horne, 2000; Horne, 1978; Pilcher & Huffcutt, 1996; Samkoff & Jacques, 1991). However, as on-call work does not generally result in total sleep deprivation, this is not a focus of this thesis.

2.4.2 Laboratory findings

Much of the research into sleep restriction has been performed under laboratory conditions to control for confounding variables (Belenky et al., 2003; Dinges et al., 1997; Lowe et al., 2017; Van Dongen et al., 2003). Restricting sleep by even 30 min in a laboratory environment has been shown to negatively impact cognitive performance, including reaction time, decision-making ability, vigilance, attention, and hand-eye coordination (Belenky et al., 2003). Belenky et al. (2003) also found that individuals who had 3- or 5-h sleep opportunities each night experienced greater lapses in vigilance and attention as the number of consecutive nights with restricted sleep increased (Belenky et al., 2003). As such, it appears that sleep restriction can significantly impact performance, as measured by a psychomotor vigilance task (PVT), and that this degradation increases over consecutive nights of sleep restriction (Belenky et al., 2003). The PVT is currently the gold standard of cognitive performance measurement and is used widely in the literature (Killgore, 2010). This task measures sustained attention, vigilance and reaction time, and has been highly correlated with sleep decrements (Dinges et al., 2004). The PVT has also been validated in the context of other psychological measures (e.g., alertness, problem-solving) and as such is used widely as a measure of cognitive performance (Dinges & Powell, 1985; Drummond et al., 2005). The finding from Belenky et al. (2003) is supported by another dose-response study, performed over 14 consecutive days by Van Dongen et al. (2003), which demonstrated that having a 6-h sleep opportunity or less each night resulted in cumulative dose-response decrements in cognitive performance. It was found that after this 14-day period, cognitive performance was similar to that of participants who had had two nights of total sleep deprivation (Van Dongen et al., 2003). This is further supported by Dinges et al. (1997), who found that when participants slept for less than 5 h per night, PVT performance worsened, as did mood and subjective perceptions of sleepiness. In addition to these seminal investigations on the effects of sleep restriction on cognitive performance, countless other laboratory studies have found similar results (Lowe et al., 2017). This relationship between sleep restriction and cognitive performance has been seen in laboratory studies across different age groups, e.g., children (Cassoff et al., 2014), adolescents (de Bruin et al., 2017), and older adults (Lo et al., 2016), in addition to under different laboratory simulations of occupational conditions, e.g., simulated night shifts (Morris et al., 2017) and simulated spaceflight missions (Barger et al., 2014).

2.4.3 Field research

The practical outcomes of laboratory observed cognitive deficits are reflected in the workplace, where sleep restriction has resulted in decrements in work performance and productivity (Åkerstedt, 1995; During & Kawai, 2017; Folkard & Tucker, 2003). In a study of mining operators, for example, it was shown that sleep obtained over the previous 24 h was able to predict performance on a 5-min PVT at the start and end of each shift (Ferguson et al., 2011). These data indicate that total sleep time mediated PVT performance, i.e., when individuals experienced sleep restriction, their cognitive performance was impaired (Ferguson et al., 2011), which is similar to much of the laboratory-based research that has been performed (Belenky et al., 2003; Dinges et al., 1997; Van Dongen et al., 2003). This study also took into consideration time of day, rostering pattern, and prior wake, indicating that the effects of prior sleep on cognitive performance were not caused by confounding factors (Ferguson et al., 2011). Poorer cognitive performance and sleepiness have also been found in other shift working populations (Dall'Ora et al., 2016; Folkard & Tucker, 2003; Wolf et al., 2017). For example, in a quantitative correlational study of over 1500 nurses, 47% reported finding it difficult to provide safe patient care at least some of the time due to poor sleep (Wolf et al., 2017). While this study relies on self-reports, rather than objectively collected error rates, the high rate of reported cognitive performance decrements suggests that sleep restriction can have severe consequences for those affected (Wolf et al., 2017). It has also been found that in emergency situations, including military or disaster response, decision making is poorer when individuals are sleep deprived (Leger, 1994; Van Dongen & Hursh, 2010).

The cognitive performance decrements seen when sleep is restricted can also lead to a heightened risk of error or accident (Folkard et al., 2005; Folkard & Tucker, 2003). A systematic review and meta-analysis of the available literature demonstrated a significant increase in the likelihood of personal injury while at work if the individual has experienced what the authors describe as “sleep problems” (Uehli et al., 2014). Similarly, driving ability also declines when sleep is restricted (Banks & Dinges, 2007; Philip et al., 2005). For example, a study on professional drivers found increased lane position and speed variability, in addition to poorer braking reaction times, after a night of sleep deprivation (27 h awake) (Jackson et al., 2013). Though this study was performed on professional drivers, rather than members of the public or shift workers, it is clear that performance decrements associated with poor sleep could have serious consequences for not only the driver, but passengers, pedestrians and other vehicles. Research has demonstrated that motor vehicle accidents that occur as a result of fatigue are similar in nature and severity to those associated with driving under the influence of alcohol (Knipling & Wang, 1994). While it is often difficult to definitively classify many vehicular accidents as being caused by sleep deprivation or restriction, there is certainly a heightened risk when the driver has not had adequate rest (Horne & Reyner, 1999; Jackson et al., 2013). These decrements to cognitive performance seen as a result of poor or shortened sleep may have significant effects for on-call workers, due to the safety-critical nature of the work. Specifically, the inability to perform work tasks appropriately may have significant consequences for personal, workplace, or public safety.

2.4.4 On-call and performance

Limited research has been conducted on the effects of on-call work on cognitive performance. There has been some research into on-call work in healthcare, which indicates that performance may be negatively affected while on-call (Aran et al., 2017; Grantcharov et al., 2001; Kikuchi et al., 2018; Reddy et al., 2009; Wali, 2011). Grantcharov et al. (2001) found that after one night on-call, surgeons performed more slowly and made more unnecessary movements and errors when engaged in laparoscopic tasks. However, post on-call performance was compared with performance prior to participants' overnight on-call shift, so it is difficult to attribute these decrements to on-call specifically, as sleep loss, workload or time of day effects may have had a role (Grantcharov et al., 2001). Weinger et al. (1996) also found that overnight residents on-call took longer to perform medical tasks, such as intubation, and reported increased feelings of tiredness or drowsiness compared to when not on-call. However, similarly to Grantcharov et al. (2001), performance during these overnight on-call periods was compared with daytime performance. As a result, time of day may have been a confounding factor, as performance during the night shift is well known to be poorer than during day work (Wilson et al., 2017). As such, we cannot assume that it is on-call work specifically that is the direct cause of these decrements, rather than the timing of these shifts or sleep restriction.

Additional findings from research performed on healthcare workers include poorer performance on driving, number comparison and concentration testing following on-call shifts in internal medicine house staff (Robbins & Gottlieb, 1990), experiencing severe sleepiness in nurses (Kikuchi et al., 2018) and medical residents (Reddy et al., 2009), and more risk taking behaviours exhibited by paediatric residents (Aran et al., 2017). Poorer performance has also been shown on-call in junior hospital doctors, who performed worse in a variety of tasks reflecting domains of both cognitive and work performance (Lingenfelser et al., 1994). These doctors also experienced poorer mood while on-call, compared with being off-duty

(Lingenfelser et al., 1994). However, the authors of this study point out that, as junior doctors, these individuals may be particularly susceptible to the stresses and high workloads associated with this role, suggesting some kind of acclimatisation in more senior staff. Concerningly, Marcus and Loughlin (1996) reported that of the medical housestaff they investigated, 49% had fallen asleep while driving, and 90% of these incidents occurred following an on-call shift. Though these findings are based on self-report measures, they indicate that these individuals are aware of their own performance decrements, which is concerning given that self-reports may be associated with under rather than over-reporting (i.e., it is likely that performance decrements and driving errors occur more frequently than is reported) (Lajunen & Summala, 2003). Poorer performance has also been shown on the PVT as a result of on-call work, with medical residents showing significant deterioration post-call (Geer et al., 1996). This study, however, has a possible confounding variable of prior sleep debt for the resident population (Geer et al., 1996). In opposition to the findings produced by Geer et al. (1996), Woo et al. (2004) found no differences in PVT performance after one simulated night on-call, though the surgeons who participated in the study performed poorer on measures of “graft pressure”, which is significant in terms of patient health outcomes. This is particularly interesting as it is a reminder that not all tasks utilise the same cognitive capacities, and even small changes to performance can be significant in terms of real world application.

Outside of healthcare, very little research has been conducted on on-call performance. Within the research that does exist, there have been significantly different outcomes regarding the performance effects of on-call work (Cebola et al., 2013; Pilcher et al., 2002; Ziebertz et al., 2015). A recent cross-sectional study of Dutch employed persons indicated that respondents believed there were no links between on-call and fatigue, performance difficulties, or work/home interference (Ziebertz et al., 2015). However, 93% of respondents indicated that their on-call periods occurred during the day, suggesting that sleep disruption may not have been a factor (Ziebertz et al., 2015). Conversely, a study of American locomotor engineers found that the time that workers received a call during their on-call shifts was the second most significant predictor of alertness, after circadian effects (i.e., how alert they would have been at a specific time even without receiving any calls) (Pilcher et al., 2002). This study did not include any measures of cognitive or work performance, but alertness has been shown to significantly correlate with cognitive outcomes, such as working memory, cognitive throughput and recall (Wright et al., 2002). Furthermore, an investigation into rail workers found that 13.3% of respondents reported that they felt they were not able to manage the call out as required during an on-call shift (Cebola et al., 2013). However, in this study 62.0% felt that they were "able" or "very able" (Cebola et al., 2013). Similarly to the outcomes reported by Pilcher et al. (2002), these reports are also not directly indicative of cognitive performance. As such, while there has been extensive research into the effects of sleep restriction on cognitive performance, there is limited information available about the effects of on-call work. However, because sleep is likely to be poorer on-call, we can infer that cognitive performance may also decrease.

While some research into the cognitive performance outcomes of on-call work does not suggest a relationship, the extensive body of research in the healthcare context, combined with the findings from Pilcher et al., (2002) and Cebola et al., (2013), indicate that being on-call may lead to cognitive performance decrements. However, much of this literature has focussed on performance decrements that appear to be linked with sleep deprivation or restriction, rather than as a result of being on-call specifically (Grantcharov et al., 2001; Kikuchi et al., 2018; Robbins & Gottlieb, 1990; Wali, 2011). In fact, little of the available literature includes a focus on on-call periods where no calls occur, and how these shifts may affect cognitive performance (Wuyts et al., 2012). Therefore, this thesis aims to understand the effects of being on-call on cognitive performance and other outcomes independently from the effects of receiving calls.

2.5 Components of on-call work that may affect anxiety, sleep and performance

A review of the relevant literature suggests that on-call periods may result in increased anxiety, which may then affect sleep, regardless of whether calls are received or not. Based on the literature available, it is also reasonable to expect that poorer anxiety and sleep outcomes may then result in poorer cognitive performance the next day. There are a number of components that may impact these outcomes for on-call workers, including work factors, non-work factors, individual factors, and those that relate specifically to the calls that are received. However, non-work, and individual factors are outside of the scope of this thesis, which instead focuses on components associated with calls. These components have been specifically chosen based on the findings of prior research, described in this section, in addition to being factors that could be controlled within workplaces that utilise on-call working arrangements. These components are therefore particularly important to understand as they may lead to practical and realistic strategies that organisations can implement to better support their on-call workforce.

Increased anxiety, and subsequent poor sleep and cognitive performance on-call, may be associated with the expectation of a call, worry about missing the alarm, or anticipating that the type of work required during upcoming on-call shifts will be difficult or stressful (e.g., roles with serious consequences if performed incorrectly, or involvement in situations that are inherently stressful, such as motor vehicle accidents) (Paterson et al., 2016; Wuyts et al., 2012). However, to date there has been little investigation of these components of on-call work and their effects on anxiety, sleep, and next-day cognitive performance. This section presents the current understanding of the effects of the likelihood of receiving a call, task stress, and the perceived chance of missing the alarm in the on-call context.

2.5.1 Likelihood of a call

The likelihood of receiving a call varies significantly between on-call roles. These differences are a function of both the type of on-call work (proximal or distal) and the nature of the industry. Some on-call occupations require constant coverage over long periods of time, with the understanding that it is unlikely that a call will be received during any given period (Birch & McLennan, 2007; Ganewatta & Handmer, 2009). An example is in rural settings, where people living in the area may be on-call volunteers with their local firefighting service, but are only called if a significant emergency occurs (Birch & McLennan, 2007). Conversely, on-call workers in transport or maintenance industries may operate off-site, but have on-call as a standard component of their working arrangement, and as such are more likely to be called (Nicol & Botterill, 2004). However, there are often significant variations in call likelihood even within the same role. For example, on-call rail workers may not be called at all, or have just one or two calls during a “good” week, whereas they may receive upwards of 20 calls per week at other times (Cebola et al., 2012). Further, proximal on-call working arrangements are often used as a result of a high likelihood that the individual will be called. This primarily occurs in healthcare, where, for example, medical house officers remain at their workplace for extended periods, and may be called 16-25 times per shift (Lurie et al., 1989). It is clear that there is a great deal of variability in terms of how likely the worker is to receive a call.

Though limited, the available information indicates that there may be an effect of call likelihood on sleep, and changes to performance as a result (Wuyts et al., 2012). The more likely it is that the individual is called, the more likely it is that their sleep will be either shortened or disrupted, potentially degrading performance the following day (Alhola & Polo-Kantola, 2007). However, poorer sleep may also result from increased anxiety (Kim & Dimsdale, 2007). Research suggests that uncertainty around whether the individual will be called (i.e., call likelihood) may result in increased anxiety (Bamberg et al., 2012; Cebola, 2014; Hall et al., 2016; McGrath, 1976; Paterson et al., 2016). In a recent review, Hall et al (2016) suggested that this uncertainty may result in increased physiological stress, as a result of activation of the sympatho-adrenal medullary system and the HPA axis. Frequent activation of these systems (i.e., from the chronic stress associated with on-call uncertainty) may result in poorer health outcomes, such as depressed immune function or increased risk of cardiovascular disease (Mariotti, 2015). As such, it is vital to understand if the uncertainty surrounding on-call work is leading to chronic stress or anxiety in on-call workers.

In a controlled laboratory study on the effects of being on-call on sleep, Wuyts et al. (2012) found that there was more wake after sleep onset, longer sleep latency, and poorer sleep efficiency when participants were on-call compared with control nights, with poorer sleep also reflected by subjective measures. The methodology of this study included telling participants that they *could* be called during the night. In comparison, in a pilot study with similar conditions, participants were told before bed in the on-call condition to *definitely* expect an alarm during the night (Jay et al., 2016). In this second study, no significant differences in sleep quality or duration were found on-call in comparison to during the control night (Jay et al., 2016). These contradictory findings indicate that the uncertainty surrounding the possibility of being called may result in sleep disturbances.

This is further supported by a qualitative investigation of emergency services workers whose self-reported sleep disruption increased with consecutive on-call nights with few or no alarms (Paterson et al., 2016). These individuals reported that this was related to how likely they perceived a call to be during the shift (Paterson et al., 2016). Specifically, one firefighter reported that after a week with no calls he couldn't sleep well because "you're waiting for [your pager] to go off and just expecting it" (Paterson et al., 2016, p. 177). Furthermore, research conducted on engineers (Torsvall & Åkerstedt, 1988) found that when these individuals did not know if they were going to be called on a given night, their sleep was more likely to be negatively affected. Similarly, Ziebertz (2015) performed a cross-sectional survey and found that the uncertainty surrounding on-call periods resulted in increased stress and fatigue, whereas the number of hours spent on-call was not a factor. This uncertainty and unpredictability is also linked with anxiety, as a result of the inability of workers to disconnect from the workplace, as they are not able to predict their calls (Cebola et al., 2013).

Conversely, Cebola (2014) found that when individuals know they are definitely going to be called, they may find it more difficult to sleep as a result of anticipation. This study describes on-call scenarios where the worker is called at their home to engage over the phone during an on-call period. After providing information to staff on shift, the worker can then go back to sleep. However, the rostered staff are required to call back upon completion of the task. It is between these calls, when the on-call worker knows they will definitely receive a second call, that they have reported sleep difficulties (Cebola, 2014). Additionally, Richardson (2007) reported that hospital interns who were likely to be called during their shifts had poorer sleep outcomes when compared with those who were less likely to be called. These outcomes included reduced sleep efficiency and a reduced proportion of SWS (Richardson et al., 2007). As such, there appears to be a link between call likelihood and sleep outcomes, though there is not sufficient data to draw definitive conclusions about this relationship. Therefore, this thesis aims to investigate how the likelihood of receiving a call affects anxiety, sleep, and next day cognitive performance.

2.5.2 Task Stress

The type of task that the on-call worker is engaged in may also affect anxiety, sleep and cognitive performance. Specifically, the requirement for workers to perform stressful tasks may affect these outcomes (Åkerstedt, 2006; Barnes, 2000; Ferguson et al., 2016; Kecklund et al., 1997). Research indicates that performing a cognitively demanding task, or a task that has serious consequences if not performed appropriately, may be linked with heightened anxiety (Åkerstedt, 2006; Barnes, 2000; Kecklund et al., 1997). This has been found in on-call populations (Ferguson et al., 2016), in addition to shift working firefighters, airline cabin crews and general population samples (Åkerstedt, 2006; Barnes, 2000; Kecklund et al., 1997).

The effect of task stress on anxiety is particularly relevant for on-call workers, who are generally called when there has been a critical incident (e.g., a house fire or flood), which may be perceived as being particularly demanding (Drenth et al., 2000; Meijman & Mulder, 1998; Ziebertz et al., 2015). Ziebertz (2015) found that nearly half of their sample of 157 Dutch on-call workers who were social workers, health professionals, specialists (e.g., engineers) or in the service industry, described the work they performed when called as at least reasonably taxing. This was determined by participants having reported at least a score of 6 out of 10 on a scale of on-call stress asking the question “how taxing is the work that you have to do when being called during an on-call duty?” from “not at all taxing” (1) to “extremely taxing” (10) (Ziebertz et al., 2015). Further, a qualitative investigation of on-call Australian wildland firefighters indicated that the severity of the fire to be attended was positively associated with higher levels of arousal upon waking during on-call period, suggesting an increased physiological stress response (Paterson et al., 2016).

Similarly, Barnes (2000) found that firefighters who often are required to attend traumatic events such as motor vehicle accidents, reported an “endemic state of anxiety about knowing you can be called on to carry out traumatic and stressful work at any time day or night” (Barnes, 2000, p. 60). This suggests that firefighters experience more stress, and potentially more anxiety, when they know the task they must perform is of higher importance. High levels of stress have also been found in public practice radiographers who are engaged with on-call work in comparison to those in private practice (Eslick & Raj, 2002). It appears that the type of work undertaken by these radiographers is the main difference between these two categories, and as such work type may affect on-call outcomes (Eslick & Raj, 2002). In addition, there is a perception from individuals who are not engaged in this work type themselves, that on-call is more stressful than other working arrangements (Bloom & Dean, 1997). Bloom and Dean (1997) found that when presented with written, hypothetical on-call scenarios, university students perceived that they would be more stressful to work that work scenarios with no on-call element. This suggests that societally there exists the perception that on-call work is stressful, potentially based on anecdotal evidence or the understanding that on-call work is often utilised in high-stress industries.

Additionally, an increased likelihood of performing a stressful task in particular while on-call has also been linked with heightened anxiety (Cebola, 2014). A study on rail workers indicated that bad weather made participants more anxious during their on-call periods, as a result of a higher likelihood of attending a more serious incident, compared with the less serious events that are typical during fine weather (Cebola, 2014). Similarly, uncertainty about how demanding the on-call task may be can cause stress (Bamberg et al., 2012; McGrath, 1976). Additionally, research has demonstrated that workers are often worried or concerned about the decisions they make while on-call (Reid, 2010). However, these findings have not been uniform. For example, Bloom et al. (1997) found that physician-style on-call work was perceived as being no more stressful than computer-based on-call work. However, this study involved presenting theoretical scenarios to students who were not working on-call, and as such may not be representative of real world outcomes (Bloom & Dean, 1997).

Increased anxiety has also been linked with task stress outside of the on-call context, including research in healthcare (Rada & Johnson-Leong, 2004), emergency services (Barnes, 2000) and students sitting exams (Nie et al., 2011). As with the on-call results, work that is more demanding and has more time pressure is associated with increased anxiety (Melchior et al., 2007; Rugulies et al., 2012). This is demonstrated by a longitudinal study of more than a thousand individuals who were twice as likely to develop an anxiety disorder when exposed to high job demands (Melchior et al., 2007). Stressful job demands, such as impending deadlines, have also been linked with increased anxiety, and subsequent poorer sleep as a result of activation of the stress systems (Rugulies et al., 2012). Similar results have been found when comparing a stress and a non-stress condition in a laboratory setting (Hall et al., 2004). Participants who were required to perform a stress-inducing task (an oral presentation) upon waking had greater physiological signs of stress and greater feelings of worry before sleep, in addition to more disturbed sleep during the night compared with the non-stress group (reading a magazine) (Hall et al., 2004).

Sleep in on-call situations also appears to be affected by task stress (Åkerstedt, 2006; Paterson et al., 2016). Specifically, subjective reports from Australian firefighters indicate that sleep is lighter when the individual expects to attend a high consequence incident, such as a highway motor vehicle accident or health emergency (Paterson et al., 2016). In addition, it appears that there may be effects on anxiety and sleep after performing a more stressful task while on-call (Paterson et al., 2016). One firefighter reported that if "you've just been to a cardiac arrest you're going to lie thinking about the call, the other times if it's just a stock standard alarm call, you can be back in bed asleep" (p.177). This suggests that rumination associated with high consequence calls may result in poorer sleep during these on-call periods. However, these findings were in a post-call context and, therefore do not necessarily reflect the effects of perceived task stress on sleep that occurs prior to the call. This is therefore a gap in the literature, and as such, the effects of on-call task stress, prior to any calls being received, will be a focus of this thesis.

2.5.3 Chance of missing the alarm

Worry about missing the alarm is another factor that may impact sleep quality and duration while on-call, though to the author's knowledge there has been no quantitative research addressing this directly. In a laboratory based study, Wuyts et al. (2012) compared on-call nights with control in terms of sleep outcomes, and found that when participants were on-call they had poorer sleep, including increased sleep latency and reduced sleep efficiency. In this study, the alarm used to wake participants for their on-call periods was described by researchers as "meaningless" and "difficult to distinguish", which may have made participants feel as though they could potentially miss the alarm (Wuyts et al., 2012). This may have resulted in heightened anxiety, leading to poorer sleep outcomes on on-call nights (Kim & Dimsdale, 2007). In a similar study undertaken by Jay et al. (2016), which also compared on-call and control sleep, a 105 dB alarm was sounded directly outside participant bedrooms in order to wake participants during their on-call periods. Participants were aware of the volume of this alarm and were told that there was “no chance” that they would sleep through it (Jay et al., 2016). This study found there were no differences in sleep outcomes between the control and on-call conditions, including sleep efficiency, total sleep time or duration of sleep stages (Jay et al., 2016). Therefore, it may be the difference in perceived chance of missing the alarm that resulted in different sleep outcomes between these two studies.

Similarly, subjective reports from on-call workers have suggested that the idea that they may miss their alarm may result in anxiety (Bamberg et al., 2012), and as such poorer sleep (Paterson et al., 2016). Specifically, this has been reported by on-call firefighters who, after receiving no calls for a week, reported that they felt anxious about missing their pager alarm, because they were unsure if it was still functional (Paterson et al., 2016). Similarly, in airline cabin crews working early morning shifts, increased anxiety was reported by individuals who were concerned they were going to miss their alarm (Kecklund et al., 1997). Additionally, Cebola (2014) found that on-call rail workers reported sleep disruption from waking during the night thinking their alarm had gone off. In this context, it is possible that these awakenings resulted from concern and anxiety around potentially missing the alarm. Consequently, it is possible that worry about missing an alarm is a component of on-call work that could also affect sleep and therefore next day cognitive performance. However, these findings are largely based on interview style reporting and are therefore qualitative. As a result, this thesis aims to quantitatively understand how the perceived chance of missing the alarm during an on-call period affects anxiety, sleep and subsequent cognitive performance.

Overview of studies included in this thesis

The four experimental chapters presented in this thesis are taken from three studies that were conducted in a purpose-built sleep laboratory at the Appleton Institute, Central Queensland University. This facility is located in Adelaide, South Australia, and data collection occurred from February 2016 – July 2017. These three studies consisted of the same experimental protocol, barring the on-call conditions that were utilised within each study. Study 1 consisted of conditions that addressed the likelihood of receiving a call, Study 2 included conditions focussed on how stressful the tasks performed were, and Study 3 investigated the chance of missing the alarm. Study 3 includes additional information regarding participant daytime sleepiness that is not included in the other studies. Daytime sleepiness was not part of the original scope of this thesis, as sleepiness conceptually differs from cognitive performance outcomes, but was requested by a journal reviewer, and was therefore included. Studies 1, 2 and 3 are reflected in Chapters 3, 4 and 5. Chapter 6 includes data from all three studies together.

The protocol that was used for these studies is outlined in the methodology sections of Chapters 3, 4, 5 and 6. As these chapters have been published separately (Chapter 3: Chronobiology International, Chapter 4: Journal of Sleep Research, Chapter 5: Biological Psychology), or are under review in relevant journals (Chapter 6: Ergonomics), there is some duplication in methodology sections.

Chapter 3. Study 1

The impact of call likelihood on anxiety, sleep, and cognitive performance

Peer reviewed publication associated with this chapter (Appendix J):

Sprajcer, M., Jay, S.M., Vincent, G.E., Vakulin, A., Lack, L., Ferguson, S.A. (2018) Uncertain call likelihood negatively affects sleep and next-day cognitive performance while on-call in a laboratory environment. *Chronobiology International*, 35(6), 838-848.

doi: 10.1080/07420528.2018.1466788.

Full bibliographic reference to the item/publication, including authors, title, journal (vol/pages), year.	Sprajcer, M., Jay, Sarah M., Vincent, G., Vakulin, A., Lack, L., Ferguson, S. A. (2018). Uncertain call likelihood negatively affects sleep and next day cognitive performance while on-call in a laboratory environment. Chronobiology International, 35 (6), 838-848.
Status	Published

Nature of Candidate's Contribution, including percentage of total

I was responsible for laboratory set up, participant recruitment, data collection, and data management. I cleaned and analysed the data, formulated the research question, interpreted results and wrote the publication. (80%)

Nature of all Co-Authors' Contributions, including percentage of total

Sally Ferguson and Leon Lack won the funding for this project. Sarah Jay and Grace Vincent were involved in data collection. Andrew Vakulin provided me with expertise regarding qEEG data analysis. All co-authors reviewed and provided critical feedback on the manuscript and helped to prepare it for publication. (20%)

Has this paper been submitted for an award by another research degree candidate (Co-Author), either at CQUniversity or elsewhere? (if yes, give full details)

No

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Research Higher Degree Theses Policy and Procedure

……………………………………………………24/11/2018………………………

(Original signature of Candidate) Date

3.1 Abstract

On-call working arrangements are employed in a number of industries to manage unpredictable events, and often involve tasks that are safety- or time-critical. This study investigated the effects of call likelihood during an overnight on-call shift on self-reported pre-bed anxiety, sleep, and next-day cognitive performance. A four-night laboratory based protocol was employed, with an adaptation, a control and two counterbalanced on-call nights. On one on-call night, participants were instructed that they would *definitely* be called during the night, while on the other on-call night they were told they *may* be called. The STAI x-1 was used to investigate pre-bed anxiety, and sleep was assessed using PSG and power spectral analysis of the sleep EEG. Cognitive performance was assessed four times daily using a 10-min PVT. Participants felt more anxious before bed when they were *definitely* going to be called, compared with the control and *maybe* conditions. Conversely participants experienced significantly less NREM and N2 sleep, and poorer cognitive performance when told they *may* be called. Further, participants had significantly more REM in the maybe condition, which may be an adaptive response to the stress associated with this on-call condition. It appears that self-reported anxiety may not be linked with sleep outcomes while on-call. However, this research indicates that it is important to take call likelihood into consideration when constructing rosters and risk management systems for on-call workers.

3.2 Introduction

On-call work refers to working arrangements where individuals can be called during designated periods (often overnight) to start work. More than 25% of Australian (Australian Bureau of Statistics, 2016) and European (Parent-Thirion et al., 2012) employed populations perform on-call work. On-call workers often perform critical tasks to protect the health, safety and to support continued operations of communities and organisations. On-call is performed by both salaried and volunteer personnel in medicine, emergency services and maintenance areas, among others (Nicol & Botterill, 2004). Though on-call workers must be ready to respond to a call at any time, the likelihood of receiving a call during a given on-call period can vary significantly between different jobs, between different forms of employment and also from night to night. For example, internal medicine house officers who spend their on-call periods at work in a break room are understandably highly likely to be called during a given on-call shift (16-25 calls per night, on average) (Lurie et al., 1989), whereas rural Australian volunteer firefighters may be on-call every day of the year, but are far less likely to be called on any particular day (Birch & McLennan, 2007). Subjective reports from volunteer firefighters suggest that the more likely they perceive a call to be (e.g., due to weather or other environmental factors), the more anxious they feel (Paterson et al., 2016). It appears that the uncertainty surrounding the likelihood of a call may be an underlying cause of these feelings (Bamberg et al., 2012). While there has been limited research on on-call work specifically, anxiety, apprehension or rumination have all been linked with poorer sleep outcomes, both in terms of quality and duration (Åkerstedt et al., 2007).

Previous research has indicated that during on-call periods, workers may experience poorer sleep quality and quantity, both when called and when no calls are received (Paterson et al., 2016; Pilcher & Coplen, 2000; Torsvall & Åkerstedt, 1988; Ziebertz et al., 2017). Shorter total sleep times while on-call have been reported by railway engineers (Pilcher & Coplen, 2000), electricity and gas supply workers (Imbernon et al., 1993), and ships engineers (Torsvall & Åkerstedt, 1988). A recent laboratory-based on-call study indicated that during on-call shifts individuals experienced longer sleep onset latency, in addition to more wake after sleep onset, even when no calls occurred (Wuyts et al., 2012). This study also found that when on-call, participants experienced greater amounts of beta high and beta low activity during N3 (SWS), which is indicative of lighter sleep (Wuyts et al., 2012). However, the impact of call likelihood on sleep in the on-call worker is unclear. This is relevant because if sleep is different when on-call but not called then that has implications for short-term performance and long-term well-being. Understanding the factors that are associated with changes in sleep is important in developing systems to control for any negative outcomes.

The methodology of the study described by Wuyts and colleagues (2012) included informing participants that they *could* be called during the night. In comparison, in a pilot study with similar conditions performed by Jay and colleagues (2016), participants were told before bed in an on-call condition to *definitely* expect an alarm during the night (Jay et al., 2016). Jay et al. (2016) reported no significant differences in sleep quality or duration between the on-call and control conditions. Taken together, these two studies suggest that uncertain likelihood of a call may negatively impact sleep.

Further, if sleep quantity and/or quality are affected during on-call periods, this may also impact next day waking functioning (Alhola & Polo-Kantola, 2007). To the authors' knowledge, no research has been conducted on the impact of call likelihood on cognitive performance following on-call periods. Cognitive functions that may be impaired by sleep loss or disruption include reaction time, constructive thinking, processing speed, reasoning abilities and vigilance (Alhola & Polo-Kantola, 2007; Van Dongen et al., 2003). These cognitive decrements are associated with an increased risk of accident or injury, in addition to decrements in work performance and productivity (Åkerstedt, 1995). Given the high risk nature of many of the tasks that are undertaken by on-call workers (e.g., medical procedures or emergency response services), it is particularly important to understand any risk factors that may influence workers' ability to perform this on-call work safely and effectively. Therefore, the aim of this study was to understand how call likelihood impacts self-reported pre-bed state anxiety, sleep and next-day cognitive performance during while on-call.

The hypotheses are:

1) Uncertain call likelihood will be associated with heightened pre-bed state anxiety in comparison to certain call likelihood or control (not on-call) conditions.
2) Uncertain call likelihood will be associated with poorer sleep outcomes in comparison to certain call likelihood or control (not on-call) conditions.

3) Uncertain call likelihood will be associated with poorer next day cognitive performance outcomes in comparison to certain call likelihood or control (not on-call) conditions.

3.3 Methods

A four night within-subjects laboratory study was performed. All data was collected in Appleton Institute of Central Queensland University's time-isolated sleep laboratory in Adelaide, Australia. The laboratory is sound attenuated, with controlled levels of light (>100 lux during the wake periods), and ambient temperature (mean ± standard deviation, 21 ± 2°C). All participants had their own bedroom and bathroom.

3.3.1 Participants

Twenty-four healthy adult males, aged between 20 and 35 years (27.7 ± 6.4 yrs) were recruited from the Adelaide (South Australia) region. *A priori* power calculations were performed based on previous differences in sleep seen on-call (10% difference in total sleep time) (Jay et al., 2008).Females were excluded from participation because hormonal measures were taken as part of a larger study, which can be affected by menstrual phase. Participants provided written consent, and were compensated financially following study completion (AUD$480). Participation was voluntary and ethical approval obtained from the Central Queensland University Human Research Ethics Committee (H15/07-158). This protocol conforms to international ethical standards (Portaluppi et al., 2010).

Participants were screened using a general health questionnaire. Inclusion criteria were: body mass index (BMI) < 30 $kg.m^2$ (23.3 ± 1.9 $kg.m^2$), caffeinated beverage consumption ≤ 3 cups/d; non-smoker; fluent in English; non-shift worker; no previous diagnosis of psychiatric and/or neurological problems or sleep disorders; no travel across multiple time zones in the previous 4 weeks; free from medication/drugs that may influence sleep; and no history of habitual napping. Participants were also required to have an Epworth Sleepiness Scale (ESS) score < 10 (Johns, 1991), a global PSQI ≤ 5 (Buysse et al., 1989). The Depression Anxiety Stress

Scale (DASS) (Lovibond & Lovibond, 1995) and the Morningness Eveningness Questionnaire (MEQ) (Horne & Ostberg, 1975) were both also completed to rule out any severe cases of depression, anxiety, stress or morningness/eveningness. Participants were required to have bed and rise times that were similar to the bed and wake times of the study (2300 bedtime and 0700 wake time). Participants had an average self-reported bedtime of 2304 (± 53 min), and a mean rise time of 0758 (± 60 min). 66% of participants were university students, with the remaining being either unemployed, or engaged in work that was performed in regular office hours (i.e., no current shift work).

During the recruitment period, participants were screened using actigraphy (Actical MiniMitter/Respironics, Bend, OR) for one week to corroborate self-reported bed and rise times and to ensure that participants did not have detectable sleep problems (de Souza et al., 2003). In the week leading up to the study, participants were required to maintain a regular sleep schedule of at least 8 h in bed per night, within two hours of the scheduled bed and wake times. Actigraphy was combined with sleep diaries to cross reference sleep and bed times, sleep quality and awakenings. During the three nights immediately preceding the study, participants obtained an average of 7.2 h (± 1.1 hours) of sleep per night, with an average sleep efficiency of 92.2% (± 5.0%). One participant's data set was not included due to technical issues.

3.3.2 Design

The protocol consisted of four nights in the sleep laboratory (Figure 5), with participants remaining in the laboratory for the entire duration (in groups of six). Participants were not permitted any devices showing the time (e.g., watches or electronic devices), and had restricted use of their mobile phone (one half-hour period each evening). Participants were not allowed to engage in any physical activity during the protocol to avoid any potential impacts on psychological or physiological arousal. Participants were permitted to go to the common area to eat and socialise with other participants for three hours per day (3 x 1 h).

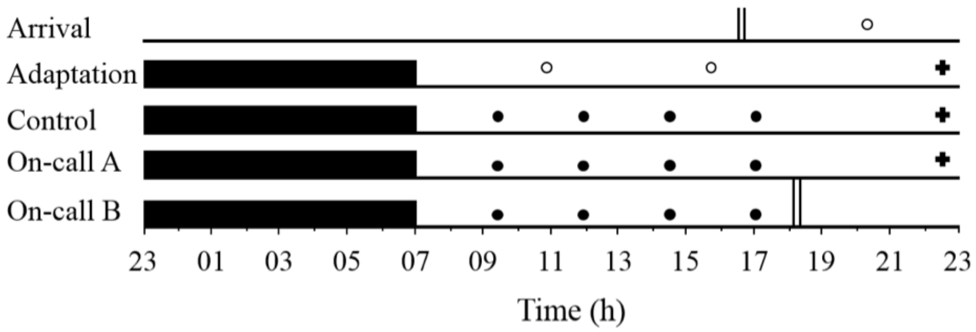

Figure 5. Study 1 Protocol

|| Arrival to and departure from the laboratory
○ 10-min psychomotor vigilance task (PVT) training
● 10-min PVT
✚ State Trait Anxiety Inventory form x-1
On-call nights A and B were counterbalanced for *definitely* and *maybe* conditions.

The first night was an adaptation night (2300 – 0700), followed by an adaptation and training day. The remaining three nights were experimental nights. At 2220 on each of these nights, participants were given instructions about their on-call status that night. Following these instructions, participants completed the STAI x-1 (Spielberger, 1983) at 2245, before lights out at 2300. The three experimental days following these nights were identical, with a wake time of 0700 on all mornings. Participants completed the PVT four times each day (0930, 1200, 1430, and 1700) (see Figure 5).

At 2220 on the control night, participants were instructed that they were not on-call and would be getting a full night of sleep. Participants were woken by a knock on their door and the overhead lights coming on. The third and fourth nights of the protocol were on-call nights where participants were instructed at 2220 that they were on-call and told that they would either *definitely* get called or *may* be called overnight. The order of the two on-call nights was counterbalanced such that half of the participants were in the *definitely* condition first, and half in the *maybe* condition first. Participants were instructed that if called, they would be required to perform cognitive testing for a short time. They were told that if their "call" was close to their final wake time they would begin their day without going back to bed, but that if the call was in earlier in the night they would be permitted to go back to sleep following testing. Participants were woken at 0700 following both on-call nights by a loud alarm (TOA transistor megaphone with siren signal, model: ER-1215S) which could be heard in the rooms at between 61.5-69.8 dB. To avoid additional stress, participants were told there was no possibility of missing the alarm (Wuyts et al., 2012). All other elements of the three nights (control, *definitely*, *maybe*) were consistent, including the actual sleep period (2300 – 0700). Participants were only called at the end of their sleep periods each night (never during the night) to avoid any confounding effects of sleep restriction. As the laboratory was time-isolated, participants were unaware of the length or timing of their sleep period. The control condition was first on all occasions to avoid participants becoming aware that all sleep opportunities in the laboratory were identical, and to avoid any effects of sleep disruption associated with on-call nights.

3.3.3 Measures

3.3.3.1 Anxiety

Anxiety was measured using the STAI x-1 (state) (Spielberger, 1983). The STAI x-1 is widely used to determine state levels of anxiety, and has been determined to be reliable and generalizable, as determined by a review of research articles that used this questionnaire between 1990 and 2000 (Barnes et al., 2002). This questionnaire includes 20 items that respondents rate between 1 and 4 depending on how much they feel like that particular item relates to them at the current time. Items on this questionnaire include statements such as “I feel calm” or “I feel content”. Participants completed the STAI x-1 each night at 2245, which was 25 min after being given their on-call instructions for the night, and 15 min prior to scheduled bedtime.

3.3.3.2 Sleep

All sleep periods were measured using PSG. A standard EEG montage as measured by the Compumedics Grael PSG/EEG system (Melbourne, Australia) was used. Recordings were taken from the three standard electrode channels, C3/M2, F4/M1 and O2/M1 (Iber, 2007) in addition to EMG recordings, from the left, right and middle of the jawline and EOG recordings (left and right outer canthi). Sleep records were blinded and scored by a trained sleep technician in 30 s epochs according to standard criteria (Iber, 2007).

Variables examined were: total sleep time, sleep onset latency (sleep onset defined as the first epoch scored as >50% of sleep), sleep efficiency, proportion and amount of time spent in each sleep stage, stage shifts, arousals, WASO, REM latency, latency to 10 min of sleep and latency to N3.

Participants provided an answer to the question “how much sleep did you think you obtained?” following completion of the first PVT each day. Awareness of the amount of sleep they obtained reflects both awareness of the potential sleep opportunity (i.e. if they knew their bed and wake times) in addition to awareness of their own sleep efficiency. Quantitative EEG sleep analysis

Analysis of the electroencephalographic sleep recordings was used to identify the makeup of sleep stages based on frequency composition, and is more sensitive to changes in sleep than manual sleep scoring of PSG data (Campbell, 2009). After converting the original PSG recordings to European Data Format (EDF) files, Fast Fourier transformations (FFT) were used on the Cz channel, in order to identify the frequency of the EEG recordings over non-overlapping 5s periods of the sleep opportunity. Frequency was categorised into standard bands (delta – 0.5-4.5 Hz, theta – 4.5-8.0 Hz, alpha – 8.0-12.0 Hz, sigma – 12.0-15.0 Hz and beta 15.0-32.0 Hz) (Vakulin et al., 2016). EEG spectral power was calculated for each 30s period by averaging data from up to 6 artefact-free 5s blocks. Any epochs with artefact were automatically excluded from analyses by the software, but were checked for accuracy by a manual assessment of 10% of sleep periods (Vakulin et al., 2016). Data are presented as the proportion of time during REM and NREM sleep that occurred within each frequency band. Further, the ratio between slow and fast frequency ((delta + theta) / (alpha + sigma + beta)) was assessed (EEG slowing ratio), as was the delta/alpha ratio, for each sleep stage. Greater proportions of delta and theta frequency indicates deeper sleep, which is related to greater sleep need and occurs more when individuals have been awake for extended periods of time (Campbell, 2009). Conversely, greater proportions of high frequency (alpha, sigma, beta) activity indicate higher levels of arousal during sleep and may be associated with more sleep disruption (Campbell, 2009).

3.3.3.3 Cognitive performance

Cognitive performance was measured using a 10-min PVT (Dinges & Powell, 1985) at four time points on the control and each on-call day (0930, 1200, 1430, and 1700). This task is used widely in sleep and performance literature and is sensitive to changes in sleep quality and quantity (Dinges & Powell, 1985). The PVT is a 10 min reaction time test requiring subjects to respond as quickly as possible to a visual stimulus on a hand held device, by pressing a button with the thumb of their dominant hand. This task is designed to measure reaction time, sustained attention and vigilance. Output variables are mean reciprocal reaction time (RRT (1/reaction time*1000, milliseconds)), number of lapses (when the participant does not respond to the stimulus within 500ms), mean fastest 10% of reaction time and mean slowest 10% of reciprocal reaction time. Participants completed three training sessions of the task on the adaptation day to account for any learning effects (Kribbs & Dinges, 1994).

3.3.4 Statistical analyses

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS). A linear mixed-effects analysis of variance (ANOVA) was used to compare conditions for all variables (Van Dongen et al., 2004b). For sleep and anxiety variables, a within-subject fixed effect of condition (control, *definitely* and *maybe*) and a fixed-effect of counterbalance order, and their interaction were included in the model. No main effects of order were found for any variables, and as such these values have not been reported. A random intercept over participants was used to account for individual differences (Van Dongen et al., 2004a). Further, for PVT outcomes, time of day (0930, 1200, 1430, and 1700) was also specified as a fixed effect. A Satterthwaite correction was applied to the denominator degrees of freedom. Bonferroni post-hoc tests were performed within the model to identify points of significance. All data are reported as mean ± standard deviation.

3.4 Results

3.4.1 Anxiety

STAI x-1 scores were analysed by comparing individual mean scores on the control and two on-call nights. A significant main effect of condition was found, $F_{(2, 48)} = 8.5$, $p = .001$, with participants having significantly higher anxiety scores prior to sleep in the *definitely* condition (35.7 ± 7.5) when compared with the control (32.0 ± 5.7), $p = .001$, and the *maybe* conditions (32.9 ± 5.7), $p = .013$.

3.4.2 Sleep

There was a variation in perceived sleep duration in all conditions, indicating that time isolation was effective. In the control condition, participants reported that they believed their sleep duration was 7.0 h (± 1.1), with a range of 5.0 – 10.0 h. In the *definitely* condition, participants believed their sleep duration was 6.2 h (± 1.3), with a range of 4.0 – 8.0 h). In the *maybe* condition, participants reported that they believed they had a 6.5 h (± 1.3) sleep duration, with a range of 3.5 – 8.0 h.

3.4.2.1 Polysomnography

Sleep outcomes are reported in Table 1. Overall, participants experienced less N2 sleep in the *maybe* condition, when compared with the *definitely* or control conditions. This was the case for actual minutes of N2 sleep and as a proportion of total sleep time. Participants also had fewer minutes of NREM sleep in the *maybe* condition when compared with control. Total sleep time did not vary significantly between groups, though the main effect was approaching significance (p = .060), with total sleep time in the *maybe* condition being lower than both the control and *definitely*.

Results also indicated that participants had a longer latency to REM sleep in the control condition when compared with both on-call conditions. Further, participants obtained more REM sleep when on-call, regardless of condition, both in terms of actual minutes and when considered as a proportion of total sleep time. As such, participants had less NREM sleep during both on-call conditions compared to control, when considered as a proportion of total sleep time. No significant differences were found in all other measures.

Table 1. Significant differences found in sleep variables between control, definitely, and maybe conditions

Variable	Condition			F	Post-hoc tests
	Control (C)	*Definitely (D)*	*Maybe (M)*		***p < .05**
Total sleep time (TST) (mins)	444.5 (16.7)	448.1 (14.4)	439.8 (20.3)	3.0	-
Sleep efficiency (%)	92.6 (3.5)	93.4 (3.0)	91.6 (4.2)	3.0	-
Sleep onset latency (mins)	14.0 (9.5)	11.0 (5.8)	16.5 (12.1)	2.3	-
Wake after sleep onset	21.5 (13.7)	20.8 (11.8)	23.6 (16.7)	.5	-
Minutes of N2	201.5 (20.9)	199.3 (26.3)	188.0 (19.9)	5.2	C, D > M
N2 % of TST	45.4 (4.7)	44.4 (5.1)	42.7 (3.8)	4.7	C > M
Minutes of REM	101.9 (14.3)	113.2 (15.0)	114.2 (18.9)	7.1	C < D, M
REM % of TST	22.9 (3.0)	25.3 (3.3)	25.9 (4.0)	8.0	C < D, M
Latency to REM (mins)	82.4 (26.5)	69.8 (23.6)	69.7 (13.8)	4.1	C > D, M
Minutes of NREM	342.6 (17.6)	335.0 (18.1)	325.7 (21.6)	7.6	C > M
NREM % of TST	77.1 (3.0)	74.8 (3.3)	74.1 (4.0)	8.0	C > D, M
Latency to 10 mins of sleep (mins)	16.9 (11.2)	13.4 (8.3)	18.8 (12.5)	2.8	-
Latency to N3 (mins)	13.4 (4.3)	14.7 (6.3)	13.5 (5.2)	1.0	-
Minutes of N1	29.2 (9.9)	29.9 (11.4)	28.2 (9.6)	.3	-
N1 % of TST	6.6 (2.2)	6.7 (2.7)	6.4 (2.2)	.1	-
Minutes of N3	112.0 (24.8)	105.8 (19.7)	109.5 (19.6)	1.9	-
N3 % of TST	25.2 (5.4)	23.6 (4.6)	24.9 (4.4)	2.6	-
Arousals (total sleep period)	82.3 (24.9)	85.0 (27.6)	80.6 (23.5)	.7	-
Arousals (REM)	23.6 (12.3)	26.9 (14.2)	26.8 (14.3)	2.1	-
Arousals (NREM)	58.7 (20.2)	58.1 (23.3)	53.8 (17.3)	1.4	-
Arousals per hour (total sleep period)	11.1 (3.3)	11.4 (3.9)	11.1 (3.5)	.3	-
Arousals per hour (REM)	13.9 (6.4)	14.1 (6.7)	14.2 (6.8)	.0	-
Arousals per hour (NREM)	10.3 (3.6)	10.4 (4.2)	10.0 (3.4)	.3	-
Awakenings	18.1 (6.2)	19.9 (5.7)	18.7 (6.6)	2.0	-
Stage shifts	141.9 (26.2)	138.8 (26.4)	141.0 (21.9)	.2	-

Abbreviations: REM – Rapid eye movement sleep, NREM – non-rapid eye movement sleep, N1 – stage one sleep, N2 - stage two sleep, N3 – stage three (slow wave) sleep.
Data reported as Mean (standard deviation).

3.4.2.2 Quantitative EEG sleep analysis

QEEG analysis of sleep was performed to determine the absolute power of the different ranges of brain activity frequency and is presented in units of μV2 (power spectral density). As displayed in Table 2, there were no significant differences found between conditions for any of the frequency ranges. However, ratio analyses indicated that participants had a higher rate of EEG slowing (fast/slow ratio) in the *definitely* condition when compared with control in N2. Similarly, in N1 there was a higher delta/alpha ratio in the *definitely* condition compared with control. Analyses also demonstrated that for REM sleep, there was more EEG slowing and a higher delta/alpha ratio in the *maybe* condition compared with control.

Table 2. Average qEEG power and slowing in control, definitely, and maybe conditions

qEEG range	**Sleep stage**	**Condition**			**F**	**p**	**Post-hoc tests**
		Control	*Definitely*	*Maybe*			
Delta (0.5 – 4.5 Hz)	NREM*	588.25 (312.80)	631.15 (275.09)	580.27 (303.78)	1.6	.216	-
	REM*	208.74 (134.43)	219.98 (104.15)	211.50 (115.42)	.4	.656	-
Theta (4.5 – 8 Hz)	NREM	34.41 (13.66)	37.08 (15.23)	33.84 (13.10)	1.4	.254	-
	REM*	30.65 (54.64)	20.26 (8.10)	19.88 (7.75)	.5	.610	-
Alpha (8 – 12 Hz)	NREM	15.10 (7.44)	17.26 (8.97)	15.11 (7.72)	1.2	.302	-
	REM*	10.12 (12.08)	8.62 (4.22)	7.71 (3.32)	.7	.497	-
Sigma (12 – 15 Hz)	NREM	10.89 (4.52)	11.18 (4.68)	10.37 (4.36)	2.0	.142	-
	REM*	2.84 (2.33)	2.62 (1.13)	2.32 (.76)	.6	.564	-
Beta (15 – 32 Hz)	NREM*	5.92 (2.20)	6.67 (3.53)	5.69 (1.99)	.7	.492	-
	REM*	6.62 (3.31)	6.15 (2.07)	5.74 (1.76)	1.0	.388	-
EEG slowing ratio	NREM	19.63 (5.59)	19.93 (5.54)	20.09 (6.24)	1.6	.218	-
	N1	1.05 (.12)	1.02 (.02)	1.03 (.03)	1.3	.292	-
	N2*	11.20 (2.45)	11.98 (3.24)	11.64 (2.99)	3.6	**.036**	C < D (p = .036)
	N3	32.56 (9.59)	33.59 (10.19)	32.47 (11.13)	1.9	.160	-
	REM	12.75 (3.32)	14.03 (3.99)	14.57 (4.23)	5.3	**.009**	C < M (p = .010)
Delta/ alpha ratio	NREM	42.31 (15.99)	41.83 (16.45)	42.53 (17.29)	.7	.490	-
	N1	22.77 (7.81)	26.07 (11.34)	23.83 (9.23)	3.3	**.048**	C < D (p = .055)
	N2	25.16 (8.84)	26.13 (10.04)	25.62 (9.53)	2.3	.118	-
	N3	65.34 (25.29)	65.47 (27.23)	64.52 (28.90)	1.0	.370	-
	REM	24.84 (8.13)	26.75 (7.84)	28.25 (9.29)	4.4	**.019**	C < M (p = .018)

*log transformed to normal for analysis
Abbreviations: REM – Rapid eye movement sleep, NREM – non-rapid eye movement sleep.
Data reported as Mean (standard deviation).

3.4.3 Performance

PVT performance data are reported in Table 3. There was a significant main effect of condition on mean reciprocal reaction time (RRT), p = .045. Post-hoc testing revealed that there was a significant difference between performance on the control (4.21 ± .59) and *maybe* days (4.11 ± .70), p = .039, though neither were significantly different from the *definitely* day (4.16 ± .75). Analyses also showed significantly more lapses in the *maybe* condition (1.63 ± 3.38) when compared with the control condition (.85 ± 1.26, p < .001), but not the *definitely* condition (1.24 ± 2.53). There was no significant time of day effect on mean RRT or lapses. There were no significant differences in time of day or condition for the mean fastest 10% responses times (RT) or mean slowest 10% of response times (RRT).

Table 3. Condition effects for performance on the psychomotor vigilance task

Variable	Condition			F	p	Post-hoc testing
	Control (C)	***Definitely* (D)**	***Maybe* (M)**			
Mean RRT	4.21 (.59)	4.16 (.75)	4.11 (.70)	3.1	.045	C > M, p = .039 C - D, p = .515 D - M, p = .782
Lapses	.85 (1.26)	1.24 (2.53)	1.63 (3.38)	3.9	.022	C < M, p = .017
Mean fastest 10% RT (ms)	191.52 (19.97)	194.07 (21.65)	192.17 (21.42)	2.0	.133	-
Mean slowest 10% RRT	2.87 (.65)	2.83 (.82)	2.73 (.95)	2.9	.059	-

Note. RT = reaction time; RRT = reciprocal reaction time

3.5 Discussion

This study aimed to understand whether the likelihood of being called during an on-call period impacts self-reported pre-bed anxiety, sleep and next day cognitive performance. Though previous research has suggested that uncertainty surrounding a call may result in higher anxiety (Bamberg et al., 2012; McGrath, 1976), the present results indicate that individuals experience higher levels of self-reported pre-bed anxiety when they know they are *definitely* going to be called, rather than when told that they *may* be called overnight, which does not support the relevant hypothesis. However, for sleep and performance outcomes, greater decrements occurred when individuals were instructed that they *may* be called during their overnight on-call period, which supports the hypotheses. This aligns with the study hypotheses and previous research (Jay et al., 2016; Wuyts et al., 2012). On the *maybe* nights, participants obtained significantly less N2 sleep than in the *definitely* condition (11.3 fewer minutes) or the control condition (13.5 fewer minutes). Additionally, participants had 16.9 fewer minutes of NREM sleep in the *maybe* condition compared with control but these differences did not equate to a significant difference in total sleep time between conditions. Further, there were no differences in the absolute frequency composition of any sleep stage, though there were some small differences apparent in ratio analysis, demonstrating slight increases in slow wave power in REM and light sleep (N1, N2) in the *maybe* and *definitely* conditions, respectively. Results also indicated that PVT performance in the *maybe* condition was significantly worse than after the control night, though not different from that following the *definitely* night. Though the sleep decrements in the *maybe* condition were small, these changes may be partly responsible, as even small changes to sleep can impact next day performance (Alhola & Polo-Kantola, 2007; Belenky et al., 2003). Further, no time of day effects were found for cognitive performance in any condition, which was unexpected given the circadian dip that is known to occur in the mid-afternoon. Based on the range of perceived sleep opportunities (3.5 – 10.0 h across all conditions), it appears that participants had little awareness of the amount of sleep they obtained. This also suggests that the intended time isolation was effective, indicating that outcomes were based on condition rather than perceived sleep opportunity.

It is particularly interesting that participants experienced more anxiety in the *definitely* condition, as the on-call literature (albeit limited) suggests that the uncertainty surrounding a call may result in increased anxiety (Bamberg et al., 2012; Paterson et al., 2016). However, there are some subjective reports, for example in Australian volunteer firefighters, that indicate on-call workers experience more anxiety and apprehension when they believe they are more likely to be called (Paterson et al., 2016). This may relate to the fact that individuals know they are *definitely* going to have the unpleasant experience of being woken without a full night of sleep, and will have to perform demanding tasks upon waking (Wuyts et al., 2012). Further, participants were given a demonstration of the alarm on the adaptation day and knew that it was very loud and startling. As a result, they may have been anxious about being woken in an unpleasant way (Kecklund et al., 1997). However, it is important to note that while there were statistically significant differences in pre-bed anxiety between conditions, these differences were not clinically important. Scores above 39-40 on the STAI x-1 in healthy adults are indicative of clinically significant state anxiety, while the highest mean score was 35.04 (in the *definitely* condition) (Julian, 2011).

Another unexpected outcome was the higher proportion and a greater duration of REM in both on-call conditions compared with control. Further, latency to REM was significantly shorter in both on-call conditions. This increased REM may, to some extent, be displacing N2 sleep, particularly during the *maybe* condition, where N2 minutes were fewest. These REM increases may be linked with slight possible sleep debt associated with an 8 h time in bed (Van Dongen et al., 2003), though other research has demonstrated no changes to REM with similar (8.2 h) sleep opportunities (Mollicone et al., 2007). Further, as the present study included just four nights in the laboratory, the observed changes to REM when on-call may be indicative of a heightened stress response to the on-call conditions, as increased REM can be an adaptive response to stressful situations (Suchecki et al., 2012). For example, animal-based research has suggested that increased REM may be a physiological response to punishment or adverse conditions, with rats who were subjected to shock-based learning tasks experiencing increased REM sleep (Smith et al., 1974). More recently, research has shown that humans who experienced motor vehicle accidents and subsequent increases in REM sleep were less likely to develop post-traumatic stress disorder (Mellman et al., 2007). As such, increased REM may be a physiological response to stress, and result in an increased capacity for managing stressful or adverse conditions. Further, in the on-call laboratory study conducted by Jay et al. (2016), while no significant changes in sleep were found, there was a trend towards a higher proportion of REM during sleep periods when on-call. This may suggest that the stress of being on-call provokes an adaptive sleep response in individuals. Further research is required to understand the impacts of on-call work on REM, and how this may subsequently affect any performance or safety outcomes. Specifically, research into the relationship between physiological stress and REM sleep, and associated sleep disruption while on-call may be useful.

The qEEG analysis of PSG sleep outcomes also indicated that there were some changes in the ratio of low/high frequency power, specifically regarding REM and the lighter stages of sleep (N1, N2). However, these changes were mixed between conditions, with more slow wave power in REM in the *maybe* condition, and in N1 and N2 in the *definitely* condition, indicating that there may be an effect of being on-call in general on slow wave power. While there has been no research in healthy adults, research in sleep apnea has demonstrated that increased delta power is associated with poorer cognitive performance (Vakulin et al., 2016). However, it appears that this increase occurs in individuals who are experiencing a higher sleep debt. As such, the increases in slow wave power in this case may indicate that during on-call periods, individuals are accumulating a greater sleep debt, perhaps as a result of increased stress. However, as the differences found in this study were small, and did not solely increase or decrease within conditions, it may be that these findings are somewhat spurious, and are not necessarily related to any changes based on call likelihood.

The findings from the present study suggest that the uncertainty surrounding a call results in changes to both sleep and performance. Additionally, it appears that being on-call affects anxiety, but not in the same manner as sleep or performance. Indeed, individual perception may differ from actual sleep outcomes, as seen by the difference in anxiety and sleep measures in the present study, though further research into subjective measures of sleep would provide more information. Anxiety, as determined by self-report, is a measure of an emotional state, rather than of specific physiological outcomes, and may therefore have a different relationship with sleep than objective measures of stress. Physiological or psychological stress may be involved in the relationship between on-call, sleep and performance and objective physiological measures of stress, such as pre-bed heart rate variability may be linked more intrinsically with sleep and performance outcomes, rather than subjective anxiety. The relationship between objective stress and sleep/performance outcomes must be investigated to determine what mechanism is operating between on-call conditions and sleep and performance outcomes.

The results of the current study indicate that call likelihood and uncertainty during on-call periods should be taken into consideration when planning and managing on-call rostering systems. Traditionally, on-call periods where calls are less likely may have been viewed as having less of an impact on sleep and performance because less actual work is likely to occur. In fact however, the opposite may be true. As such, call likelihood needs to be addressed when assessing fitness for duty when driving to a shift the following day, or during subsequent work shifts, particularly if an on-call worker or volunteer is expected to perform work or volunteer duties the following day.

Despite being statistically significant, it is important to note that the cognitive performance decrements in the present study are comparatively small compared with performance under conditions of total sleep deprivation or restriction over multiple nights (Lamond et al., 2007; Van Dongen et al., 2003). For example, Lamond et al. (2007) found that after just one night of sleep deprivation, PVT performance was approximately 25% poorer than the most affected condition in the present study. However, our study included just two on-call nights, whereas in the real world, many volunteer on-call workers are on-call every day of the year (Birch & McLennan, 2007). Small differences seen under on-call conditions for just one or two nights may produce cumulative decrements over consecutive nights.

Laboratory research is critical in new fields of research like on-call, as it enables us to isolate the mechanisms in play, but is limited in terms of generalisability to real world environments. Specifically, the multi-factorial nature of the real world means that factors such as work type, potential consequences of errors, stress and timing of calls may affect sleep and performance differently. Therefore, further research must be conducted in different environments, and different groups of participants, specifically women and older adults. Further, in order to isolate the impacts of on-call from those associated with sleep deprivation or restriction the present study provided for 8 h time in bed. However, as shortened sleep is often associated with on-call periods, and a large proportion of the population habitually sleep less than 8 h per night, it will be important in future research. Additionally, other components may also affect anxiety, sleep and performance, such as the effects of specific tasks that individuals perform upon waking. Further, as the possibility of missing a call during an on-call period has anecdotally been a source of stress for individuals (Paterson et al., 2016), understanding how this may interplay with anxiety and the subsequent sleep and performance outcomes may be useful. It is also important to note that a wide range of sleep variables were included in this study. This is a potential limitation due to the statistical probability of at least one variable being affected significantly (Johnstone & Titterington, 2009). However, as the sleep dimensions that may have been impacted by on-call work were largely unknown, it was important to capture all potential changes to sleep. This is one of the few studies to systematically assess on-call in a laboratory environment (Jay et al., 2016; Wuyts et al., 2012). It was found that participants experienced altered sleep and poorer performance the next day when instructed that they *may* be called during an overnight on-call shift, compared with when they were told they would *definitely* be called. However, self-reported pre-bed state anxiety does not appear to have been affected in the same way as sleep and performance, as participants reported feeling more anxious on nights when they were *definitely* going to be called. As such, future research into other, possibly physiological mechanisms by which sleep and performance are affected may be necessary. However, the results of the present study indicate that the likelihood of a call during an on-call period is a factor in sleep and performance, and as such should be taken into consideration when organisations and workplaces are making rostering decisions. Specifically, it may be more operationally effective to have a smaller pool of on-call workers rostered on simultaneously, who are more likely to be called, rather than having more available staff with a reduced likelihood of a call.

Chapter 4. Study 2

The effect of task stress on anxiety, sleep, and cognitive performance

Peer reviewed publication associated with this chapter (Appendix K):

Sprajcer, M., Jay, S.M., Vincent, G.E., Vakulin, A., Lack, L., Ferguson, S.A. (2018). The effects of anticipating a high stress task on sleep and performance during simulated on-call work. *Journal of Sleep Research*, e12691.

doi: 10.1111/jsr.12691

Declaration of co-authorship and contribution

Full bibliographic reference to the item/publication, including authors, title, journal (vol/pages), year.	Sprajcer, M., Jay, Sarah M., Vincent, G., Vakulin, A., Lack, L., Ferguson, S. A. (2018). The effects of anticipating a high stress task on sleep and performance during simulated on-call work. *Journal of Sleep Research*, e12691. doi: 10.1111/jsr.12691
Status	Published

Nature of Candidate's Contribution, including percentage of total

I was responsible for laboratory set up, participant recruitment, data collection, and data management. I cleaned and analysed the data, formulated the research question, interpreted results and wrote the publication. (80%)

Nature of all Co-Authors' Contributions, including percentage of total

Sally Ferguson and Leon Lack won the funding for this project. Sarah Jay and Grace Vincent were involved in data collection Andrew Vakulin provided me with expertise regarding qEEG data analysis. All co-authors reviewed and provided critical feedback on the manuscript and helped to prepare it for publication. (20%)

Has this paper been submitted for an award by another research degree candidate (Co-Author), either at CQUniversity or elsewhere? (if yes, give full details)

No

Candidate's Declaration
I declare that the publication above meets the requirements to be included in the thesis as outlined in the Research Higher Degree Theses Policy and Procedure

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(Original signature of Candidate)   Date

4.1 Abstract

On-call work is used to manage around the clock working requirements in a variety of industries. Often, tasks that must be performed while on-call are highly important, difficult and/or stressful by nature, and as such, may impact the level of anxiety that is experienced by on-call workers. Heightened anxiety is associated with poor sleep, which affects next-day cognitive performance. Twenty-four male participants (20 - 35 yrs) spent an adaptation, a control and two counterbalanced on-call nights in a time-isolated sleep laboratory. On one of the on-call nights they were told that they would be required to do a speech upon waking (high stress condition), whereas on the other night they were instructed that they would be required to read to themselves (low stress condition). Pre-bed anxiety was measured by the STAI x-1, and PSG and qEEG analyses were used to investigate sleep. Performance was assessed across each day using the 10-min PVT (0930, 1200, 1430, and 1700). Results indicated that participants experienced no significant changes in pre-bed anxiety or sleep between conditions. However, performance on the PVT was best in the high stress condition, possibly as a result of heightened physiological arousal caused by performing the stressful task that morning. This suggests that performing a high stress task may be protective of cognitive performance to some degree when sleep is not disrupted.

4.2 Introduction

Approximately one quarter of Australian (Australian Bureau of Statistics, 2016) and European employed persons (Parent-Thirion et al., 2012) currently perform on-call work. On-call working arrangements are common in industries such as emergency services, healthcare and information technology, and can involve performing tasks that are time sensitive, often with severe consequences if not performed appropriately (Ferguson et al., 2016). Anecdotal reports from on-call workers indicate that the possibility of being called to perform a critical task, such as attending to injured persons in a motor vehicle accident, results in heightened anxiety surrounding the on-call period (Barnes, 2000; Paterson et al., 2016). This heightened anxiety while on-call may result in poorer sleep outcomes, possibly as a result of rumination and worry, and/or physiological arousal (Åkerstedt et al., 2007). Given that poor sleep is known to adversely impact next-day cognitive performance (Van Dongen et al., 2003), sleep decrements while on-call may have negative implications for workplace or personal safety. This is particularly relevant when the tasks that must be performed are high-consequence, such as performing surgery or attending a house fire.

Previous research has highlighted that performing a task with serious consequences or a high cognitive or affective load (i.e., a difficult or stressful task) can be linked with increased anxiety (Barnes, 2000). This anxiety can be related to either knowing they will be required to perform a stressful task, or as a result of traumatic occupational experiences (Barnes, 2000). Anxiety and stress are similar concepts, with anxiety referring to the emotional state of worry, fear and agitation (Barlow, 2002), whereas the term "stress" is generally used in reference to the psychological and physiological response to adverse or demanding situations (Misra & McKean, 2000). This study aimed to understand the effects of knowing a stressful task must be performed on anxiety outcomes. The apprehension and anxiety associated with performing a stressful task has been demonstrated in a variety of fields, including healthcare (Rada & Johnson-Leong, 2004), emergency services (Barnes, 2000), in students sitting exams (Nie et al., 2011), and in home-based on-call simulations (Ziebertz et al., 2017). Further research is needed to determine whether the relationship between a stressful task and anxiety also exists in on-call environments where individuals are required, upon waking, to perform tasks that are difficult, dangerous or have far-reaching consequences.

Feelings of anxiety have been associated with poor sleep in a number of occupations (Hall et al., 2000). These industries include aviation and information technology, where anxiety has been linked with higher arousal, and as such, shorter total sleep times and lighter sleep (Åkerstedt, 2006; Hall et al., 2000; Kecklund et al., 1997). Further, stress that has been induced in experimental research has also been shown to result in changes to sleep (Kim & Dimsdale, 2007). On-call work has also been linked with adverse sleep outcomes, such as limiting sleep opportunity and impairing sleep quality (e.g. sleep latency, overnight awakenings) which have been discussed in recent reviews (Ferguson et al., 2016; Hall et al., 2016). Anecdotal and research-based evidence suggests that pre-bed anxiety may be the mechanism by which sleep is impaired during on-call periods (Hall et al., 2016; Paterson et al., 2016). Indeed, a correlational investigation of a general working population revealed that job difficulty and perceived work stress is linked with sleep quality (Marquie et al., 1999). As heightened anxiety may precede the performance of a difficult or high-consequence task, the nature of the task may be a trigger for on-call causing poorer sleep. That is, particularly stressful tasks, or tasks with severe consequences, may result in heightened pre-bed anxiety while on-call, and consequently poorer sleep during these periods.

As poor sleep (both quality and quantity) is known to result in poor cognitive performance (Alhola & Polo-Kantola, 2007), it is of particular importance to understand any effects on sleep that on-call working arrangements may have. These cognitive decrements can include attention, executive functioning, memory and processing speed, which can have a significant impact on work performance (Alhola & Polo-Kantola, 2007). This is particularly relevant given the high-risk nature of many types of on-call work.

This study aimed to determine if expecting a more stressful task upon waking resulted in increased pre-bed anxiety, poorer sleep, and subsequently impaired cognitive performance in an on-call laboratory environment. The main focus of the study was the anticipation of the task, and how this may have affected pre-bed anxiety, sleep and next-day performance. The aim of this study was to isolate one aspect of on-call with the potential to cause pre-bed anxiety. Specifically, this study aimed to isolate the effects of anticipating a stressful task, with other associated studies investigating the likelihood of receiving the call (Chapter 3) and the chance of missing the on-call alarm (Chapter 5).

The hypotheses investigated in this chapter include:

1) Performing a stressful task upon waking during on-call periods will result in higher pre-bed anxiety, compared with performing a low-stress task, or not being on-call (control).
2) Performing a stressful task upon waking during on-call periods will result in poorer sleep outcomes, compared with performing a low-stress task, or not being on-call (control).
3) Performing a stressful task upon waking during on-call periods will result in poorer next-day cognitive performance, compared with performing a low-stress task, or not being on-call (control).

The present study is particularly novel as there have only been two similar laboratory-based investigations of on-call work (Jay et al., 2016; Wuyts et al., 2012), neither of which have involved any kind of differentiation in the degree of stress elicited from tasks that participants are required to perform. One home-based on-call simulation has also been performed, finding that stress was the moderating factor between on-call and sleep outcomes, with higher stress being associated with poorer sleep (Ziebertz et al., 2017). However, none of these previous studies have investigated how the task that is to be performed upon waking affects the anxiety, sleep and next-day cognitive performance while on-call, which the current study aimed to do. This is important to understand due to the varying nature of on-call work, the wide variety of industries that utilise on-call working arrangements and potential impacts of poor sleep on performance and safety.

4.3 Methods

4.3.1 Participants

Twenty-four male participants, aged 20-35 years, completed the study (mean ± standard deviation = 27.0 ± 4.1 years). Power calculations were made prior to the design of the study, indicating that 24 participants would be sufficient, given the differences in total sleep time (approximately 10%) that have been found in doctors on-call compared with not on-call (Jay et al., 2008). Participants were recruited via online and flyer based advertising. Participants reported having good quality sleep in the previous month (PSQI score ≤ 5 (Buysse et al., 1989), an ESS score < 10 (Johns, 1991) and no diagnosed sleep disorders). Participants had body mass indexes of less than 30 $kg.m^2$ (23.7 ± 2.8 $kg.m^2$), were non-smokers, and did not report any medical conditions that may have interfered with sleep. Participants were excluded if they consumed more than two caffeinated beverages/day, reported habitual napping, travelled across multiple time zones in the previous four weeks, or were current shift workers. Ten participants were current university students, seven were employed in office-based professions, with the remainder engaged in sales, retail, hospitality, manual work or currently unemployed. No participants had previous experience with on-call work, had specific experience giving speeches, or had participated in a sleep study before. Participants were also excluded if they had extreme chronotypes determined by the MEQ (Horne & Ostberg, 1975), or severe levels of depression, anxiety or stress, as identified by the DASS (Crawford & Henry, 2003). Participants were required to maintain bed and wake times ± two hours of study bed/wake times (2300 – 0700) in the week prior to the study. This was corroborated by actigraphy (Actical MiniMitter/Respironics, Bend, OR) (de Souza et al., 2003) and sleep diaries.

4.3.2 Design

A within-subjects, repeated measures design was used. Ethics approval was provided by the Central Queensland University Human Research Ethics Committee, and written consent was provided by all participants. The study was conducted at the Appleton Institute in a temperature (21 ± 2°C) and lighting (maintained at 100 lux during wake periods) controlled time-isolation laboratory. The protocol is presented in Figure 6, and consisted of an adaptation night and a control night, followed by two counterbalanced on-call nights. All sleep opportunities were 2300-0700, and participants were not actually "called" on either of the on-call nights, to ensure that each sleep opportunity was the same. Participants were told that if they woke during the night that they must try to sleep until they were called. On the on-call nights, participants were told prior to bed that they would be called during the night and would be required to perform either a high or low stress task sometime after waking. At the end of the sleep opportunity they were called with a loud alarm (TOA transistor megaphone with siren signal, model: ER-1215S) which could be heard in the bedrooms at between 61.5-69.8 dB. 75 min after being called they performed the reading task (low stress) or speech (high stress). Participants were blinded to time, and therefore unaware of their wake time and of the fact that they were not actually called during their 8-h sleep opportunity. It was anticipated that there would be significant sleep decrements on the on-call nights. As such, the protocol was designed with the control night first for all participants, to avoid the confounding effects of sleep debt on the control sleeps.

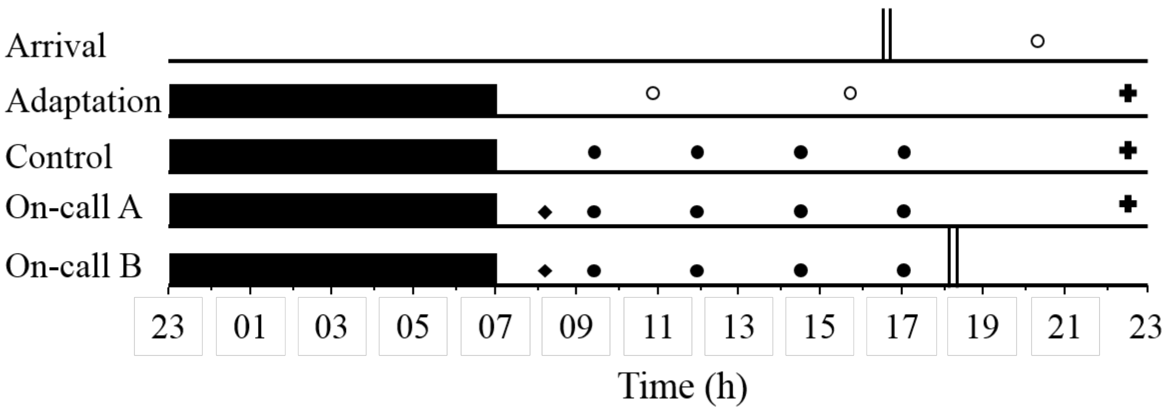

Figure 6. Study 2 Protocol

- ‖ Arrival to and departure from the laboratory
- ○ Training on 10-min psychomotor vigilance task (PVT)
- ● 10-min PVT
- ✚ State Trait Anxiety Inventory form x-1
  Speech or reading task
- ◆ On-call nights A and B were counterbalanced for high and low stress conditions

An hour prior to bed (2200) on the control night, participants were told that they were not on-call and would be getting a full night of sleep. At 2200 on both on-call nights, participants were informed that they were on-call overnight, and would definitely be called. In the high stress condition, participants were told that they would be required to do a 5-min assessed speech upon waking in front of a researcher. Participants were instructed that their performance would be assessed for quality and content, and that they would be recorded. Participants were not given any additional information about the content of the speech or in what context they would be performing. In the low stress condition, participants were told that they would be required to read to themselves from a National Geographic magazine for 5-min. Participants were not told that these tests were designed to elicit stress responses. These tasks were based on the modified Trier Social Stress Test, validated to produce psychological and physiological stress responses (e.g., increased cortisol, heart rate) (Hall et al., 2004).

4.3.3 Measures

4.3.3.1 Task stress

Task stress was measured by heart rate recordings during the 5 min that participants were performing their speech and reading tasks. Kubios HRV Software was used for analysis (Tarvainen et al., 2014).

4.3.3.2 Anxiety

Pre-bed anxiety was assessed using the STAI x-1 (Spielberger, 1983). This questionnaire includes items such as "I feel secure" and "I am regretful" in regards to how the individual felt *at that moment*. On-call instructions were given at 2215, the STAI x-1 was completed at 2245, and bedtime was 15 min later (2300) on the control and two on-call nights. STAI scores range from 20-80, with higher scores indicative of higher anxiety. Scores above 39-40 suggest clinically significant anxiety (Julian, 2011).

4.3.3.3 Sleep

Sleep was measured using PSG recording (Bloch, 1997). QEEG analysis was performed on the scored PSG output to determine EEG frequency compositions across sleep stages using a validated algorithm (D'Rozario et al., 2015). Methodological details for PSG and qEEG assessment are reported elsewhere (Chapter 3).

Participants provided an answer to the question “how much sleep did you think you obtained?” following completion of the first PVT each day. Awareness of the amount of sleep they obtained reflects both awareness of the potential sleep opportunity (i.e. if they knew their bed and wake times) in addition to awareness of their own sleep efficiency. Cognitive performance

Performance was assessed by a 10-min PVT (Dinges & Powell, 1985), which was performed at 0930, 1200, 1430, and 1700 on the control and on-call days. The PVT is sensitive to sleep loss and disruption, and is often used as a of measure sustained attention, a major component of cognitive performance (Dinges & Powell, 1985). Output measures are mean reciprocal reaction time (RRT), number of lapses (response time > 500ms), mean fastest 10% of reaction time (RT) and mean slowest 10% of RRT (Jewett et al., 1999). Participants completed three practice tests before the control condition to minimise learning effects across order of conditions (Kribbs & Dinges, 1994).

4.3.4 Statistical analyses

The statistical software package SPSS Statistics 22 (IBM Corporation) was used for all analyses. Heart rate data was assessed using a standard t-test. All other data were analysed using linear mixed-effects ANOVA. The fixed effects in this model were condition (within subjects - control, high stress, low stress), and counterbalancing order, with participant as a random effect. No significant effects of order were found and as such are not reported. A Satterthwaite correction was applied to denominator degrees of freedom. In addition to condition and order, time of day (0930, 1200, 1430, and 1700) was entered as a fixed effect for PVT analyses. Data that was non-normally distributed was log transformed for analysis. Bonferroni post-hoc testing were used for all analyses within the model. All data are reported as means ± standard deviation with significance set at $p = .05$.

4.4 Results

4.4.1 Task stress

Heart rate was measured during the speech and reading tasks. Results showed that participants had a significantly elevated heart rate when doing the speech task (high stress condition) (95.8 ± 14.5 bpm) compared to doing the reading task (low stress condition) (70.8 ± 9.0 bpm), $t(22) = -10.71$, $p < .001$.

4.4.2 State anxiety

No significant differences were found in self-reported pre-bed state anxiety between the control (41.3 ± 5.5), high stress (40.4 ± 5.1) and low stress conditions (40.8 ± 4.7), $p = .398$.

4.4.3 Sleep

4.4.3.1 Polysomnography

In the four days prior to the study, participants obtained an average of 7.2 ± 1.1 h of sleep per night, with an average sleep efficiency of 91.1 ± 5.6% according to actigraphic recordings (bedtime 2245 ± 0039; wake time 0743 ± 0059). Sleep data are presented for n = 22 as two participants' data were excluded (each participant lost one night due to technical issues, and one night was excluded due to noncompliance with the protocol). All sleep data are presented in Table 4. There was a main effect of condition for percentage of NREM sleep ($p = .035$), with a higher proportion of NREM sleep in the high stress condition compared to the low stress condition, $p = .031$. There was also a main effect of condition for minutes of NREM ($p = .040$). Post-hoc tests did not reveal any statistically significant differences between conditions, although the difference between the high and low stress conditions approached significance, $p = .062$. A main effect of condition was found for number of arousals during REM $p = .028$, with more arousals during REM in the low stress condition compared to the high stress condition, ($p = .024$).

On four occasions a participant was awake before the alarm. On two of these occasions the participant was awake for less than 2 min, and on all occasions, participants were awake for no longer than 20 min prior to the alarm sounding. As cognitive testing did not begin for 2.5 h after waking, and only in two instances did a participant have shortened sleep for this reason, it is unlikely that increased prior wake had any measurable effect on performance.

In the control condition, participants reported a mean perceived sleep duration of 7.3 h (± 0.9), with a range of 6.0 – 9.0 h. In the *high stress* condition, participants reported a mean sleep duration of 6.4 h (± 1.1), with a range of 4.5 – 8.0 h). In the *low stress* condition, participants reported that they believed they had a 6.6 h (± 0.9) sleep duration, with a range of 5.0 – 8.0 h.

Table 4. Sleep outcomes for control, high, and low stress conditions (n = 22)

Variable	Condition Mean (SD)			F	p**	Post-hoc
	Control (C)	High stress (H)	Low stress (L)			
TST (mins)	449.7 (14.0)	445.9 (16.3)	445.9 (16.5)	.939	.399	-
Sleep efficiency (%)	93.7 (2.9)	92.9 (3.4)	92.6 (4.0)	1.033	.364	-
Sleep onset latency (mins)*	11.9 (9.6)	11.5 (7.1)	13.6 (10.6)	.168	.846	-
Wake after sleep onset	18.4 (10.3)	22.7 (11.9)	19.2 (11.4)	1.725	.190	-
Minutes of N1	28.8 (9.7)	33.3 (11.2)	29.5 (9.5)	2.545	.090	-
N1 % of TST	6.4 (2.3)	7.5 (2.5)	6.6 (2.1)	2.490	.095	-
Minutes of N2	195.1 (39.4)	195.6 (34.6)	188.4 (39.5)	2.119	.132	-
N2 % of TST	43.3 (8.3)	43.8 (7.1)	42.2 (8.2)	2.157	.128	-
Minutes of N3	116.2 (35.7)	112.1 (29.7)	114.2 (32.0)	.473	.626	-
N3 % of TST	25.9 (7.8)	25.2 (7.0)	25.7 (7.3)	.210	.812	-
Minutes of NREM	340.1 (24.4)	341.0 (23.9)	332.1 (27.1)	3.476	**.040**	H > L (p = .062)
NREM % of TST	75.6 (4.9)	76.5 (5.3)	74.4 (4.8)	3.619	**.035**	H > L (p = .031)
Minutes of REM	109.6 (22.0)	104.8 (24.8)	113.8 (21.3)	3.184	.051	H < L (p = .046)
REM % of TST	24.4 (4.9)	23.5 (5.3)	28.3 (12.5)	2.650	.082	-
REM latency	67.8 (17.2)	75.2 (12.1)	71.9 (6.8)	1.303	.283	-
Latency to 10 mins of sleep (mins)*	15.6 (14.7)	13.9 (9.2)	19.8 (18.9)	.612	.547	-
Latency to N3 (mins)	13.9 (8.36)	16.0 (18.0)	13.3 (12.4)	.700	.502	-
Wake (mins)	18.4 (10.3)	21.7 (10.6)	18.7 (11.3)	1.024	.367	-
Arousals (total sleep period)	84.7 (19.4)	82.1 (27.6)	85.5 (22.6)	.537	.588	-
Arousals (REM)	27.5 (12.6)	24.3 (13.3)	29.7 (15.0)	5.091	**.010**	L > H (p = .024)
Arousals (NREM)	57.2 (16.5)	57.8 (25.0)	55.8 (18.8)	.241	.787	-
Arousals per hour (total sleep period)	11.3 (2.6)	11.0 (3.6)	11.5 (3.0)	.471	.627	-
Arousals per hour (REM)	15.0 (5.8)	14.0 (6.7)	15.7 (6.9)	2.002	.147	-
Arousals per hour (NREM)	10.1 (2.9)	10.2 (4.2)	10.0 (3.0)	.075	.928	-
Awakenings	18.7 (7.3)	19.7 (6.6)	19.5 (6.1)	.532	.591	-
Stage shifts	139.1 (22.9)	145.5 (23.1)	144.8 (23.2)	.837	.440	-

Note. TST = Total sleep time; REM = Rapid eye movement sleep; NREM = non rapid eye movement sleep; N1 = stage one sleep; N2 = stage two sleep; N3 = stage three (slow wave) sleep
*data not normally distributed so log transformed
**main effect of condition

4.4.3.2 Quantitative EEG sleep analysis

QEEG sleep analysis indicated that there were no significant differences in frequency composition of any sleep stages between conditions. QEEG data are presented in Table 5. Ratio analysis comparing high and low frequency ranges is presented in Table 6. While there appeared to be a main effect in high/low frequency power ratios (N2: $p = .047$, N3: $p = .048$), post-hoc testing revealed no significant differences between conditions for either sleep stage (see Table 6).

Table 5. Average qEEG power in control, high stress, and low stress condition (n = 22)

qEEG range	Sleep stage	Condition						F	p
		Control		High Stress		Low Stress			
		Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range		
Delta	NREM	638.18 (230.22)	194.60 - 1109.73	604.79 (261.47)	157.29 - 1130.87	649.12 (28.52)	176.57 - 1231.51	.263	.770
(0.5 - 4.5 Hz)	REM*	222.48 (78.57)	87.41 - 406.49	262.48 (184.22)	90.62 - 772.15	250.31 (143.54)	94.80 - 697.22	.648	.529
Theta	NREM*	37.68 (16.30)	11.12 - 89.33	37.16 (20.05)	10.45 - 100.12	38.44 (20.36)	11.23 - 105.92	.390	.679
(4.5 - 8 Hz)	REM*	20.35 (6.50)	10.78 - 34.22	21.38 (8.59)	11.88 - 40.54	21.46 (8.95)	9.52 - 43.85	.430	.653
Alpha	NREM*	16.22 (8.44)	5.30 - 47.22	16.37 (9.66)	5.66 -49.75	16.90 (9.68)	4.63 - 51.64	.232	.794
(8 - 12 Hz)	REM*	8.03 (3.21)	3.46 - 15.98	9.05 (5.17)	4.41 - 26.23	8.59 (4.90)	3.01 - 25.99	.998	.377
Sigma	NREM*	10.89 (5.65)	2.89 - 22.70	10.67 (5.64)	3.09 - 21.91	11.79 (6.99)	2.48 - 28.12	.095	.910
(12 - 15 Hz)	REM*	2.85 (1.02)	1.07 - 5.79	3.08 (1.45)	1.45 - 7.44	3.00 (1.56)	1.03 - 8.13	.404	.670
Beta	NREM	7.06 (2.59)	3.36 - 12.52	6.69 (2.62)	3.58 - 11.91	7.94 (4.91)	3.13 - 23.72	.255	.776
(15 - 32 Hz)	REM*	6.79 (2.08)	3.43 - 11.77	8.86 (2.54)	3.84 - 11.43	7.09 (2.97)	3.09 - 14.08	.166	.848

*data not normally distributed so log transformed

Table 6. qEEG slowing and ratio analysis in control, high stress, and low stress conditions (n = 22)

	Sleep stage	Condition Mean (SD)			F	p**	Post-hoc
		Control	High stress (H)	Low stress (L)			
EEG slowing ratio							
	NREM	21.34 (7.88)	17.54 (9.61)	20.67 (8.40)	2.768	.074	-
	N1*	1.03 (.021)	1.02 (.03)	1.03 (.02)	1.537	.226	-
	N2	13.00 (3.93)	10.77 (5.76)	12.74 (4.58)	3.288	**.047**	(C > H, p = .079)
	N3	33.88 (12.55)	27.74 (14.12)	33.13 (14.04)	3.253	**.048**	(C > H, P = .084)
	REM	14.24 (4.36)	13.64 (7.37)	15.13 (5.74)	1.267	.292	-
Delta/alpha ratio							
	NREM*	43.53 (16.34)	36.56 (19.17)	42.40 (17.50)	3.214	.050	-
	N1*	25.43 (10.09)	23.91 (13.18)	24.35 (8.23)	1.126	.333	-
	N2	27.30 (8.50)	23.10 (11.76)	27.30 (10.23)	2.728	.076	-
	N3*	65.55 (26.61)	54.87 (27.57)	63.83 (28.69)	2.515	.092	-
	REM*	29.74 (10.58)	28.86 (15.42)	30.18 (14.86)	1.848	.170	-

Note. REM = Rapid eye movement sleep; NREM = non rapid eye movement sleep; N1 = stage one sleep; N2 = stage two sleep; N3 = stage three (slow wave) sleep
*data not normally distributed so log transformed
**main effect of condition

4.4.4 Cognitive performance

One participant consistently had PVT responses that were outside of the normal range (3.7 standard deviations outside the mean for reciprocal reaction time (1/RT*1000)), and as such was excluded from analyses (Ratcliff, 1993). Consequently, the following data includes 23 participants. All performance data are presented in Table 7. Mean RRT, lapses and mean fastest 10% of RT were slower in the low stress condition compared with the control and high stress conditions, $p \leq 0.004$. Mean slowest 10% of RRT was slower in the low stress condition compared with control. There were no time of day effects for any outcome variable.

Table 7. Performance on the psychomotor vigilance task in control, high stress, and low stress conditions

Variable	Condition	Time of day* Mean (standard deviation)				Day mean (SD)	F**	P**	Post-hoc**
		0930	1200	1430	1700				
RRT (1/RT*1000)	Control	4.43 (.47)	4.43 (.50)	4.39 (.51)	4.45 (.44)	4.42 (.48)	8.250	.000	C, H > L
	High stress (H)	4.40 (.44)	4.37 (.54)	4.44 (.46)	4.39 (.51)	4.40 (.48)			
	Low stress (L)	4.32 (.52)	4.29 (.50)	4.07 (1.00)	4.31 (.58)	4.30 (.52)			
Lapses	Control	.57 (1.5)	.61 (1.70)	.87 (2.0)	.65 (1.07)	.66 (1.57)	5.684	.004	C, H < L
	High stress (H)	.57 (.95)	1.04 (1.85)	.74 (1.32)	.70 (1.72)	.76 (1.49)			
	Low stress (L)	1.35 (3.34)	.87 (1.39)	1.75 (2.68)	1.57 (3.27)	1.32 (2.71)			
Mean Fastest 10% of RT (ms)	Control	186.84 (18.21)	186.20 (15.00)	186.23 (17.08)	185.99 (18.48)	186.32 (16.96)	6.861	.001	C, H < L
	High stress (H)	189.05 (18.71)	188.96 (20.46)	183.40 (16.21)	186.05 (19.39)	186.86 (18.60)			
	Low stress (L)	190.33 (17.71)	192.83 (20.56)	191.42 (18.94)	188.71 (19.83)	190.82 (19.03)			
Mean slowest 10% of RRT	Control	3.16 (.57)	3.10 (.65)	3.00 (.70)	3.06 (.51)	3.07 (.61)	5.847	.003	C > L
	High stress (H)	3.03 (.51)	2.96 (.61)	3.00 (.60)	3.02 (.65)	3.01 (.58)			
	Low stress (L)	3.00 (.74)	2.97 (.62)	2.69 (.89)	2.88 (.81)	2.91 (.71)			

*p > .05 for all time of day main effects
**Main effect of condition
Note. RT = reaction time; RRT = reciprocal reaction time

4.5 Discussion

This study aimed to understand how the expectation of performing a stressful task upon waking impacts pre-bed anxiety, sleep and next-day cognitive performance. It was anticipated that prior to overnight on-call periods, participants would feel more anxious, particularly when they knew that they would be performing a stressful task (a speech) the following morning. However, results showed that there were no differences in pre-bed anxiety in either of the on-call conditions compared with control, which does not support the hypothesis. It was expected that there would be negative consequences for sleep due to anticipation of stressful task the following morning. However, and in opposition to previous research, which has shown significant decrements to on-call sleep (Wuyts et al., 2012) the only differences to sleep that were seen in the present study were fewer arousals during REM, and a slightly higher (1%) proportion of NREM in the high stress condition compared with the low stress condition. However, the fewer total arousals during REM in the high stress condition are not indicative of an actual decrease in arousals (this would be reflected in the arousals in REM per hour if it were the case), but is instead reflected by a slightly higher proportion of NREM compared with REM sleep in this condition. Further, in the high stress condition, a small decrease in REM sleep, approaching statistical significance, aligns with the fewer minutes of NREM. This may indicate that to a small degree, REM is replacing NREM minutes of sleep in the low stress condition. As the differences in sleep between conditions are small (1% more NREM sleep in the high stress condition compared with the low stress condition), it may be that differences between conditions were a result of normal night to night variation in sleep outcomes (Bei et al., 2016). As such, though the differences in sleep are statistically different, they may not be clinically meaningful – i.e., the outcomes of a 1% difference in sleep outcomes between conditions may not be large enough to have any practical effects. Further, there were no differences in other sleep variables, including qEEG sleep outcomes. As such, one hypothesis of this study, that being on-call would result in changes to sleep, has not been supported. This may indicate that there are aspects of on-call work that were not replicated in this simulation in a way that elicited the changes to anxiety and sleep that have been found in real world on-call workers. For example, it may be that being on-call in a typical home environment, with the potential additional stressors of children and other commitments may be responsible for increased anxiety levels and poorer sleep in on-call workers, rather than the nature of the task to be performed upon waking. Additionally, it may be that while the speech task increased heart rate during the task itself, it was not stressful enough to result in changes to anxiety or sleep. Further, the wide range of perceived sleep obtained across all conditions suggests that participants had little awareness of their bed/wake times, in addition to sleep duration. This suggests that time isolation was effective, and differences in anxiety, sleep, and cognitive performance outcomes were associated with condition rather than perceived sleep duration.

As it was expected that there would be meaningful changes to sleep, it was also predicted that there would be resulting changes to next-day cognitive performance. However, the differences in performance between conditions do not appear to be linked with the changes to sleep, because these sleep decrements were small. Next day cognitive performance was affected by condition, with poorer performance on all PVT outcome measures in the low stress condition, in opposition to hypothesis three. As such, sleep does not appear to have been the mechanism by which cognitive performance was impacted. Instead, undertaking the speech task increased arousal, as shown by the significant increase in heart rate during performance compared with the reading task. This arousal may have resulted in better cognitive performance on the PVTs that followed (Kjellberg, 1977; Sanbonmatsu & Kardes, 1988). However, in the relevant literature, higher stress tasks appear to be associated with improved performance compared with lower stress tasks, as a result of heightened arousal, combined with the understanding that any mistakes may have safety- or health-critical outcomes (LeBlanc et al., 2008). This has been demonstrated, for example, in the medical field, with surgical residents rated as performing better by blinded assessors when under high-stress examination conditions compared with a low-stress condition (LeBlanc et al., 2008). However, this previous research has shown an improvement in performance during the high stress task rather than following it, as in the present study. Instead, the present results suggest that these performance improvements as a result of arousal may continue, as shown by the consistently higher performance on the PVT during the high stress condition, up to nine hours after completing the task.

As this study was performed in a laboratory, there are several inherent limitations in terms of generalisability. While laboratory research allows us to isolate specific factors for analysis, further research is necessary to allow for application to real world on-call working arrangements, where other factors may influence anxiety, sleep and performance, including individual (e.g., trait anxiety, age, gender) and situational factors (e.g., rostering schedules, second jobs, family relationships). The effects of trait characteristics, particularly in terms of anxiety (e.g., trait anxiety), may be worth investigating in future research. As all participants in the present study were healthy males aged 20-35, this limits the generalisability of these results to that demographic. On-call workers may be older, with different health statuses and include females (Jay et al., 2018). However, as the field of on-call research is currently so limited, it is important to understand initially the effects of this kind of work on a standard population, without potential factors such as age, health or menstrual phase as confounders. Further, it is important to note that this study included just two nights on-call, and it may be necessary to perform research over additional nights, as it may be that the impacts of on-call work accumulate over extended periods of time. Future research must also look at the combined effects of sleep restriction and on-call work to more accurately reflect the scenario of being woken to a call overnight, or having shorter sleep due to family or social activities.

The present study aimed to understand the impact of the nature of the task to be performed on anxiety, sleep and performance outcomes during on-call periods. No changes were found to pre-bed anxiety, and sleep was largely unaffected. However, cognitive performance was significantly better after performing the high stress task than the low stress task. Overall, these findings indicate that after an on-call night where no calls are received, the negative impacts of on-call may be mitigated when the task to be performed is more stressful, potentially as a result of heightened arousal and/or relief that the task is over. It is particularly interesting that these performance benefits lasted throughout the day, rather than exclusively immediately following the stressful task. The results of this study may be useful for workplaces that utilize on-call working arrangements, though it is important to consider these findings in the context of an undisturbed 8-h sleep opportunity. Specifically, workplaces may be able to use this information to schedule more complex or high risk work for times when performance may be less affected by on-call work. Further, these findings suggest that work that does not produce an arousal response (e.g., monotonous or repetitive tasks) may be more likely to be negatively affected during on-call periods, and as such, workplaces may need to employ additional fatigue countermeasures in these situations.

Chapter 5. Study 3

How the perceived chance of missing the alarm affects anxiety, sleep, and cognitive performance on-call

Peer reviewed publication associated with this chapter (Appendix L):

Sprajcer, M., Jay, S.M., Vincent, G.E., Vakulin, A., Lack, L., Ferguson, S.A. (2018). How the chance of missing the alarm during an on-call shift affects pre-bed anxiety, sleep and next day cognitive performance. *Biological Psychology*, 137, 133-139.

doi: https://doi.org/10.1016/j.biopsycho.2018.07.008

Declaration of co-authorship and contribution

Full bibliographic reference to the item/publication, including authors, title, journal (vol/pages), year.	Sprajcer, M., Jay, Sarah M., Vincent, G., Vakulin, A., Lack, L., Ferguson, S. A. (2018). How the chance of missing the alarm during an on-call shift affects pre-bed anxiety, sleep and next day cognitive performance. *Biological Psychology*, 137, 133-139. https://doi.org/10.1016/j.biopsycho.2018.07.008
Status	Published

Nature of Candidate's Contribution, including percentage of total

I was responsible for laboratory set up, participant recruitment, data collection, and data management. I cleaned and analysed the data, formulated the research question, interpreted results and wrote the publication. (80%)

Nature of all Co-Authors' Contributions, including percentage of total

Sally Ferguson and Leon Lack won the funding for this project. Sarah Jay and Grace Vincent were involved with data collection. Andrew Vakulin provided me with expertise regarding qEEG data analysis. All co-authors reviewed and provided critical feedback on the manuscript and helped to prepare it for publication.

Has this paper been submitted for an award by another research degree candidate (Co-Author), either at CQUniversity or elsewhere? (if yes, give full details)

No

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Research Higher Degree Theses Policy and Procedure

………………………………………….. ……24/11/2018……………………………

(Original signature of Candidate) Date

5.1 Abstract

This study investigated how the chance of missing an alarm affects pre-bed anxiety, sleep and next day cognitive performance during on-call shifts. Participants (n=24) completed one adaptation night, one control night and two on-call nights in a time-isolated sleep laboratory. On one of the on-call nights, participants were informed that they would be woken by a loud alarm that they would *definitely* not be able to sleep through (low chance of missing the alarm). On the other on-call night, participants were informed that they would be woken by a quiet alarm that they *may* sleep through (high chance of missing the alarm). The two on-call nights were counterbalanced. Pre-bed anxiety was measured using the STAI x-1, while sleep macro- and micro-architecture was examined via routine PSG and qEEG analyses respectively. Following each sleep, cognitive performance was assessed four times (0930, 1200, 1430, 1700) using the 10-min PVT. Results indicated that while pre-bed anxiety was similarly increased during both high and low chance of missing the on-call alarm conditions compared with control, only in the high chance condition was total sleep time shorter and sleep efficiency lower compared with the control condition. However, more wake after sleep onset was found in the low chance condition compared with control. PVT data indicate that response times (mean reciprocal and mean fastest 10% of reaction time) were fastest in the low chance condition, indicating better performance when compared with both other conditions. However, there were significantly more lapses in the low chance condition compared with control. No significant qEEG differences were observed. As such, it appears that there are detrimental effects of both on-call conditions on anxiety, sleep and performance, with sleep poorest when the chance of missing the alarm is high. The adverse impacts on sleep and performance outcomes while on-call may be mitigated by the implementation of workplace systems to reduce the chance of missing alarms (e.g., having two available options for contacting on-call workers).

5.2 Introduction

On-call is a working arrangement where employees are away from their workplace, but are available to attend to a call, and possibly resume work at any time if required (Ferguson et al., 2016). Industries that commonly use these working arrangements include emergency services, healthcare and information technology (Nicol & Botterill, 2004). Periods of time spent on-call but where individuals are not working are considered by many organisations and legal policy as “time off” (2011). However, it appears that being on-call, even when no calls occur, can have implications for workers’ anxiety and sleep (Bamberg et al., 2012; Ferguson et al., 2016; Hall et al., 2016). Specifically, it has been demonstrated that during on-call periods, anxiety may be heightened (Cebola, 2014; Nicol & Botterill, 2004; Sprajcer et al., 2018) and increased anxiety may result in poorer sleep outcomes for on-call workers (Nicol & Botterill, 2004; Torsvall et al., 1987). This is concerning given that poor sleep can result in adverse cognitive, behavioural and physical outcomes, which can significantly impact work performance, safety and productivity (Alhola & Polo-Kantola, 2007; Belenky et al., 2003; Van Dongen et al., 2003). Further, increases in anxiety may result in poorer health outcomes for on-call workers over the longer term, including detriments to cardiovascular health (Kawachi et al., 1994) and increased respiratory problems (Katon et al., 2004). One factor that may influence how much anxiety on-call workers experience is their perception of how likely it is that they will miss a call.

Anecdotally, on-call workers report feelings of anxiety related to the potential of missing their alarm (or phone call, or page) (Bamberg et al., 2012; Paterson et al., 2016). For example, on-call firefighters reported anxiety surrounding the possibility that their pager may not go off because of a technical issue or similar (Paterson et al., 2016). One firefighter specifically indicated that “once it goes beyond a week (without a call) you really start to think is your pager working?” (Paterson et al., 2016, p. 177). A perceived increase in the chance of missing an alarm was also found in airline cabin crew, where self-reports indicated that individuals experienced increased anxiety and apprehension when they believed they may miss their alarm before early morning work (Kecklund et al., 1997). This suggests that a higher chance of missing an alarm is associated with anxiety, which may subsequently lead to poorer sleep.

Though there is limited research in the on-call area, two laboratory-based studies provide insight into the relationship between on-call work, anxiety and poorer sleep and cognitive performance outcomes. Wuyts et al. (2012) compared on-call nights with nights not on-call, and found that when participants were on-call they experienced a longer sleep latency and reduced sleep efficiency. The alarm used to wake on-call participants was described by the researchers as “difficult to distinguish”, which may have made participants feel as though they would potentially miss the call. The observed sleep decrements in the on-call condition may be explained by higher levels of anxiety associated with potentially missing the alarm. In a similar study undertaken by Jay et al. (2016), which also compared sleep outcomes both when on-call and not on-call, a very loud (105 dB) alarm was sounded to wake participants during their on-call periods. The participants were aware of the volume of this alarm and that the chance of missing it was extremely low. No differences were reported in sleep outcomes between the on-call and not on-call conditions, including sleep efficiency, total sleep time or duration of sleep stages. Taken together, these two studies suggest that the anxiety produced by a higher chance of missing the alarm while on-call may impact sleep, though given the different designs employed in these studies, it is difficult to be definitive.

If sleep is negatively affected, there may also be adverse effects on cognitive performance. The negative effects of poor sleep quantity or quality on cognitive performance outcomes are well documented, with potential decrements to reaction time (Van Dongen et al., 2003), constructive thinking (Killgore et al., 2008), reasoning abilities (Harrison & Horne, 2000) and vigilant attention (Lim & Dinges, 2008), all of which potentially have adverse consequences for on-call workers’ performance and personal safety (Allahyari et al., 2014; Wallace & Vodanovich, 2003). Therefore, this study will investigate the effects of the chance of missing an alarm on pre-bed state anxiety, sleep and next day performance outcomes. However, the complex inter-relationships between state anxiety, sleep and next day cognitive performance is outside the scope of this study. Instead, this study focuses on the direct impact of on-call periods (and the impact of the chance of missing the alarm) on these outcomes.

The hypotheses for this chapter include:

1) When there is a high chance of missing the on-call alarm, participants will have higher pre-bed state anxiety when compared to either a low chance of missing the on-call alarm, or not on-call (control) conditions.
2) When there is a high chance of missing the on-call alarm, participants will have poorer sleep when compared to either a low chance of missing the on-call alarm, or not on-call (control) conditions.
3) When there is a high chance of missing the on-call alarm, participants will have poorer next-day cognitive performance when compared to either a low chance of missing the on-call alarm, or not on-call (control) conditions.

5.3 Methods

5.3.1 Participants

Twenty-four male participants were recruited for the study. This sample size was calculated *a priori* by a magnitude based statistical power analysis (Hopkins, 2000), utilising G*Power 3.1.9.2 software (Faul et al., 2007). Effect size was calculated utilising a 10% difference in total sleep time seen in on-call medical doctors (Jay et al., 2008), with an $\alpha = 0.05$ and $\beta = 0.80$, resulting in resulting in $n = 24$ to account for a 5-10% attrition rate. Participants were screened using a general health questionnaire and were all non-smokers who reported good quality sleep in the previous month (PSQI ≤ 5) (Buysse et al., 1989). Participant characteristics are presented in Table 8. Participants habitually consumed no more than two caffeinated beverages/day, and reported no medical concerns or medications (e.g., selective serotonin reuptake inhibitors) known to impact sleep. Participants were excluded if they had travelled across multiple time zones in the previous four weeks, were a current shift worker, or reported napping regularly. No participants had previous experience with on-call work. In addition, participants completed the DASS and were excluded if they had severe levels of anxiety, stress or depression (Crawford & Henry, 2003). Similarly, participants with extreme morning and evening chronotypes, as assessed using the MEQ, were excluded (Horne & Ostberg, 1975).

In the week preceding participation, participants were required to maintain regular bed/wake times within an hour of the bed (2300) and wake times (0700) of the protocol. Participants wore an activity monitor (Actical MiniMitter/Respironics, Bend, OR) (de Souza et al., 2003) and completed sleep diaries to corroborate timing and duration of sleep periods. Participants had an average of 7.02 ± 1.1 h of sleep per night, with a mean bedtime of 2348 ± 1.3 h and a mean wake time of 0738 ± 0.9 h, based on activity monitor recordings, corroborated by sleep diaries.

Table 8. Participant characteristics (n = 24)

Variable	Range	Mean ± SD
Age (years)	20 – 33	25.0 ± 3.8
Body Mass Index (BMI) (kg.m^2)	18.6 - 28.5	23.6 ± 3.0
Pittsburgh Sleep Quality Index (PSQI) score	0 – 5	2.5 ± 1.3
Epworth Sleepiness Scale (ESS) score	0 – 9	3.9 ± 2.4
Habitual bed times (h)	2130 - 0000	2259 ± 0.65
Habitual wake times (h)	0530 - 0930	0738 ± 0.98

5.3.2 Design

Participants completed the four-night protocol at the Appleton Institute in Adelaide, South Australia, between February 2016 and May 2017 in groups of six (n = 24). This facility is a temperature (21 ± 2°C) and light (maintained at 100 lux for wake) controlled time-isolation laboratory. This study employed a within-subjects, repeated measures design, with one adaptation night, followed by one control night and two on-call nights. The protocol for the study is presented in Figure 7. The adaptation night was included to acclimatise to sleeping in the laboratory, and as such has not been included in analyses. As significant changes to sleep were expected in the on-call conditions, the control night was always first, followed by the two counterbalanced on-call nights. This was done to prevent any residual sleep debt from the on-call night/s from confounding the control night. For all conditions, bedtime was 2300, and wake was 0700. On both on-call nights, participants were told that they would definitely be called at some point during the sleep period. However, they were not actually "called" until the end of their sleep period. As the laboratory is time-isolated, the participants were not aware of the time of these "calls", and as such did not know how much sleep they had obtained.

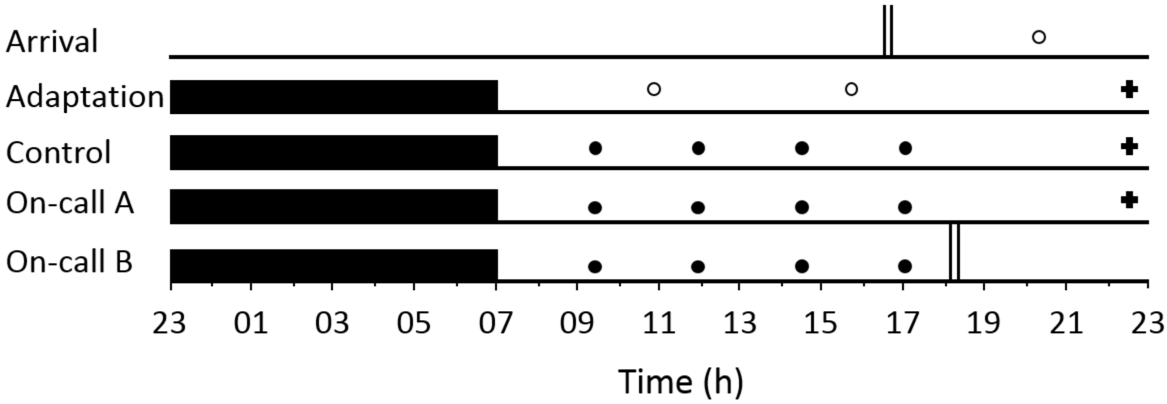

Figure 7. Study 3 Protocol

|| Arrival to and departure from the laboratory
○ 10-min psychomotor vigilance task (PVT) training
● 10-min PVT
✚ State Trait Anxiety Inventory form x-1
On-call nights A and B were counterbalanced for high and low chance of missing the alarm conditions

The on-call conditions were a *low chance of missing the alarm* (loud alarm) and *high chance of missing the alarm* (quiet alarm), with twelve participants completing the low chance condition first, and twelve the high chance condition. On the adaptation day, demonstrations of both the loud and quiet alarms were given to participants. The loud alarm was an 81.2 – 94.6 dB alarm (TOA transistor megaphone with siren signal, model: ER-1215S) and participants were informed that they would definitely wake when it was sounded, and that no participant had ever missed this alarm. At 0700 in the low chance condition, participants' bedroom doors were opened simultaneously as the alarm was sounded from the adjacent hallway. The alarm that was demonstrated in the high chance condition was a recording of white noise played through a small set of speakers. Participants were told that other participants had missed this alarm in the past, but that it was very important for them not to miss it. At 0700 on the high chance morning, participants were woken by a knock at their door and the lights coming on, and were informed that they had missed the alarm, but it was now time to wake up. In this condition, the alarm was never actually sounded, to ensure that all participants were woken simultaneously. In both conditions, participants were instructed to respond to the alarm by pressing a button next to their bed as soon as they thought they heard the alarm.

5.3.3 Measures

5.3.3.1 State anxiety

State anxiety was measured using the STAI x-1 (Spielberger, 1983). This 20-item questionnaire includes items such as "I feel at ease" and "I feel nervous", where responses range from 1 ("not at all") to 4 ("very much so"). Participants are required to respond in relation to how they feel "right now, that is *at this moment*". Reverse coding is employed as required for positive items. Scores range from 20-80 with higher scores representing higher levels of state anxiety, with clinically significant scores beginning at 39-40 (Julian, 2011).

5.3.3.2 Sleep

PSG recordings were taken during each sleep period (Bloch, 1997) and used to examine the impact of experimental conditions sleep macro-architecture derived from traditional sleep scoring. Electrodes were used in a standard configuration, with EEG, EMG and EOG recordings taken for each participant. C3/M2, F4/M1 and O2/M1 channels were used, and a trained sleep technician scored each sleep period in 30-s epochs according to standard criteria (Iber, 2007). Variables generated include total sleep time (TST), sleep onset latency, wake after sleep onset, sleep efficiency ((TST/time in bed)*100), latency to 10 min of sleep, latency to N3, REM latency, minutes and proportion of total sleep time for each sleep stage (N1, N2, N3, REM, NREM), stage shifts, awakenings and arousals in each sleep stage.

Participants provided an answer to the question “how much sleep did you think you obtained?” following completion of the first PVT each day. Awareness of the amount of sleep they obtained reflects both awareness of the potential sleep opportunity (i.e. if they knew their bed and wake times) in addition to awareness of their own sleep efficiency. Quantitative EEG sleep analysis

To examine the impact of experimental conditions on sleep micro-architecture, qEEG analysis was performed using a validated algorithm (D'Rozario et al., 2015). PSG recordings from the Cz channel for each overnight sleep study were used to determine the EEG frequency composition of each sleep stage using FFT to derive the frequency bands (delta (0.5 - 4.5 Hz), theta (4.5 - 8.0 Hz), alpha (8.0 - 12.0 Hz), sigma (12.0 - 15.0 Hz), and beta (15.0 - 32.0 Hz)) (Vakulin et al., 2016). Any epochs with artefacts were automatically excluded from analyses, but were checked for accuracy by a manual assessment of 10% of sleep periods. It was found that the automatic artefact removal was 97% accurate. EEG spectral power was calculated for each 30-s period by averaging data from up to 6 artefact-free 5-s blocks. The spectral power within the defined frequency bands was computed for NREM sleep (stages 2 and 3) and REM sleep. Further, the ratio between slow and fast frequency ((delta + theta) / (alpha + sigma + beta)) was assessed (EEG slowing ratio), as was the delta/alpha ratio, for NREM and REM sleep stages. The proportion of frequency bands within each sleep stage are indicative of the quality of sleep, with low frequency (e.g., delta) indicative of deeper sleep (Campbell, 2009).

5.3.3.3 Subjective sleepiness

Subjective sleepiness was measured using the Karolinska Sleepiness Scale (KSS), a validated, one-item questionnaire that requires respondents to rate themselves from 1 ("extremely alert") to 9 ("very sleepy, great effort to keep awake, fighting sleep") (Åkerstedt & Gillberg, 1990). The KSS was administered at 0700, 0815, 0930, 1200, 1430 and 1700 each day, prior to the completion of each PVT.

5.3.3.4 Cognitive performance

Next-day performance was assessed using the 10-min PVT performed on the control day and both on-call days at four time points (0930, 1200, 1430, and 1700). This task is a standard measure for cognitive performance, including sustained attention and vigilance, and is sensitive to sleep loss (Dinges & Powell, 1985). Three training PVTs were performed on the adaptation day to minimise learning effects (Kribbs & Dinges, 1994). Output measures include lapses of more than 500 ms, reciprocal reaction time (RRT), mean fastest 10% of reaction time (RT) and mean slowest 10% of RRT (Jewett et al., 1999).

5.3.4 Statistical analyses

Linear mixed effects ANOVAs were used to compare all outcome variables between conditions. Fixed effects included condition (control, low chance, high chance) and order. Time of day (0930, 1200, 1430, and 1700) was also included as an additional fixed effect for PVT analysis. Subject was a random effect in the model to account for individual differences. A Satterthwaite correction was applied to denominator degrees of freedom. Data that had non-normal distributions were log transformed for analysis. Significance was at the $p < .05$ level, and all significant effects had Bonferroni post-hoc testing applied.

5.4 Results

5.4.1 State anxiety

There was a significant main effect of condition on pre-bed state anxiety, $F_{(2, 48)} = 19.4$, $p < 0.001$. Pairwise comparisons revealed that state anxiety was significantly lower in the control condition (29.4 ± 4.1) compared to both the low chance (34.0 ± 4.9), $p < 0.001$ and high chance conditions (33.7 ± 6.1), $p < 0.001$. However, order was also included as a fixed effect in the model, and was found to be significant, $F_{(1, 24)} = 7.966$, $p = 0.009$. Results also showed that participants who experienced the low chance condition as their first on-call night (30.2 ± 5.3) had lower levels of pre-bed state anxiety than those who were in the high chance condition on their first night (34.6 ± 4.8).

5.4.2 Sleep

Mean perceived sleep duration ranged widely in all conditions, suggesting that time isolation was effective. In the control condition, participants reported that they believed their sleep duration was 7.5 h (± 1.1), with a range of 5.0 – 9.0 h. In the low chance condition, participants reported a perceived sleep duration of 6.6 h (± 0.9), with a range of 5.0 – 8.0 h). In the high chance condition, the mean perceived sleep duration was 6.4 h (± 1.1) sleep duration, with a range of 5.0 – 8.0 h.

There was a significant main effect of condition on TST, sleep efficiency, WASO, and the amount of N1 sleep as a proportion of TST. See Table 9 for these results. No significant differences were found for all other sleep variables, including qEEG outcomes (see Table 10). Participants appeared to take the on-call instructions seriously, as in the high likelihood condition, four participants pressed their button thinking they had heard the alarm, with one pressing the button twice on the same night. On only one occasion did a participant press their button overnight during the low chance condition. Additionally, when participants were debriefed, they all indicated that they had pressed their button upon waking.

Table 9. Sleep outcomes in control, low, and high chance of missing the alarm conditions (n = 24)

Variable	Condition			$F_{(2, 48)}$	p	Post-hoc tests
	Control (C)	Low chance (L)	High chance (H)			
Total sleep time (TST) (mins)	447.8 (13.4)	441.9 (17.4)	439.9 (17.2)	4.846	0.012	C > H, p = 0.013
Sleep efficiency (%)	93.3 (2.8)	92.1 (3.6)	91.6 (3.6)	4.841	0.012	C > H, p = 0.013
Sleep onset latency (mins)*	11.2 (7.1)	10.9 (5.9)	15.9 (14.0)	2.157	0.127	-
Wake after sleep onset*	21.0 (12.5)	27.2 (15.3)	24.2 (15.0)	5.166	0.009	C < L, p = 0.007
Latency to REM (mins)*	74.3 (24.7)	76.0 (39.4)	70.9 (31.6)	0.689	0.507	-
Latency to 10 mins of sleep (mins)*	13.4 (7.2)	12.5 (5.4)	17.4 (13.6)	1.969	0.151	-
Latency to N3 (mins)*	12.3 (4.8)	11.2 (3.4)	10.8 (2.2)	1.056	0.356	-
Minutes of N1*	27.0 (18.5)	29.9 (19.7)	29.6 (15.3)	2.575	0.087	-
N1 % of TST*	6.1 (4.3)	6.9 (4.9)	6.8 (3.7)	3.225	0.049	C < H, p = 0.078
Minutes of N2	179.2 (30.2)	172.1 (29.6)	176.8 (27.5)	1.382	0.261	-
N2 % of TST	40.1 (6.6)	39.0 (6.6)	40.2 (6.4)	0.975	0.385	-
Minutes of N3	126.3 (36.4)	124.0 (35.9)	118.8 (32.2)	1.917	0.158	-
N3 % of TST	28.1 (7.8)	28.0 (7.6)	26.9 (7.0)	1.182	0.315	-
Minutes of REM*	115.3 (18.7)	115.9 (23.6)	114.7 (17.8)	0.014	0.986	-
REM % of TST*	25.7 (4.1)	26.2 (5.2)	26.1 (4.0)	0.099	0.906	-
Minutes of NREM	332.5 (21.5)	326.1 (27.1)	325.2 (22.0)	2.020	0.144	-
NREM % of TST	74.3 (4.1)	73.8 (5.2)	73.9 (4.0)	0.174	0.841	-
Arousals (total sleep period)*	85.0 (37.8)	81.3 (30.5)	78.0 (24.6)	1.313	0.278	-
Arousals (REM)	26.0 (10.7)	26.2 (11.4)	26.3 (11.7)	0.008	0.992	-
Arousals (NREM)*	59.0 (36.1)	55.1 (29.4)	51.8 (21.3)	1.497	0.234	-
Arousals per hour (total sleep period)*	11.4 (5.3)	11.1 (4.4)	10.7 (3.5)	0.694	0.505	-
Arousals per hour (REM)	13.4 (4.4)	13.6 (5.1)	13.9 (6.0)	0.132	0.877	-
Arousals per hour (NREM)	10.7 (6.7)	10.1 (5.3)	9.5 (4.0)	1.007	0.373	-
Awakenings	22.0 (8.8)	23.4 (7.6)	22.7 (6.5)	0.774	0.467	-
Stage shifts	146.3 (34.2)	150.6 (29.5)	147.7 (28.8)	0.458	0.635	-

Abbreviations: REM – Rapid eye movement sleep, NREM – non-rapid eye movement sleep, N1 – stage one sleep, N2 - stage two sleep, N3 – stage three (slow wave) sleep.

Data reported as Mean (SD).

*Data log transformed to normal for analysis

Table 10. qEEG outcomes in control, low, and high chance of missing the alarm conditions

qEEG range	Sleep stage	Condition Mean (SD)			F	df	p
		Control	Low chance	High chance			
Delta (0.5 – 4.5 Hz)	NREM	681.1 (251.3)	706.6 (309.4)	687.5 (335.2)	0.228	2, 40	0.797
	REM	237.7 (91.9)	233.5 (81.8)	220.0 (87.5)	0.540	2, 43	0.587
Theta (4.5 – 8 Hz)	NREM	41.8 (18.7)	40.8 (17.1)	40.7 (18.1)	1.348	2, 40	0.271
	REM	20.7 (4.9)	20.0 (5.2)	20.1 (5.4)	1.873	2, 40	0.167
Alpha (8 – 12 Hz)	NREM	19.2 (8.8)	18.6 (8.1)	19.9 (10.2)	1.352	2, 39	0.270
	REM	8.6 (3.8)	8.1 (2.8)	8.4 (4.3)	0.936	2, 40	0.401
Sigma (12 – 15 Hz)	NREM	12.2 (5.9)	11.7 (5.3)	12.7 (5.9)	1.089	2, 40	0.346
	REM	2.8 (1.0)	2.9 (1.5)	2.9 (1.4)	0.638	2, 40	0.534
Beta (15 – 32 Hz)	NREM	7.3 (3.0)	8.0 (4.5)	7.3 (3.3)	1.346	2, 42	0.271
	REM	7.6 (4.7)	10.1 (12.9)	8.5 (6.4)	1.070	2, 44	0.352
EEG slowing ratio	NREM	19.45 (5.16)	20.40 (6.65)	18.94 (6.90)	0.117	2, 40	0.890
	REM	14.99 (5.57)	14.34 (5.20)	13.75 (5.02)	0.585	2, 41	0.562
Delta/alpha ratio	NREM	37.36 (10.10)	39.75 (12.75)	36.26 (12.73)	0.467	2, 40	0.631
	REM	29.93 (10.78)	29.87 (8.74)	28.59 (9.77)	0.171	2, 40	0.843

Abbreviations: REM – Rapid eye movement sleep, NREM – non-rapid eye movement sleep, N1 – stage one sleep, N2 - stage two sleep, N3 – stage three (slow wave) sleep

5.4.3 Subjective sleepiness

There were significant main effects of both condition, $F_{(2, 403)} = 11.583$, $p < .001$, and time of day, $F_{(5, 403)} = 67.743$, $p < .001$, on subjective sleepiness as measured by the Karolinska Sleepiness Scale. Participants were significantly sleepier in the high chance of missing the alarm condition (4.10 ± 1.95) than in the control (3.49 ± 1.75), $p < .001$, and the low chance of missing the alarm condition (3.77 ± 1.71), $p = .039$. Participants were significantly sleepier at 0700 (5.99 ± 1.82) compared with 0815 (3.35 ± 1.39), 0930 (3.17 ± 1.43), 1200 (3.24 ± 1.58), 1430 (3.37 ± 1.42) or 1700 (3.59 ± 1.48), $p < .001$ for all comparisons.

5.4.4 Cognitive performance

There were significant differences in cognitive performance on the PVT between conditions (Table 11) as measured by mean reciprocal reaction time (RRT), mean fastest 10% of reaction time (RT) and lapses. No significant differences between conditions were found in the mean slowest 10% of RT.

There was a significant main effect of time of day for mean RRT, $F_{(3, 264)} = 3.668$, $p = 0.013$. Mean RRT was faster at 1700 (4.43 ± .51) compared with 0930 (4.29 ± .54), $p = 0.007$. There was also a significant main effect of time of day on mean fastest 10% of RT, $F_{(3, 264)} = 4.090$, $p = 0.007$. Mean fastest 10% of RT was significantly faster at 1700 (185.31ms ± 18.65) than at 0930 (189.93ms ± 19.29), $p = 0.004$. The main time of day effect for mean slowest 10% of RRT was significant, $F_{(3, 264)} = 3.208$, $p = 0.024$. Mean slowest 10% of RRT was also faster at 1700 (3.19 1/RT*1000 ± 0.61) than at 0930 (3.00 1/RT*1000 ± 0.74), $p = 0.040$. There were no significant time of day effects for lapses.

Table 11. Condition effects for performance on the psychomotor vigilance task

Variable	Condition			F	df	p	Post-hoc testing
	Control (C)	Low chance (L)	High chance (H)				
Mean RRT (1/RT*1000)	4.21 (.49)	4.51 (.54)	4.37 (.50)	27.529	2, 275	0.000	C < L, p < .001; H < L, p < 0.001
Lapses	0.67 (1.13)	0.83 (1.76)	0.25 (.67)	4.331	2, 238	0.014	H < L, p = 0.016
Mean fastest 10% RT (ms)	191.42 (15.69)	179.63 (18.06)	191.24 (20.72)	70.606	2, 273	0.000	C > L, p < .001; H > L, p < 0.001
Mean slowest 10% RRT	2.97 (.60)	3.04 (.78)	3.20 (.51)	2.789	2, 284	0.063	-

RT – reaction time. RRT - reciprocal reaction time

5.5 Discussion

This study aimed to investigate how the chance of missing an alarm impacts anxiety, sleep and performance outcomes during simulated on-call periods. Findings indicated that anxiety was higher on both on-call nights compared with control, but that generally, both sleep and next-day performance were poorest when there was a high chance of missing the alarm while on-call.

Pre-bed anxiety was significantly lower on the control night compared with both on-call nights, suggesting that participants felt more anxious before bed when they knew they were on-call, regardless of the chance of missing the alarm, which does not support the hypothesis that a higher chance of missing the alarm would be associated with higher anxiety. However, mean scores on the STAI x-1 prior to bed were not indicative of clinically important anxiety (indicated by scores of above 39-40 (Julian, 2011)). In the high chance condition, sleep decrements were seen in addition to the increase in anxiety. In the low chance condition however, the same degree of sleep decrements was not seen, and indeed, response times were faster (0.3 RRT) in this condition compared with control. However, it is also important to note that while there were significant differences in several sleep measures between conditions, these differences were not large.

Total sleep time was significantly shorter (7.9 min) when the chance of missing the alarm was high compared with the control condition, which supports the hypothesis. Similarly, sleep efficiency was significantly (1.7%) lower in the high chance condition compared with control. Conversely, the highest proportion of WASO was seen in the low chance condition, with 6.2 min more than the control condition. The discrepancy between WASO and sleep efficiency may be explained by a non-significant trend towards a longer sleep latency in the high likelihood condition (p = .127). A potential explanation is that sleep efficiency scores are calculated based on time in bed and therefore include sleep latency, whereas WASO is calculated from the time the individual first fell asleep. Though participants had slightly more wake overnight in the low chance condition, their longer sleep latency, shorter sleep times and poorer sleep efficiency in the high chance condition suggest that sleep overall was poorer when the chance of missing the alarm was higher. This assessment is largely based on the importance of total sleep time, sleep latency, and sleep efficiency compared with wake overnight, which may simply be indicative of slightly earlier wake times, or bathroom breaks (Shrivastava et al., 2014). These variables are also directly linked with next day cognitive performance, and as such are frequently used as markers of sleep quality (Alhola & Polo-Kantola, 2007). It is possible that sleep on the on-call nights was affected by having two full 8-h sleep opportunities on the preceding adaptation and control nights, resulting in a slightly decreased sleep need (Horne, 2011). However, this is unlikely, as the changes in on-call sleep differed between conditions, despite being counterbalanced. As such, had they been affected by these 8-h sleep opportunities on the preceding nights, each on-call night would have been affected the same way. Further, as sleep was monitored prior to attending the sleep laboratory, participants were well rested and not experiencing sleep debt that may have influenced subsequent sleep periods. Additionally, the range of perceived sleep duration (5.0 – 9.0 h across all nights) suggests that participants had little awareness of both how much sleep that obtained, and their bed/wake times. This suggests that time isolation was effective, and outcomes were not based on participant perception of sleep/wake timing.

Despite the small but statistically significant sleep PSG outcome differences, there were no significant differences observed when sleep micro-architecture was examined using qEEG analysis which is independent of sleep/stage timing and duration. These findings suggest that there was no significant impact of on-call periods on quantitatively measured brain activity. The impacts of experimental conditions on PSG sleep and performance outcomes were very subtle and therefore may not be detected in the EEG due to significant variation in EEG power phenotypes between individuals.

In addition to slightly poorer sleep outcomes in the high chance condition, participants also felt sleepier in this condition, based on their responses on the KSS. This suggests that when participants knew they may miss the on-call alarm, they experienced heightened sleepiness, potentially as a result of the slightly poorer sleep the preceding night. However, as scores on the KSS were within one point between all conditions, this effect is small. Additionally, mean daily scores on the KSS were in the range of “alert” to “fairly alert” in all conditions. This suggests that while there are some statistically significant differences between conditions, real world outcomes may be similar.

In addition to feeling sleepier during the day, performance outcomes were poorer in the high chance condition, which supports hypothesis three. Participants responded faster (mean RRT and mean fastest 10% RT) in the low chance condition compared with both the high chance condition (0.14 1/RT*1000 and 11.61 ms, respectively), and control (0.3 1/RT*1000 and 11.79 ms difference). While the increase in arousal caused by the loud alarm may provide an explanation for these findings, this is unlikely given that the alarm occurred 2.5 h prior to the first 10-min PVT each day. Further, participants had 0.58 more lapses in the low chance condition compared with the high chance condition. However, mean lapses and response times in all conditions were within normal ranges for performance (Lim & Dinges, 2008). In the real world, differences such as these may not be significant enough for any personal or operational changes to be required (Alhola & Polo-Kantola, 2007). However, it is important to consider that while individuals who have experienced these small changes to sleep or performance may be fit for duty, the multi-factorial nature of the world outside of the laboratory may mean that these small decrements add to other factors that affect work performance and/or safety (e.g., operational or family demands). Further, there may be cumulative effects of multiple and/or consecutive nights on-call based on small changes to sleep (Belenky et al., 2003; Van Dongen et al., 2003).

While this study provides insight into the effects of the chance of missing an alarm while on-call, there are some limitations. Specifically, laboratory research is limited in terms of practical applications, as the real world involves additional stressors and environmental differences. As such, further research is required to apply these findings to real world on-call scenarios, including research with current on-call workers as participants. Additionally, the control night was first in the protocol for all participants to ensure these nights were not adulterated by prior restricted sleep in the on-call conditions. While this design was necessary, it is also a limitation. Further, though participants were instructed several times that it was very important that they wake to the on-call alarms, there is the possibility that they did not take this instruction seriously. However, as several participants woke during the high chance condition, it appears that they were aware of the importance of waking. Additionally, participants reported anecdotally during their participation that they believed they may miss the quiet alarm. As the current study represents preliminary, controlled research in a new field, it was necessary to control for the differences to sleep that can occur with age and gender. As such, our sample consisted only of young males (20-33 years), which may limit the generalisability of findings. Additionally, as a large proportion of on-call workers fall into older age brackets, it is important for future research to include older participants. Further, future research should include female participants, to ensure findings are generalizable. Overall the findings of this study indicate that a higher chance of missing the alarm (i.e., the alarm being quiet and easy to miss) is associated with somewhat negatively affected sleep and next day performance. Further, heightened anxiety was found in both on-call conditions, regardless of how likely it was that participants would miss the alarm. As changes to sleep and performance are linked with work performance and increased risk in the workplace, it is important for workplaces to take factors such as the chance of missing an alarm into consideration when designing workplace policy. Specifically, ensuring that the alarm system used for waking workers is effective and is known to wake individuals easily, for example by having a backup alarm system, may be a simple way that workplaces can mitigate these negative effects of on-call on sleep and performance outcomes.

Chapter 6. Are individuals with low trait anxiety better suited to on-call work? Individual differences in Study 1, 2, and 3

Sprajcer, M., Jay, S.M., Vincent, G.E., Zhou, X., Vakulin, A., Lack, L., Ferguson, S.A. Are individuals with low trait anxiety better suited to on-call work: a laboratory study on anxiety, sleep, and cognitive performance. Under review at Ergonomics.

Declaration of co-authorship and contribution

Full bibliographic reference to the item/publication, including authors, title, journal (vol/pages), year.	Sprajcer, M., Jay, Sarah M., Vincent, G., Vakulin, Zhou, Z., A., Lack, L., Ferguson, S. A. (under review). Are individuals with low trait anxiety better suited to on-call work: a laboratory study on anxiety, sleep, and cognitive performance.
Status	Under review

Nature of Candidate's Contribution, including percentage of total

I was responsible for laboratory set up, participant recruitment, data collection, and data management. I cleaned and analysed the data, formulated the research question, interpreted results and wrote the publication. (80%)

Nature of all Co-Authors' Contributions, including percentage of total

Sally Ferguson and Leon Lack won the funding for this project. Sarah Jay and Grace Vincent were involved with data collection. Andrew Vakulin provided me with expertise regarding qEEG data analysis. Xuan Zhou assisted with data analysis. All co-authors reviewed and provided critical feedback on the manuscript and helped to prepare it for publication. (20%)

Has this paper been submitted for an award by another research degree candidate (Co-Author), either at CQUniversity or elsewhere? (if yes, give full details)

No

Candidate's Declaration

I declare that the publication above meets the requirements to be included in the thesis as outlined in the Research Higher Degree Theses Policy and Procedure

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(Original signature of Candidate)   Date

6.1 Abstract

Individuals with certain traits (e.g., age, health status, personality traits) may be better suited to non-standard working arrangements. This study investigated trait anxiety and on-call suitability. Seventy-two participants completed an adaptation night, a control night, and two counterbalanced on-call nights in a laboratory. On-call conditions determined the effects of the likelihood of being called, task stress, and the chance of missing the alarm. The STAI x-1 and x-1 were used to assess state and trait anxiety. Sleep was measured using PSG and qEEG. Performance was assessed using a 10-min PVT. The effects of trait anxiety on state anxiety, sleep and performance on-call were limited. However, higher trait anxiety individuals performed worse on the PVT under control conditions than lower trait anxiety individuals. Under on-call conditions this disadvantage disappeared. Therefore, on-call tolerance does not appear to be affected by non-clinical levels of trait anxiety.

6.2 Introduction

Shift work and non-standard working arrangements have become ubiquitous in modern workplaces (Costa, 2014; Parent-Thirion et al., 2012). A growing body of research into the personal and professional health and safety consequences of such arrangements for employees (Kecklund & Axelsson, 2016; Wagstaff & Lie, 2011) demonstrates a range of consequences, including shortened or disturbed sleep, poorer work performance, and overall ill health (Kecklund & Axelsson, 2016). With this increased understanding of negative outcomes comes the opportunity to understand any protective factors or individual differences that may help employees to overcome, or be less susceptible to these adverse consequences.

One type of non-standard working arrangement is on-call work, which is often employed by workplaces to minimise costs while ensuring continuous coverage of work roles (Ferguson et al., 2016; Vincent et al., 2018). On-call periods often occur overnight, with workers allowed to sleep, with the understanding that they may be disturbed at any time (Ferguson et al., 2016).

In previous research, the knowledge that workers will be woken has been linked with increased anxiety and apprehension, for example in subjective reports from firefighters (Jay et al., 2018; Paterson et al., 2016), and on-call rail workers (Cebola et al., 2013). Anxiety and apprehension have also been linked with poor sleep (Galbiati et al., 2018), as has on-call work, both with, and in the absence of, calls overnight (Torsvall & Åkerstedt, 1988; Wuyts et al., 2012; Ziebertz et al., 2017). Further, poor quality or shortened sleep is linked with poorer cognitive performance the following day (Krause et al., 2017; Lowe et al., 2017), in addition to negative outcomes for workplace health and safety (Litwiller et al., 2017).

Increased anxiety and poor sleep associated with on-call work may have significant negative effects on the performance, safety, and mental health of employees (Bamberg et al., 2012; Ferguson et al., 2016). Thus, it is important to understand any individual factors that make this kind of work easier or more difficult to tolerate. Research into shift work tolerance, including the ability to manage factors such as night work, shortened sleep, and roster types (Saksvik et al., 2011) has shown that individuals who are younger, and who have lower scores on neuroticism and trait anxiety scales, are more likely to be able to tolerate non-standard working hours (Saksvik et al., 2011). However, there is no research specifically addressing traits that may be linked with an increased or decreased ability to manage on-call work.

As anxiety has been reported to increase during on-call periods (Gonzalez-Cabrera et al., 2018; Heponiemi et al., 2015; Paterson et al., 2016; Ziebertz et al., 2015), it is logical to surmise that individual differences in trait anxiety (i.e., an individual's inherent base level of anxiety) may be linked with how anxious they may feel on-call. Further, given that previous research has indicated that individuals with higher trait anxiety struggle to cope with the demands of shift work more than those with lower trait anxiety (Saksvik et al., 2011; Tamagawa et al., 2007), it follows that this relationship may also occur when individuals are on-call. There are reported associations between trait anxiety and a reduced ability to manage stressful situations (Spielberger, 2013), including work stressors (Stokes & Kite, 2017) and even large scale natural disasters (Weems et al., 2007). In addition, individuals with higher trait anxiety may be more reactive to stressful situations and, as such, when faced with a stressor, may have a heightened state anxiety response (Spielberger, 1966, 1971, 2013). Indeed, Stokes and Kite (2017) note that “the trait anxious person is more likely to perceive a given situation as threatening, and to react to this apparent threat with higher levels of state anxiety” (p.25). As such, higher levels of trait anxiety may be associated with greater state anxiety during on-call periods, which may result in poorer or shortened sleep, and subsequent decrements to both cognitive and work performance (Alhola & Polo-Kantola, 2007). This is supported by Putman et al. (2014), who indicate that individuals with higher levels of trait anxiety are more likely to have poorer attentional control, and be more negatively affected under stressful conditions.

In addition to the potential effects of trait anxiety on individual outcomes on-call, there are factors inherent to on-call work that may affect this relationship. These include how likely it is that the individual will receive a call overnight (Chapter 3), the nature of the task the individual will be required to perform upon waking (Chapter 4)and how likely it is that the individual will miss their alarm for the on-call incident (Chapter 5). The aforementioned factors have been shown to affect anxiety, sleep, or performance outcomes during on-call work. As such, we pooled data from the three aforementioned studies to understand how trait anxiety may affect these outcomes.

This study aims to investigate if individuals who have higher trait anxiety are more susceptible to the negative effects of being on-call, and how the on-call context may affect this relationship. Specifically, we hypothesised that higher trait anxiety would be associated with higher pre-bed state anxiety during on-call periods, in addition to being associated with poorer sleep and poorer next day cognitive performance. Further, we anticipated that this relationship would exist under a variety of on-call conditions.

6.3 Methods

6.3.1 Participants

Participants were healthy males aged between 20 and 35 years (n = 72). Participants were screened to ensure that they were non-smokers, had a BMI of under 30 kg/m^2, and did not have any medical concerns likely to interfere with sleep. Participants were also screened if they were excessively sleepy (ESS (Johns, 1991) score > 10) and showed signs of sleep disturbance (a PSQI (Buysse et al., 1989) score of > 5. Participants were also screened with the DASS (Crawford & Henry, 2003) and the MEQ (Horne & Ostberg, 1975) to exclude individuals who were "severe" or "extreme" on either scale. Recruitment and additional screening procedures have been reported elsewhere (Chapters 3, 4, and 5).

6.3.2 Design

The data reported in this paper comes from three independent but related, four-night studies that were conducted in a sleep laboratory in Adelaide, Australia (2016 - 2017) (Chapters 3, 4, and 5). Ethical approval was obtained from the relevant human research ethics committee (H15/08-158). Each participant in each study completed an adaptation, a control and two consecutive on-call nights, see Figure 8. Bedtime on all nights was 2300, with a 0700 wake time. On the control night, participants were told they were not on-call and would be having a full night of sleep, and on the on-call nights, 45 min prior to bed, participants were told that they were on-call, and what on-call condition they were in. As this was a time-isolated facility, participants were unaware of the time at which they were woken each morning.

In all studies, the two on-call nights were counterbalanced but different on-call conditions were included in each of the three studies.

- In Study 1 (Chapter 3), participants were told before bed on one on-call night that they would definitely be called during the night, and on the other that they may be called. The aim of this study was to determine the effects of the likelihood of being called.
- In Study 2 (Chapter 4), on one on-call morning the participant was required to do a 5-min silent reading task (a low stress task), and on the other they were required to do a 5-min speech in front of a researcher (a high stress task). Participants were told about these activities before bed on the preceding night. This study investigated the effects of how stressful the task to be performed upon waking was.
- In Study 3 (Chapter 5), participants were demonstrated a loud (105 dB(A)) alarm and a quiet (white noise) alarm prior to the study. Researchers told them that no one had ever missed the loud alarm, but that some previous participants had missed the quiet alarm. On one on-call night participants were told they would be woken by the loud alarm, and on the other, the quiet alarm. This study investigated the effects of the perceived chance of missing the on-call alarm.

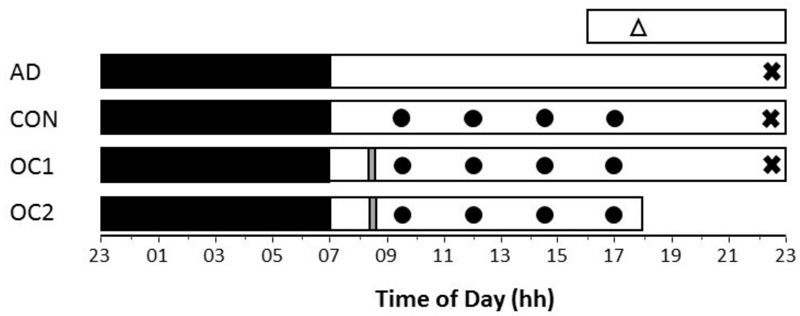

Figure 8. Protocol diagrams for Study 1, 2, and 3

AD = Adaptation night, CON = Control night, OC1 = On-call night 1, OC2 = On-call night 2

△ STAI x-2
✖ STAI x-1 and on-call instructions administered
● PVT
▮ High or low stress task performance (Study 2 only)

6.3.3 Measures

6.3.3.1 Anxiety

Both state and trait anxiety were measured for all studies. Trait anxiety was measured shortly following first arrival at the laboratory (1730) by self-report, with the completion of the STAI x-2 (Spielberger, 1983). This questionnaire requires respondents to answer questions relating to how they feel *generally*, including items such as “I feel pleasant” or “I wish I could be as happy as others seem to be”. Positive items were reverse coded for scoring, according to standard practice. State anxiety was measured prior to bed on control and on-call nights (2245h) by the STAI x-1 (Spielberger, 1983). This questionnaire asks similar questions to the x-2 form, but requires participants to respond in terms of how they feel *right now*. Scores on both questionnaires range from 20-80, with higher scores reflective of higher trait or state anxiety. Anxiety of clinical significance is reflected by scores over 39 (Julian, 2011).

6.3.3.2 Sleep

Sleep was measured using PSG. Electrodes were applied to the head, face, neck, and torso to take EEG, EMG and EOG recordings. The channels used were C3/M2, F4/M1 and O2/M1, with Cz also recorded for use in qEEG analysis. Standard criteria were used for scoring each 30-s epoch (Iber, 2007) and a trained technician who was blinded to study conditions performed all scoring. Variables included TST, sleep efficiency (time asleep as a proportion of the total sleep opportunity), WASO, sleep onset latency, latency to 10 min of sleep, REM latency and latency to N3. The proportion (as a percentage of total sleep time) and minutes of each sleep stage (N1, N2, N3, REM, NREM (non-REM)) were also calculated.

6.3.3.3 Quantitative EEG sleep analysis

QEEG analyses were performed on the PSG output of the Cz electrode for each night. This involves use of a validated algorithm (D'Rozario et al., 2015) and FFT to assess the frequency composition of each sleep stage. Artefacts were automatically removed from the PSG output, with manual checking performed for 10% of the recordings. Manual checking revealed an accuracy of 98.0%. Frequency bands included delta (0.5 - 4.5 Hz), theta (4.5 - 8.0 Hz), alpha

(8.0 - 12.0 Hz), sigma (12.0 - 15.0 Hz), and beta (15.0 - 32.0 Hz) (Vakulin et al., 2016). Due to its greater sensitivity to smaller changes in sleep than traditional PSG, qEEG was used to reveal the makeup of each sleep stage in terms of frequency composition. A sleep stage with a lower frequency makeup (e.g., a higher proportion of delta) may be indicative of deeper sleep, while a higher proportion of beta may be indicative of lighter, less restful sleep (Campbell, 2009). The variables included in these analyses were a delta/alpha ratio, with higher scores indicative of increased slowing, and an overall EEG slowing ratio variable, calculated by ((delta + theta) / (alpha + sigma + beta)). These ratio variables were calculated for both REM and NREM sleep.

6.3.3.4 Cognitive performance

Cognitive performance was assessed using the 10-min PVT (Dinges & Powell, 1985), administered at four time points on the control and both on-call days (0930, 1200, 1430, 1700). PVTs are a measure of sustained attention and vigilance that is sensitive to sleep loss (Dinges & Powell, 1985). Variables include mean reciprocal reaction time (RRT, reaction speed), mean fastest 10% of reaction time, mean slowest 10% of reciprocal reaction time, and lapses (>500ms) (Jewett et al., 1999). Learning effects were accounted for by three practice sessions on the adaptation day (Kribbs & Dinges, 1994).

6.3.4 Statistical Analyses

All statistical analyses were performed using R, and all models were fitted using the LmerTest package (version 3.0) (R Development Core Team, 2008).

To compare between studies and conditions for trait anxiety (i.e., to determine if trait anxiety was different between study cohorts), one way ANOVAs were performed. Bonferroni post hoc analyses were used to determine differences. These analyses were also performed on state anxiety scores between both study cohorts and conditions. The potential effects of study conditions are accounted for in these statistical analyses.

To investigate the relationship between trait anxiety and state anxiety, sleep, and performance outcomes in each of the three studies, we fitted separate linear mixed-effect models. These linear mixed-effect models were performed to directly compare the correlations between trait anxiety and outcome variables between conditions (i.e., how is the relationship between trait anxiety and an outcome measure affected by on-call condition). The fixed effects included condition (3 levels: control, on-call condition 1, on-call condition 2), trait (as a covariate) and condition × trait interaction, and a random effect of participant. To account for the covariance between repeated measures within the same participant, the random effect imposed a compound symmetry variance-covariance structure to the data. By fitting the models, we estimated the effect of trait anxiety on the outcome measures under all three conditions of a given study.

For a given outcome variable, we tested, using three separate linear contrasts of model parameters, whether the effect of trait anxiety under the control condition of a study was different from zero (a slope of zero indicating no relationship between trait anxiety and the given outcome variable); and whether the effects of trait anxiety under the two on-call conditions deviated from the relationship between trait anxiety and the outcome variable in the control condition. Each contrast involved a t-test, the degree of freedom of which was approximated using the Satterthwaite method. For all tests, the alpha level was set at 0.05.

In simple terms, these analyses found the slope of the relationship between trait anxiety and an outcome variable. For control conditions, this slope was compared with zero. In the on-call conditions, this slope was compared to the control slope of the same study (acting as a baseline).

6.4 Results

6.4.1 Trait anxiety

No significant differences were found between studies in trait scores on the STAI form x-2 (Mean ± SD) (Study 1: 30.8 ± 4.3, Study 2: 30.5 ± 5.5, Study 3: 32.2 ± 4.6), $F_{(2, 143)} = 1.63$, $p = .200$.

6.4.2 State anxiety

Significant differences were found between studies for overall levels of state anxiety, $F_{(2, 212)} = 45.44$ $p < .001$. Bonferroni post-hoc testing revealed that participants in Study 2 (which investigated task stress) had higher overall pre-bed state anxiety (40.8 ± 5.0) compared with Study 1 (which examined call likelihood) (33.6 ± 6.5), $p < .001$ and Study 3 (which investigated the chance of missing the alarm) (32.4 ± 5.5), $p < .001$. See Table 12. State anxiety in the control condition in Study 2 (41.3 ± 5.5) was found to be significantly different from the control conditions for Study 1 (32.0 ± 5.7), $p <.001$ and Study 3 (29.4 ± 4.1), $p < .001$.

Table 12. Trait and state anxiety under control and on-call conditions descriptive statistics

Study	Condition	Pre-bed state anxiety Mean (SD)
Study 1		
	Control	32.0 (5.7)
	Definitely	35.7 (7.5)
	Maybe	32.9 (5.7)
Study 2*		
	Control	41.3 (5.5)
	High task stress	40.4 (5.1)
	Low task stress	40.8 (4.7)
Study 3		
	Control	29.4 (4.1)
	Low chance of missing alarm	34.0 (4.9)
	High chance of missing alarm	33.7 (6.1)

*Study 2 means were significantly ($p < .05$) higher than Study 1 and Study 3 means (control and on-call nights)

6.4.3 Trait anxiety and state anxiety

Linear mixed-effects models showed that there was no significant effect of trait anxiety on state anxiety in Study 1, or Study 3, $p > .05$. In Study 2, there was a significant effect of trait anxiety on state anxiety within the high task stress condition, $t(41.39) = 2.43$, $p = .019$, when compared with the effects of control. However, the effect of trait anxiety on state anxiety in the control condition of this study was not significant, $t(31.74) = -1.95$, $p = .060$, nor was this relationship significant in the low stress condition when compared with control, $t(41.39) = 1.93$, $p = .061$. See Table 13 and Figure 9.

Table 13. The relationship between trait anxiety and on-call state anxiety in Study 1, Study 2, and Study 3 compared with control

Study	Condition	β*	SE	df	t	p**	p ***
Study 1							
	Control	0.29	0.29	33.56	1.01	0.322	
	Definitely	0.61	0.23	44.00	1.40		0.169
	Maybe	0.44	0.23	44.00	0.65		0.521
Study 2							
	Control	-0.37	0.19	31.75	-1.95	0.060	
	High task stress	-0.04	0.13	41.39	2.43		**0.019**
	Low task stress	-0.11	0.13	41.39	1.93		0.061
Study 3							
	Control	0.06	0.23	35.438	0.25	0.801	
	Low chance of missing alarm	0.42	0.19	44.00	1.92		0.061
	High chance of missing alarm	0.35	0.19	44.00	1.58		0.121

* Estimated effect of trait anxiety on state anxiety

**Significance of the relationship between trait anxiety and state anxiety in the control condition (compared with zero)

*** Significance of the relationship between trait anxiety and state anxiety on on-call nights compared with control relationship

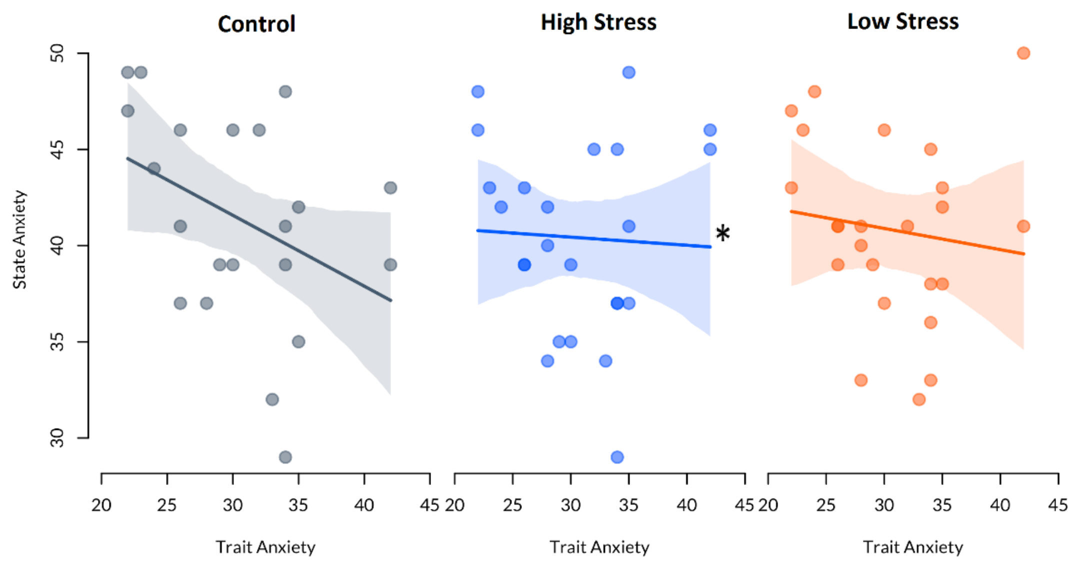

Figure 9. Relationship between state anxiety and trait anxiety in Study 2 conditions

*Significantly different from control relationship

6.4.4 Trait anxiety and sleep outcomes

Full descriptive data regarding sleep outcomes for all three studies are reported elsewhere (Chapters 3, 4, and 5).

Linear mixed effects models showed no significant impact of trait anxiety on TST, sleep efficiency, WASO, latency to REM, latency to 10 min of sleep, minutes and proportion of each sleep stage (N1, N2, N3, REM, and NREM), arousals during sleep and NREM, awakenings and stage shifts, $p > .05$. Significant effects were found for sleep latency, latency to N3, number of arousals during REM overall, and number of arousals per hour during REM. See Figure 10 and Table 14.

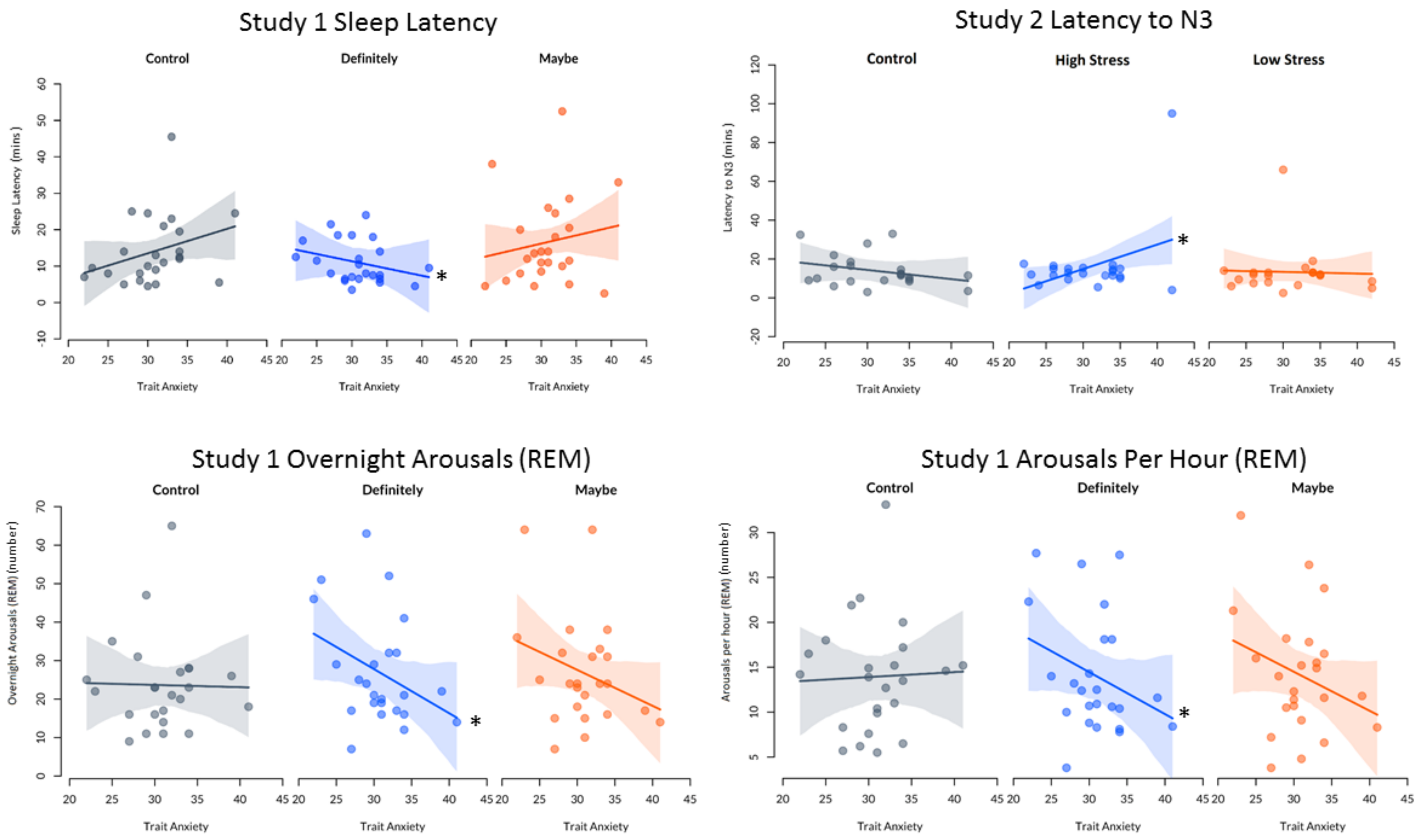

Figure 10. Relationships between trait anxiety and sleep variables in Study 1, Study 2, and Study 3

*Significantly different from control slope

Table 14. Effect of trait anxiety on on-call sleep variables in Study 1, Study 2, and Study 3 compared with control

Variable	Study	Condition	β*	SE	df	t	p**	p ***
Total sleep time (TST)	Study 1							
		Control	0.25	0.84	45.06	0.30	.768	
		Definitely	0.55	0.85	44.00	0.36		.721
		Maybe	0.50	0.85	44.00	0.29		.772
	Study 2							
		Control	0.30	0.63	39.05	0.47	.642	
		High task stress	0.30	0.62	40.00	0.00		.999
		Low task stress	-0.41	0.62	40.00	-1.14		.262
	Study 3							
		Control	-0.09	0.73	36.43	-0.12	.908	
		Low chance of missing alarm	0.24	0.62	44.00	0.52		.603
		High chance of missing alarm	-0.89	0.62	44.00	-1.30		.201
Wake after sleep onset	Study 1							
		Control	-0.92	0.67	50.66	-1.37	.176	
		Definitely	-0.16	0.74	44.00	1.03		.309
		Maybe	-0.95	0.74	44.00	-0.03		.973
	Study 2							
		Control	0.10	0.46	49.03	0.21	.832	
		High task stress	-0.23	0.53	40.00	-0.62		.540
		Low task stress	0.05	0.53	40.00	-0.09		.933
	Study 3							
		Control	-0.06	0.65	30.58	-0.10	.922	
		Low chance of missing alarm	-0.37	0.45	44.00	-1.22		.505
		High chance of missing alarm	0.18	0.45	44.00	-0.67		.588
Sleep efficiency	Study 1							
		Control	0.05	0.17	44.93	0.31	.760	
		Definitely	0.11	0.18	44.00	0.34		.734
		Maybe	0.10	0.18	44.00	0.28		.777
	Study 2							
		Control	0.06	0.14	44.80	0.45	.657	
		High task stress	0.06	0.15	40.00	-0.01		.991
		Low task stress	-0.13	0.15	40.00	-1.29		.204

	Study 3							
		Control	-0.02	0.15	36.51	-0.12	.906	
		Low chance of missing alarm	0.05	0.13	44.00	0.52		.606
		High chance of missing alarm	-0.19	0.13	44.00	-1.29		.203
Sleep latency	Study 1							
		Control	0.67	0.45	46.26	1.50	0.141	
		Definitely	-0.40	0.47	44.00	-2.30		**0.026**
		Maybe	0.45	0.47	44.00	-0.48		0.635
	Study 2							
		Control	-0.40	0.44	44.13	-0.90	0.372	
		High task stress	-0.07	0.47	40.00	0.69		0.492
		Low task stress	0.33	0.47	40.00	1.54		0.131
	Study 3							
		Control	0.15	0.43	55.81	0.35	0.731	
		Low chance of missing alarm	0.13	0.51	44.0	-0.04		0.966
		High chance of missing alarm	0.71	0.51	44.0	1.09		0.280
Latency to N3	Study 1							
		Control	0.15	0.25	39.75	0.62	0.541	
		Definitely	0.52	0.23	44.00	1.56		0.126
		Maybe	0.09	0.23	44.00	-0.30		0.764
	Study 2							
		Control	-0.47	0.52	57.31	-0.90	0.371	
		High task stress	1.26	0.68	40.00	2.54		**0.015**
		Low task stress	-0.09	0.68	40.00	0.57		0.574
	Study 3							
		Control	0.12	0.17	43.05	0.74	0.464	
		Low chance of missing alarm	0.13	0.16	44.0	0.02		0.985
		High chance of missing alarm	0.16	0.16	44.0	0.22		0.825
REM Arousals (overnight)	Study 1							
		Control	-0.06	0.64	31.03	-0.09	0.927	
		Definitely	-1.15	0.45	44.00	-2.42		**0.020**
		Maybe	-0.93	0.45	44.00	-1.94		0.058
	Study 2							

		Control	0.26	0.54	27.26	0.48	0.636	
		High task stress	0.75	0.36	40.00	1.35		0.186
		Low task stress	0.75	0.36	40.00	1.35		0.185
	Study 3							
		Control	0.13	0.51	33.85	0.26	0.797	
		Low chance of missing alarm	0.29	0.40	44.00	0.39		0.701
		High chance of missing alarm	-0.44	0.40	44.00	-1.42		0.164
REM Arousals (per hour)	Study 1							
		Control	0.06	0.31	31.09	0.18	0.860	
		Definitely	-0.47	0.22	44.00	-2.36		**0.022**
		Maybe	-0.43	0.22	44.00	-2.21		**0.032**
	Study 2							
		Control	0.28	0.25	26.61	1.12	0.274	
		High task stress	0.46	0.16	40.00	1.14		0.263
		Low task stress	0.37	0.16	40.00	0.57		0.571
	Study 3							
		Control	0.06	0.24	33.42	0.27	0.789	
		Low chance of missing alarm	0.06	0.19	44.00	-0.01		0.993
		High chance of missing alarm	-0.14	0.19	44.00	-1.12		0.267
REM Latency	Study 1							
		Control	-0.44	1.06	58.70	-0.41	.680	
		Definitely	1.03	1.30	44.00	1.13		.264
		Maybe	-0.23	1.30	44.00	0.17		.869
	Study 2							
		Control	0.79	1.00	51.54	0.79	.432	
		High task stress	-1.24	1.19	40.00	-1.70		.097
		Low task stress		1.19	40.00	-1.51		.138
	Study 3							
		Control	-1.10	1.40	49.61	-0.78	.438	
		Low chance of missing alarm	-3.81	1.53	44.00	-1.77		.083
		High chance of missing alarm	1.17	1.53	44.00	-0.05		.964
Latency to 10 min of sleep	Study 1							
		Control	0.75	0.51	44.05	1.47	.150	

		Definitely	-0.19	0.51	44.00	-1.83		.073
		Maybe	0.36	0.51	44.00	-0.77		.448
	Study 2							
		Control	-0.82	0.59	50.34	-1.38	.173	
		High task stress	-0.32	0.69	40.00	0.71		.479
		Low task stress	0.34	0.69	40.00	1.67		.102
	Study 3							
		Control	0.11	0.42	47.62	0.26	.797	
		Low chance of missing alarm	0.27	0.45	44.00	0.36		.722
		High chance of missing alarm	0.71	0.45	44.00	1.35		.184
Minutes of N1	Study 1							
		Control	0.02	0.50	47.95	0.05	.963	
		Definitely	0.66	0.53	44.00	1.21		.232
		Maybe	0.19	0.53	44.00	0.31		.760
	Study 2							
		Control	0.75	0.39	46.52	1.94	.059	
		High task stress	0.53	0.43	40.00	-0.53		.601
		Low task stress	0.62	0.43	40.00	-0.31		.759
	Study 3							
		Control	-0.12	0.82	26.60	-0.14	.888	
		Low chance of missing alarm	-0.12	0.43	44.00	0.00		.999
		High chance of missing alarm	-0.32	0.43	44.00	-0.47		.642
N1 % of TST	Study 1							
		Control	0.00	0.11	47.98	0.04	.967	
		Definitely	0.14	0.12	44.00	1.13		.265
		Maybe	0.03	0.12	44.00	0.22		.830
	Study 2							
		Control	0.16	0.09	47.97	1.83	.074	
		High task stress	0.11	0.10	40.00	-0.50		.620
		Low task stress	0.14	0.10	40.00	-0.19		.847
	Study 3							
		Control	-0.03	0.20	26.21	-0.15	.880	
		Low chance of missing alarm	-0.05	0.10	44.00	-0.15		.881

		High chance of missing alarm	-0.06	0.10	44.00	-0.32		.749
Minutes of N2	Study 1							
		Control	1.92	1.03	47.98	1.86	.069	
		Definitely	2.25	1.10	44.00	0.30		.766
		Maybe	0.54	1.10	44.00	-1.26		.216
	Study 2							
		Control	-2.36	1.42	24.37	-1.66	.109	
		High task stress	-2.49	0.76	40.00	-0.16		.871
		Low task stress	-3.31	0.76	40.00	-1.24		.222
	Study 3							
		Control	1.67	1.28	37.83	1.30	.200	
		Low chance of missing alarm	0.76	1.13	44.00	-0.80		.427
		High chance of missing alarm	2.65	1.13	44.00	0.87		.388
N2 % of TST	Study 1							
		Control	0.41	0.21	45.54	1.96	.056	
		Definitely	0.45	0.21	44.00	0.17		.864
		Maybe	0.06	0.21	44.00	-1.63		.110
	Study 2							
		Control	-0.55	0.29	24.93	-1.88	.072	
		High task stress	-0.58	0.17	40.00	-0.37		.824
		Low task stress	-0.70	0.17	40.00	-0.49		.356
	Study 3							
		Control	0.37	0.29	35.83	1.30	.204	
		Low chance of missing alarm	0.14	0.24	44.00	-0.95		.350
		High chance of missing alarm	0.68	0.24	44.00	1.28		.209
Minutes of N3	Study 1							
		Control	-1.06	1.02	32.71	-1.04	.307	
		Definitely	-1.39	0.77	44.00	-0.43		.673
		Maybe	0.35	0.77	44.00	1.82		.076
	Study 2							
		Control	2.34	1.24	26.18	1.89	.070	
		High task stress	2.10	0.78	40.00	-0.32		.751
		Low task stress	1.94	0.78	40.00	-0.52		.607

	Study 3							
		Control	-1.90	1.55	28.08	-1.22	.232	
		Low chance of missing alarm	-1.42	0.93	44.00	0.51		.609
		High chance of missing alarm	-2.10	0.93	44.00	-0.22		.829
N3 % of TST	Study 1							
		Control	-0.26	0.23	32.66	-1.15	.259	
		Definitely	-0.34	0.17	44.00	-0.44		.659
		Maybe	0.06	0.17	44.00	1.86		.070
	Study 2							
		Control	0.50	0.28	25.71	1.77	.088	
		High task stress	0.45	0.17	40.00	-0.29		.777
		Low task stress	0.46	0.17	40.00	-0.24		.809
	Study 3							
		Control	-0.40	0.33	28.62	-1.08	.238	
		Low chance of missing alarm	-0.32	0.21	44.00	-0.33		.686
		High chance of missing alarm	-0.42	0.21	44.00	-0.44		.920
Minutes of REM	Study 1							
		Control	-0.64	0.77	53.13	-0.83	.411	
		Definitely	-0.97	0.88	44.00	-0.38		.707
		Maybe	-0.58	0.88	44.00	0.07		.943
	Study 2							
		Control	-0.44	0.93	34.62	-0.47	.638	
		High task stress	0.16	0.82	40.00	0.73		.468
		Low task stress	0.34	0.82	40.00	0.95		.350
	Study 3							
		Control	0.26	0.91	44.46	0.28	.778	
		Low chance of missing alarm	1.01	0.92	44.00	0.82		.415
		High chance of missing alarm	-1.13	0.92	44.00	-1.52		.137
REM % of TST	Study 1							
		Control	-0.15	0.16	56.34	-0.95	.349	
		Definitely	-0.10	0.19	44.00	-0.51		.616
		Maybe	-0.15	0.19	44.00	0.00		.997
	Study 2							

		Control	-0.11	0.34	56.02	-0.33	.746	
		High task stress	0.02	0.43	40.00	0.30		.763
		Low task stress	-0.18	0.43	40.00	-0.17		.865
	Study 3							
		Control	0.06	0.20	45.19	0.31	.760	
		Low chance of missing alarm	0.22	0.21	44.00	0.75		.460
		High chance of missing alarm	-0.19	0.21	44.00	-1.23		.226
Minutes of NREM	Study 1							
		Control	0.89	0.90	56.08	0.99	.326	
		Definitely	1.53	1.06	44.00	0.60		.550
		Maybe	1.07	1.06	44.00	0.17		.863
	Study 2							
		Control	0.74	1.02	29.72	0.72	.475	
		High task stress	0.14	0.77	40.00	-0.78		.440
		Low task stress	-0.75	0.77	40.00	-1.92		.061
	Study 3							
		Control	-0.34	1.08	41.64	-0.32	.752	
		Low chance of missing alarm	-0.77	1.04	44.00	-0.41		.682
		High chance of missing alarm	0.24	1.04	44.00	0.56		.578
NREM % of TST	Study 1							
		Control	0.15	0.16	56.33	0.94	.349	
		Definitely	0.25	0.19	44.00	0.51		.616
		Maybe	0.15	0.19	44.00	-0.00		.998
	Study 2							
		Control	0.11	0.20	33.74	0.54	.592	
		High task stress	-0.02	0.18	40.00	-0.74		.462
		Low task stress	-0.10	0.18	40.00	-1.19		.239
	Study 3							
		Control	-0.06	0.20	45.19	-0.31	.760	
		Low chance of missing alarm	-0.21	0.21	44.00	-0.75		.460
		High chance of missing alarm	0.19	0.21	44.00	1.23		.226
Arousals (total sleep period)	Study 1							
		Control	-0.09	1.23	32.19	-0.07	.943	
		Definitely	-0.62	0.91	44.00	-0.58		.566

		Maybe	-0.14	0.91	44.00	-0.05		.960
	Study 2							
		Control	0.34	0.95	32.45	0.36	.722	
		High task stress	0.51	0.79	40.00	0.22		.829
		Low task stress	0.44	0.79	40.00	0.21		.904
	Study 3							
		Control	-0.78	1.44	27.50	-0.54	.593	
		Low chance of missing alarm	-0.13	0.82	44.00	0.79		.436
		High chance of missing alarm	-1.07	0.82	44.00	-0.36		.721
Arousals (NREM)	Study 1							
		Control	-0.03	0.99	34.63	-0.03	.976	
		Definitely	0.53	0.80	44.00	0.70		.485
		Maybe	0.80	0.80	44.00	1.04		.304
	Study 2							
		Control	0.08	0.83	32.85	0.10	.921	
		High task stress	-0.32	0.70	40.00	-0.45		.656
		Low task stress	-0.39	0.70	40.00	-0.56		.581
	Study 3							
		Control	-0.910	1.35	27.85	-0.67	.506	
		Low chance of missing alarm	-0.421	0.79	44.00	0.62		.541
		High chance of missing alarm	-0.63	0.79	44.00	0.35		.728
Arousals per hour (total sleep period)	Study 1							
		Control	-0.02	0.17	32.18	-0.12	.904	
		Definitely	-0.10	0.13	44.00	-0.60		.554
		Maybe	-0.03	0.13	44.00	-0.10		.921
	Study 2							
		Control	0.04	0.13	32.90	0.29	.774	
		High task stress	0.06	0.11	40.00	0.20		.844
		Low task stress	0.07	0.11	40.00	0.29		.774
	Study 3							
		Control	-0.11	0.20	26.86	-0.55	.590	
		Low chance of missing alarm	-0.03	0.11	44.00	-0.14		.477
		High chance of missing alarm	-0.13	0.11	44.00	-0.24		.855

Arousals per hour (REM)	Study 1							
		Control	0.06	0.31	31.09	0.18	.860	
		Definitely	-0.47	0.22	44.00	-2.36		.023
		Maybe	-0.43	0.22	44.00	-2.21		.032
	Study 2							
		Control	0.28	0.25	26.61	1.12	.274	
		High task stress	0.46	0.16	40.00	1.14		.263
		Low task stress	0.37	0.16	40.00	0.57		.571
	Study 3							
		Control	0.06	0.24	33.42	0.27	.789	
		Low chance of missing alarm	0.06	0.19	44.00	-0.01		.993
		High chance of missing alarm	-0.14	0.19	44.00	-1.12		.267
Arousals per hour (NREM)	Study 1							
		Control	-0.03	0.18	34.18	-0.18	.858	
		Definitely	0.05	0.14	44.00	0.60		.554
		Maybe	0.10	0.14	44.00	0.92		.363
	Study 2							
		Control	-0.02	0.14	34.49	-0.14	.893	
		High task stress	-0.06	0.12	40.00	-0.35		.727
		Low task stress	-0.04	0.12	40.00	-0.13		.897
	Study 3							
		Control	-0.17	0.25	27.30	-0.69	.498	
		Low chance of missing alarm	-0.06	0.14	44.00	0.76		.453
		High chance of missing alarm	-0.13	0.14	44.00	0.32		.747
Awakenings	Study 1							
		Control	-0.49	0.29	32.36	-1.68	.102	
		Definitely	-0.15	0.22	44.00	1.55		.127
		Maybe	-0.36	0.22	44.00	0.62		.539
	Study 2							
		Control	-0.11	0.26	34.56	-0.40	.688	
		High task stress	-0.51	0.23	40.00	-1.76		.087
		Low task stress	-0.32	0.23	40.00	-0.92		.361
	Study 3							

		Control	-0.19	0.35	33.16	-0.54	.595	
		Low chance of missing alarm	-0.12	0.27	44.00	0.24		.808
		High chance of missing alarm	-0.21	0.27	44.00	-0.08		.937
Stage shifts	Study 1							
		Control	-0.58	1.20	44.46	-0.48	.632	
		Definitely	1.02	1.21	44.00	1.32		.192
		Maybe	0.30	1.21	44.00	0.73		.470
	Study 2							
		Control	0.99	0.93	46.75	1.06	.293	
		High task stress	-0.08	1.04	40.00	-1.03		.311
		Low task stress	-0.15	1.04	40.00	-1.10		.279
	Study 3							
		Control	-1.61	1.40	33.46	-1.15	.259	
		Low chance of missing alarm	-0.97	1.09	44.00	0.59		.560
		High chance of missing alarm	-0.90	1.09	44.00	0.65		.519
Delta/alpha ratio (REM)	Study 1							
		Control	0.29	0.42	33.90	0.69	.494	
		Definitely	-0.05	0.31	39.83	-1.12		.268
		Maybe	0.27	0.31	38.32	-0.09		.932
	Study 2							
		Control	0.31	0.50	34.33	0.62	.541	
		High task stress	0.53	0.49	38.24	0.44		.659
		Low task stress	0.21	0.46	37.96	-0.22		.824
	Study 3							
		Control	0.44	0.44	32.26	1.01	.319	
		Low chance of missing alarm	-0.03	0.34	37.80	-1.40		.171
		High chance of missing alarm	0.04	0.34	37.95	-1.18		.244
Delta/alpha ratio (NREM)	Study 1							
		Control	-0.66	0.82	25.21	-0.81	.427	
		Definitely	-0.29	0.33	38.49	1.11		.273
		Maybe	-0.67	0.34	38.01	-0.01		.996
	Study 2							
		Control	1.04	0.64	25.01	1.64	.114	
		High task stress	1.41	0.35	35.79	1.05		.300

		Low task stress	0.95	0.33	35.74	-0.27		.790
	Study 3							
		Control	-0.47	0.55	29.94	-0.85	.404	
		Low chance of missing alarm	-0.05	0.41	36.78	-0.13		.896
		High chance of missing alarm	-0.12	0.41	36.92	-0.29		.774
EEG slowing (REM)	Study 1							
		Control	0.10	0.19	34.13	0.51	.613	
		Definitely	0.00	0.14	39.99	-0.67		.507
		Maybe	0.11	0.14	38.47	0.07		.945
	Study 2							
		Control	0.18	0.21	34.42	0.84	.405	
		High task stress	0,27	0.21	37.99	0.42		.680
		Low task stress	0.15	0.20	37.69	-0.16		.871
	Study 3							
		Control	0.18	0.23	31.72	0.79	.434	
		Low chance of missing alarm	-0.09	0.18	37.87	-1.56		.127
		High chance of missing alarm	0.01	0.18	38.01	-0.97		.340
EEG slowing (NREM)	Study 1							
		Control	-0.49	0.28	27.19	-1.77	.087	
		Definitely	-0.34	0.14	38.83	1.09		.284
		Maybe	-0.51	0.14	38.10	-0.11		.916
	Study 2							
		Control	0.56	0.30	24.65	1.85	.077	
		High task stress	0.74	0.16	35.60	1.09		.281
		Low task stress	0.55	0.15	35.55	-0.05		.956
	Study 3							
		Control	-0.38	0.28	28.29	-1.37	.183	
		Low chance of missing alarm	-0.44	0.18	36.93	-0.31		.762
		High chance of missing alarm	-0.46	0.19	37.04	-0.40		.689

* Relationship between trait anxiety and the relevant variable
**Significance of relationship between trait anxiety and the relevant variable compared with zero (no relationship)
*** Significance of the relationship between trait anxiety and the relevant variable compared with control

6.4.5 Trait anxiety and quantitative EEG outcomes

No significant effects of trait anxiety were found for the qEEG ratio outcomes that were investigated, $p > .05$. See Table 14.

6.4.6 Trait anxiety and cognitive performance

Significant effects of trait anxiety were found for the cognitive performance outcomes and are described below. See Figure 11 and Table 15.

*6.4.6.1 Mean RRT (1/RRT*1000)*

A significant relationship was found between trait anxiety and mean RRT in the control condition of Study 3, $\beta = -0.04$, $t(38.42) = -2.07$, $p = .045$ (i.e., higher trait anxiety was associated with slower reaction times). In comparison with this relationship, no significance was seen in the low, $\beta = -0.02$, $t(44.00) = 1.12$, $p = .270$, or high chance of missing the alarm conditions, $\beta = -0.00$, $t(44.00) = 1.04$, $p = .306$. No significant differences in the relationship between trait anxiety and mean reciprocal reaction time were found between conditions in Study 1 or 2, $p > .05$.

6.4.6.2 Lapses

In Study 3 significant deviation from zero in the slope of the relationship between trait anxiety and lapses was seen in the control condition, $\beta = 0.17$, $t(35.04) = 2.67$, $p = .012$. (i.e., higher anxiety was associated with more lapses). Compared with this relationship, there was a significantly smaller positive relationship between trait anxiety and lapses in the low chance of missing the alarm condition, $\beta = 0.06$, $t(44.00) = -2.16$, $p = .036$. However, there was no significant difference between the control slope and the high chance of missing the alarm condition, $\beta = -0.02$, $t(44.00) = -1.40$, $p = .167$. No significant differences in the relationship between trait anxiety and lapses on the PVT were seen in Studies 1 or 2.

6.4.6.3 Mean fastest 10% of reaction time

No significant differences between trait anxiety and the mean fastest 10% of reaction time on the PVT were found between conditions in Study 1, 2 or 3 in the relationship.

6.4.6.4 Mean slowest 10% of reciprocal reaction time

A significant difference was seen in the relationship between trait anxiety and the mean slowest 10% of reciprocal reaction time compared with zero in the control condition of Study 3, $\beta = -0.06$, $t(47.75) = -2.39$, $p = .021$. This relationship was not significantly different from control in either the low, $\beta = -0.01$, $t(44.00) = 1.71$, $p = .094$, or high chance of missing the alarm condition, $\beta = 0.01$, $t(44.00) = 0.99$, $p = .328$. No significant differences in the relationship between trait anxiety and lapses on the PVT were seen in Studies 1 or 2.

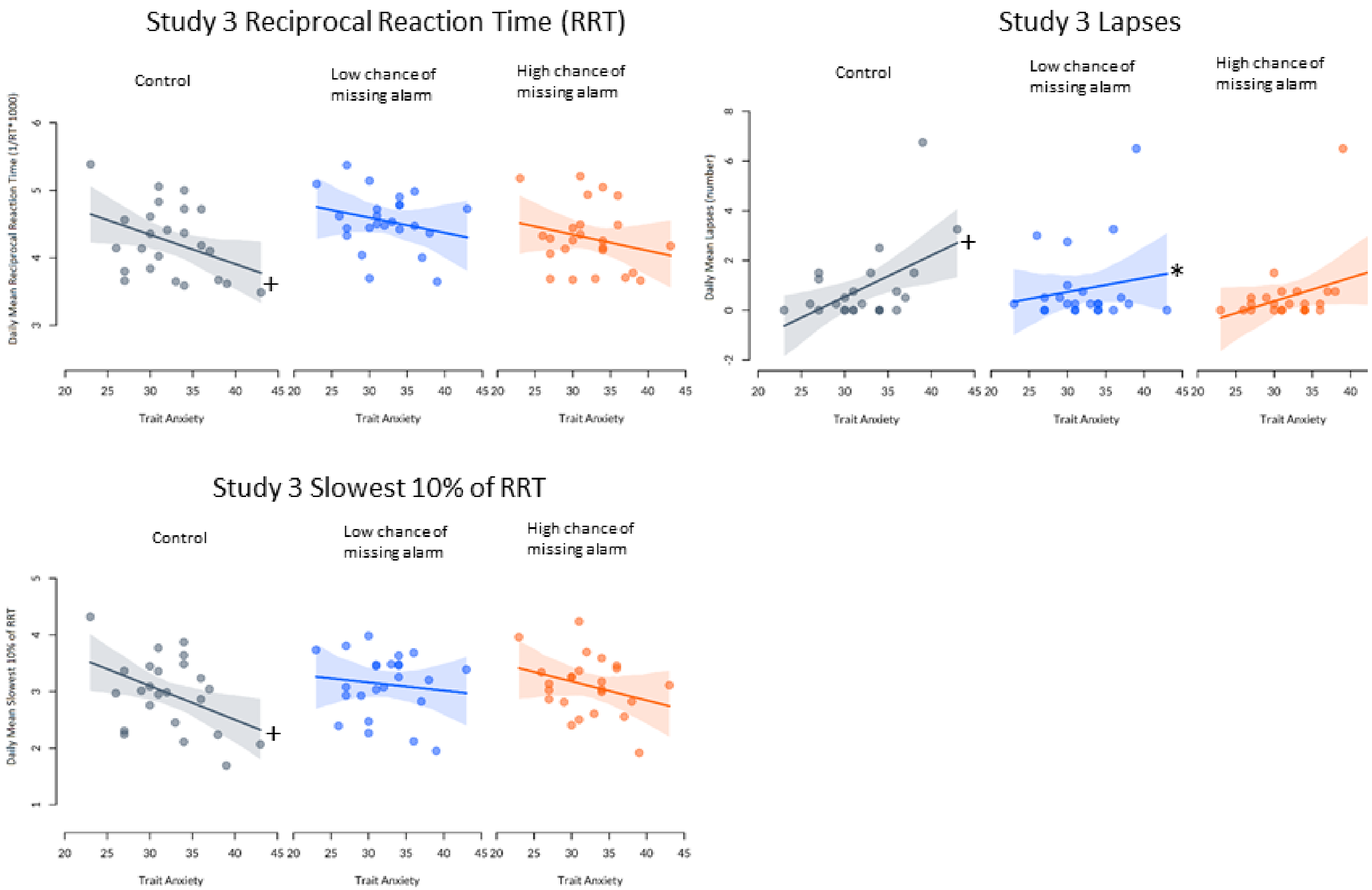

Figure 11. Relationships between trait anxiety and performance variables in Study 1, Study 2, and Study 3

+ Significantly different from slope of zero
* Significantly different from control slope

Table 15. The effect of trait anxiety on on-call performance outcomes from Study 1, Study 2, and Study 3 compared with control

Variable	Study	Condition	β*	SE	df	t	p**	p ***
Mean RRT (1/RRT*1000)	Study 1							
		Control	0.04	0.03	26.45	1.15	.261	
		Definitely	0.03	0.02	44.00	-0.33		.740
		Maybe	0.02	0.02	44.00	-0.39		.696
	Study 2							
		Control	0.02	0.02	24.92	1.08	.289	
		High task stress	0.02	0.01	44.00	0.08		.939
		Low task stress	0.02	0.01	44.00	-0.38		.709
	Study 3							
		Control	-0.04	0.02	38.42	-2.07	**.045**	
		Low chance of missing alarm	-0.02	0.02	44.00	1.12		.270
		High chance of missing alarm	-0.00	0.02	44.00	1.04		.306
Lapses	Study 1							
		Control	-0.12	0.21	37.43	-0.56	.579	
		Definitely	-0.11	0.19	44.00	0.04		.971
		Maybe	-0.08	0.19	44.00	0.17		.863
	Study 2							
		Control	-0.28	0.14	26.89	-1.97	.060	
		High task stress	-0.24	0.08	44.00	0.50		.617
		Low task stress	-0.12	0.08	44.00	1.60		.116
	Study 3							
		Control	0.17	0.06	35.04	2.67	**.012**	
		Low chance of missing alarm	0.06	0.05	44.00	-2.16		**.036**
		High chance of missing alarm	-0.02	0.05	44.00	-1.40		.167
Mean fastest 10% RT	Study 1							
		Control	-1.01	0.96	24.91	-1.06	.300	
		Definitely	-0.69	0.41	44.00	0.79		.431
		Maybe	-0.09	0.41	44.00	1.45		.153
	Study 2							
		Control	-0.74	0.78	25.86	-0.95	.351	
		High task stress	-0.91	0.38	44.00	-0.44		.661
		Low task stress	-0.82	0.38	44.00	0.24		.815

	Study 3							
		Control	0.90	0.75	38.21	1.19	.240	
		Low chance of missing alarm	0.85	0.67	44.00	-0.07		.943
		High chance of missing alarm	0.65	0.67	44.00	-0.30		.766
Mean slowest 10% RRT	Study 1							
		Control	0.04	0.04	28.45	1.20	.239	
		Definitely	0.04	0.02	44.00	-0.36		.723
		Maybe	0.02	0.02	44.00	-0.52		.603
	Study 2							
		Control	0.03	0.03	24.96	1.05	.305	
		High task stress	0.03	0.01	44.00	0.31		.759
		Low task stress	0.03	0.01	44.00	0.29		.771
	Study 3							
		Control	-0.06	0.02	47.75	-2.39	**.021**	
		Low chance of missing alarm	-0.01	0.03	44.00	1.71		.094
		High chance of missing alarm	0.01	0.03	44.00	0.99		.328

* Slope of relationship between trait anxiety and the relevant variable
**Significance of the slope of the relationship between trait anxiety and the relevant variable compared with zero (no relationship)
*** Significance of the slope of the relationship between trait anxiety and the relevant variable compared with control slope

6.5 Discussion

The aim of these analyses was to understand if individuals who have lower trait anxiety are better able to cope with on-call working arrangements. Results indicated that trait anxiety was the same across all three studies, suggesting that all individuals were starting from a similar baseline level of anxiety. As all participants were screened for severe levels of anxiety prior to participation, this result is not surprising. However, the state anxiety experienced by participants across all conditions in Study 2 was significantly higher than in either Study 1 or Study 3. Had these increases been limited to Study 2's on-call nights (high and low stress conditions), we may have posited that being required to perform a specific task upon waking while on-call may be responsible for increased pre-bed state anxiety. However, as the level of state anxiety experienced prior to bed in the control condition was similarly heightened compared with trait anxiety levels (i.e. when state anxiety was compared in individuals with either high or low trait anxiety), we cannot conclude that it was the on-call conditions that resulted in significantly higher state anxiety. Additionally, participants were only informed prior to bed on the on-call nights that they would be required to perform the speech task, and as such were unaware of this requirement on the control night. Demographic composition, including age, BMI and nationality, were equally distributed between studies, suggesting that this finding was unlikely to be a function of the particular group of participants. There was a slightly higher proportion of students in Study 1 (63%) and Study 3 (63%) compared with Study 2 (42%), but a one-way ANOVA indicated that occupation was not linked with state anxiety, $p = .232$. Further, as all studies were completed in the same laboratory, with the same conditions (including staff and internal laboratory processes), we must consider alternative explanations for the clinically significant levels of trait anxiety prior to bed for every condition in Study 2. As Study 2 was conducted in the latter half of 2016 (whereas Study 1 was performed in the first half of 2016, and Study 3 in the first half of 2017), external global events, seasonal differences or differences in workload (e.g., student examinations) in the latter half of 2016 may have contributed to the significantly higher levels of state anxiety across all conditions in Study 2. However, the reason for this difference in state anxiety between studies is unclear.

When we investigated the effect of trait anxiety on sleep, state anxiety and cognitive outcomes over the different on-call conditions of each study, while there were a few significant results, the degree to which any one variable was affected is minimal. As such, the hypothesis was not supported. These findings will be discussed in the context of each study individually.

Study 1 investigated the effects of the likelihood of being called (*definitely* or *maybe*) and found that there was no relationship between trait anxiety and either state anxiety or performance outcomes under these conditions. However, in the control condition, a non-significant trend for higher levels of trait anxiety to be associated with longer sleep latencies was found. When this is compared with the definitely being called condition of this study, this relationship is no longer present. This may suggest that more anxious individuals are not as susceptible to poorer sleep outcomes under on-call conditions where they know they will definitely be called. Additionally, in the definitely condition, lower levels of trait anxiety were associated with a higher number of arousals during REM (both overnight and per hour) when compared with the control condition. As such, it appears that there is a slight trend for individuals with higher trait anxiety to fall asleep faster and to have fewer arousals when they know they will definitely be called. This is contrary to the original hypothesis. These findings may be reflective of the higher baseline level of anxiety that these individuals experience, meaning that when faced with on-call scenarios, they are less reactive than those who have lower levels of baseline anxiety (Villada et al., 2016). This is supported by research under stressful conditions, where individuals with higher levels of trait anxiety displayed higher emotional reactivity to a stressful situation, but lower levels of physiological reactivity (cortisol) than individuals with lower trait anxiety (Villada et al., 2016). As heightened cortisol appears to be linked with poor sleep outcomes (Steiger, 2002), it is possible that under stressful conditions (i.e., knowing that the individual will definitely be called), individuals with lower trait anxiety in fact have higher levels of physiological reactivity, and as such poorer sleep outcomes than those with higher trait anxiety.

In Study 2, results indicated that under control conditions, there was a non-significant trend of high trait anxiety to be associated with lower state anxiety. This was significantly different from the relationship under the high stress condition. In the high stress condition, this trend was not apparent, and there was no relationship between trait and state anxiety (Figure 9). However, while this is a statistically significant trend, the magnitude of the changes in state anxiety are very small between control and the high stress condition (within 5 points), suggesting that this difference is largely inconsequential. There was also a relationship of trait anxiety with how long it took participants to reach N3 sleep in the high stress condition of this study. In the high stress condition, higher trait anxiety was linked with a longer latency to N3 compared with control. As such, when a high stress task is to be performed, sleep may be slightly altered for those who have higher levels of trait anxiety. As latency to N3 differed by less than 10 min between conditions, and the proportion or amount of N3 that was obtained did not differ, this does not appear to be reflective of poorer sleep overall. Further, there were no significant effects of trait anxiety on any performance outcomes for Study 2. This may also be explained by the lack of cortisol reactivity in higher anxiety individuals under stressful conditions (Villada et al., 2016). When we look at the relationship between trait anxiety and state anxiety and sleep outcomes in these studies, it is important to understand the size of these differences in a real world context. Specifically, the magnitude of the changes to these outcomes is small for all variables and, as such, should be considered trends only. For example, the difference in latency to N3 seen in Study 2 is only representative of an additional sleep latency of under 10 min for individuals with a STAI x-2 score which was 20 points higher.

Though no relationship was found between trait anxiety and either state anxiety or any sleep variables for Study 3, significant differences were found in performance outcomes. In the control condition, individuals with higher trait anxiety had slower reciprocal reaction times (RRT), mean slowest 10% of RRT, and more lapses, though no relationship between trait anxiety and performance was seen in either on-call condition. As such, it appears that being on-call, regardless of the chance of missing the alarm or quality/quantity of sleep, resulted in improved cognitive performance for individuals with high trait anxiety, but did not change performance for those with lower trait anxiety. These performance changes improved the cognitive performance of higher trait anxiety individuals to the same level as those with lower trait anxiety. One explanation for this change is that individuals who have higher levels of trait anxiety are less physiologically reactive to stressful situations (i.e., lower levels of hormones of the hypothalamo–pituitary–adrenocortical axis, epinephrine, norepinephrine and prolactin) (Jezova et al., 2004). This may be explained in part by the higher levels of anxiety they experience day-to-day, which may blunt the hormonal response to acute stress. Specifically, under stressful conditions (i.e., attending a motor vehicle collision), individuals with higher trait anxiety actually had lower levels of these physiological stress symptoms, which may be linked with performance (Jezova et al., 2004). As such, under the stressful on-call conditions, individuals with higher trait anxiety may be more habituated to the physiological responses, and may respond better than those with lower trait anxiety. It is also important to consider the magnitude of these results – a 20 point increase on the STAI x-2 (trait anxiety) resulted in cognitive performance that was impaired by approximately two lapses, an increase in reaction time of 100 ms. These differences, while significant, are not large in magnitude. However, it is important to note that operationally, if lapses constitute a microsleep, there may be significant negative consequences. Additionally, under certain on-call conditions, this performance advantage may disappear. Further research into the effects of trait anxiety on performance on-call is certainly warranted, as with the additional stressors of real world on-call work, these differences may be more severe.

While this study was designed to look at the effects of different aspects of on-call work (likelihood of receiving a call, task stress, chance of missing the alarm), the separation of these elements means that this study is limited in terms of real world applicability. Real on-call workers often experience these factors concurrently, with the addition of actual calls occurring overnight, resulting in sleep restriction. As such, future research must address the effect of combined or additional stressors, including sleep restriction, in addition to including participants that are more representative of on-call workers as a whole (i.e., women and individuals over the age of 35). It is necessary to include individuals who are experiencing higher levels of depression, stress, or anxiety in future research, as this may be more representative of real world on-call populations. Further, trait anxiety is just one individual factor that may play a role in on-call suitability, and as such, future research must examine other personality and individual factors that may play a role.

Another major limitation that must be considered is the sample size of each group within these studies, combined with the number of outcome measures that have been examined. As a result of these factors, we must refrain from considering the outcomes of these studies to be strong, but instead must take the exploratory nature of this analysis into consideration. Therefore, these findings may have limited practical applicability, but instead pave the way for further research into the relationship between personal factors, such as trait anxiety, and the ability to manage on-call work.

This study was the first to investigate the effects of trait anxiety on state anxiety, sleep, and cognitive performance outcomes under a range of on-call conditions. We can conclude from this study that there are some slight changes to anxiety, sleep, and cognitive performance that occur under certain on-call conditions. The effects of trait anxiety on state anxiety and sleep outcomes were very small in magnitude and may not have any practical implications for on-call work. However, the trend seen in Study 3 suggests that being on-call may blunt the cognitive performance disadvantage that individuals with higher trait anxiety appear to have under control conditions. Additionally, this research suggests that there may be a trend for individuals with higher levels of trait anxiety to be less physiologically reactive to stressful situations, resulting in slightly improved sleep under certain on-call conditions. As such, having higher, non-clinical levels of trait anxiety does not appear to preclude individuals from being able to manage the stress of on-call work.

Chapter 7. General Discussion

7.1 Introduction

This chapter is a general discussion of the findings of this thesis. It includes an overview of the rationale behind the research questions, including on-call work generally, in addition to anxiety, sleep, and cognitive performance, and the components of on-call work that may affect these factors. This is followed by an overview of the main findings from Chapters 3 - 6. A discussion of the contributions of this thesis to the field is also included, as is an overview of the practical steps that can be taken in the on-call field in light of relevant findings from this thesis. Additionally, future directions and limitations are discussed.

7.2 Background

This section provides an overview of the background behind the research questions addressed in this thesis, to refresh the reader on the importance of this topic.

Increased production and service demands have necessitated and precipitated the growth of non-standard working arrangements in many industries (Costa, 2014; Parent-Thirion et al., 2012). One such arrangement that has been utilised increasingly in recent years is on-call work (McCrate, 2018; Ziebertz et al., 2015). On-call is often used by organisations to ensure that work duties are completed on an as-needed basis, without the need for rostered on staff (Nicol & Botterill, 2004). Despite the fact that on-call is currently performed by more than a quarter of Australian workers (Australian Bureau of Statistics, 2016), there has been limited research into potential adverse outcomes for these individuals and their workplaces. Increased anxiety has been reported in on-call workers (Gonzalez-Cabrera et al., 2018; Heponiemi et al., 2015; Paterson et al., 2016; Ziebertz et al., 2015), which is suggested to result in poorer sleep during on-call periods (Cebola, 2014; Nicol & Botterill, 2004; Torsvall et al., 1987). Research performed prior to this thesis indicates that workers obtain fewer hours of sleep, and/or sleep of poorer quality during on-call periods, compared with not being on-call (Paterson et al., 2016; Torsvall & Åkerstedt, 1988; Ziebertz et al., 2017). These reports have been both subjective (Billings & Focht, 2016; Cebola, 2014; Iversen et al., 2002; Paterson et al., 2016) and objective (Åkerstedt et al., 1990; Imbernon et al., 1993; Jay et al., 2008; Torsvall & Åkerstedt, 1988; Ziebertz et al., 2017). Additionally, poorer sleep outcomes have been seen during on-call periods where no calls are received (Jay et al., 2008; Torsvall & Åkerstedt, 1988; van de Ven et al., 2015; Van Gelder & Kao, 2006), suggesting that it is not just the interruption from calls leading to poorer sleep, but also feelings of anxiety or apprehension, which this thesis aimed to understand. However, no research had previously investigated which components of on-call work may lead to higher anxiety and poorer sleep outcomes. As such, this thesis focused on three specific components of on-call work that may cause anxiety: the likelihood of receiving a call, how stressful the task to be performed upon waking is, and the perceived chance of missing the alarm. Although there may be other components of on-call work that affect individual outcomes, these three components have been identified by the literature as being potential direct causes of changes to anxiety, sleep, and cognitive performance in operational settings. Other components, such as experience with on-call work, or pre-existing health problems, are outside the scope of this thesis. The components addressed by this thesis are important to understand because poor sleep can have significant negative ramifications for next day cognitive performance (e.g., reaction time, work performance) (Krause et al., 2017; Lowe et al., 2017). As on-call work tends to be utilised in industries that are regarded as high-risk (e.g., emergency services) (Nicol & Botterill, 2004), it is imperative to understand any components that may result in performance decrements and, consequently, increased safety risks, and poorer productivity (Christian et al., 2009). This information is vital for organisations that aim to minimise the risks associated with on-call work.

7.3 Summary of findings

This section presents a general summary of the findings from this thesis. The findings of Chapters 3, 4 and 5 provide valuable insight into the effects of differing components of on-call work on anxiety, sleep and cognitive performance, and Chapter 6 explores how trait anxiety may affect these outcomes in the on-call context. The findings of these chapters together indicate that uncertainty is a primary factor affecting on-call anxiety, sleep and cognitive performance, including the uncertainty surrounding both whether a person will be called, and whether they will miss the alarm. The impact of uncertainty is evidenced by poorer sleep and cognitive performance in the *maybe* receiving a call condition in Study 1, and in the *high chance of missing the alarm* condition in Study 3. Interestingly, participants experienced more anxiety when they knew a call was *definitely* coming (in Study 1) than when they were unsure about the call likelihood (*maybe* condition), but in these conditions, increased anxiety did not translate into poorer sleep and cognitive performance outcomes. This may suggest that individual perception may differ from objective sleep outcomes. There were no differences in anxiety between control or on-call conditions in Study 2, which investigated the effects of on-call task stress, even when participants knew they would be required to perform a stressful task upon waking on one of the two on-call nights (*high stress* condition). Similarly, there were no changes in sleep in this study. However, participants performed significantly better on a cognitive performance task (PVT) in the *high stress* condition of this study compared with the *low stress* condition, which is important given that PVT performance is known to correspond with work performance (Dinges et al., 2004). A possible explanation of this finding is that the arousal associated with delivering an oral presentation resulted in faster reaction times (Kjellberg, 1977; Sanbonmatsu & Kardes, 1988). Additionally, analysis of the impact of trait anxiety on the ability to tolerate on-call work (as measured by pre-bed state anxiety, sleep and next day cognitive performance across all three studies) indicated that while there were some small differences between those who had higher and lower levels of trait anxiety, the effects on anxiety, sleep and cognitive performance were negligible. As such, it appears that non-clinical levels of trait anxiety do not play a major role in the ability of individuals to cope with on-call work in a simulated setting.

7.4 Contributions to the field

There are a number of novel contributions to the on-call field that have been presented in this thesis. These contributions include the quantitative and validated tools that were used, in addition to the outcome variables that were measured in conjunction with one another (i.e., anxiety, sleep, and cognitive performance). Furthermore, methodological factors add to the body of research that has been performed in the on-call area, including the components of on-call work that were identified and analysed, qEEG analysis of on-call sleep data, and the measurement of trait anxiety in on-call individuals. This section provides detailed information about these contributions.

7.4.1 Outcome measures

Prior to this thesis, studies had separately investigated the relationships between on-call and anxiety (Cebola, 2014; Ziebertz et al., 2015), on-call and sleep (Ferguson et al., 2016), and on-call and cognitive performance (Grantcharov et al., 2001; Weinger et al., 1996). However, this thesis presents the first body of work that has investigated all three of these outcomes together in a systematic way, in order to identify how they interact and are affected under on-call conditions. As a result, these data provide insight into the relationships not only between these outcomes and on-call work generally, but also how they may relate to each other. While statistical associations between anxiety, sleep, and cognitive performance outcomes were outside of the scope of this thesis, these findings provide a first look into the potential relationships that may exist between these factors. For example, by examining anxiety, sleep, and cognitive performance within the same studies we can see that changes in cognitive performance on-call may not necessarily be preceded by sleep decrements, as seen in Chapter 4. Further, the findings from this thesis also indicate that pre-bed anxiety on-call is not necessarily reflective of sleep, as seen in Chapters 3, 4, and 5.

7.4.2 Quantitative and validated data collection methods

Prior to this research, on-call anxiety, sleep, and cognitive performance were typically measured via qualitative reporting and interviews (Cebola, 2014; Jay et al., 2018; Paterson et al., 2016). While qualitative data is certainly valuable, quantitative data is fundamental to understanding the objective effects of on-call periods. This is particularly relevant for the studies presented in this thesis, as qualitative reports are not necessarily reflective of objective changes, particularly to sleep (Bastien et al., 2003; Lauderdale et al., 2008) and cognitive performance (Dorrian et al., 2003; Dorrian et al., 2007). As such, one of the major contributions of this body of work is the use of objective and validated tools to measure anxiety, sleep and cognitive performance during on-call periods. This thesis therefore adds to the limited pool of controlled, quantitative data that has been produced in the on-call literature (Jay et al., 2016; Wuyts et al., 2012; Ziebertz et al., 2017). Findings that reflect objective changes to sleep and cognitive performance have resulted, which provide information that is potentially more objectively accurate and applicable to broader settings than qualitative reports.

7.4.3 Components of on-call work

The present studies have also contributed to the on-call field by deliberately differentiating between on-call components, to determine what it is about on-call work that may negatively affect workers. Previous on-call laboratory research only compared on-call with control (not on-call) conditions (Jay et al., 2016; Wuyts et al., 2012). While this information is useful, it does not differentiate the specific aspects of working on-call that are detrimental to employees. This is important because on-call work takes many forms, including having differences in operational requirements, tasks that are performed, contact methods, and times of the 24-h day when work is required (Nicol & Botterill, 2004). Because of these differences, it is logical to assume that findings from generic on-call/control comparisons may not necessarily apply to all organisations or industries. This thesis was the first to investigate the effects of specific components of on-call work (i.e., the likelihood of being called, task stress, and the chance of missing the alarm) on anxiety, sleep, and cognitive performance. Therefore, this research can be used by organisations to identify on-call management strategies that can be tailored based on workplace and organisational needs. For example, workplaces whose employees are engaged in high stress on-call tasks (e.g., emergency services) may be able to identify strategies based on the findings from Chapter 4, which investigated the impact of such tasks specifically.

7.4.4 On-call periods with no calls

Previous laboratory and simulation based research in the on-call area typically focused on the effects of receiving calls during overnight periods (Jay et al., 2016; Ziebertz et al., 2017). Therefore, this thesis presents some of the first research that has deliberately isolated the effects of on-call from the effects of sleep restriction or deprivation in a laboratory context, by not interrupting on-call sleep with calls until the end of the sleep opportunity. Prior to this thesis, just one on-call laboratory simulation had been performed where overnight calls did not disturb sleep (Wuyts et al., 2012). In the study performed by Wuyts et al. (2012), significant differences were seen between control and on-call conditions, with poorer sleep outcomes under on-call conditions (e.g., poorer sleep efficiency, WASO, and sleep latency). While similar sleep decrements were found in the on-call conditions in Chapters 3 and 5, these effects were not seen in Chapter 4 of this thesis. These results support the findings presented by Wuyts et al. (2012) indicating that the changes to anxiety, sleep, and cognitive performance discussed in this thesis are caused by *being* on-call, rather than by the interruption of sleep periods that is often associated with this working arrangement. These findings support the notion that organisations need to be aware of the potential negative effects of on-call periods without calls, particularly in regard to worker safety and performance.

7.4.5 Next day cognitive performance

Unlike previous research, this thesis also investigated the effects of on-call periods on next-day cognitive performance. On-call cognitive performance has typically been assessed *during* on-call shifts, rather than the following day (Cebola et al., 2013; Pilcher et al., 2002; Ziebertz et al., 2015). While there has been some research on next-day cognitive performance, this has focused on real world driving ability (Marcus & Loughlin, 1996). In contrast, this thesis investigated next day cognitive performance on a PVT at regular intervals (0930, 1200, 1430, and 1700) throughout the day. The PVT is a particularly useful measure, as it is known to be sensitive to sleep loss and is analogous to work performance (Dinges et al., 2004). Therefore, PVT findings in this context add value to the previously available driving performance data, as they correspond to changes to other work performance outcomes (e.g., the ability to perform complex cognitive tasks in the workplace) (Dinges et al., 2004). This thesis has indicated that under certain on-call conditions, PVT performance the next day can be positively affected (by performing a stressful task, as seen in Chapter 4) or negatively affected (by uncertainty, which resulted in poorer sleep and next day cognitive performance outcomes, as seen in Chapters 3 and 5). This information may be useful for organisations that require on-call employees to work the day following their on-call periods (e.g., medical staff) (Nicol & Botterill, 2004), or for workers who are on-call for extended periods of time (e.g., volunteer fire fighters who are on-call 24/7) (Jay et al., 2018; Paterson et al., 2016). Additionally, this information provides a basis for further research into cognitive performance the day after on-call periods, independent from sleep restriction, which was previously unknown.

This thesis has also presented the valuable contribution of finding that certain on-call conditions (i.e., when a stressful task is performed upon waking) appear to have a protective effect on cognitive performance. This is not a finding that has been suggested in the on-call area previously (Hall et al., 2016; Nicol & Botterill, 2004), and as such presents a new perspective on the potential outcomes of on-call periods in regard to work performance. Specifically, these findings suggest that performing stressful tasks on-call may have protective benefits for cognitive performance, although these findings are just the first step in understanding this relationship. As such, these findings present the opportunity for further research to be performed regarding on-call task stress, and how organisations may use these potential effects to their advantage operationally.

7.4.6 qEEG methods for on-call sleep analysis

Prior to this thesis, just two studies had investigated on-call sleep utilising qEEG methods (Torsvall & Åkerstedt, 1988; Wuyts et al., 2012). Torsvall et al. (1988) applied this technique to the sleep of real world maritime engineers who were on-call, while Wuyts et al. (2012) performed qEEG analyses during an on-call laboratory study similar to those described in this thesis. As such, this thesis adds to the research that has utilised this technique to understand the nuanced changes to sleep that appear during on-call periods. QEEG provides further understanding of within-sleep arousal and previously imperceptible changes to sleep, which may be used to identify biomarkers indicative of next day neurobehavioural performance (D'Rozario et al., 2017; Dijk, 2009). In contrast to the studies performed by Wuyts et al. (2012) and Torsvall and Åkerstedt (1988), under the current laboratory conditions no changes were seen qEEG variables on-call. This suggests that future research is required to determine why the findings from these two previous studies (Torsvall & Åkerstedt, 1988; Wuyts et al., 2012) conflict with the findings presented in this thesis.

7.4.7 Individual differences in trait anxiety in the on-call context

Little prior research had been performed investigating how individual differences in trait anxiety affect on-call tolerance (Heponiemi et al., 2015), despite the apparent impact on shift work tolerance (Bamberg et al., 2012; Reid, 2010). Previous research investigated how some individual differences (e.g., age, work experience) affect on-call tolerance (Heponiemi et al., 2015), but the study described in Chapter 6 was the first to investigate the effects of trait anxiety. Therefore, a further novel contribution of this thesis was the measurement of the effect of trait anxiety on state anxiety, sleep, and cognitive performance on-call. This research is the first to determine that higher, non-clinical, levels of trait anxiety do not preclude individuals from tolerating on-call work. This provides a basis for further research into on-call tolerance, for example regarding other personality characteristics, chronotypes, or biological variables (Saksvik et al., 2011), to help determine which individuals may be best suited to this working arrangement.

7.4.8 Beyond on-call work

This thesis provides novel information that may also be applicable to contexts outside of on-call work. For example, this thesis found that uncertainty related to being on-call was linked with poorer sleep and next day cognitive performance. This finding may also apply to other situations where uncertainty is present, for example, in parents of young children (Acebo et al., 2005; Gay et al., 2004; Holm et al., 2008). It is possible that the uncertainty associated with not knowing if/when a child will wake overnight (particularly those with newborns, who have been described as having “random sleep-wake cycles (Gay et al., 2004, p. 311)) may have similar effects to the uncertainty of on-call work. Furthermore, the finding that pre-bed anxiety is not necessarily linked with poorer sleep may be particularly helpful for those individuals experiencing sleep difficulties, such as insomnia (Talamini et al., 2013). An awareness that feeling anxious does not necessarily result in poor sleep may be of comfort to these individuals (Jansson & Linton, 2006). Additionally, the finding that performing a stressful task resulted in improved cognitive performance, relative to performing a non-stressful task, may be useful for individuals engaged in work that is not necessarily on-call. For example, doctors performing surgery may feel less anxious about their performance with the knowledge that there is a protective effect from the stressful nature of the task (Wetzel et al., 2006). However, future research is required to determine if findings seen in this on-call laboratory study are applicable to broader contexts.

7.4.9 Conclusion

Overall, the research presented in this thesis has contributed to the on-call field by investigating three of the major outcomes of on-call work together (anxiety, sleep, and cognitive performance). Using quantitative and validated measures, this research has determined the effects of components of on-call work on these outcomes, to better understand why on-call work is reportedly difficult to manage (Bamberg et al., 2012; Jay et al., 2018; Paterson et al., 2016). Furthermore, by isolating the effect of on-call periods from the effects of sleep disruption or restriction, this research has progressed the on-call field by giving evidence that decrements to anxiety, sleep, and cognitive performance can be seen even when on-call periods are not disturbed by calls. As a result, this thesis paves the way for further research into on-call work, a currently under-researched area. These laboratory findings can now be taken into the real world (e.g., in emergency services, healthcare, or rail industries), for further investigation into the effects of specific components of on-call periods, in addition to the effects of on-call periods with no calls, which we now know may impact worker and organisational outcomes.

7.5 On-call conditions: what works and what doesn't work

The evaluation of anxiety, sleep, and cognitive performance within this thesis has enabled a comparison of the components of on-call work that may be particularly problematic for workers and workplaces. While the magnitude of the findings presented in this thesis were relatively small, they indicated that sleep outcomes and associated performance decrements are most likely to be adversely affected by the uncertainty surrounding the call itself during on-call periods. This is particularly problematic as on-call work in the real world is inherently uncertain (Cebola, 2014; Jay et al., 2018; Paterson et al., 2016). These findings are supported by literature investigating work stressors, including the impact of work related uncertainty on sleep (Nixon et al., 2011). Specifically, a lack of control over work hours and tasks, in addition to role ambiguity has been linked with poorer sleep outcomes (Kubo et al., 2013; Nixon et al., 2011; Salo et al., 2014). While these stressors are not the same as those experienced on-call, they appear to manifest in similar ways (i.e., increased uncertainty surrounding work acting as a stressor subsequently resulting in poorer sleep) (Kubo et al., 2013; Nixon et al., 2011). Interestingly, sleep and cognitive deficits were not preceded by higher self-reported anxiety in the present studies. This suggests that perception of the degree of anxiety provoked by being on-call may not directly translate to sleep and cognitive performance outcomes. As a result, if on-call workers use their level of anxiety as a marker of how well they are likely to sleep, or how they slept the preceding night, they may be either under- or over-estimating the quality or quantity of their sleep.

This thesis found that when there is uncertainty relating to whether there will or will not be a call, or whether the individual will hear the alarm when it occurs, decrements to sleep and associated negative effects to cognitive performance are seen the following day. Therefore, these operational aspects of receiving a call appear to be the main factors that affect sleep, in contrast with what the on-call work itself may entail. Indeed, the results presented in this thesis suggest that even when the task to be performed the following day is more stressful, sleep is not impacted in the same way it is by concerns about the call itself. This may be because the individual is aware that this task, while stressful, will not disturb their sleep, as an actual call may (i.e., it is concern about the call itself that may affect sleep, rather than about what may follow the call).

It is also particularly interesting that there was significantly better cognitive performance on the days where participants performed a stressful task. This may be explained by increased arousal, which is known to improve performance under certain conditions (Eysenck, 2012; LeBlanc et al., 2008). However, it is important to understand that this finding was apparent in a laboratory environment with just two on-call nights, rather than in the real world, where additional consecutive on-call shifts may be performed and work tasks are higher risk (Hall et al., 2016; Heponiemi et al., 2015; Lindfors et al., 2006; Nicol & Botterill, 2004). As such, while it appears that performing a stressful or difficult task may have a protective effect on subsequent performance, this may not be the case for real world on-call workers. However, subjective reports from on-call workers describe feeling more alert when responding to a stressful incident (Cebola, 2014; Paterson et al., 2016). For example, one firefighter stated that in response to confirmed incidents “there’s that urgency that kicks in and everyone moves a bit quicker”, with another reporting in response to an alarm that “the adrenaline starts pumping, and you start worrying about everybody else and what just happened” (Paterson et al., 2016, p. 178). Therefore, it is possible that the stress of on-call tasks may result in improved cognitive performance under real world on-call conditions, as reflected by prior qualitative research (Paterson et al., 2016).

Despite the potential impacts of on-call work suggested by this thesis, it is important to note the magnitude of the changes that were seen. In particular, while some discussed differences in outcome measures between conditions were statistically significant, the magnitude of these differences was generally small. As such, while it is possible that the differences seen here may be magnified under stressful real-world conditions, it is also possible that on-call workers may develop adaptive responses to minimise these effects. Further research is therefore required to determine the degree to which these impacts are seen in the real world context.

7.6 Industry implications

The findings of this thesis have produced several important implications for industries that utilise on-call working arrangements. The studies suggest that small, easy to implement, changes to on-call working arrangements may have significant effects on worker performance and safety. There are several specific areas where these changes could be implemented; controlling the uncertainty of on-call shifts, alarm types, awareness of the relationship between on-call tasks and individual outcomes, in addition to employee perceptions of impairment, on-call recruitment, and, where possible, potentially eliminating the use of on-call work. However, it is important to be aware of the magnitude of the differences seen in anxiety, sleep, and cognitive performance outcomes in all studies that comprise this thesis. The differences between conditions were generally small, and as such, there may be some limits to the efficacy of the suggested operational changes. However, strategies that improve on-call anxiety, sleep, or cognitive performance by even a small amount are worth considering and implementing if possible, due to the potentially devastating effects of errors or accidents in many on-call industries (Gaba, 2000).

7.6.1 Uncertainty of on-call work

The findings from Study 1 (Chapter 3), which evaluated the effects of call likelihood, suggest that negative sleep and performance outcomes result from the uncertainty surrounding whether the individual will receive a call. As such, controlling uncertainty may be a way that organisations could mitigate these negative effects. Quantifying the likelihood of a call during a given shift may be useful for implementing protocols to support employee safety during and after shifts with a high degree of uncertainty. If shifts are designated to be highly uncertain, this may assist in deciding which employees are rostered on, which duties are performed, or what additional safety measures are employed. For example, if an on-call period is designated as being “highly uncertain”, the organisation may ensure that the rostered on individual has had appropriate prior time off, or that the shift is not extended. Another way of managing the uncertainty of on-call periods may be to establish periods of time when calls are likely, and to spread these brackets over the individuals who are on-call during that shift. For example, if an organisation has two workers on-call overnight, the supervisor may designate one individual as the first on-call point of contact during the first half of the night, which then would swap to the second on-call worker for the rest of the night. This may also be a useful strategy for alternating entire nights, rather than portions of a night. This is supported by research in the healthcare industry regarding “protected time” – periods of time where a night float staff member takes all calls, and on-call staff can sleep with limited interruptions (Reed et al., 2010; Richardson et al., 1996). Under these protected conditions, sleep efficiency is higher than during on-call periods without protected time (Richardson et al., 1996). Furthermore, protected time for sleep may also be linked with reduced stress (Chambers et al., 1996). Therefore, this strategy may also be helpful in ensuring that each on-call worker has periods of on-call time where they are more certain about their call likelihood, and therefore have improved sleep.

If on-call rostering policies that considered on-call uncertainty were implemented there would need to be appropriate control measures to ensure that workers were adequately prepared for their on-call shifts even when call likelihood is designated as being low. Control measures may include the use of both appropriate compensation for on-call shifts (financial and/or time off in lieu), combined with on-call management education, and relevant organisational policies (SafeWork Australia, 2013). However, this strategy does present the risk that employees may not prioritise their sleep prior to shifts where calls are unlikely. Another approach to address the issue of call uncertainty is the pool of on-call workers itself. If fewer workers are on-call at a given time, it may be more likely that they will be called. This strategy has the potential for reducing the uncertainty around potential calls, in addition to the number of employees who are on-call. Further, safety control measures, such as double/triple checking or "buddying up" may be implemented during shifts (either on-call or rostered shifts following on-call periods) where the individuals may have had poorer sleep and, as such, may not be performing safely (Dawson & McCulloch, 2005; SafeWork Australia, 2013). It is important to note that the effects seen in this thesis regarding uncertainty and on-call outcomes were small, and therefore, these applications may be limited in efficacy. However, even small changes in anxiety or sleep may have significant long term effects, particularly regarding health outcomes (Rosekind et al., 2010; Spiegel, 2008; Suinn, 2001; Suls & Bunde, 2005). Further, small decrements to sleep over days or weeks can result in significantly impaired cognitive performance (Belenky et al., 2003), which may have devastating effects for safety (Christian et al., 2009).

7.6.2 Alarm types

In this thesis the on-call condition that produced the most pronounced sleep decrements was when participants believed it was likely that they would miss their alarm, although these effects were still small. This finding is supported by sleep decrements seen during on-call periods with easy to miss alarms (Wuyts et al., 2012), compared with the lack of changes to sleep seen during on-call periods where loud, difficult to miss alarms were used (Jay et al., 2016). Simply utilising an alarm system that the on-call workers know they will not miss would be a straightforward and cost-effective way of managing the anxiety that leads to potential sleep and cognitive performance decrements. This may include having two ways of contacting the on-call worker, such as a mobile phone and a pager, or a mobile phone and a landline. Organisations may also be able to mitigate the negative effects of potentially missing an alarm by providing phones or pagers that have particularly loud ringtones, have some degree of vibration/light emission, or require the individual to perform a task (e.g., shaking the phone or completing an arithmetic problem to stop the alarm) (Ko et al., 2015). However, ensuring that the noise emitted by alarms does not startle on-call workers and produce a stress response must also be considered (Berndt-Zipfel et al., 2011). This is particularly important as startle responses have been shown to result in poorer performance under critical conditions (Martin et al., 2015). To manage potential startle responses from on-call alarms, it may be beneficial to use specific alarm tones, or ensure that the volume of the alarms is within a certain range. Additionally, in on-call environments where workers are required to be on-site, it may be beneficial to have one individual who is responsible for ensuring that all other workers are woken to respond to the call. This may be applicable in fire stations or hospitals, where on-call workers are permitted to sleep in a designated area (Arora et al., 2008; Paterson et al., 2016). If these workers understand that it is not their own responsibility to respond to the alarm, but the designated individual for that shift, they may be less likely to worry that they may miss the alarm.

7.6.3 The nature of on-call tasks

The results from Study 2 (Chapter 4) suggest that performing a stressful task may result in arousal, leading to improved post-task cognitive performance. Workplaces and employees may be able to use this finding to their benefit. Specifically, this finding suggests that when faced with an emergency situation, individual performance may improve as a result of physiological arousal (Eysenck, 2012). While this information may be comforting for some organisations (e.g., emergency services during a bushfire), it is important to be cautious in applying this finding, particularly due to the small effect sizes seen in this thesis. Caution in application is also required because these performance outcomes were shown in a laboratory environment without consecutive on-call nights, or real world consequences for errors or accidents. Additionally, this effect over time is not well understood, so consideration must be given to the management of stressful on-call work types over more than one shift, or over extended working hours (Hall et al., 2016).

The differences in PVT performance seen in this thesis may not reflect the differences seen in other on-call outcomes, including stress, changes in other cognitive domains, or longer term health outcomes (Cebola, 2014; Hall et al., 2017; Harbeck et al., 2015). For example, stress responses, as measured by salivary alpha amylase, have been found to be unaffected by on-call conditions (Hall et al., 2017), as have measures of cortisol, epinephrine and norepinephrine (Harbeck et al., 2015), which contradicts the PVT findings from this thesis. Furthermore, it is likely that frequent exposure to high stress situations will result in poor health outcomes, such as immune function and cardiovascular disease (Mariotti, 2015), despite the immediate improvement in PVT response times. Additionally, frequent exposure to on-call periods may result in some degree of desensitisation or adaptation (Cebola, 2014), which may blunt the arousal response to calls (McEwen, 2007). Blunted arousal responses may be of concern as there is evidence to suggest a link between these responses and poor mental health outcomes (Ayer et al., 2013). Any health outcomes, including blunted arousal responses, may have significant ramifications for both on-call workers and organisations, and are therefore important to address.

7.6.4 Perception of impairment

Interestingly, subjectively reported pre-bed anxiety did not appear to be affected by on-call work in a similar way to either sleep or performance outcomes in this thesis. This suggests that although on-call workers may perceive an on-call period as producing anxiety, these feelings do not directly translate to poorer sleep outcomes, as may have been expected from previous research linking anxiety with sleep (Alvaro et al., 2013; Shanahan et al., 2014). This is potentially problematic, as individuals may interpret feelings of anxiety as markers of sleep quality (i.e., if you feel anxious before bed, you may assume that you will have/did have a poor night of sleep). However, the research presented in this thesis suggests that pre-bed anxiety does not necessarily reflect subsequent sleep quality. Therefore, individuals may perceive their sleep quality incorrectly. This is supported by research in individuals with insomnia, who often report anxiety prior to sleep (Baglioni et al., 2010), and who tend to underestimate the amount of sleep they actually obtain, and overestimate the time it takes to fall asleep (Harvey & Tang, 2012). These findings indicate that within insomnia research, heightened levels of anxiety are also not necessarily linked with subsequent sleep (Harvey & Tang, 2012). Therefore, if individuals are relying on their feelings of anxiety to determine their sleep quality when they consider their level of impairment, this may be an inaccurate perception of their prior sleep. This is problematic from a risk assessment point of view, as operational systems typically rely on self-reports of poor sleep and other impairment (Dawson & McCulloch, 2005). As such, organisations need to be aware that self-reported information from on-call workers may not be representative of their actual sleep and degree of impairment, including both potential over- and under-reporting. Therefore, more effective strategies may include objective sleep measurement, sleep/wake diaries, bio-mathematical modelling, and reporting based on time of day (Dawson et al., 2011). It is also important to note that regardless of the potential effects on sleep and cognitive performance, prolonged anxiety can have potentially harmful effects, particularly with regards to health (Suinn, 2001; Suls & Bunde, 2005). As a result, future research is necessary to determine which internal markers individuals currently use to interpret their sleep quality (i.e., *do* individuals think that feeling anxious before bed leads to poorer sleep?), and also which markers or states *are* linked with objective sleep outcomes, and therefore potential performance decrements.

7.6.5 On-call recruitment

Although individuals with high trait anxiety may be less tolerant of shift work (Saksvik et al., 2011), the findings of this thesis suggest that low trait anxiety individuals may be slightly more reactive to on-call situations in terms of their post-call performance. However, these performance decrements were seen only in Study 3, and did not result in performance that was lower than those with higher trait anxiety. In fact, under the on-call conditions in this study, there were no differences in performance based on individual levels of trait anxiety. As such, it appears that non-clinical levels of trait anxiety do not have meaningful ramifications for on-call tolerance in a simulated setting. As such, organisations can be equally confident in the ability of employees with both high and low (non-clinical) levels of trait anxiety to manage on-call work. However, it is important to note that there are many other individual differences that may affect on-call tolerance, including other personality factors (e.g., neuroticism), age, gender, and health status, as these factors impact shift work tolerance (Bamberg et al., 2012; Heponiemi et al., 2015; Reid, 2010). These additional characteristics were outside of the scope of this thesis, and further research is required to determine if they impact on-call tolerance.

7.6.6 Elimination of on-call work

Although the effects of on-call work on anxiety, sleep and cognitive performance were not large, it is clear that on-call work can be detrimental under the laboratory conditions described in this thesis. It is possible that under real world on-call conditions, including consecutive nights on-call, and the stress associated with real world on-call scenarios, these effects may be exacerbated. For example, although the changes to sleep seen between conditions in this thesis were small, it is likely that over the long term these small changes could have negative effects on daytime functioning (Bartlett et al., 2008; Belenky et al., 2003; Carskadon & Dement, 1981; Van Dongen et al., 2003). However, much of the literature investigating sleep restriction has shortened sleep opportunities by hours, rather than minutes (as the differences in sleep were within thesis), and therefore, the degree of impairment that would be apparent over the long term in this case is unclear (Bartlett et al., 2008; Belenky et al., 2003; Carskadon & Dement, 1981; Van Dongen et al., 2003). Despite this, eliminating or minimising on-call work may be a strategy to help promote better outcomes, particularly in industries where errors or adverse events may have serious consequences for safety (Gaba, 2000). For example, even small errors made in healthcare settings, such as miscalculating drug dosages, can have catastrophic consequences for patients (McDowell et al., 2009), which may be avoided by minimising the use of on-call work. In some instances, utilising standard shift work may be preferable, as employees have no uncertainty surrounding their shifts, and can better plan their sleep to ensure they are fit for duty (Peate, 2007).

Not only would the elimination of on-call work be an effective safety measure, but organisations may consider the potential associated cost benefits (McCrate, 2018; Vincent et al., 2018). Currently, it is estimated that on-call work costs businesses in Australia between $1.71 – 2.73 billion per year as a result of lost sleep from on-call work (i.e., injury risk) (Vincent et al., 2018). Additionally, there are other associated costs of on-call work to employers, including higher rates of turnover and absenteeism, increased errors, decreased organisational loyalty, decreased productivity, a higher proportion of overtime payments, and in some cases, higher tax rates (McCrate, 2018). In fact, the long-term cost may be greater than employing workers for regularly scheduled shifts (McCrate, 2018; Vincent et al., 2018). However, it is important to note that there are also costs associated with traditional shift work, including lost sleep and health impacts (Caruso, 2014; Rosekind et al., 2010; Shantha, 2013). Despite this, the human and financial cost of on-call work has started to be taken into account in some industries, including in the retail sector in New York, where a change to fair scheduling ordinances has resulted in the elimination of on-call working arrangements (McCrate, 2018). However, as this ordinance was passed in May 2017, there are no data available to date regarding how this has affected organisations, workers, or employment levels.

7.7 Future directions and limitations

7.7.1 Laboratory versus real world research context

All studies included in this thesis were conducted in a time-isolated sleep laboratory, in order to identify the specific effects of variables and conditions. Laboratory research is vital in areas where there is a limited pool of data because it allows researchers to disentangle the specific effects of each variable without the presence of confounding elements. This makes it possible to determine which elements of on-call work result in poorer outcomes. Specifically, these studies were designed to control all variables (e.g., time in bed, light exposure, workload), other than those which were being examined, to understand how certain aspects of on-call work affect anxiety, sleep, and cognitive performance. By isolating the specific on-call components (i.e., the likelihood of being called, task stress, and the chance of missing the alarm), more evidence is presented regarding their direct effects than had these studies been performed under real world on-call conditions. Based on these findings, field research studies can now be designed with more certainty and confidence, and resources can be more effectively allocated.

However, laboratory research is inherently limited, particularly regarding both external and ecological validity, and the real world application of findings. In a real on-call situation, there may be external factors that influence anxiety, sleep and performance outcomes. For example, anxiety and sleep may be impacted by having a sick child, interpersonal relationship difficulties, chronic pain, or high workloads (Dahlgren et al., 2005; Israel et al., 1989; Sayar et al., 2002). Furthermore, the perception of the urgency and stress of on-call periods in a laboratory are unavoidably different from those experienced in a real world context (Hall et al., 2017). Additionally, the on-call conditions that were measured in this thesis are likely to occur concurrently in the real world (i.e., the individual may have to perform a stressful task upon waking, and also be concerned that they will miss their alarm) (Jay et al., 2018; Paterson et al., 2016). The type of work that is performed on-call in the real world is also inherently different to that which is performed in the laboratory (Jay et al., 2016). For example, real world on-call work is often performed in industries such as emergency services and medicine (Nicol & Botterill, 2004), where tasks may include attending to a house fire or driving an emergency services vehicle, whereas the performance measure used in the current thesis was the PVT. The PVT is a general measure of cognitive performance impairment, and is typically used as a proxy for work performance (Loh et al., 2004). However, this measure is a laboratory-based task, and as such may not necessarily be representative of real-world outcomes, particularly with regards to the consequences for error. The ramifications of poor performance during on-call work in the real world are potentially very serious (i.e., crashing a car, making an error during surgery), resulting in stress responses that cannot be replicated in a laboratory environment. The next step for on-call research is to focus on real world data, where the multifactorial nature of the world can be included in on-call models, and both external and ecological validity can be addressed. This has been done in the on-call literature to some degree, with recent investigations into physiological outcomes of on-call work (e.g., salivary alpha amylase) showing that the impact of on-call work on these outcomes may be negligible under certain circumstances (Hall et al., 2017). However, research into anxiety, sleep, and cognitive performance is still limited. Future studies may also include hybrid models, where simulations of real world tasks are performed under controlled conditions. This type of simulation has been performed successfully in firefighter populations (Cvirn et al., 2017; Vincent et al., 2015; Wolkow et al., 2015), and therefore may also be appropriate for further on-call research.

7.7.2 Participants

All participants in these studies were healthy males between the ages of twenty and thirty-five, which allowed us to isolate the effects of on-call periods without the confounding factors of age, health status, gender (female menstrual phase) or on-call experience. However, this sample group is not reflective of the demographics of all on-call workers (Nicol & Botterill, 2004). On-call populations include individuals who are over 35, female, or who experience a range of health concerns that may have an effect on their anxiety, sleep, or cognitive performance (Jay et al., 2018; Nicol & Botterill, 2004).

There is extensive evidence to suggest that there is a link between age and anxiety, sleep, and cognitive performance outcomes (Jorm, 2000). Specifically, a review of literature on anxiety and ageing demonstrated that adults tend to experience decreased anxiety as they age, in addition to lower levels of depression and distress (Jorm, 2000). This means that the general population may have a different experience of the anxiety associated with on-call work. Further, overnight sleep structure and duration changes dramatically with age (Ohayon et al., 2004), as does the experience of shift work (Marquie & Foret, 1999), with older workers reporting more strategies for managing unusual working arrangements (Harma & Ilmarinen, 1999). This is particularly important to investigate in future research because of the changing demographics of our ageing workforce (Radford et al., 2018). Furthermore, no current on-call workers were included in the sample in the studies discussed in this thesis, to ensure that on-call experience was not a confounding factor. However, this again is not reflective of real world on-call workers, many of whom have extensive experience with these working arrangements and the tasks that are typically performed (Cebola, 2014; Jay et al., 2018).

Additionally, on-call work is not solely performed by males (Jay et al., 2018). Women were excluded from these studies due to the variable nature of hormonal responses during different menstrual phases (Maki et al., 2015; Wolfram et al., 2011). As cortisol was collected as part of the studies presented in this thesis (although this measure was outside the scope of this thesis and is reported elsewhere), it was important to control any factors that may have affected cortisol responses (i.e., menstrual phase). Additionally, hormonal levels and menstrual phase can also affect anxiety and sleep (Baker & Driver, 2007; Driver et al., 1996; Manikandan et al., 2016). However, as males and females do not respond the same way to external stressors (Kajantie & Phillips, 2006), it follows that their responses to stressful working arrangements may also differ. Therefore, future research must utilise a broader range of participants, including both male and female participants, older individuals, and those with different health statuses and on-call experiences, to better reflect the demographics of the on-call population.

7.7.3 Sleep restriction or deprivation

The studies that make up this thesis were designed to isolate the effects of anticipation associated with on-call work, rather than to investigate the effects of sleep deprivation and disruption. Therefore, participants were only woken by an alarm at the end of their 8-h sleep opportunities rather than overnight during the on-call conditions. While this resulted in the isolation of the effects of on-call periods from sleep restriction, real world on-call periods often include actual calls or alarms during sleep, and so, future research must include these sleep disturbances. Indeed, it is vital that future research aims to understand the effects on anxiety, sleep and cognitive performance of on-call periods where individuals receive calls, have shortened sleep periods, or are required to perform work duties overnight. This is particularly important as sleep restriction and deprivation are known to be bidirectionally linked with heightened anxiety (Amaral et al., 2018; Kalmbach et al.; Pires et al., 2016; Sagaspe et al., 2006; Shanahan et al., 2014), which is also an outcome of on-call work (Cebola, 2014; Jay et al., 2018; Paterson et al., 2016). In the real world, workers have on-call periods both with and without calls, unlike the conditions within this thesis (on-call periods with no calls). As such, the practical implications of these findings for *all* on-call shifts are somewhat limited. It is therefore important for future research to include on-call periods where calls are received during overnight sleep opportunities, to understand the practical impact of on-call periods more generally.

7.7.4 Number of outcome variables

In each of the studies examined within this thesis, a large number of variables were examined. Specifically, 39 sleep variables were assessed in Chapters 3, 4, and 5, based on both polysomnographic and qEEG output. While the inclusion of this number of variables is useful from an exploratory standpoint, or to generate hypotheses, it is also associated with limitations for hypothesis testing. When a large number of variables are examined, the likelihood that at least one, or a small number, point of significance increases based on probability (Johnstone & Titterington, 2009). Based on the findings of this thesis, future research may include fewer outcome variables, in order to specifically target desired hypotheses.

7.8 Conclusion

This thesis demonstrates that not all on-call periods affect anxiety, sleep, and cognitive performance outcomes in the same way, or at all. An evaluation of the likelihood of receiving a call, task stress, and the chance of missing the alarm revealed strategies that organisations may use to mitigate the negative impact of on-call work. These strategies include the way work tasks are allocated, rostering options, and the type of on-call alarm systems that are utilised. This thesis also presents the first insight into individual differences in on-call tolerance. This novel research provides an experimental laboratory basis for real world on-call research, with information that may help organisations to promote worker health and wellbeing, in addition to enhancing workplace safety and productivity.

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Appendices

Appendix A: Ethics approval

Secretary, Human Research Ethics Committee
Ph: 07 4923 2603
Fax: 07 4923 2600
Email: ethics@cqu.edu.au

Dr Sarah Jay
Appleton Institute
44 Greenhill Road
Wayville SA 5034

18 August 2015

Dear Dr Jay

HUMAN RESEARCH ETHICS COMMITTEE OUTCOME PROJECT: H15/07-158, *SLEEPING WITH ONE EAR OPEN: THE IMPACT OF BEING 'ON-CALL' ON SLEEP, STRESS RESPONSE AND NEUROBEHAVIOURAL FUNCTION*

The Human Research Ethics Committee is an approved institutional ethics committee constituted in accord with guidelines formulated by the National Health and Medical Research Council (NHMRC) and governed by policies and procedures consistent with principles as contained in publications such as the joint Universities Australia and NHMRC *Australian Code for the Responsible Conduct of Research.* This is available at http://www.nhmrc.gov.au/publications/synopses/_files/r39.pdf.

On 28 July 2015, the committee considered your application. The project was assessed as being greater than low risk, as defined in the National Statement. On 18 August, the committee the committee acknowledged compliance with the conditions imposed on your research project *Sleeping with one ear open: The impact of being 'on-call' on sleep, stress response and neurobehavioural function* (Project Number H15/07-158) and it is now **APPROVED**.

The period of ethics approval will be from 18 August 2015 to 30 September 2017. The approval number is H15/08-158; please quote this number in all dealings with the Committee. HREC wishes you well with the undertaking of the project and looks forward to receiving the final report and statement of findings.

The standard conditions of approval for this research project are that:

(a) you conduct the research project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments required to be made to the proposal by the Human Research Ethics Committee;

(b) you advise the Human Research Ethics Committee (email ethics@cqu.edu.au) immediately if any complaints are made, or expressions of concern are raised, or any other issue in relation to the project which may warrant review of ethics approval of the project. *(A written report detailing the adverse occurrence or unforeseen event must be submitted to the Committee Chair within one working day after the event.)*

(c) you make submission to the Human Research Ethics Committee for approval of any proposed variations or modifications to the approved project before making any such changes;

(d) you provide the Human Research Ethics Committee with a written "Annual Report" on each anniversary date of approval (for projects of greater than 12 months) and "Final Report" by no later than one (1) month after the approval expiry date; *(A copy of the reporting pro formas may be obtained from the Human Research Ethics Committee Secretary, Sue Evans please contact at the telephone or email given on the first page.)*

(e) you accept that the Human Research Ethics Committee reserves the right to conduct scheduled or random inspections to confirm that the project is being conducted in

Central Queensland University CRICOS Provider Codes: QLD - 00219C, NSW - 01315F,VIC - 01624D

accordance to its approval. Inspections may include asking questions of the research team, inspecting all consent documents and records and being guided through any physical experiments associated with the project

(f) if the research project is discontinued, you advise the Committee in writing within five (5) working days of the discontinuation;

(g) A copy of the Statement of Findings is provided to the Human Research Ethics Committee when it is forwarded to participants.

Please note that failure to comply with the conditions of approval and the *National Statement on Ethical Conduct in Human Research* may result in withdrawal of approval for the project.

The Human Research Ethics Committee is committed to supporting researchers in achieving positive research outcomes through sound ethical research projects. If you have issues where the Human Research Ethics Committee may be of assistance or have any queries in relation to this approval please do not hesitate to contact the Ethics Officer or myself.

Yours sincerely,

A/Prof Tania Signal
Chair, Human Research Ethics Committee

Cc: Prof Sally Ferguson (CQUniversity co-researcher), Prof Leon Lack, Dr Brad Aisbett (Partner researchers)
Project file

APPROVED

Appendix B: Recruitment flyer

VOLUNTEERS NEEDED!

CQUniversity's Appleton Institute in Adelaide is seeking **healthy, non-smoking males, aged 20-35** years to participate in a sleep study.

During your participation, you will "live" in our laboratory for **four** days and nights. You will have your own bedroom and bathroom and all your meals will be provided.

Volunteers will be paid an honorarium **up to $480** to compensate them for their time.

We are now recruiting for our study beginning;

17th May 2017 (4.30pm) until 21st May 2017 (6pm)

Please contact Madeline for more information:

madeline.sprajcer@cqumail.com

Appendix C: Information sheet

"Sleeping with one ear open"

INFORMATION SHEET

PROJECT OVERVIEW:

Nearly 2 million employees in the Australian workforce work with on-call as part of their employment. Despite this, there is limited research specifically investigating the impact of on-call on sleep and next-day performance.

Research has demonstrated that stress and worry prior to bedtime are associated with poorer sleep and there are certain characteristics of being on-call that could cause stress or worry prior to sleep. This may explain why many people report sleeping poorly when expecting a call.

Adverse sleep and subsequent health and performance effects have costs for the individual and the organisations. Therefore, if we can better understand the impact of on-call, we can use that knowledge to develop appropriate safety practices in those workplaces. This will directly help not only those working on-call but the communities they serve as well.

The aim of this study is to quantify changes to levels of stress/worry, sleep and next-day performance under different on-call conditions.

PARTICIPATION PROCEDURE:

Participants will be required to attend the Appleton Institute for four consecutive days and nights. During this time participants will complete a battery of neurobehavioural tasks, including response time, hand-eye coordination and memory tasks, as well as measures of subjective stress. Saliva samples and heart rate data will also be collected. Sleep will be monitored using electrodes attached to the face and head. On two of the four nights, participants will be "on-call" and required to respond to the call sound by waking up and completing various on-call tasks.

BENEFITS AND RISKS:

Individual participants will not receive any direct benefit from their participation in the research. In general terms, however, their participation will assist the research team better understand the impact of being "on-call" on sleep and subsequent performance. In turn, this knowledge may help in the development of strategies that safeguard the health and safety of the 1.7 million Australians who work on-call. In terms of risk, some of the call sounds will be loud, but only maintained for a very short period and will closely resemble the normal safety alarms used in many workplaces.

CONFIDENTIALITY:

All data collected will be de-identified to protect confidentiality. Data will be published as group averages to prevent recognition of individual results. Data from the study will be retained, in de-identified form, for a minimum of five years after the publication date of the last publication based on the data, in line with CQU's policy for data storage.

PUBLICATION OF RESULTS:

The outcomes of the study will be published in peer-reviewed journals and presented at academic and industry conferences. Copies of publications and presentations will be available to participants upon request.

CONSENT:

Participants will receive a written consent form, along with this information sheet. Signing this form will indicate the participant's informed consent to participate.

RIGHT TO WITHDRAW:

Participants have the right to withdraw their participation at any time throughout the study. This will not affect their relationship with the researchers, the research institution or the university in any way. Participants will receive a pro rata payment for the time spent in the study.

QUESTIONS?

Please contact Madeline Sprajcer (E-mail: madeline.sprajcer@cqumail.com) or Dr. Sarah Jay (E-mail: s.jay@cqu.edu.au) at the Appleton Institute (Tel: 08 8378 4518

CONCERNS OR COMPLAINTS?

Please contact CQUniversity's Office of Research (Tel: 07 4923 2603; E-mail: ethics@cqu.edu.au; Mailing address: Building 361, CQUniversity, Rockhampton QLD 4702) should there be concerns about the nature and/or conduct of this research project.

Appendix D: Consent form

"Sleeping with one ear open"

CONSENT FORM

I consent to participation in this research project and agree that:

1. An Information Sheet has been provided to me that I have read and understood;
2. I have had any questions I had about the project answered to my satisfaction by the Information Sheet and any further verbal explanation provided;
3. I understand that I have the right to withdraw from the project at any time without penalty;
4. I understand that the research findings will be included in the researcher's publication(s) on the project and this may include conferences and articles written for journals and other methods of dissemination stated in the Information Sheet;
5. I understand that all data I provide will be de-identified;
6. I agree that I am providing informed consent to participate in this project.

Signature: ______________________________ Date: __________

Name (please print): ______________________________

I wish to have a plain English statement of results posted to me at the address I provide below YES / NO

POSTAL ADDRESS: ______________________________

____

EMAIL ADDRESS: ______________________________

CQUHREC Clearance Number H15/07-158

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Appendix E: General Health Questionnaire

DOB: ____________ Age: ____________ yrs Gender: Male ☐ Female ☐

Weight: ____________ kg Height: ____________ cm

Left-handed ☐ Right-handed ☐

Occupation: ____________________________________

Are you vegetarian or do you have any other dietary requirements? ___________________________

Do you have a sleep disorder? YES ☐ NO ☐

Is English your first language? YES ☐ NO ☐

Do you smoke? YES ☐ NO ☐

Section One: General

1. Have you travelled through time zones in the last 3 months? (i.e., internationally or within Australia) ☐ YES ☐ NO

If yes, please provide trip details, including when you arrived here

____

2. Are you, or have you ever been involved in shift work? (shift work means any work you have performed outside of the 8am – 6pm range) ☐ YES ☐ NO

If so: how long ago? ____________ yrs ____________ months

For how long? ____________ yrs ____________ months

Please provide details about the shift schedule:

____ (e.g., times, durations)

3. Please list the average amount of caffeine you consume per day *(e.g., cups of tea/coffee, cans of caffeinated soft drink and chocolate bars)*

____

4. Do you have any children living with you at home? ☐ YES ☐ NO

If so, how many? ______

Section Two: Health

5. Have you had any serious accidents, head injuries, or concussion? ☐ YES ☐ NO

If yes, please give details:

____

6. Are you currently on any medication? ☐ YES ☐ NO

If yes, please give details:

____

7. What exercise do you do?

____

8. How much exercise do you do, on average per week? ______ hrs

9. On average, how much alcohol do you drink per week? ________________________

10. Have you ever experienced any of the following medical conditions, and if so, when?

Don't know = 0 No = 1 Yes, in the past = 2 Yes, sometimes = 3 Yes, at present = 4

(a) Asthma______ (b) Hay fever______

(c) Eczema______ (d) Allergies (Food or other)______

(e) Thyroid Problems______ (f) Undue anxiety______

(g) Sleepwalking ______ (h) Loud snoring______

(I) Nightmares______

(j) Bruxism (grinding teeth) _____

(k) Difficulty reading/writing______

(l) Arthritis/Rheumatism______

(m) Depression______

(n) Heart problems______

(o) Stomach problems______

(p) Waking with a jolt______

(q) Waking up excessively early______

(r) Difficulty falling asleep______

(s) Stress/anxiety at home/work______

(t) Epilepsy______

(u) Migraine______

(v) Colour blindness______

(w) STD / STI _______

11. Do you currently have any of the following (yes/no):

(a) Bed bugs_______

(b) Impetigo______

(c) Tinea_______

(d) Mite/Tick bites______

(e) Scabies ______

(f) any other contagious condition______

Section Three: Sleep

12. What time do you normally wake up?

______ week ______ weekend

13. What time do you normally go to sleep?

______ week ______ weekend

14. Do you normally nap during the day?

☐ YES ☐ NO

If so, how often does this occur? ______

15. How well do you usually sleep (circle)?

very poorly____very well

1 2 3 4 5

16. On average, how many times per night do you wake up?

☐ never ☐ hardly ever ☐ 1 or 2 ☐ < 5 ☐ 5 – 10

☐ >10 ☐ don't know

The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month.

17. During the past month, when have you usually gone to bed at night?

    Usual Bedtime ____________

18. During the past month, how long (in minutes) has it usually taken you to fall asleep each night?

    Number of Minutes ____________

19. During the past month, when have you usually gotten up in the morning?

    Usual getting up time ____________

20. During the past month, how many hours of *actual sleep* did you get at night? (This may be different to the number of hours you spend in bed)

    Hours of sleep per night ____________

21. For each of the remaining questions, check the one best response:

    During the past month, how often have you had trouble sleeping because you…

(a) Cannot get to sleep within 30 minutes:

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(b) Wake up in the middle of the night or early morning

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(c) Have to get up to use the bathroom

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(d) Cannot breathe comfortably

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(e) Cough or snore loudly

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(f) Feel too cold

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(g) Feel too hot

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(h) Had bad dreams

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(i) Have pain

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

(j) Other reason(s), please describe:_________________________________

How often during the past month have you had trouble sleeping because of this?

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

22. During the past month, how would you rate your sleep quality overall?

☐ very good ☐ fairly good ☐ fairly bad ☐ very bad

23. During the past month, how often have you taken medicine (prescribed or over the counter) to help you sleep?

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

24. During the past month, how often have you had trouble staying awake while driving, eating meals or engaging in social activity?

☐ not during the past month ☐ less than once/week ☐ once or twice/week

☐ 3 or more times/week

25. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?

☐ not a problem at all ☐ only a very slight problem ☐ somewhat of a problem

☐ a very big problem

How likely are you to fall asleep or doze off in the following situations, rather than just feeling tired? This refers to your usual way of life in recent times. Even if you have not done some of these things recently try to work out how they would have affected you. Use the following scale to choose the most appropriate number for each situation.

0	**=**	**would *never* doze**
1	**=**	***slight* chance of dozing**
2	**=**	***moderate* chance of dozing**
3	**=**	***high* chance of dozing**

Sitting and reading____________

Watching TV____________

Sitting inactive in a public place (e.g., theatre/meeting) ____________

As a passenger in a car for an hour without a break____________

Lying down in the afternoon when circumstances permit____________

Sitting and talking to someone____________

Sitting quietly after lunch without alcohol ____________

In a car, while stopped for a few minutes in the traffic____________

TOTAL____________

Section 4: Stress and Workload

26. Do you have exams/assignments due/other tests scheduled for one week before or during the study? ☐ YES ☐ NO

Comments: ____

27. Are you currently experiencing a greater than your normal amount of stress? (e.g., sick relative, relationship break-up, getting married, moving house) ☐ YES ☐ NO

Comments: ____

Appendix F: Morningness Eveningness Questionnaire

Instructions:

- Please read each question very carefully before answering.
- Please answer each question as honestly as possible. Answer ALL questions
- Each question should be answered independently of others. Do NOT go back and check your answers.

1. What time would you get up if you were entirely free to plan your day?

5:00 – 6:30 AM ☐

6:30 – 7:45 AM ☐

7:45 – 9:45 AM ☐

9:45 – 11:00 AM ☐

11:00 – 12 Noon ☐

12 Noon – 5:00 AM ☐

2. What time would you go to bed if you were entirely free to plan your evening?

8:00 – 9:00 PM ☐

9:00 – 10:15 PM ☐

10:15 – 12:30 AM ☐

12:30 – 1:45 AM ☐

1:45 – 3:00 AM ☐

3:00 AM – 8:00 PM ☐

3. If there is a specific time at which you have to get up in the morning, to what extent do you depend on being woken up by an alarm clock?

Not all dependent ☐

Slightly dependent ☐

Fairly dependent ☐

Very dependent ☐

4. How easy do you find it to get up in the morning (when you are not woken up unexpectedly)?

Not all easy ☐

Not very easy ☐

Fairly easy ☐

Very easy ☐

5. How alert do you feel during the first half-hour after you wake up in the morning?

Not all alert ☐

Slightly alert ☐

Fairly alert ☐

Very alert ☐

6. How hungry do you feel during the first half hour after you wake up in the morning?

Not all hungry ☐

Slightly hungry ☐

Fairly hungry ☐

Very hungry ☐

7. During the first half-hour after you wake up in the morning, how tired do you feel?

- Very tired ☐
- Fairly tired ☐
- Fairly refreshed ☐
- Very refreshed ☐

8. If you have no commitments the next day, what time would you go to bed compared to your usual bedtime?

- Seldom or never later ☐
- Less than one hour later ☐
- 1 – 2 hours later ☐
- More than two hours later ☐

9. You have decided to engage in some physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 7:00 – 8:00 am. Bearing in mind nothing but your own internal "clock", how do you think you would perform?

- Would be in good form ☐
- Would be in reasonable form ☐
- Would find it difficult ☐
- Would find it very difficult ☐

10. At what time of day do you feel you become tired as a result of need for sleep?

- 8:00 – 9:00 PM ☐
- 9:00 – 10:15 PM ☐
- 10:15 PM – 12:45 AM ☐
- 12:45 – 2:00 AM ☐
- 2:00 – 3:00 AM ☐

11. You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last for two hours. You are entirely free to plan your day. Considering only your own internal "clock", which ONE of the four testing times would you choose?

- 8:00 AM – 10:00 AM ☐
- 11:00 AM – 1:00 PM ☐
- 3:00 PM – 5:00 PM ☐
- 7:00 PM – 9:00 PM ☐

12. If you got into bed at 11:00 PM, how tired would you be?

- Not at all tired ☐
- A little tired ☐
- Fairly tired ☐
- Very tired ☐

13. For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which ONE of the following are you most likely to do?

- Will wake up at usual time, but will NOT fall back asleep ☐
- Will wake up at usual time and will doze thereafter ☐
- Will wake up at usual time but will fall asleep again ☐
- Will NOT wake up until later than usual ☐

14. One night you have to remain awake between 4:00 – 6:00 AM in order to carry out a night watch. You have no commitments the next day. Which ONE of the alternatives will suite you best?

- Would NOT go to bed until watch was over ☐
- Would take a nap before and sleep after ☐
- Would take a good sleep before and nap after ☐
- Would sleep only before watch ☐

15. You have to do two hours of hard physical work. You are entirely free to plan your day and considering only your own internal "clock" which ONE of the following time would you choose?

- 8:00 AM – 10:00 AM ☐
- 11:00 AM – 1:00 PM ☐
- 3:00 PM – 5:00 PM ☐
- 7:00 PM – 9:00 PM ☐

16. You have decided to engage in hard physical exercise. A friend suggests that you do this for one hour twice a week and the best time for him is between 10:00 – 11:00 PM. Bearing in mind nothing else but your own internal "clock" how well do you think you would perform?

- Would be in good form ☐
- Would be in reasonable form ☐
- Would find it difficult ☐
- Would find it very difficult ☐

17. **Suppose that you can choose your own work hours. Assume that you worked a FIVE hour day (including breaks) and that your job was interesting and paid by results). Which FIVE CONSECUTIVE HOURS would you select?**

5 hours starting between 4:00 AM and 8:00 AM	☐
5 hours starting between 8:00 AM and 9:00 AM	☐
5 hours starting between 9:00 AM and 2:00 PM	☐
5 hours starting between 2:00 PM and 5:00 PM	☐
5 hours starting between 5:00 PM and 4:00 AM	☐

18. **At what time of the day do you think that you reach your "feeling best" peak?**

5:00 – 8:00 AM	☐
8:00 – 10:00 AM	☐
10:00 AM – 5:00 PM	☐
5:00 – 10:00 PM	☐
10:00 PM – 5:00 AM	☐

19. **One hears about "morning" and "evening" types of people. Which ONE of these types do you consider yourself to be?**

Definitely a "morning" type	☐
Rather more a "morning" than an "evening" type	☐
Rather more an "evening" than a "morning" type	☐
Definitely an "evening" type	☐

Appendix G: Depression Anxiety Stress Scale

Please read each statement and circle a number 0, 1, 2 or 3 which indicates how much the statement applied to you *over the past week*. There are no right or wrong answers. Do not spend too much time on any statement.

The rating scale is as follows:

0 Did not apply to me at all

1 Applied to me to some degree, or some of the time

2 Applied to me to a considerable degree, or a good part of time

3 Applied to me very much, or most of the time

1	I found myself getting upset by quite trivial things	0	1	2	3
2	I was aware of dryness of my mouth	0	1	2	3
3	I couldn't seem to experience any positive feeling at all	0	1	2	3
4	I experienced breathing difficulty (e.g., excessively rapid breathing, breathlessness in the absence of physical exertion)	0	1	2	3
5	I just couldn't seem to get going	0	1	2	3
6	I tended to over-react to situations	0	1	2	3
7	I had a feeling of shakiness (e.g., legs going to give way)	0	1	2	3
8	I found it difficult to relax	0	1	2	3
9	I found myself in situations that made me so anxious I was most relieved when they ended	0	1	2	3
10	I felt that I had nothing to look forward to	0	1	2	3
11	I found myself getting upset rather easily	0	1	2	3
12	I felt that I was using a lot of nervous energy	0	1	2	3
13	I felt sad and depressed	0	1	2	3
14	I found myself getting impatient when I was delayed in any way (e.g., lifts, traffic lights, being kept waiting)	0	1	2	3
15	I had a feeling of faintness	0	1	2	3
16	I felt that I had lost interest in just about everything	0	1	2	3
17	I felt I wasn't worth much as a person	0	1	2	3
18	I felt that I was rather touchy	0	1	2	3
19	I perspired noticeably (e.g., hands sweaty) in the absence of high temperatures or physical exertion	0	1	2	3
20	I felt scared without any good reason	0	1	2	3
21	I felt that life wasn't worthwhile	0	1	2	3

Reminder of rating scale:

0 Did not apply to me at all

1 Applied to me to some degree, or some of the time

2 Applied to me to a considerable degree, or a good part of time

3 Applied to me very much, or most of the time

22	I found it hard to wind down	0	1	2	3
23	I had difficulty in swallowing	0	1	2	3
24	I couldn't seem to get any enjoyment out of the things I did	0	1	2	3
25	I was aware of the action of my heart in the absence of physical exertion (e.g., sense of heart rate increase, heart missing a beat)	0	1	2	3
26	I felt down-hearted and blue	0	1	2	3
27	I found that I was very irritable	0	1	2	3
28	I felt I was close to panic	0	1	2	3
29	I found it hard to calm down after something upset me	0	1	2	3
30	I feared that I would be "thrown" by some trivial but unfamiliar task	0	1	2	3
31	I was unable to become enthusiastic about anything	0	1	2	3
32	I found it difficult to tolerate interruptions to what I was doing	0	1	2	3
33	I was in a state of nervous tension	0	1	2	3
34	I felt I was pretty worthless	0	1	2	3
35	I was intolerant of anything that kept me from getting on with what I was doing	0	1	2	3
36	I felt terrified	0	1	2	3
37	I could see nothing in the future to be hopeful about	0	1	2	3
38	I felt that life was meaningless	0	1	2	3
39	I found myself getting agitated	0	1	2	3
40	I was worried about situations in which I might panic and make a fool of myself	0	1	2	3
41	I experienced trembling (e.g., in the hands)	0	1	2	3
42	I found it difficult to work up the initiative to do things	0	1	2	3

Appendix H: Sleep Diary

SLEEP DIARY INSTRUCTIONS

STEP ONE: Record the time you go to bed and the time that you get out of bed. Also record the time you that you actually went to sleep and at what time you finally wake up. This should be done for ANY and EVERY sleep period, including short naps.

Also record how many times you woke up during the sleep period, and the TOTAL amount of time you were awake for after you add each of these awakenings together.

STEP TWO: The second step involves rating how sleepy/awake you feel just before you go to bed and as soon as you wake up. Do this using the SLEEPINESS SCALE below. Choose the statement which best describes your state of sleepiness immediately BEFORE and AFTER the sleep period.

SLEEPINESS SCALE
1 = Feeling active and vital. Alert and wide awake
2 = Functioning at a high level but not at peak. Able to concentrate.
3 = Relaxed, awake, responsive, not at full alertness.
4 = A little foggy. Not at peak. Let down.
5 = Fogginess. Beginning to lose interest in remaining awake. Slowed down.
6 = Sleepy. Prefer to be lying down. Fighting sleep. Woozy.
7 = Almost in reverie. Sleep onset will be soon. Lost struggle to remain awake.

STEP THREE: The third step requires a subjective evaluation to be made about how well you slept. Simply select a number from the following scale, and record it in the column marked "SLEEP QUALITY":

HOW YOU SLEPT

1 = Very Well
2 = Well
3 = Average
4 = Poorly
5 = Very Poorly

STEP FOUR: Finally, first thing after waking, please record how many hours of sleep it felt like you obtained. Accuracy is not important – we are more interested in your subjective estimate.

Name:				**Study ID:**							
		SLEEP PERIOD[1]						SLEEPINESS[2]		SUBJECTIVE RATINGS[3-4]	
DATE (dd/mm/yy)	DAY (Mon-Sun)	BED TIME (hh:mm)	SLEEP ONSET TIME (hh:mm)	FINAL WAKE TIME (hh:mm)	END of SLEEP PERIOD (hh:mm)	No. OF AWAKENINGS	TOTAL TIME AWAKE (minutes)	BEFORE (1-7)	AFTER (1-7)	SLEEP QUALITY (1-5)	HOURS OF SLEEP

Appendix I: State Trait Anxiety Inventory

SELF-EVALUATION QUESTIONNAIRE

Developed by C. D. Spielberger, R. L. Gorsuch and R. Lushene

STAI FORM X-1

NAME ______________________ DATE __________

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then blacken in the appropriate circle to the right of the statement to indicate how you *feel* right now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	①	②	③	④
2. I feel secure	①	②	③	④
3. I am tense	①	②	③	④
4. I am regretful	①	②	③	④
5. I feel at ease	①	②	③	④
6. I feel upset	①	②	③	④
7. I am presently worrying over possible misfortunes	①	②	③	④
8. I feel rested	①	②	③	④
9. I feel anxious	①	②	③	④
10. I feel comfortable	①	②	③	④
11. I feel self-confident	①	②	③	④
12. I feel nervous	①	②	③	④
13. I am jittery	①	②	③	④
14. I feel "high strung"	①	②	③	④
15. I am relaxed	①	②	③	④
16. I feel content	①	②	③	④
17. I am worried	①	②	③	④
18. I feel over-excited and "rattled"	①	②	③	④
19. I feel joyful	①	②	③	④
20. I feel pleasant	①	②	③	④

20

SELF-EVALUATION QUESTIONNAIRE

STAI FORM X-2

NAME ____________________________ DATE ____________

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then blacken in the appropriate circle to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant	①	②	③	④
22. I tire quickly	①	②	③	④
23. I feel like crying	①	②	③	④
24. I wish I could be as happy as others seem to be	①	②	③	④
25. I am losing out on things because I can't make up my mind soon enough	①	②	③	④
26. I feel rested	①	②	③	④
27. I am "calm, cool, and collected"	①	②	③	④
28. I feel that difficulties are piling up so that I cannot overcome them	①	②	③	④
29. I worry too much over something that really doesn't matter	①	②	③	④
30. I am happy	①	②	③	④
31. I am inclined to take things hard	①	②	③	④
32. I lack self-confidence	①	②	③	④
33. I feel secure	①	②	③	④
34. I try to avoid facing a crisis or difficulty	①	②	③	④
35. I feel blue	①	②	③	④
36. I am content	①	②	③	④
37. Some unimportant thought runs through my mind and bothers me	①	②	③	④
38. I take disappointments so keenly that I can't put them out of my mind	①	②	③	④
39. I am a steady person	①	②	③	④
40. I get in a state of tension or turmoil as I think over my recent concerns and interests	①	②	③	④

Appendix J: Study 1 published paper

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Appendix K: Study 2 published paper

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Appendix L: Study 3 published paper

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